How to Select a Surface-Capacitive Touch-Screen Controller

Controllers are critical to the performance of all capacitive touch screens, and selecting the right one for your application is critical to the product's success. This article serves as a how-to guide to selecting and integrating a surface-capacitive touch-screen controller and software.

by Carl Bauman

MANY of the larger touch-system suppliers will only sell their components as a complete system, and generally will not support second-source solutions that mix and match the three primary component parts of the system: the physical touch screen (often referred to as the "sensor"), the control electronics (known as the "controller"), and the supporting software (typically device drivers for various operating systems) and calibration utilities.

Obviously, this approach can create supply-chain and system-design challenges. For example, a dedicated product design that uses a specific company's touch-screen system must incorporate all elements of that company's touch system. Later, if there is a need to substitute the physical touch screen from a different supplier into the design, in general the electronics will not be compatible and the original supplier typically will not assist with the substitution. Additionally, many smaller touch-screen suppliers do not have the resources to develop their own dedicated electronics; they either license them from someone else or leave the controller selection in the hands of the product designer.

Hampshire Company specializes in general-purpose touch-screen controller electronics that can support numerous screens and a wide variety of system implementations. Hampshire Company does not make touch sensors, but rather specializes in the electronics that allow them to operate.

The essence of ensuring that any touch-screen technology performs properly lies firmly within the touch-screen controller electronics and the associated software drivers and utilities. While a high-performance controller can greatly improve the performance of an otherwise mediocre touch screen, an inferior touch-screen controller can significantly decrease the performance and apparent lifetime of even the most superbly designed touch screen. Thus, it makes fiscal sense to spend as much time as possible identifying the best-performing controller and then choose the best-value touch screen.

This article focuses on the elements of selecting and integrating a surface-capacitive touch-screen controller and software. It includes a summary of the construction and material science used to produce a typical surface-capacitive touch screen, the theory of operation, problems, and solutions associated with the technology, and, finally, a summary of tests that can be used to identify a quality controller.

Construction

The construction of all surface-capacitive touch screens begins with the deposition of a high-resistance transparent conductive coating onto a glass substrate. As shown in Fig. 1, the transparent conductive layer is connected via a linearization pattern made of printed silver frit (also sometimes referred to as "bus bars"), which in turn is connected to a flex tail that is finally connected to the touch-screen controller.

Transparent Conductor. Suppliers use various materials to make transparent conductive films including:

- Antimony tin oxide (ATO) was used in the original surface-capacitive touch screens because it could be deposited on glass to create a uniform transparent coating with a very high resistivity (1200 – 2000 Ω/□.).
- Tin oxide (TO) has similar properties to ATO with slightly lower resistance values (but still over 1000 Ω/□) at considerably lower cost.
- Indium tin oxide (ITO) as the transparent conductor is now being attempted by some touch-screen manufacturers because it is more readily available and less expensive than ATO. However, to

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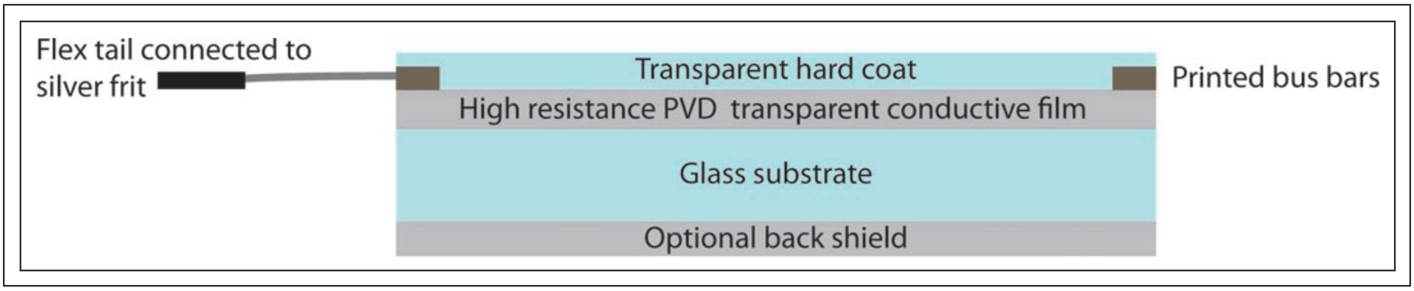

Fig. 1: *Schematic illustration of a typical surface-capacitive touch-screen sensor.*

date it has been very difficult to deposit a *uniform* ITO film on glass with a resistivity greater than 1000 Ω/□.

Touch-screen manufacturers have had difficulty finding multiple suppliers that can consistently produce acceptably coated substrates. Fewer than five companies supply all coated substrates used to manufacture surface-capacitive touch screens worldwide. This leads to sole-source problems where touch-screen manufacturers have little choice but to accept the quality, lead times, and pricing associated with a very limited number of suppliers.

This is also true of controller manufacturers – while there are at least 15 manufacturers of surface-capacitive touch screens worldwide, there are only five commonly known controller manufacturers. These include 3M™ Touch Systems (U.S.A.), DigiTech (Korea), eGalax_eMPIA Technology (EETI, Taiwan), Interaction Systems (ISI, U.S.A.), and Hampshire Company (U.S.A). 3M, DigiTech, and ISI primarily supply controllers to support their own sensors – they do not look at other uses by outside companies, in general. EETI has a range of independent touch-screen controller products that may be used with third-party touch screens, and also supplies USB video-capture devices and audio IC products.

Linearization Pattern. The linearization pattern is typically a silver frit material printed on top of the transparent conductive film along each edge of the touch screen. The primary functions of the linearization pattern are (a) to correct the inherent bow non-linearity associated with the properties of electrical currents flowing between corners of a rectangular conductive surface and (b) to connect the transparent conductive film to the flex tail. There will be more on the linearization pattern later in this article.

Transparent Dielectric Hardcoat. Typically made of silicon dioxide, this is applied to the touch screen to protect the transparent conductive coating.

Transparent Conductive Back Shield. This transparent conductive coating made of ATO, TO, or ITO shields the transparent conductor from EMI emitted by the display. Since it is used only as a shield, the linearity and uniformity of this layer is not important; only the conductivity and optical clarity really matter. The negative effects of back-shielded touch screens are the added costs of applying it and the 5–8% degradation in light transmission through the coating.

Many touch-screen manufacturers are trying to eliminate the back shield in an effort to reduce costs and improve optics; however, the side effects of doing so may not be worth the benefits. In some applications, a back-shielded touch screen is the only acceptable solution; in other cases, a non-shielded screen will function well, assuming the controller can effectively compensate for the EMI noise not being eliminated by a back shield. The choice of where the effects of EMI should be handled (on the sensor via electro-mechanical means or through the controller electronics and software) should be discussed with the controller manufacturer in light of the application and system design.

Theory of Operation

A capacitive touch screen operates by detecting a change in a known electrical current that occurs when the screen is touched. An ac signal voltage is applied to the front conductive surface of the sensor through the four corner wires. All four corners are driven with exactly the same voltage, phase, and frequency. When a user's finger comes in contact with the transparent hardcoat (top layer), a small amount of electrical energy is coupled capacitively from the sensor to the user, causing a small but measureable amount of current to flow through each corner wire. The atmosphere and a path from ground back to the controller complete the circuit.

Thus, the system identifies a touch by comparing a known "baseline" current (when the screen is not being touched) with the change in the current that occurs when someone touches the screen. Most controller manufacturers drive touch screens at frequencies between 25 and 200 kHz with a sine or square waveform. The current absorbed by someone touching the screen is typically around 1 µA. The touch-screen controller identifies a touch location by measuring the amount of current it needs to supply to each corner of the touch screen to return to the baseline voltage level. The amount of current that must be supplied to each of the four corners is directly proportional to the proximity of the touch location to the corners. Once these values are identified, the absolute value of the reported position depends on resolution of the touch-screen controller's analog-to-digital converter (ADC). For example, a 10-bit ADC reports one of 1024 positions on each axis, while a 12-bit ADC reports one of 4096 positions.

As shown in Fig. 2, each corner of the capacitive touch screen is powered with an oscillating drive signal. The back shield, if used, is also powered using the same signal. A form of current-measurement technique is used to produce an instantaneous signal corresponding to the current flowing through each corner output. The ac-to-dc converter then rectifies the oscillating signal, producing a dc value that is then passed into the analog filter section. The analog filter section removes much of the ambient noise left in the RMS signal, resulting in a stable measurement. From there, the signal passes to the amplification and gain stages, which amplify the very small measurement signal and apply various levels of automatic gain control. This ampli-

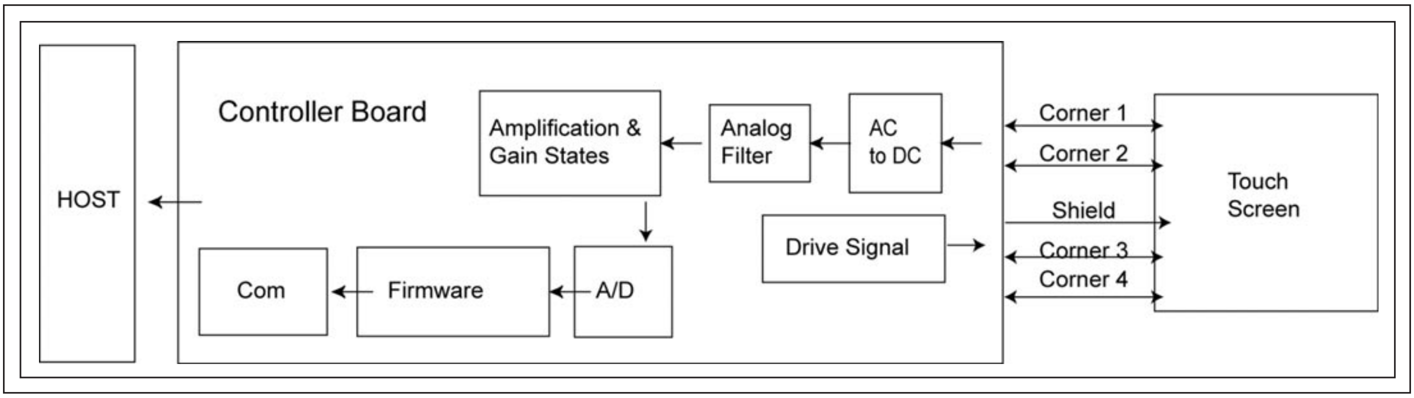

Fig. 2: *A schematic illustration of a typical capacitive touch-screen controller.*

fied "good signal" is then converted to digital data by the A/D converter. Once the signal passes through the A/D converter, the firmware further scrutinizes the touch signal, determines touch location, and sets other properties such as sensitivity. Finally, this touch information is sent on to the HOST computer via the communication protocol used.

Important Characteristics in Surface-Capacitive Technology

Surface-capacitive touch technology does encounter some real-world issues, many of which are detailed below. Most of these can be solved by the use of a high-performance touch controller as illustrated above.

Sensor Linearization. Linearity in a touch screen means that the resistance measurement from any point in a row or column to the parallel edge of the touch screen remains the same regardless of the position of the point in the row or column. A straight line drawn across a perfectly linear touch-screen sensor should result in a set of coordinates that produce a perfectly straight line on the display, without the controller having to apply any software correction. In the real world, however, imperfections in the linearization pattern, and anomalies in the transparent conductor, mean that the controller must always apply some correction (Figs. 3 and 4).

Human Variation. The human fingertip is almost always used to activate a surface-capacitive touch screen (this article does not discuss the use of an electrically tethered stylus). People come in all shapes and sizes and have different electrical characteristics (*e.g.*, moisture content) associated with their body chemistry. A small person draws less current than a big person; a big finger draws more current than a small finger; a small finger on a big person may draw more current than a big finger on a small person. Even more important is that a person's electrical characteristics may change if they come into contact with a grounded object while operating a touch screen. This is the most difficult problem of all – many controllers cannot compensate for this variation. These changes account for as much as an order of magnitude in measured touch-signal strength. In addition, most surface-capacitive sensors have a very thin dielectric space between the conductive surface and the user's finger. Even slight increases in this spacing result in order-of-magnitude reductions in signal strength. Therefore, since a non-conductive glove acts as an additional spacer, a gloved hand in general does not draw enough current to be recognized by a surface-capacitive touch screen.

Screen Size. The physical size of the touch screen also impacts its overall performance. Larger touch screens are more susceptible to EMI from the display and the environment (they act like a larger antenna). The higher level of interference can demand more performance from the controller electronics in identifying and rejecting noise that mimics touch-screen activation. The linearity pattern and the transparent conductive coating are both more difficult to control on larger screens and as such increase the inherent non-linearity problem associated with producing these screens.

Grounding. The touch screen's system ground can have a tremendous effect on how well the system performs. A surface-capacitive touch-screen system *must* have a stable system ground so the controller can establish a baseline power level. In the absence of a solid ground connection, the controller continually attempts to find a stable baseline that does not exist. This is a primary reason that surface-capacitive touch screens are almost exclusively used in stationary applications.

Integration. The touch screen must be firmly mounted to the display and insulated from the conductive portions of the display – if not, the controller will not be able to establish a baseline. Further, if the touch screen is not securely fastened to the display and is allowed to move (relative to the display) during operation, the controller will not be able to establish a consistent baseline. Lastly, the tail must be shielded in order to greatly reduce EMI noise and improve the chances of being able to use a non-back-shielded touch screen. Improper integration of a surface-capacitive touch screen always produces an inconsistent poor-performing system, even in the presence of a high-performance controller and touch-screen sensor.

Dynamic Amplification and Signal Isolation. Because the signal associated with an actual touch is very small (1 μA), it must be amplified in order to use it. While this can be done quite easily using standard amplification techniques, the difficulty is in isolating the signal associated with the touch from the ever-present noise. Different controller manufactures use different signal isolation methods; some work better than others. Dynamic amplification (gain states) and signal-isolation processes work very closely together; if the touch-screen controller cannot perform the isolation function effectively, it may miss touches or recognize touches that

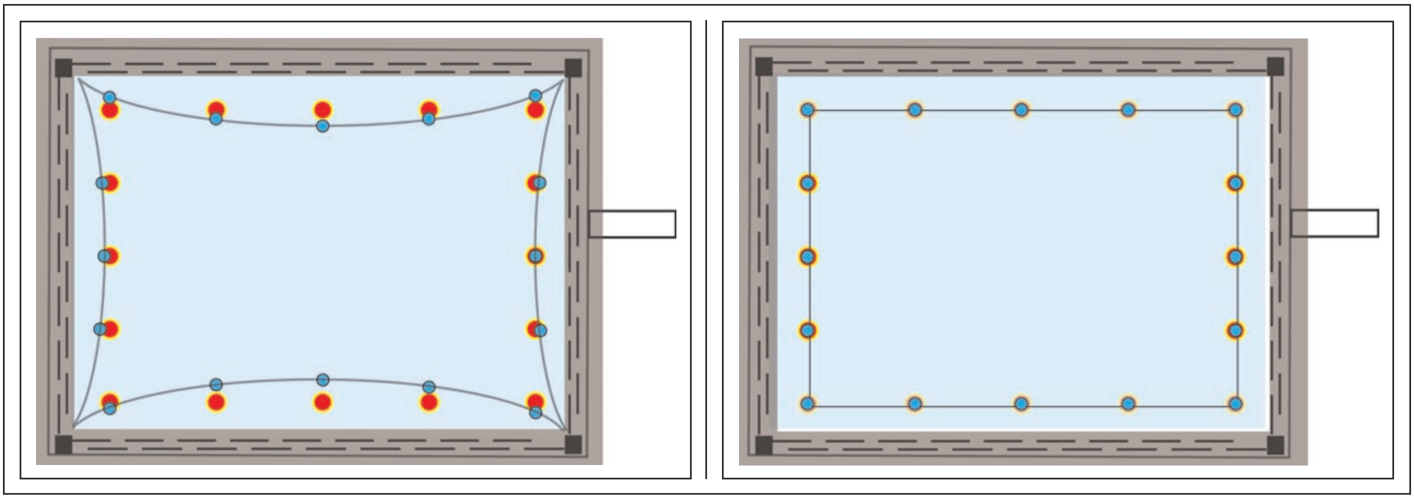

Fig. 3: Before-and-after illustrations of the characteristic "bow" shape of un-linearized reported points and how a linearization utility remaps physical locations (red) to reported locations (blue).

never really happened. The solution is dependent on the cooperation between the controller's circuit and the onboard decoding firmware. A controller's ability to maintain a stable position while changing gain states is therefore a critical performance characteristic.

Operating Frequency. As previously noted, controller operating frequencies range from 25 to 200 kHz. The unique default frequency selected by each manufacturer is chosen to limit the impact of noise generated in a typical environment. In order to allow for the essentially infinite range of environments in which a touch screen has to function, a properly designed controller must allow the frequency to change to best suit the environment.

Noise Filtering. Hardware and software noise filtering can be used to reduce the effects of EMI; higher-performance filtering allows a touch screen to be used in a wider range of environments. It also has the potential of allowing the use of less-expensive non-back-shielded touch screens. That said, sometimes the noise associated with a specific application is just too great to be handled by the controller alone and a more-expensive back-shielded touch screen is still the best option.

Static Protection. Static electricity can be a big problem for all touch-screen applications. Static electricity typically travels along the surface of the touch screen to the closest edge and then into the controller electronics via the flex tail. While some integration techniques can help reduce the effect of static problems at the system level, the controller should be able to absorb and eliminate a charge up to 27 kV without damage. (This voltage specification comes from the gaming industry.)

Testing Surface-Capacitive Touch-Screen Controllers

There are several elements to test when looking at touch-screen controllers:

Test the Hardware. Test each controller with various manufacturers' touch screens. Test how it performs with back-shielded as well as non-back-shielded sensors. Keep in

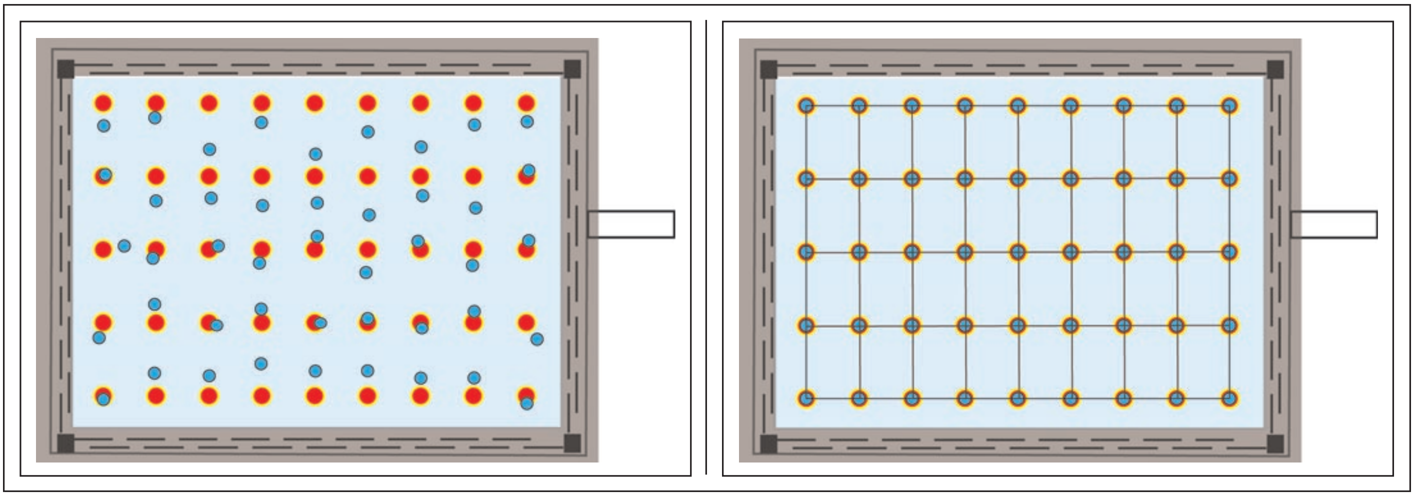

Fig. 4: Before-and-after illustrations of un-linearized and linearized reported points.

mind that this is a relative test. It is possible that your system is simply too noisy to use a non-back-shielded touch screen and it may not work with *any* controller. Investigate the controller-obsolescence frequency and whether they have issued last-time-buys in the past. Determine if they use an ASIC that cannot easily be updated. Find out if their drivers and software utilities have consistently been backward-compatible with prior releases of their controllers.

Test the Dynamic Gain-State Processes, Speed, and Sensitivity. While holding your finger on the touch screen, touch a grounded object such as the metal chassis of a PC and observe if the cursor remains stable. If the cursor moves, the controller is not handling the gain-state changes properly. Draw a line and observe the smoothness of the line with each controller. Draw fast and slow circles and observe if the cursor keeps up with your finger, and if fast circles remain circles rather than turning into polygons. Quickly flick the screen with your finger (gaming companies call this "swooshing") and observe if the touch is consistently recognized. Turn off the computer and turn it back on (without touching the screen while the computer is booting). Repeat the tests and observe if any of the results have changed.

Test the Drivers and Software Utilities. Once the driver is installed, test that it can be completely un-installed and then re-installed. This has been an industry problem for a long time. Once a specific manufacturer's driver is installed, it can sometimes prevent another manufacturer's driver from being installed properly – even after un-installation – unless the entire operating system is re-installed.

Summary

A high-performance touch-screen controller should be able to be configured (or automatically configure itself) for a wide range of touch-screen manufacturing specifications. A controller with a limited operations window may cause a touch-screen system to fail prematurely if the sensor reports positions that exceed the controller's acceptable range. The controller should enable use of standard communication protocols as well as migrate across industry standard commands. It should enable the choice between touch-screen constructions, materials, and manufacturers. The controller should provide the freedom to choose options rather than limiting options. ■