

WHITE PAPER

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Noise Immunity of Touchscreen Devices

Abstract

Dealing with noise is an important aspect of any real-world electronic system, including a touchscreen in a cell phone or tablet. While there are many sources of noise that can interfere with capacitive touch sensing, the most prominent ones originate in displays and battery chargers. This white paper explores considerations for dealing with noise issues in touchscreen design.

Dealing with noise is an important aspect of any real-world electronic system, including a touchscreen in a cell phone or tablet. While there are many sources of noise that can interfere with capacitive touch sensing, the most prominent ones originate in displays and battery chargers. For example, LCD displays, which are tightly coupled to a touchscreen sensor, can easily produce noise levels exceeding that of the finger signal. This is because operating signals for LCDs often reach 10–20V amplitude, and these signal lines are very close to the sensor layer, causing significant disturbance.

Likewise, charger noise can exceed touch signals by a large factor. Unlike LCD noise, the charger noise spectra can be wide and time-variant, making rejection very challenging. Charger noise magnitude can exceed LCD noise and may exceed even 60Vpp. LCD and charger noise have different characteristics and couple differently to the touchscreen, and thus it is worthwhile to briefly explain the nature of those noise sources, followed by the methods to deal with them in a touchscreen environment.

LCD Noise

Noise from an LCD display couples into a capacitive touch sensor through close physical proximity, nominally some 0.2–0.4 mm away from the capacitive touch sensor layer of a phone or tablet. Sometimes an air gap is present, reducing the coupling between the display and the touch sensor. However, the industrial design trend towards thinner display/sensor stack-ups results in even tighter coupling between the display noise source and the touch sensor. Consequently, LCD noise will become even more significant in the future.

Fortunately, LCD noise is an inherent and fairly predictable characteristic of the display at hand, and thus it can be dealt with during the touch solution development process. In other words, LCD noise doesn't significantly change after the design phase of the product. However, this situation is quite different for charger noise.

Charger Noise

With the near-universal shift to USB-based chargers for portable touch-controlled devices, "charger noise" has become a major noise source as well. The underlying reason is that the common USB connector enables aftermarket companies to push inexpensive chargers into the market. To achieve this low cost, many of these chargers leave out critical noise suppression

components, and in turn create a serious noise problem which can interfere with the operation of a touchscreen. While excessive charger noise can be detected and flagged, very few products currently display a warning message that a non-certified charger is being used.

It is helpful to further understand the nature of charger noise. At first, one might think that the 5V output voltage of the USB charger may be noisy, but that is not the problem facing touchscreen controllers. Instead, the charger noise problem is a result of so-called “common-mode” fluctuations (noise) of both output leads.

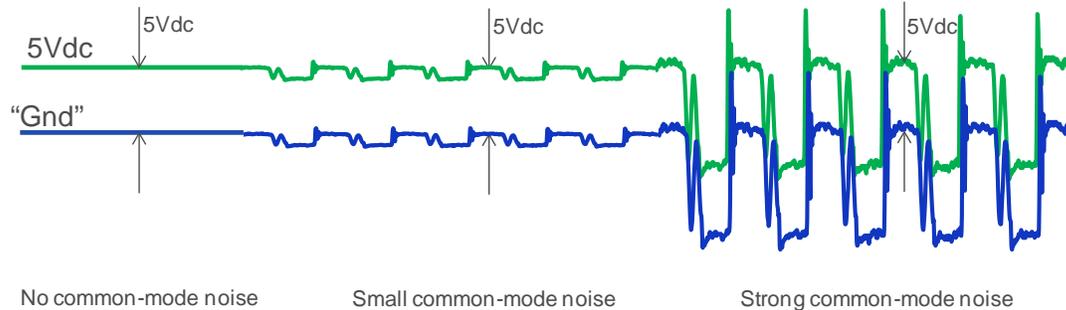


Figure 1. Various levels of common-mode noise in chargers

As Figure 1 illustrates, both the 5V and the 0V output leads of the charger remain 5V from each other, but present noise to the phone in that they move up and down *together*, in a “common mode” manner. The best chargers keep the common-mode noise at low levels, such as 1–3V, whereas poor chargers may exhibit 40V of peak common-mode noise (and some are even worse).

When a phone is connected to a charger with common-mode noise, the entire phone “moves” relative to earth ground as it follows the common-mode noise. This is not a problem, *until* a finger touch occurs on the screen which introduces a (capacitive) path to that same earth ground. That touch creates a path for charge flow, which is equivalent to a noise signal injected exactly at the finger location (see Figure 2). Note that when the phone is held in someone’s hand, the entire phone may very well be grounded to earth sufficiently and no significant “common-mode” noise charge would flow through the touching finger to earth. However, if the phone is connected to the charger and placed on a desk, a touch of the screen, as illustrated in Figure 2, can introduce a problematic discharge path to ground.



Figure 2. Coupling of the common-mode noise through the touchscreen

Other Noise Sources

There are additional noise sources affecting everyday touch operation. For example, fluorescent lights, with their electronic ballasts, and AC mains (e.g., 110/220V) easily couple capacitively onto a human body, and thus find their way into the touchscreen sensor. One can see this simply by touching the tip of an oscilloscope probe with a finger to produce a very large and easily visible signal. The same happens when touching a phone's screen.

At Cypress, we have also investigated the impact of other noise sources produced in airplanes, trains, cars, machinery, factories, electronic laboratories, and alternative wireless chargers (i.e., mats or pads placed under a phone for wireless charging). All these sources of noise have their respective characteristics and vary substantially over amplitude and spectral content. In addition, noise sources are often applied simultaneously to a touchscreen, not just one at a time. For example, LCD noise tends to be present whenever a touch operation occurs, combining with AC mains coupling and charger noise sources.

Why Noise Matters So Much

As the following example illustrates, finger-touch signals are very small and can be easily overshadowed by the noise sources mentioned here. For a Touchscreen Controller (TSC) to perform well in these systems, it must pick out the useful signal and suppress the noise. Unfortunately, LCDs and chargers tend to produce noise in the same range of frequencies that TSCs use to sense touch – typically around 100–500 kHz. Noise that falls into this frequency range disturbs the sensing operation, just like RF interference on a radio channel can cause an audible disturbance.

Most noise sources do not consist of a signal at just a single frequency. Rather, the noise signal is often “wideband”, meaning it occurs over a wide range of frequencies such as 100 kHz to 1 MHz, although typically with lower amplitudes at higher frequencies.

All this would be acceptable if the noise amplitudes were small, but in many cases, noise can exceed the finger signal by a factor of 10x or more. To put this in perspective, let’s compare the actual magnitude of finger and noise signals.

When a finger makes contact with a projected-capacitance touchscreen, the actual signal of interest is the change in mutual capacitance between certain elements of the sensor at the touch location. Such a finger touch changes the sensor capacitance by often no more than 0.2 pF. Note that this is the full-scale signal. For accurate coordinate calculations, it is important to pick up partial touch signals of adjacent elements of the sensor as well. Thus, we want to resolve touch with at least 0.002 pF resolution or just 2 fF. A stimulus (“TX”) signal driving the touch sensor is often in the range of 2-3V. We can calculate the total signal charge produced by the touch event:

$$\delta Q = \delta C * V_{TX} \quad (1)$$

where δC is the change in capacitance, and V_{TX} is TX driver voltage. So the change in charge δQ produced by finger touch is in the range of 5–500 fC.

Now, consider that a touching finger also introduces coupling capacitance from the sensor to earth ground of around 1–3 pF. Let’s use 2 pF for our example. If the noise amplitude from a charger is somewhere around 5–50 V, we can use equation (1) and we’ll find that the noise charge injected by the finger is

$$Q = C * V = 2 \text{ pF} * 5..50 \text{ V} = 10..100 \text{ pC}$$

For our example case, the noise signal exceeds the full-scale finger charge by 10–100 times, and partial touch by 200–2000 times. Clearly, it’s not a trivial task to extract the finger signal out of so much noise.

Charger (Common-Mode) Noise Characteristics

To better understand the issues caused by common-mode noise, we need to take a closer look at actual charger common-mode noise spectra. Two examples are shown in Figure 3. Charger A exhibits “narrow-band” noise, having several distinct peaks of high amplitude, each centered around a fundamental frequency and its harmonics (150, 300, and 450 kHz in this example).

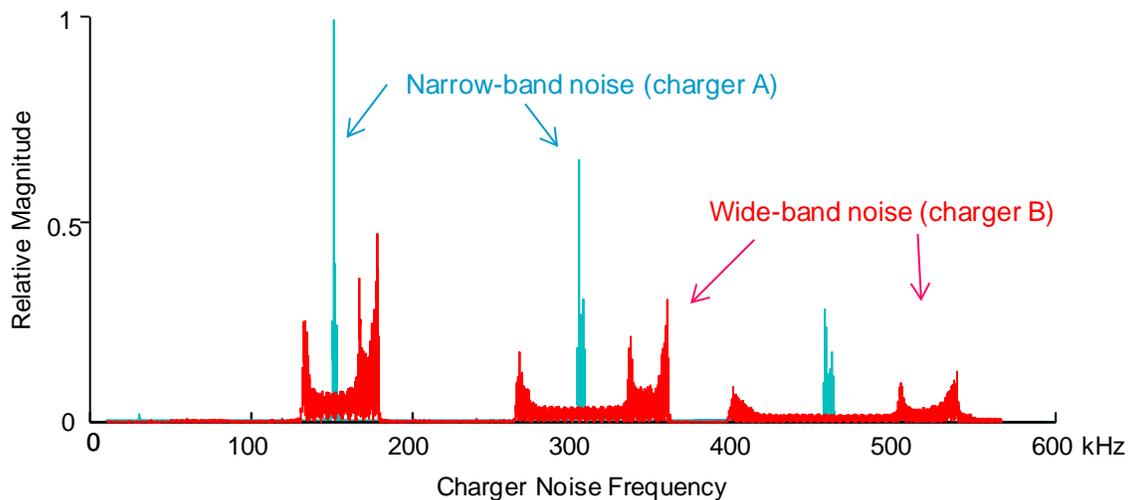


Figure 3. Examples of charger noise spectra

Charger B exhibits a more “wide-band” noise behavior. This charger also exhibits somewhat lower peak amplitudes than the first charger, as it spreads its energy over a wider spectrum, all the way from 130 kHz to over 500 kHz. This broad-band nature can make it more challenging for the TSC to find a “quiet” operating frequency.

To make matters more complicated, the chargers’ noise spectra are not constant. While the battery is being charged, the noise spectrum gradually changes because the load current eases off. Figure 4 illustrates this behavior for two different chargers (top and bottom row). Each charger is loaded at 0%, 50%, and 100% of its maximum rated load current (left, center, and right columns). The charger in the top row exhibits not only very large noise amplitudes, but its spectrum also easily exceeds 1 MHz. Note that while the charger in the bottom row seems much quieter, both chargers exceed the industry-endorsed charger noise specs¹ by at least a factor of 10. Clearly, if these chargers would comply with the EN specifications, charger noise would not be a problem at all.

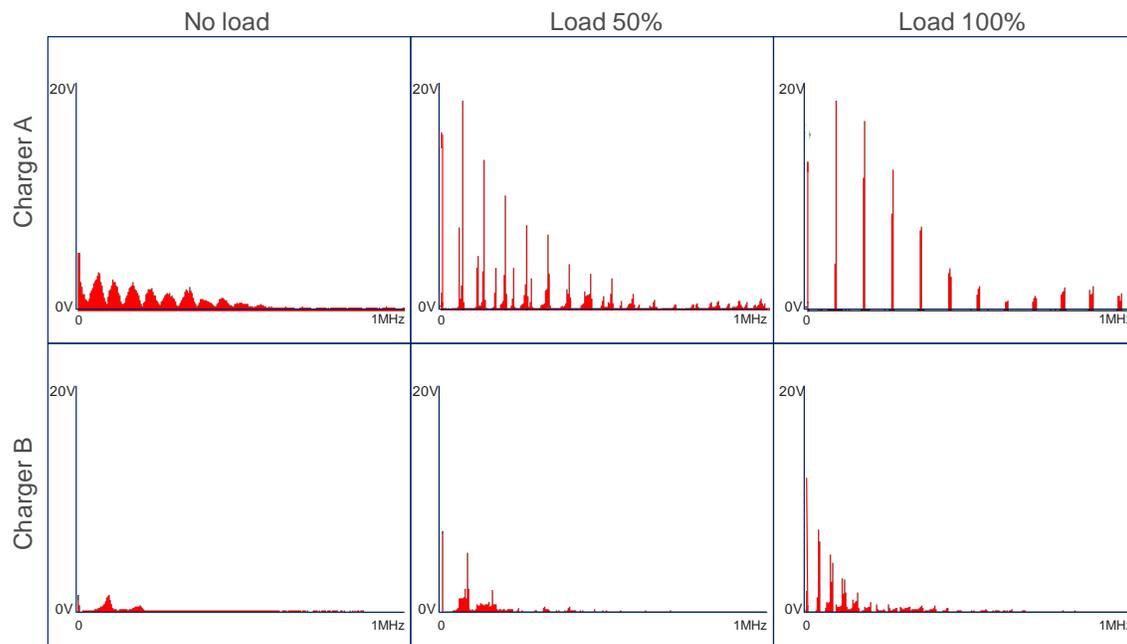


Figure 4, Common-mode noise spectra for 2 chargers (top, bottom) and vs. 3 load currents

Inspecting the load variation impact further, the charger in the top row changes the magnitude of the spectral lines over 10 times, as the load current varies from 0 to 100%. With such highly unpredictable noise situations in actual use, it is important to assess the noise-handling performance of a TSC.

Noise Tests

The charger noise examples in Figure 3 and Figure 4 are just a few out of a countless variety of chargers. Even for the same model of chargers, noise characteristics can vary significantly from one unit to another. This is because not only does the tolerance of internal charger components vary, the circuit design may change over time while the manufacturer keeps the product name unchanged. This makes it difficult to determine what’s going on inside a charger and how much it may interfere with touchscreen operation.

¹ EN 62684-2010 and EN 301489-34v1.1.1, allowing for a max peak amplitude of 1V up to 100 kHz, lower thereafter

To create reliable devices, developers need to be able to determine noise performance of a TSC as well as predict how the TSC will perform under unpredictable charger noise situations. Currently there are no standardized tests for assessing LCD or charger noise performance. In lieu of a standard, Cypress uses several noise characterization methods, including synthetic square wave tests as well as a suite of notoriously noisy chargers.

The Square-Wave Method

One characterization method for comparing products and producing an objective performance metric is based on a square wave stimulus coupled into the touchscreen by an artificial finger. While the square wave method is “synthetic” and doesn’t mimic real-world charger noise, it can be used to provide a repeatable and objective figure-of-merit for charger noise performance. It is also a simple enough approach that it can be easily reproduced by both TSC vendors and phone/tablet developers before/during/after the development phase. It can also be applied to field returns.

Duty Cycle

There are several options available for the square wave method. For example, one may use a 50% duty cycle square wave as a test signal. As the spectrum plot in Figure 5 (left) indicates, such a waveform contains only odd harmonics with the well-known 1/3, 1/5, 1/7, etc. harmonic decay.

A 30/70% duty cycle square wave has a more populated spectrum (i.e., more harmonics), as the spectrum plot in Figure 5 (right) indicates. The presence of both even and odd harmonics produces smaller “gaps” in the spectrum, making this a more difficult test to pass.

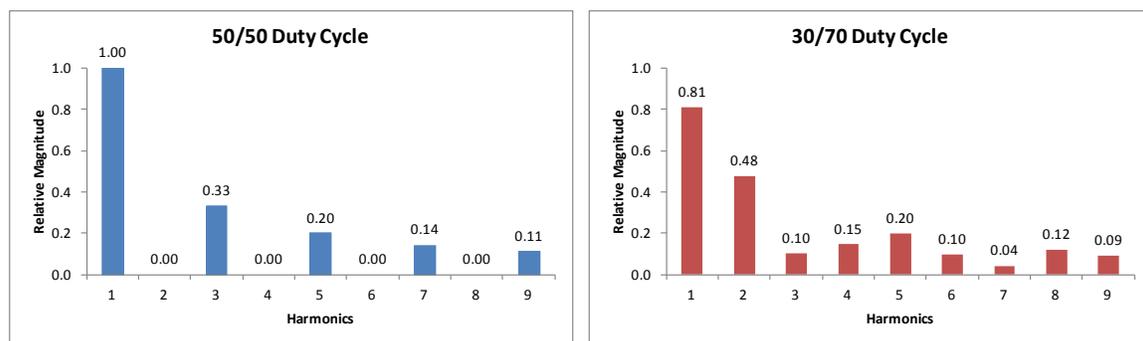


Figure 5. Spectra of a square wave with 50/50 (left) and 30/70 (right) duty cycle

This harmonic spectrum is the reason for choosing such a test signal, as opposed to a sine wave. A sine wave would perhaps deliver a more accurate picture of single-frequency response, but such interference is also much easier to escape. The real challenge in a TSC is that it has to tolerate noise across the entire noise *spectrum*, not just one frequency at a time.

Frequency

Next, developers need to decide which frequencies or frequency range should be chosen for the square-wave method. A quick noise-performance assessment can be reached if only a few frequencies are applied. On the other hand, such an abbreviated test will likely not catch sensitive portions of the TSC’s receive spectrum. Thus, a more reliable picture emerges from applying the square wave over a large frequency range, such as 1 kHz² to 500 kHz, and in small increments, such as 1 kHz. Combined with the 30/70 spectrum, such comprehensive characterization explores the noise immunity spectrum of a TSC with greater thoroughness.

² Although 1 kHz is not a frequency generated by chargers, we might as well cover low-frequency noise response while running the test

It should be noted that a 30/70 square wave with a fundamental at 500 kHz creates a harmonic spectrum with much higher frequencies than what most chargers will ever produce. This can be seen from Figure 4, shown earlier, where the harmonic content of the chargers substantially decayed when approaching 1 MHz. By contrast, a square wave signal with a fundamental at 500 kHz creates notable harmonics well beyond 1 MHz.

Finger Size

For noise tests, finger size plays a big role as well; a larger finger couples more charger noise into the touch sensor. To a first order, the injected noise increases proportional to finger size. Thus, the artificial finger (so-called “slug”) should represent a reasonably large, yet realistic finger, such as 12 mm diameter. However, to explore the robustness limits of a TSC, it also makes sense to apply the equivalent of a large thumb. For that reason, a 22 mm slug should also be applied for thorough noise characterization.

Stationary vs. Moving

To mimic actual use cases, noise tests can be executed using a *moving* finger rather than a stationary one. On the other hand, to make such characterizations highly reproducible, a more elaborate robotic test setup becomes necessary; however, it is not easily replicated in multiple lab locations by multiple vendors and customers. Thus, a stationary-finger test is much better suited for “everyday” tests.

Nevertheless, it is necessary to have some form of motion-based test to detect if a TSC’s firmware is simply locking a coordinate in place or whether it continues to properly track the finger. While not a reproducible test without a robot-controlled finger, simply moving the noise-injecting slug around on the screen quickly reveals if finger tracking is still functional. This will expose the vulnerability of a product that exhibits good static noise performance, but shows erratic behavior once the finger starts moving.

Location

Yet another parameter for noise characterization is the physical location of the slug on the panel during testing. The center of a panel is easy to determine and thus easy to reproduce (see Figure 6). Other methods may cover multiple locations, reporting an average performance number or worst case results. A comprehensive worst-case test would require searching each touch location, leading to many tests in many locations and substantially longer test time.

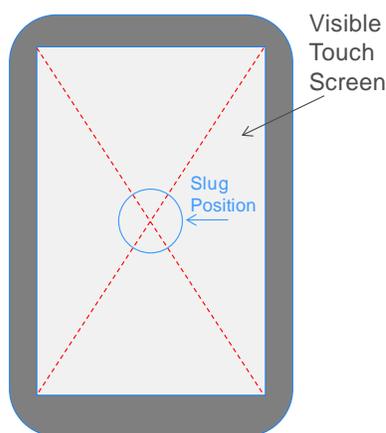


Figure 6. Finger position during noise injection

Given these considerations, at Cypress we use a characterization test suite based on both 50/50% and 30/70% duty cycle square wave signals, stepped from 1 to 500 kHz in 1 kHz increments, as one of the key noise performance metrics. These signals are coupled into a touchscreen via slugs of up to 22 mm diameter placed at the center of the panel. This is complemented by basic motion tracking and touch-down tests using a robot-controlled slug, again

under noise exposure. And finally, there is a suite of real-world chargers, including notoriously poor chargers. Those charger noise signals are pre-recorded and played back as a test signal using a programmable waveform generator.

Characterization of TSC Noise Performance

It is useful to graphically express how a TSC performs under noise exposure because it will likely respond differently to low and high frequencies. Thus, some form of spectral plot is in order. Then, a set of pass/fail criteria needs to be established so that a simple graph can be constructed.

In a charger noise test, the pass/fail criteria should be based on detection of false touches (i.e., detected touches at locations where no touch is present), no-touch (also known as lift-off, or reporting that a touch no longer exists when the test slug is still present on the touch sensor), and acceptable jitter of the reported finger coordinates. In other words, to report whether a TSC “passes” a certain noise level, we observe any evidence of false touches appearing in the location where there is no touch, disappearing real touches, and excessive jitter. All these are recorded with the noise level at which these effects start appearing.

When running this type of test across all frequencies, there will be a threshold noise amplitude at which the device still passes and above which it will fail known as the “noise ceiling.” When plotted in a graph (see Figure 7), a profile can be generated that represents the noise-handling capability of a TSC in conjunction with a sensor stackup and overlay thickness.

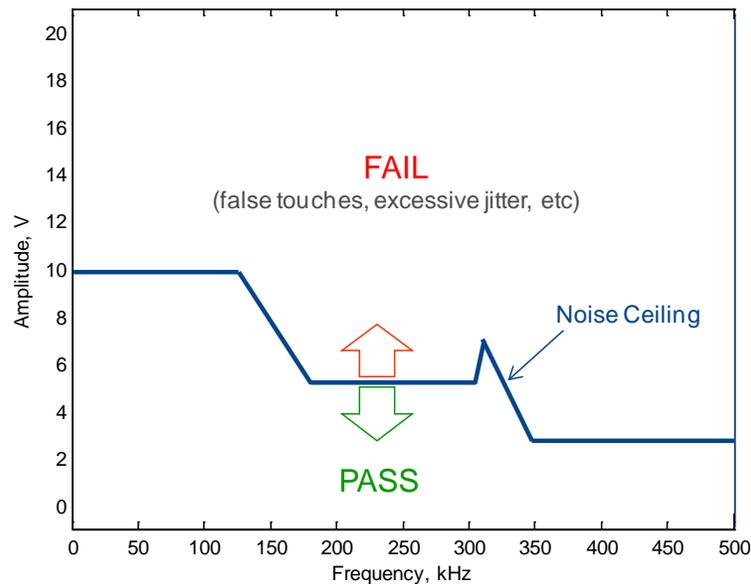


Figure 7. Example of a noise ceiling

The way to read the above graph is that the system is immune to noise test signals up to the voltage level indicated by the “Noise Ceiling” line. Below the line no errors occur (“pass”), while above the line the system produces errors (“fail”), such as reporting false touches, false lift-offs, or excessive jitter. Better noise performance results in a line that is higher on the graph.

Techniques to Combat Noise

For situations where large noise energy swamps out tiny signals of interest, a variety of robust techniques have been developed. Some of these techniques, such as OFDM or CDMA, are highly successful in enabling reliable cell-phone communication. However, a touchscreen solution is highly constrained by its total cost (sensor + silicon), power consumption, and available bandwidth through the sensor. The challenge is to find implementations that are simpler than OFDM, for example, and yet are effective in extracting tiny touch signals in the presence of large noise. In reality, there is no single method for overcoming the noise challenge; rather, a combination of techniques is required.

For example, although LCD noise changes with the image displayed, it can be quite similar (common) anywhere across the display and as it couples fairly uniformly into the sensor. This makes the noise signal appear as a similar signal across all the receive circuits of a touchscreen controller. This high correlation of noise signals across all sensor signals can be utilized for effective removal of LCD noise from the touch signals.

When LCD noise becomes very large, as is the case with some “in/on-cell” LCD stackups³, special timing alignment (synchronization) may be used to combat the noise.

In contrast, one cannot rely on a predictable spectrum with charger noise because many different chargers may be connected to a phone/tablet throughout its useful life. Even when only a single charger is used, the noise characteristics change with the load current and charge state of the device battery. Thus, synchronization will not address charger noise. Furthermore, charger noise does not uniformly couple into the touch sensor like display noise does. Because charger noise appears exactly the same at all touch locations, it interferes with the normal signals of the touchscreen scanning process. To address the unique challenges of charger noise, sophisticated scanning and processing methods are required, including multiple linear and non-linear filters as well as adaptive selection of best operating frequency, sometimes referred to as frequency hopping.

Since finger signals are very small compared to noise, it helps to maximize the finger signal in the first place. Several TSCs from Cypress, for example, have built-in boost capability to increase the sensor stimulus (“TX”) signal from typically ~2.7V to 10V, thus producing a highly desirable 4x increase in SNR.

Real-World Examples

To illustrate the use of the measurement techniques described above, let us review a real performance test example. The production phone tested here has a third-party touchscreen controller, supporting a 5” touchscreen with a low-noise IPS⁴ LCD. Using a 22 mm finger (slug), a 30/70% duty cycle square wave is applied from 1–500 kHz in 1 kHz increments. As explained before, the test seeks the largest tolerated test signal producing no false touch, no false lift-off, and no excessive jitter.

The graph in Figure 8 shows a “noise ceiling” profile for this combination of phone and synthetic noise source: noise signals with amplitudes below the red line produce no error.

³ A stackup is a combination of multiple layers of materials, forming an LCD display. For example, with in/on-cell stackups, the sensing layer is not situated on top of the display stackup but rather is part of the lower layers of the stackup and thus much closer to the noise-generating LCD layers.

⁴ IPS = in-plane-switching, a technique for controlling LCD operation

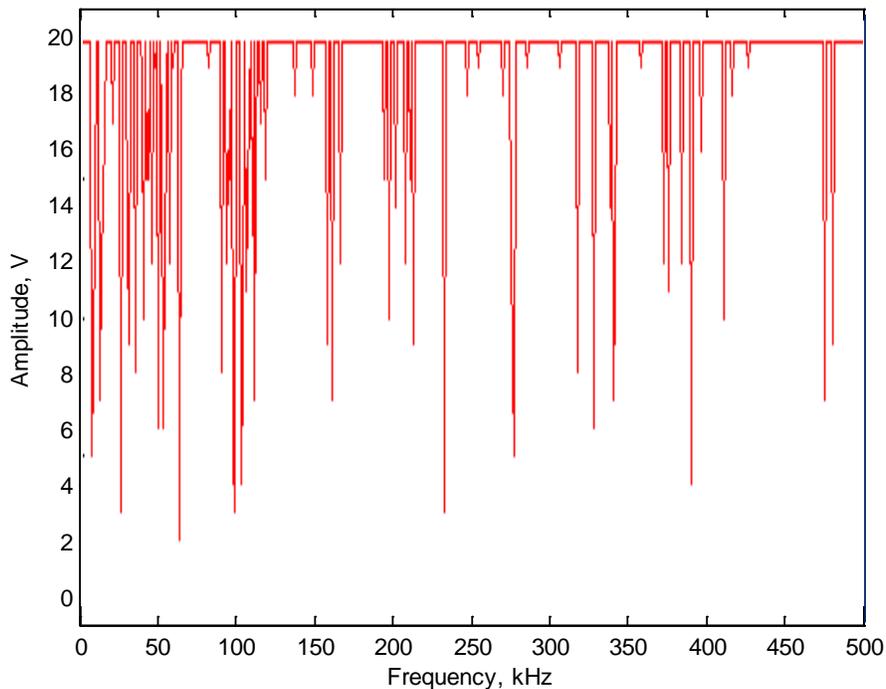


Figure 8. Actual noise performance example of a production 5" phone

Figure 8 indicates multiple frequency bands of very good performance, i.e., hitting the 20V limit of the test equipment used here. But the graph also reveals many frequencies with very low tolerance to noise, i.e., just 2.3 V of noise (e.g., at 25, 70, 100, 230, and 380 kHz), despite the TSC's attempt to "frequency-hop" away as best it can. These low-voltage dips are the most concerning areas, especially when they occur near the frequencies most often generated by chargers. In other words, when a charger produces noise at those frequencies, the product starts reporting false/no touches, or shows excessive jitter.

An example for this situation is shown in Figure 9. Here, we have overlaid the spectrum of an actual USB charger exhibiting "wide-band noise". The blue circles indicate the areas where the charger's noise spectrum overlaps with the sensitive frequencies of the TSC.

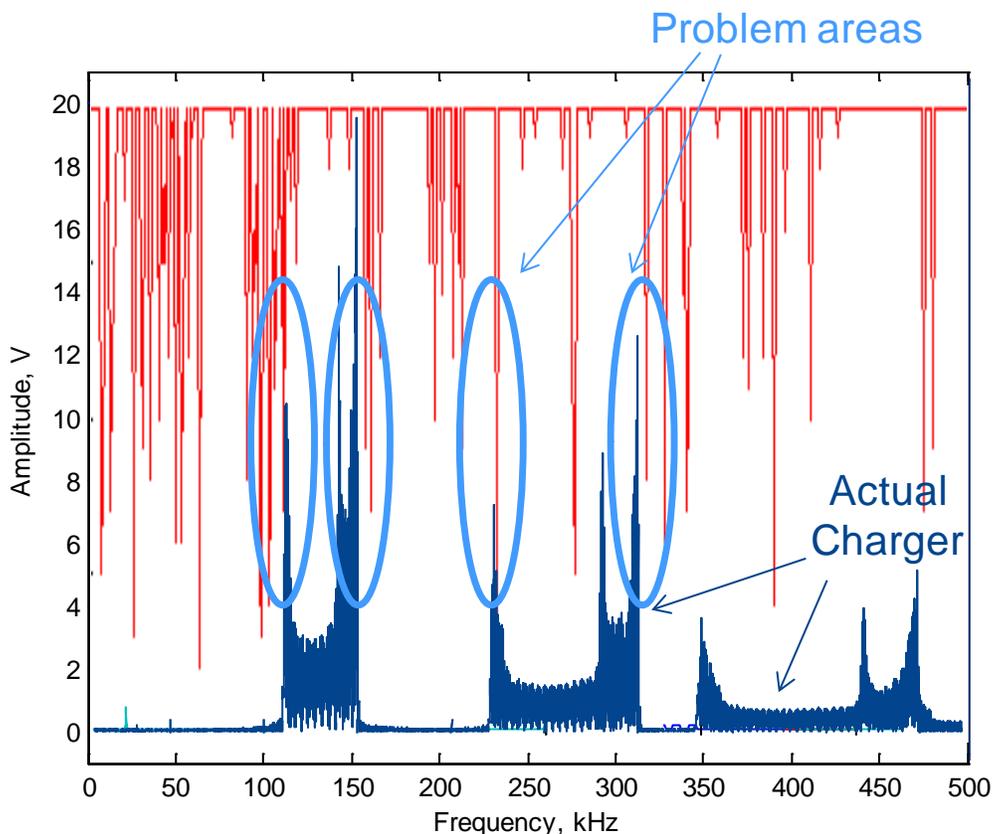


Figure 9. Noise sensitivity profile and a “wide-band” charger noise spectrum

Note that when the Noise Ceiling (red) curve was measured, a single-frequency square wave was used which produced certain frequency harmonics. The real-world charger in our example also produces harmonics, although in this case it is not a spectrum of nicely distributed frequencies at just the even and odd harmonics of a fundamental. Rather, the charger produces a “wide-band” spectrum that makes it much harder for the TSC to avoid.

This example shows that while synthetic noise tests can be useful to create one metric of noise performance, the method cannot obsolete tests using real chargers. Despite this inadequacy of the synthetic noise test, the device under test was also exposed to several real chargers, and indeed it failed with most of them, even at artificially reduced noise levels. This means that the noise immunity profile as shown in the graph of Figure 9, while not perfect, is a strong indicator for real-world charger noise performance.

Another test example is based on a charger with “narrow-band” noise. Such noise is easier to overcome by choosing the best touch-sensing operating frequency for the TSC, although harmonics of the charger noise may still make this a challenge, as shown in Figure 10.

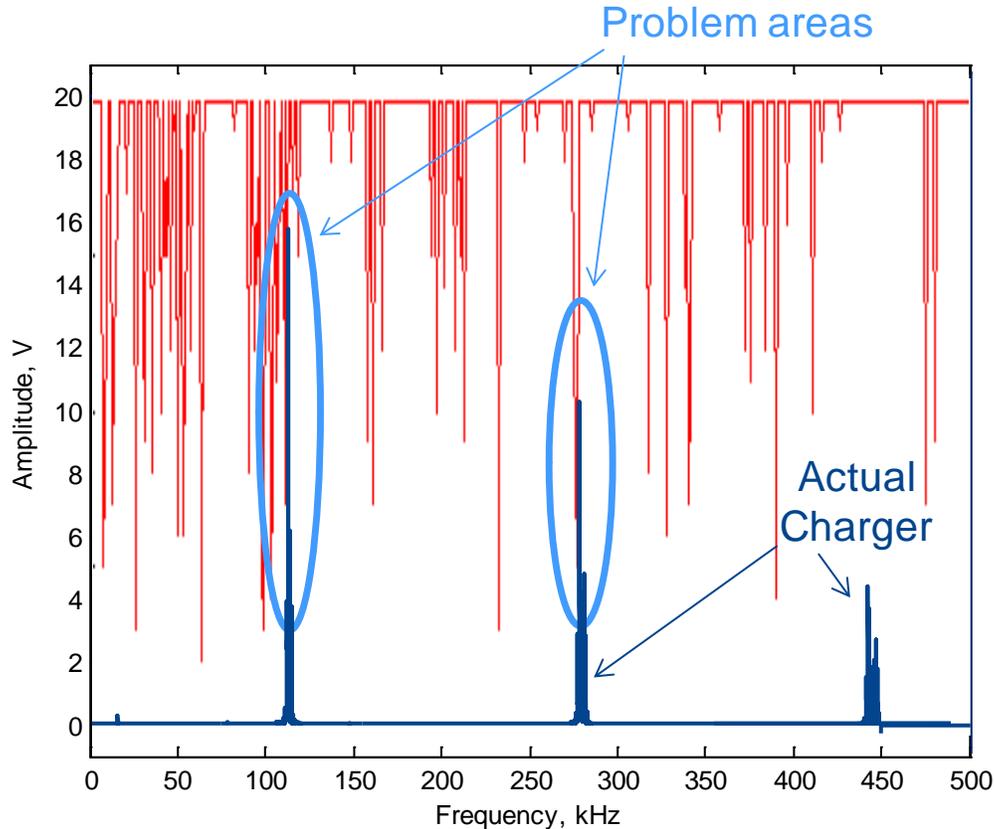


Figure 10. Noise sensitivity profile and a “narrow-band” charger noise spectrum

Outlook

Problems caused by excessive common-mode charger noise could be easily eliminated by slightly better charger design, but the reality of the cost pressures of the consumer electronics market is 1) there will always be noisy chargers, and 2) it is nearly impossible for a customer to know which ones are noisy and which are quiet. Thus, in order to assure a positive customer experience, some TSC suppliers have developed increasingly sophisticated techniques to combat charger noise, as well as noise from many other sources.

Cypress, for example, operates a Noise Lab and has dedicated significant research resources to continually improving the noise performance of its TSCs. Adaptive adjustment of touch-sensing frequency, linear and non-linear filtering, boosted TX amplitude, and several other proprietary techniques are all brought to play to combat noise.

Figure 11 shows a comparison of an older TSC from Cypress (on the left) and a new-generation TSC under identical test conditions. When some of the more advanced noise-combat features are activated, noise performance can be a “flat-line” 20V in this example setup. In fact, with all noise-combat features enabled, these new generation products can reach and even exceed 40V noise levels.

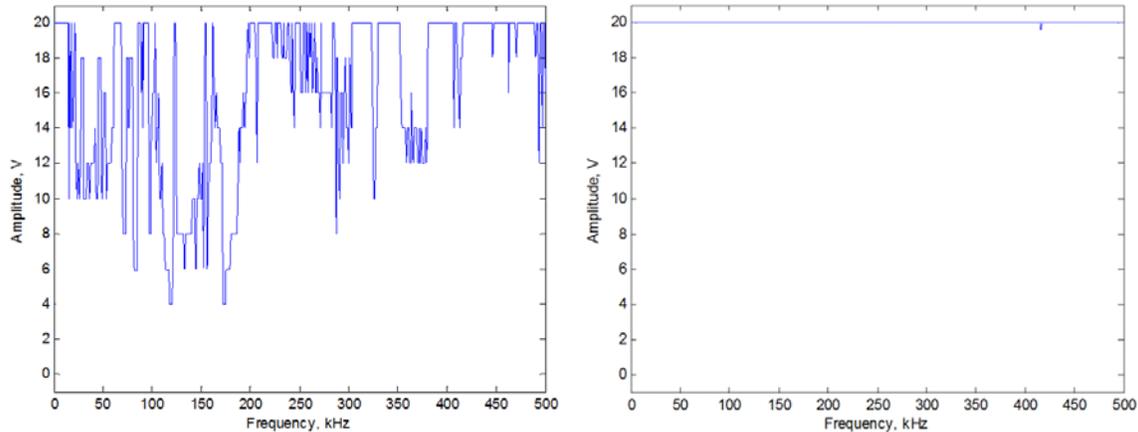


Figure 11. Noise performance of an older and newer-generation Cypress TSC, which can reach and even exceed 40V noise levels

Noise immunity is an important aspect of touch-screen controller performance. If not addressed properly at the architectural, circuit, and algorithmic levels, noise can cause poor operation of the end product. This is especially true for common-mode charger noise, which is among the most severe and unpredictable noise sources.

Several methods for measuring noise performance have been discussed here. The most objective and most repeatable methods are based on synthetic test signals, such as square wave “noise” signals with controlled amplitude and duty cycles, swept over a large frequency range. We promote the use of a square wave with 30/70 duty cycle, stepped from 1 kHz to 500 kHz in 1 kHz increments, applied to the center of a panel with a 22 mm slug.

A format for displaying the noise performance has also been presented. Standardizing on these measurement and plotting techniques makes it easier to predict real-world noise performance, and to compare TSCs from various vendors. Measurement examples were given that show that a TSC can be very immune to noise in certain frequency bands, but quite sensitive in others, resulting in incorrect touch reporting when exposed to real-world common-mode charger noise. Also, examples were given that illustrate the substantial progress being made in raising noise immunity.

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About the Author

Hans W. Klein is the Analog CTO at Cypress Semiconductor. His responsibilities include Research and Architecture Development of Advanced Touch-screen solutions. Hans has an MSEE and a PhD from the Technical University of Aachen, Germany. The main themes throughout his career were analog signal processing, and making analog chips more programmable. You may reach him at hans.klein@cypress.com.

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