WHITE PAPER

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Noise Wars:
Projected Capacitance Strikes Back

Abstract

Touchscreen performance in the presence of noise is one of the major obstacles facing mobile electronics device designers today. This article will discuss the two major sources of noise, display noise and charger noise. It will discuss design techniques and available solutions that can be used to overcome these challenges.

Introduction

While the touch experience is the most critical feature shaping mobile phone innovation today, the speed and complexity at which the components under the hood are evolving is astounding! Enabling multi-touch systems that perform with the precision today's users expect while still dealing with demanding environmental conditions is no small feat. This challenge is heightened given that the internal environment is rapidly changing. In the war for touchscreen dominance, new battlegrounds are emerging.

One current trend is the push to make phones thinner. This means direct lamination of capacitive touch sensors to the display, migration of the sensor inside the display, and many other challenges with antennas and ground loading. Gone are the days where it was acceptable to just throw a shield layer onto the sensor structure to block display noise. This adds too much cost.

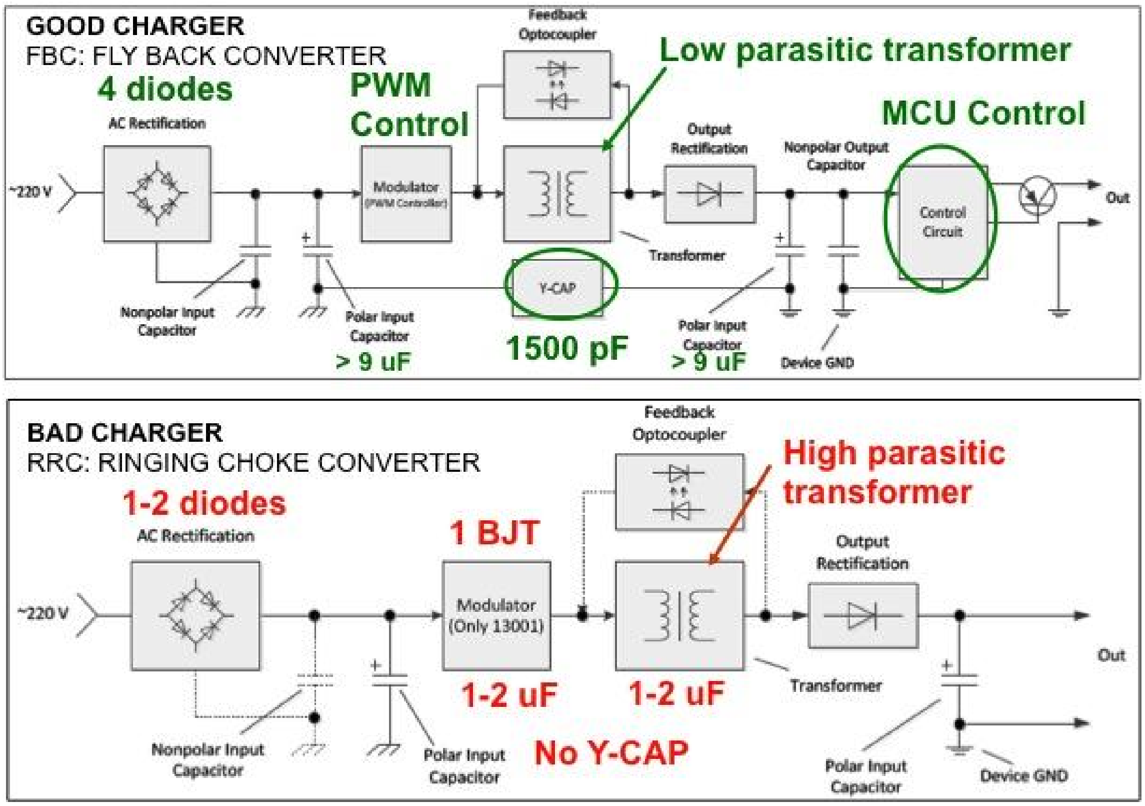
Beyond displays, the prevalence of USB charging connectors has commoditized battery chargers to the level of pulling every last cent from these devices. Now capacitive touchscreen IC's are being asked to sense pico-Coulombs of change in the presence of up to 40Vpp AC noise. All of these factors add up to requirements for touchscreen ICs that are far more complex than where the market started. New innovations are required. So begins, the noise wars.

Charger Noise

Charger noise is one of the most talked about noise sources when it comes to capacitive touchscreens. This is noise that is physically coupled into the sensor during the presence of touch through the battery charger. It can be seen as degraded accuracy or linearity of touch, false or phantom touches, or even a touchscreen that just becomes unresponsive or erratic. The culprit is typically an aftermarket low cost charger.

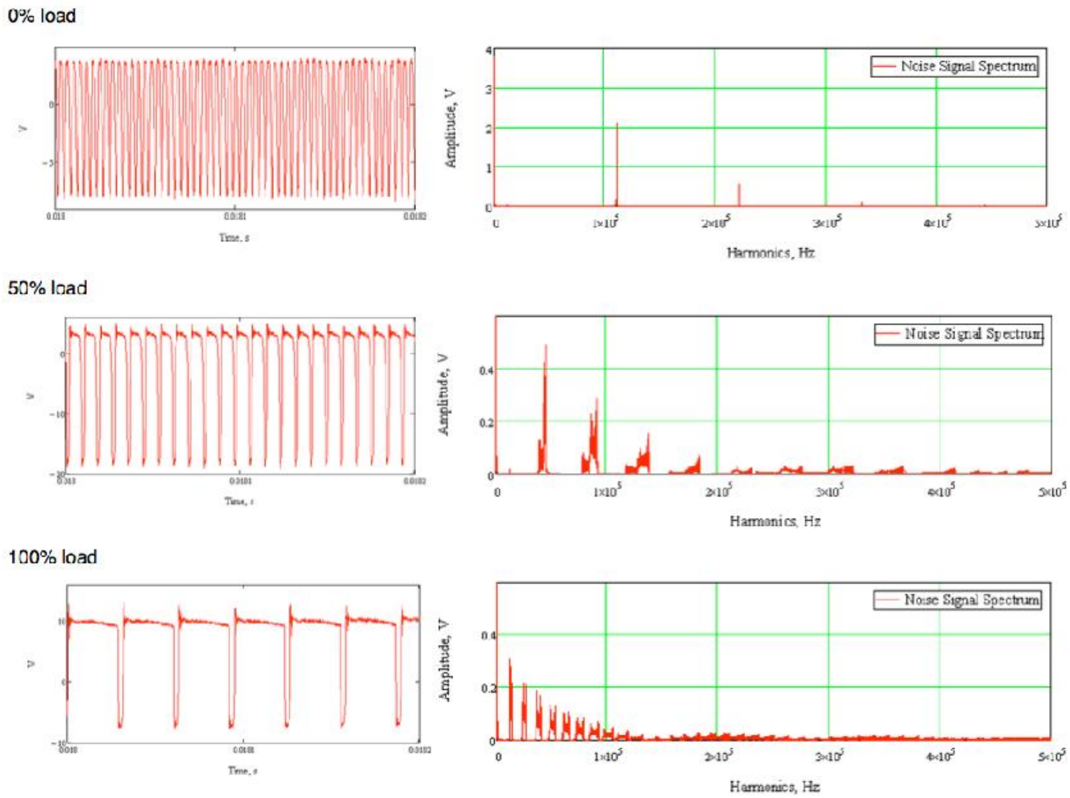
While the OEM chargers designed to work with a particular phone have tighter specifications on noise, the widespread adoption of USB connectors for charging circuits has created a massive aftermarket opportunity. Fighting to compete in this space, aftermarket manufacturers are dropping every last cent out of these chargers. The result of the low cost electronics, a charger that will charge your phone and inject so much noise into your touchscreen, it may be unusable.

Two of the most widely used types of battery chargers are the ringing choke converter and the fly-back converter. The fly-back converter charger typically uses a pulse-width modulation (PWM) circuit whereas the ringing choke converter is a very low cost self-oscillating variant of the fly-back. Below is a diagram illustrating the architectural differences between the two.

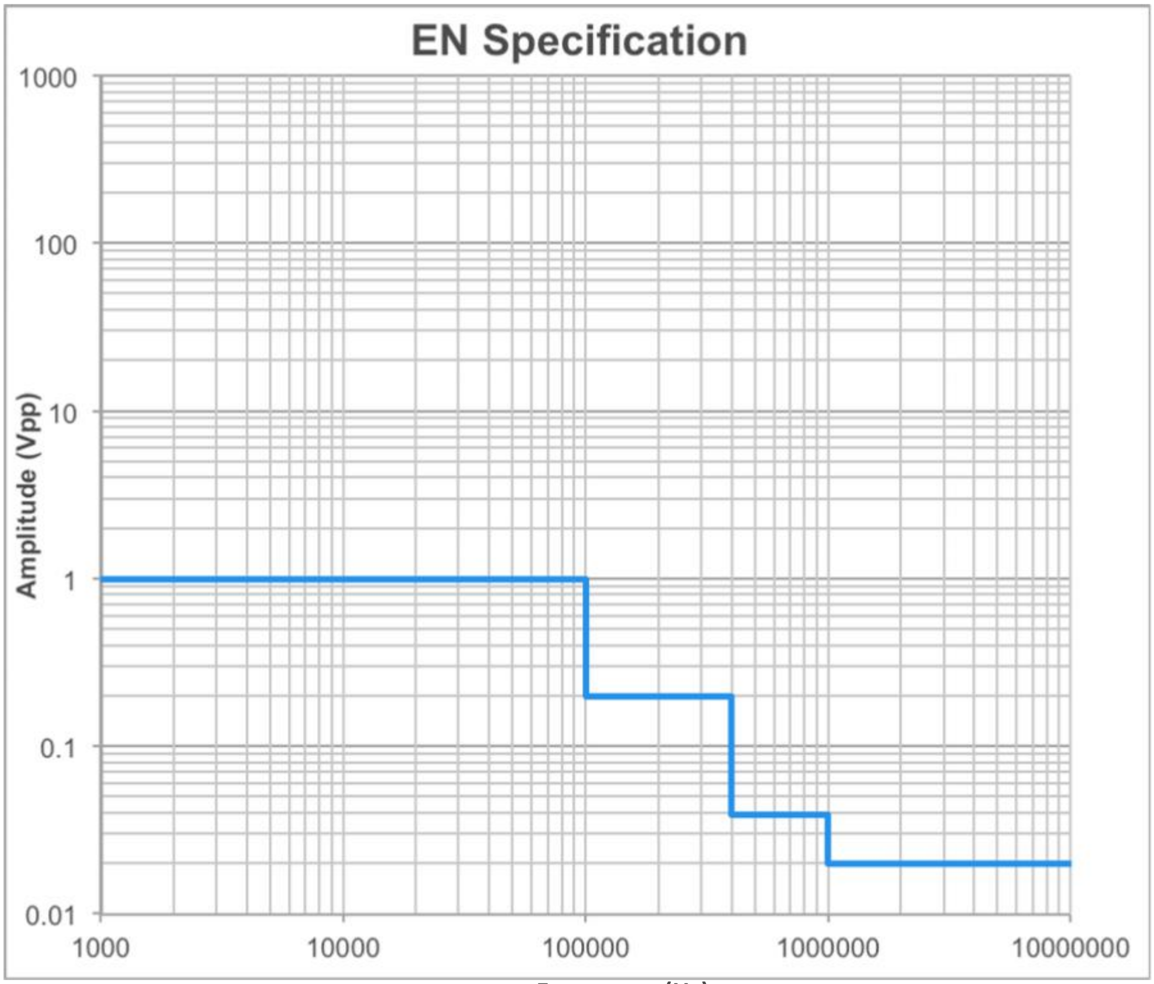


It is clear that much has been pulled out from the fly back converter with the ringing choke converter. There is no longer an MCU, a lack of PWM control, no Y-cap, a lower cost transformer, fewer diodes and lower capacitance polar input caps. This equates to quite a bit of cost savings for the manufacturer. The result is a very noisy system.

Some ringing choke converter chargers verge on the grounds of becoming classified as broadband noise generators, as they are putting out as much as 40 Vpp noise ranging from 1 kHz up through nearly 100 kHz. Most end up having more periodic noise tendencies with many harmonics. One well known charger has been measured to output anywhere from 10 to 25Vpp. Below is a look at measurements of this device with varying loads.



It is easy to see the various harmonics generated from this charger, and peak voltages can range up to 25Vpp. It is also noteworthy that its response is quite dependent on the battery state itself. To fight against this phenomenon, many OEMs banded together to create EN specifications that govern the maximum noise levels a charger should emit at any frequency. EN 62684-2010 and EN 301489-34v1.1.1 govern these noise levels and can be seen below.



Frequency (Hz)

From 1k Hz through 100 kHz, a charger is expected to output no more than 1 Vpp noise, and the levels degrade exponentially from there as frequency increases. While this specification is stringent, none of the aftermarket chargers conform. As such, OEM's are now asking touchscreen ICs to deal with noise at much higher levels. Some specifications are requiring 40Vpp from 1 kHz through 400 kHz, with 95 Vpp immunity in the 50-60 Hz range. Fortunately there are specialized algorithms and methodologies on the market such as Charger Armor, from Cypress, which can meet stringent requirements and provide upwards of 95 Vpp noise immunity to battery chargers. These levels are achieved through a variety of mediums, be it nonlinear filtering, frequency hopping, or other hardware methodologies.

Achieving noise immunity that meets the specifications of today's mobile industry requirements is not trivial. Typical touchscreens solve the problem with filtering in the processor. While the age-old saying of "garbage in, garbage out" is not 100 percent accurate, it is still critical to start with a clean signal. One of the best ways to overcome noise from chargers, especially those that output broadband noise is to overcome the noise with pure signal. As the raw SNR generated from the analog side of the touch controller is directly proportional to the voltage at which the device drives the panel, high voltage Tx is desired.

$$SNR \propto V_{Tx}$$

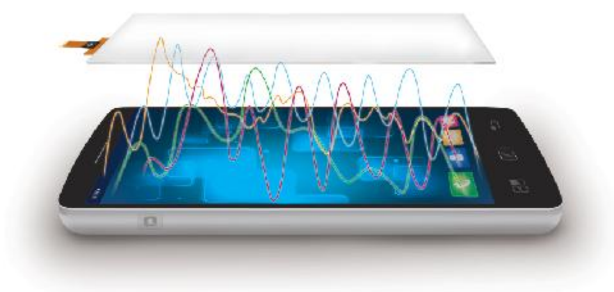
Typical touchscreen controllers drive the panel at the supplied 2.7-V rail to the device. The Gen4 controller from Cypress does something different. It takes in the same 2.7-V analog supply, but actually drives the panel at 10 V. The charge pump and 10-V transistors are built into the Gen4 device, and this allows it to deliver 3.7 times the raw SNR of any other chip.

Once the signal is acquired, all of the typical things like median filtering or other more advanced non-linear filtering techniques can be used to further boost SNR, at the expense of refresh rate. 10 V Tx has been shown to deal with chargers outputting noise as high as 31 Vpp in-band though, without the need for this advanced type of filtering.

But what happens when the in-band noise is too high? This is where other advanced techniques are important. If the in-band noise becomes too large for the device to cope with, Gen4 has the unique ability to deal with this by dynamically adjusting its Tx frequency, and moving the channel to avoid the noise. Adaptive frequency hopping is another key piece of solving the charger noise problem in touchscreens.

Display Noise

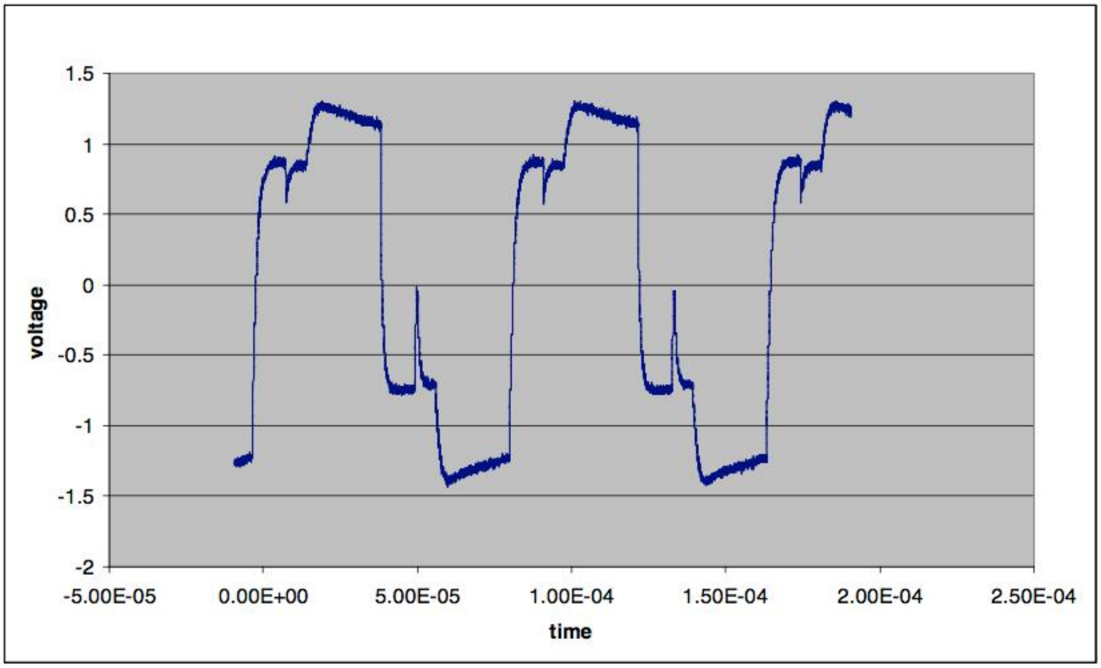
Displays offer many challenges for projected capacitive touchscreen systems. This is because they can generate quite a bit of noise that can be conducted directly into the capacitive touchscreen sensor. To make matters more difficult, OEMs are demanding thinner industrial designs for their phone models, which means moving the actual touchscreen sensor closer to the display, and even i



For years now, the industry has used a shield layer to protect the sensor from the noise generated by the display. This adds both cost and thickness to any phone, but is quite effective. The industry has also used a small air gap, typically about 0.3 mm in height between the display and the sensor to allow the natural properties of air to dissipate the conducted noise from the display. However, as the industry is moving to make phones as thin as possible, both of these options are non-ideal for today’s designs.

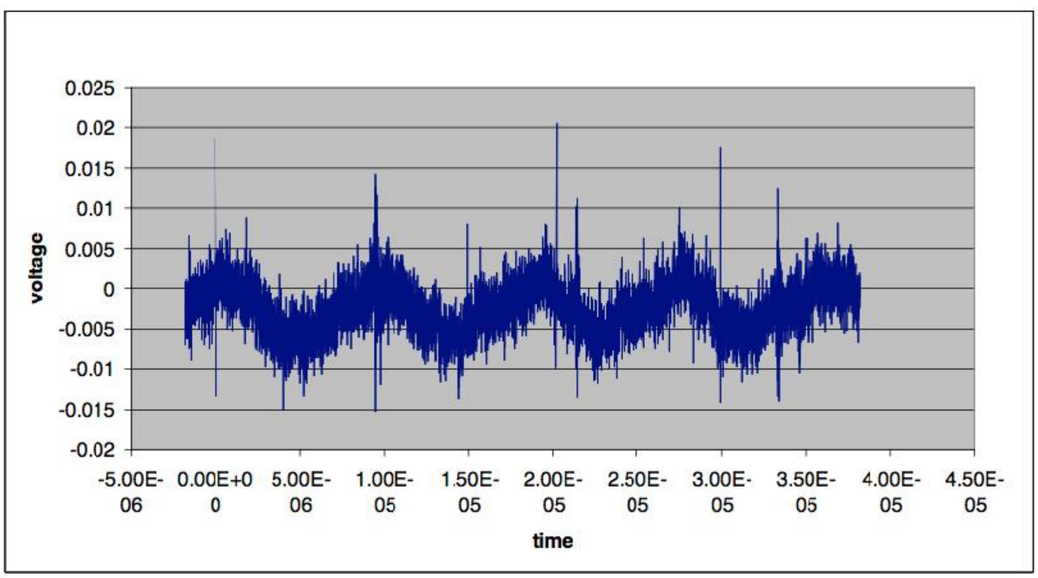
Fortunately the levels of noise that are emitted from displays are far lower than the noise levels from chargers. That being said, they are directly coupled across the entire surface of the sensor, and still quite difficult to deal with.

In traditional TFT LCDs, the common electrode (VCOM) is driven by either a DC or an AC voltage. An ACVCOM layer is typically used to lower the operating voltage of the display driver while keeping constant the voltage across the liquid crystal. It's a relatively low-cost display, and one should expect higher power consumption in this type of display versus DCVCOM, and also a noisier profile. A quick look at a typical waveform from an ACVCOM display is shown below.



Typical ACVCOM type displays will have noise profiles centered around 10-30 kHz, and anywhere from 500 mVpp to 3 Vpp (as shown above). DCVCOM can be quieter. When measuring noise from a display it can be done as simply as adding a little copper tape to the top of the display, connecting the oscilloscope to that tape with ground connected to the display's circuit ground, and running the display to catch the waveforms.

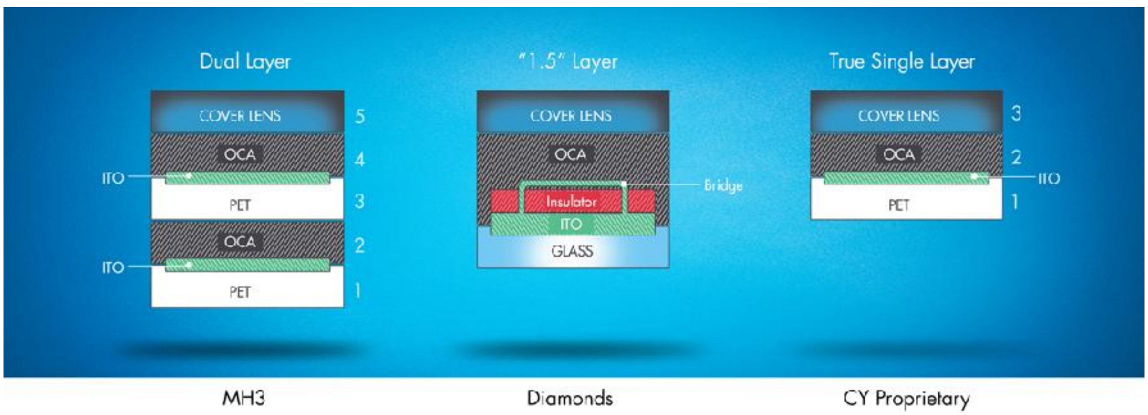
AMOLED is gaining a lot of traction in mobile phones. It has a very wide viewing angle and can provide very bright colors and deep contrast. Amazingly enough AMOLED displays are also very quiet, though this functionality does come with a price. Below is an example of a typical AMOLED display noise profile.



Note that the AMOLED display is outputting maybe 30 mVpp in the peak spikes. This is 1% of the noise from an ACVCOM display, and greatly helps with touchscreen design. In fact, integrating the sensor inside the physical display to create an on-cell or in-cell topology is actually quite easy with this type of display. However, it is much more expensive than a traditional LCD.

With on-cell designs, the sensor layer is physically deposited on top of the color filter glass inside the display. This brings it much closer to the chemistry of the display since it is now physically inside the stackup. Not only does the noise increase, but so does the parasitic loading. Fortunately AMOLED is inherently quiet, and makes for a very good platform for on-cell or in-cell (sensor beneath the color filter glass) design.

So how do touchscreen IC's deal with display noise when they can't use an air gap or a shield layer? Fortunately when designing sensors in PET, one well accepted sensor structure is to use a two layer sensor, where the Tx lines are in the lower part of the senor, and the Rx lines are in the top. As the Rx lines are sensitive to display noise, the wide Tx lines in the bottom of the sensor form a barrier against the noise generated in the display. This effectively builds the shield functionality into the sensor pattern. The following diagram shows the various types of sensor structures.



MH3 is the dual layer stackup referenced, where the bottom layer of ITO acts as a shield to display noise. Unfortunately, this solution is not often used in glass based sensors, and it still increases thickness and cost. As such, the industry is pushing to build sensors on a single substrate layer with no shield. To enable true single substrate layer sensors without shielding requires the touchscreen IC to be resilient to display noise. This is not an easy task, as display noise can easily reach 3 Vpp in AC or DCVCOM type displays.

Fortunately display noise can be mitigated even in direct lamination (where the sensor structure is laminated to the top of the display with no air gap or shield) or display integrated types of designs. Display Armor from Cypress is the industry's most advanced adopted method for combating display noise. By integrating a built-in listening channel to the touchscreen device, touchscreen ICs can eliminate display noise in two distinct ways. One way is to make advanced algorithmic decisions on what information is noise vs. data. Another is to detect the noise source and latch on to the waveform such that capacitive measurements are made during quiet times. Either way, the result is advanced and thinner capacitive touchscreen stackups at lower costs.

Summary

Aside from noisy displays and chargers, many other challenges face capacitive touchscreen designers today. Antennas are huge sources of noise challenges. With the real estate within a phone becoming further threatened, components are literally being placed on top of each other. This is the case with antennas and the touchscreen sensor. Such design challenges can create real issues in dealing with that portion of the touchscreen. Fortunately the same innovations that are helping display and charger noise are also helping other noise sources like antennas. Be it simple IIR filters, advanced nonlinear filtering methods, built-in noise avoidance hardware, hopping capabilities, or any other methods; capacitive touchscreens enable some of the most advanced functionality in the whole embedded device.

While the projected capacitive touchscreen controller space is going to continue to evolve, it is clear that noise immunity is the biggest trend in this space. Whether it is noise from displays, chargers, antennas or other sources; touchscreen ICs are required to perform with the same level of user experience. Innovation is happening daily in capacitive touch, and touchscreen ICs continue to wage the war against noise.

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