AN2547
Application note

Recommendations for designing a capacitive touch sensor board with QST devices

Introduction

This application note applies to 'simple' electrode designs for touch controls, especially those designs where the electrode(s) and QST chip are on one PCB that is bonded to the back of an operator panel (such as plastic or glass). This is often the least expensive construction method.

'Simple' touch electrodes operate by emitting a pulsed electric field through a control panel from behind; a finger on the panel will cause the capacitance of the electrode to ground to increase by about 0.5pF to 5pF due to the extra coupling of the human body to the surrounding environment. This increase in capacitance is processed to result in an output signal. The QST family technology uses patented charge-transfer methods to sense this slight increase in load capacitance, even on electrodes that have a high background capacitance.

Simple electrodes are 1-part conductors formed behind a control panel; they are connected to chips such as the QST108. Electrode shapes are simple to create and are very forgiving to design.

While it may seem that there should be a simple scientific way to predict electrode performance, 3D electric field prediction is not easily solvable with a few equations as there are a multiple independent variables and complex spatial considerations. Simulations can be performed using expensive finite element analysis software (for example, Ansoft's Maxwell 3D™), but the cost and time of doing so usually compares unfavorably to just tweaking a sample board.

This application note is designed to give you a confident head start in making a successful design with a minimum number of iterations, by showing you what works well and what does not, along with some suggestions for making a more creative and robust design.

Contents

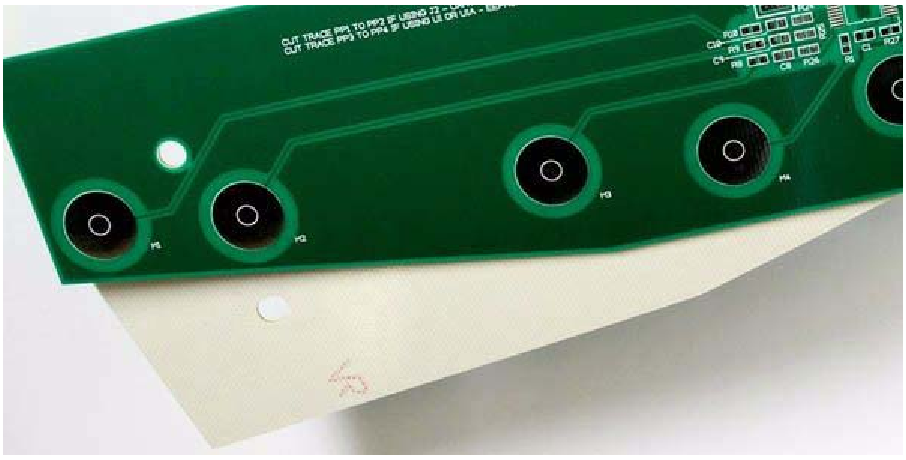
1 Electrode construction

1.1 Choosing a substrate

An electrode substrate is the material on which the key electrodes are fashioned. The electrodes must be electrically conductive and in contact with the rear of the panel, whether directly or indirectly, in order to fashion a touch key. Various materials are available for different design objectives (*Figure 1*).

Figure 1. Various materials can be used to implement QTouch™ electrodes

CEM-1 (1-sided paper + fiberglass based)



FR4 (2-sided epoxy-fiberglass)

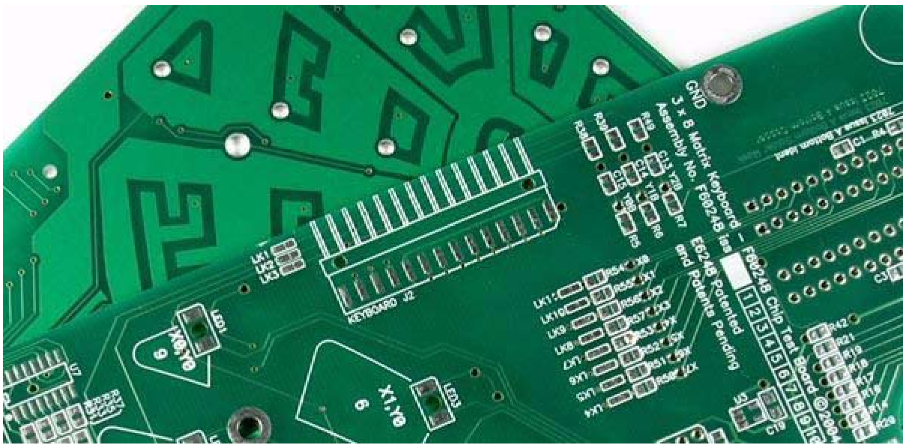
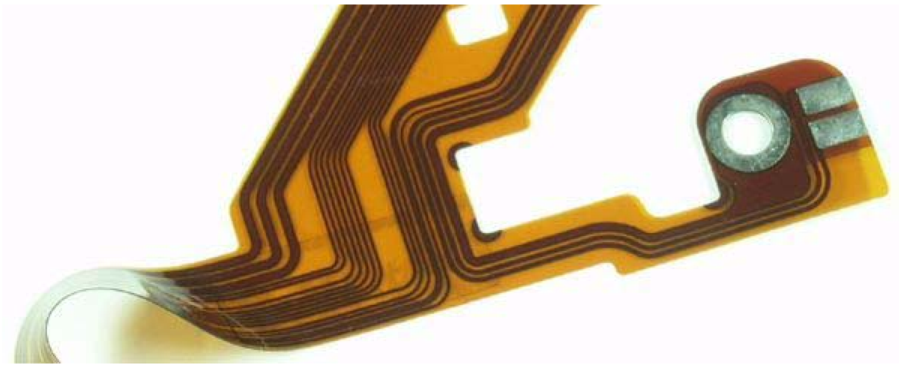
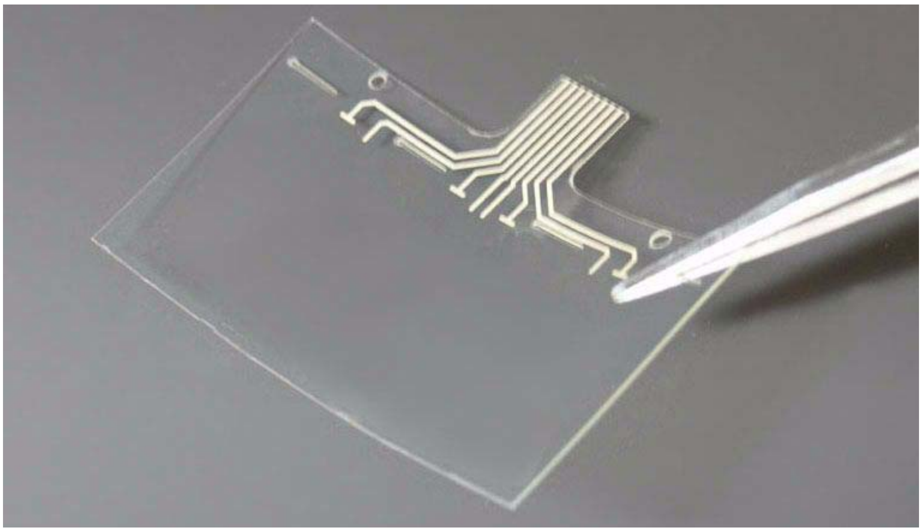


Figure 1. Various materials can be used to implement QTouch™ electrodes (continued)

Flex circuit (Kapton™ polyamide)



Clear ITO on PET with silver connections



The substrate material is often a big factor in the cost of the design, as is the number of layers. The lowest cost designs use single-sided low cost laminates such as CEM-1 (as opposed to more costly FR-4). When bonded to the back of a panel, a single-sided PCB will have the electrodes and the circuit on the inside of the product, and the electrodes will fire the sense fields through the PCB, an adhesive layer, and the front panel to get to the user surface (*Figure 3*).

CEM-1 is punchable (unlike FR4, which must be routed), making its fabrication cost extremely low. However it is only available as a single sided material. There is a 2-sided version known as CEM-3, in common use in consumer electronics. These materials are mostly known in Asia.

Flex circuits can also be used, such as Kapton™ when the expense is justified, or simply silk-screened silver traces on plastic film, like PET (polyethylene terephthalate), which is quite inexpensive.

For applications requiring clear electrodes for use over small displays, Indium Tin Oxide (ITO) coated PET films are available from various suppliers who can etch them into electrode shapes with screened-on silver tracks leading to a tail connector. ITO is a resistive material; long thin traces of ITO can produce resistance values that are excessively high for use with capacitive sensors, so care must be taken in the design of these films.

A good source of general PCB information at the time of this writing is the FAQ found on http://www.felsweb.com.

1.2 Panel thickness

The panel thickness and its epsilon ('dielectric constant') play a large part in determining the strength of electric field at the surface of the control panel. If the metal electrodes are on the inside surface of the substrate then the thickness and epsilon of the substrate are also factors.

Glass has an epsilon range from 7.6 to 8 compared with most plastics which range from 2 to 3 (see *Appendix A: Dielectric properties of common materials on page 22*). Higher numbers mean the fields will propagate through more effectively. A 5mm panel with an epsilon of 8 will perform similarly in sensitivity to a 2.5mm panel with an epsilon of 4, all other factors being equal.

Up to 10mm of plastic panel is quite usable, depending on key spacing and size. During development, the circuit sensitivity needs to be adjusted to compensate for panel thickness, epsilon, and electrode size. As a rule, the electrode shape should have a minimum dimension of at least 4 times the panel thickness for reliable operation.

Once the design is transferred to production, the panel composition and thickness should not be changed without re-testing.

Adjacent Key Suppression: Thicker panels also will give signals from adjacent keys an opportunity to bleed into each other, which can lead to two or more keys being triggered by a single touch. Quantum's patented Adjacent Key Suppression (AKSTM) can be used to validate ambiguous touches on two or more keys where keys are closely spaced, or where a thick panel bleeds fields from one key to another. AKS works by selecting only the key having the largest signal change.

1.3 PCB to panel bonding

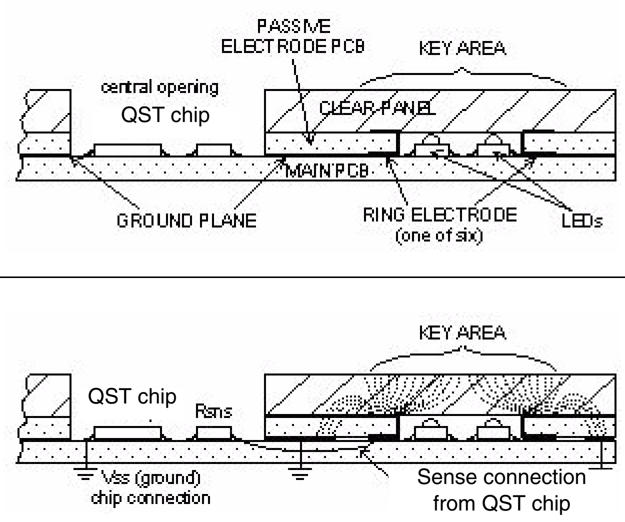
Good contact between the substrate and the panel is essential for reliable performance. An unreliable interface which can change by even 100 microns after being pressed with a finger can cause unacceptable signal fluctuations. Adhesives or compression mechanisms can be used to reliably overcome these problems. Non-adhesive solutions can for example involve the use of co-convex surfaces that are placed under preloaded pressure when clamped together, to ensure complete surface mating.

Various methods have been used to mechanically clamp electrode substrates to panels, including heat staking plastic posts, screws, ultrasonic welding, spring clips, non-conductive foam rubber pressing from behind, etc.

See *Section 2.1* for more discussion on one popular way to bond a sensor board to a panel using adhesive.

This board shown in *Figure 2* illustrates one simple way to backlight keys, using passive ring shaped spacer electrodes sandwiched between the main PCB and the panel. Fields couple capacitively from the main PCB ring into the spacer ring, then migrate from the spacer ring into the clear area over the LEDs. A ground plane on the main PCB sinks the fields so that the key areas are sharply defined at the surface (*Figure 2*, top). What is really amazing about this board is the path length from the electrode to a finger: the clear panel is 5mm thick, and the fields traverse another 5mm laterally to a finger in the middle of the key.

Figure 2. Evaluation board construction

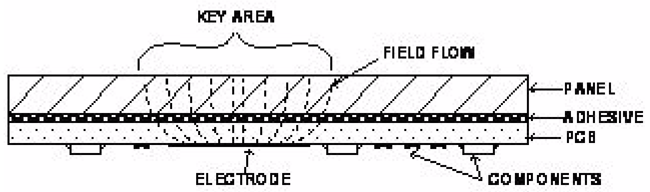


2 Electrodes and wiring

2.1 Electrode and key shapes

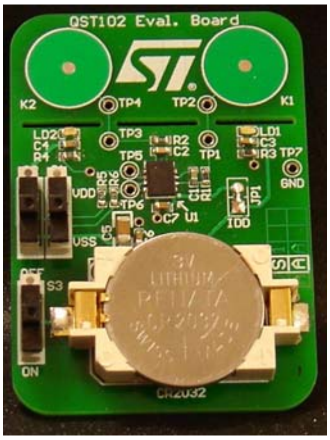
Electrodes and key graphics can be made in many different shapes and sizes. QST chips liberate designs from the need to have all keys the same size and shape - in fact, QST devices are highly tolerant of electrode size, shape, and placement. Almost anything will work; there are no hard and fast rules for key diameter or spacing, just a few simple guidelines.

Figure 3. 'Back-firing' sandwich-style touch panel



A 1-sided PCB (*Figure 3* and *Figure 4*) adhered to the back of a panel can create a sense field back through the PCB and out through the panel to create a touch key. The total stack thickness can easily exceed 10mm.

Figure 4. Example of a compact 1-sided layout



Note that components C_S and R_S of this circuit are all grouped close to the chip.

Electrode sizes: It is a common mistake to assume that the electrode shape and the graphic key symbol on the panel should be the same. In fact, it is often better to make the electrodes larger than the graphic especially with small key sizes since key sensitivity falls off at the edges; an oversize electrode not only compensates for this but also allows for off-center touch with good response. Generally, it is a good idea to make the electrode shape extend 2-3mm beyond the graphic symbol. Of course this is not always possible, for example on a densely spaced panel.

As a rule, the electrode shape should have a minimum dimension of at least 4 times the panel thickness for reliable operation. It should at least match the diameter of a small finger - about 6~7mm. Bigger is better: bigger electrodes get more signal swing from touch and decreases the effect that noise can have on the signal by percentage. Other than that, there are no hard and fast rules for size. Even these rules can be broken by compensating for low sensitivity with higher values of Cs, but it's not an optimal solution.

Electrodes when not acquiring are held at ground potential, and therefore act on neighboring acquiring electrodes as a ground plane which diminishes sensitivity overall particularly at the edges (*Section 2.2* and *Section 2.3*). While these effects can be overcome by increasing the value of Cs, it is still helpful to understand why these effects happen, even if they cannot be improved due to panel design constraints.

The most common form of electrode is a filled circle or rectangle of copper on a PCB, corresponding loosely in shape to the key graphic. The PCB is then usually glued with an industrial adhesive such as a 2-sided acrylic sheet to the inside of the operator panel (*Figure 3*). One example of acrylic bonding sheet includes 3M type 467MP, although there are other suppliers and types which may prove more suitable.

What is interesting about this type of construction is that the PCB can be 1-sided, with both the components and electrodes on the side away from the user's finger. The electrode 'back-fires' its electric field through the PCB, the adhesive layer, and the panel. QST devices are unique in having a sufficient signal range to detect through thick panel construction and yet remain highly reliable and sensitive (10mm is a common thickness for QST circuits). This results in a very low cost touch panel.

One variation allows for back illumination via an opening in the electrode. The width of the copper should be at least as wide as the panel is thick to provide adequate coupling; the electric field penetrates the clear panel and 'focuses' inwards by migrating through the panel material (*Figure 2*, top) while being terminated outwards from the ring by a ground plane.

This method only works well if the panel material is thick enough and with a high enough epsilon to conduct the fields inwards. If the hole in the middle is too big and/or the panel has a low epsilon and/or is too thin, the fields in the middle will be weak and the key will not function as intended there.

Properly constructed, the result will be a very sensitive key even in the middle. This method allows for simple, low cost backlighting of the key area to back-illuminate a graphic symbol.

Note the need to bypass LEDs with capacitors in some cases if they or their traces run near an electrode or its wiring (*Section 3.6 on page 18*).

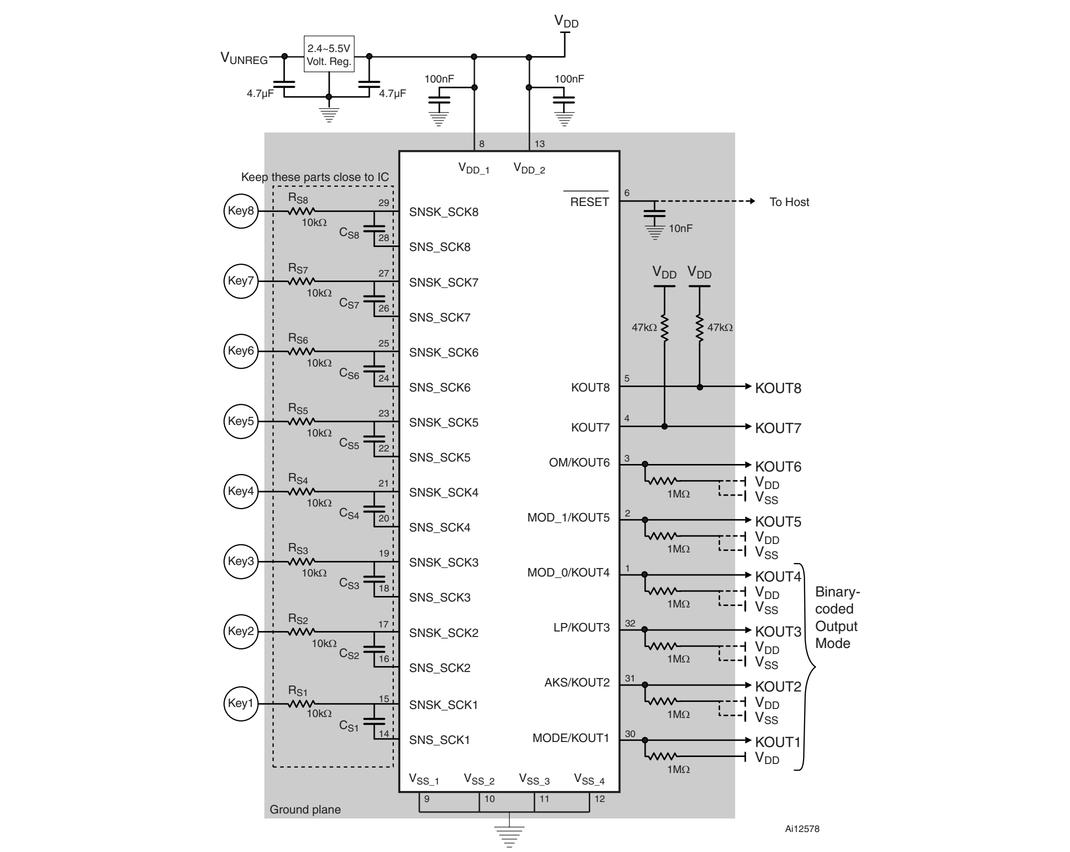
2.2 Field shaping

Electrodes will propagate fields into the panel material and laterally around the key area as well. These fields will drop off gradually with distance from the edge of the key; sometimes this can result in key detection some distance away from the key itself. One simple solution to this problem is to place a ground area around the electrode, thus terminating the fields abruptly (*Figure 2*). While this is an effective approach, it should be remembered that ground areas near the key also increase the capacitive loading (Cx), thereby also reducing sensitivity to touch. While this effect can be compensated by increasing the sample capacitor Cs, an overall decrease in signal-to-noise ratio (SNR) and an increase in power consumption will occur (*Section 2.3*).

A compromise is to place a ground ring around the electrode with a 3-5mm gap. The electric fields will terminate sharply across this gap yet capacitive loading on the key is minimized. A ground plane near an electrode will cause the key to be less sensitive near its edges since the field lines are shunted away from the panel surface. The width of the ground plane also matters: a thin ground track next to an electrode will have less of an effect than a wide ground pour.

Ground planes or tracks should only be used to define a key area as a last resort for a specific purpose. Key fields will naturally decay with distance from an electrode edge, and this drop in field strength is usually enough to define a key boundary.

Figure 5. Where to put a ground plane



Ground planes are optional and are to be used sparingly. If used, they should only be placed under or around the chip and its immediate components as shown in *Figure 5*. All parts should be placed and routed tightly to the chip.

Back-shielding: Sometimes it is desirable to shield an electrode on its rear side to prevent false detection from moving parts to the rear, or to prevent interference from high voltage AC signals (such as from EL backlighting or driver circuitry). Either an active shield can be used with a solid metal plane behind the electrodes (*Section 3.4*), or, a rear ground plane can be used.

If a ground plane is used, the ground should be connected directly to the chip's V_{SS} pin to provide a clean ground having no relative voltage spikes on it; since the ground will form a parallel plate capacitor with the electrode it will strongly couple any low-level electrical noise it might have directly into the signal. Also, the electrode and ground plane should be separated by the maximum distance of air or thickness of insulator possible.

To reduce C_X loading on the electrode further, the back shield can be an open mesh rather than a solid metal plane. Start with a 50% open mesh and test for interference, and adjust the mesh density accordingly.

2.3 Ground planes

Figure 1 (top) is an object lesson in how not to make a sensor PCB. This figure shows a close ground pour all around the keys and the connection traces. Figure 5 shows the proper outline of a ground plane, if one is used.

It is tempting to place a ground plane around electrodes and connecting traces for noise reasons. However, this is actually counterproductive since the extra capacitive loading on the electrodes will render keys less sensitive, reducing the signal-to-noise ratio (SNR). Any ground pours or other adjacent traces should be as distant as possible from the electrode traces.

Grounding can be used under the QST chip and its associated circuit, but should kept away from sense traces and electrodes as much as possible. However, even a ground under the chip is optional except in cases where RF interference is an actual problem.

Figure 4 shows a single-sided layout where there is no ground plane at all. As long as the supply bypass capacitor is located very close to the V_{DD} and V_{SS} pins and the channel components are close to the chip, there should be no problem with EMC compliance or false detection in the vast majority of consumer applications.

Some multichannel QST chips acquire channels in time sequence, and this results in special trace routing considerations. Given a choice to put two such sense traces very close to each other on one side or to put them on opposite sides of the PCB, it is usually better to do the latter.

2.4 Solving water film problems

Water films on the touch panel surface are inevitable in some applications, for example kitchen appliances and outdoor keypads. Films can vary from a mist layer to standing pools of liquid. While capacitive sensors have historically been unable to deal with water films, QPROX™ charge-transfer methods have evolved to suppress most water related problems.

A water film's most serious effect is to cause false detection; this is caused by the fact that water is usually contaminated by dissolved ionic molecules which allow strong electrical conduction. A conductive water film acts very much like a human finger to cause a false detection, provided the film is large and continuous enough to absorb and transport the fields away from a key. Nearby ground planes make this problem much worse by enhancing the capacitive load on electrodes (Figure 6, middle) and spreading the signal into unwanted areas.

QST devices have drift compensation built into them to slowly compensate for the build-up of moisture films. QST devices will allow the internal signal reference to move slowly over time in the direction of a drifting signal. However, if the moisture build-up happens too quickly, the signal will move faster than the compensation mechanism and a false detection will occur. If the compensation mechanism is made too fast, then it is possible that a slow moving human finger will also be ignored.

QST chips help to suppress water effects by using relatively short charge-transfer pulses. It is easily shown that short pulses do not propagate into moisture films as readily as long ones. Conversely, it is readily shown that capacitive sensors using low frequency methods like relaxation oscillators are highly susceptible to moisture effects.

In some cases, water suppression is seemingly a hopeless task. For example, some applications require an occasional panel 'wipedown' with a wet cloth. The signals during a wipedown are so large that accidental key activation is seemingly impossible to prevent.

One way to inhibit this kind of false activation is to use a spare sensing channel to create a 'wipedown detector', whose only purpose is to detect out-of-position touch due to a wet cloth (which in practice will have a footprint much larger than a single key). The spare channel is coupled to an electrode formed near or around the key electrodes, perhaps using a copper pour. When the 'wipedown channel' is active, the other keys in the area are simply ignored.

Figure 6. Water film effects on a key with nearby ground

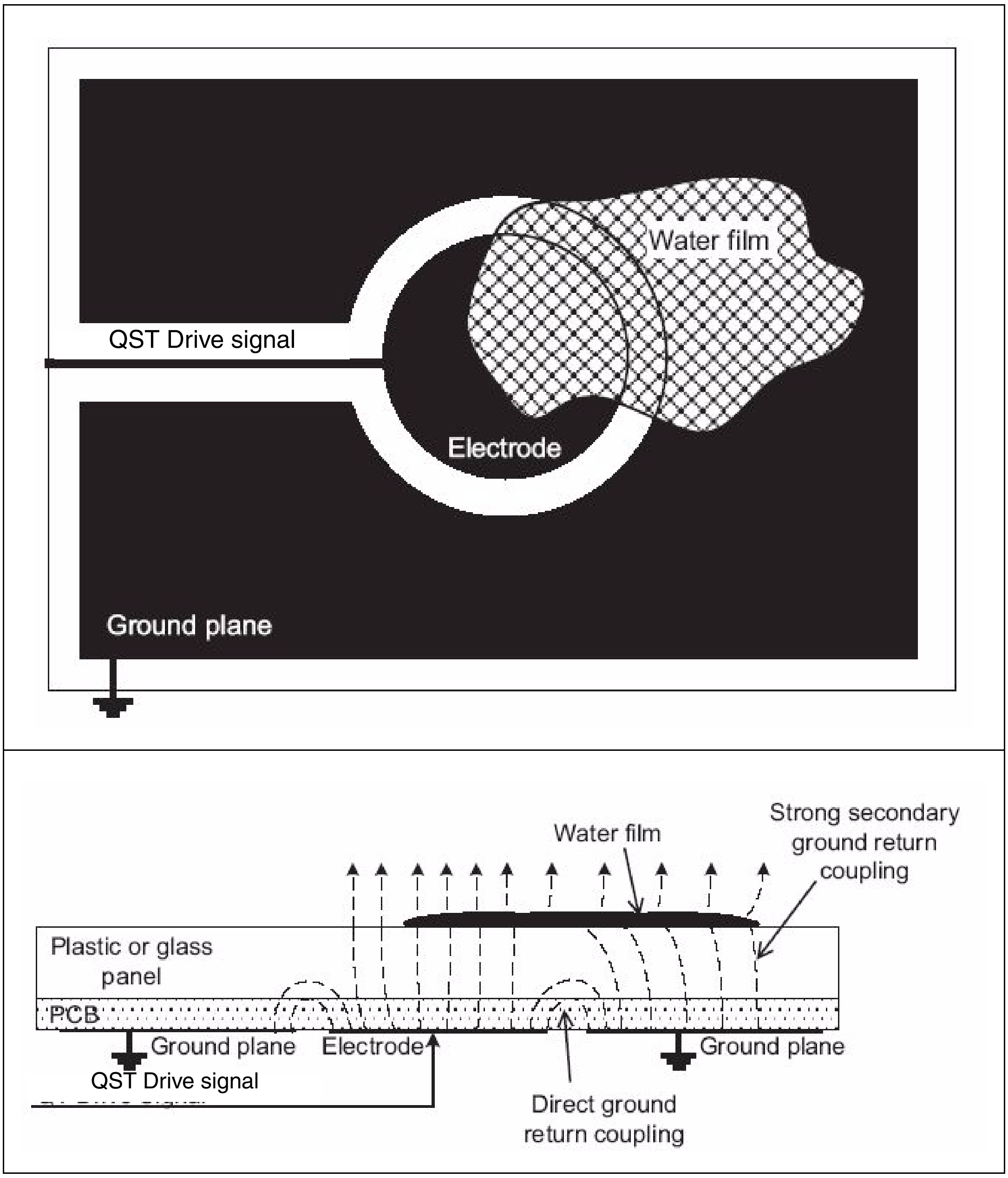


Figure 6. Water film effects on a key with nearby ground (continued)

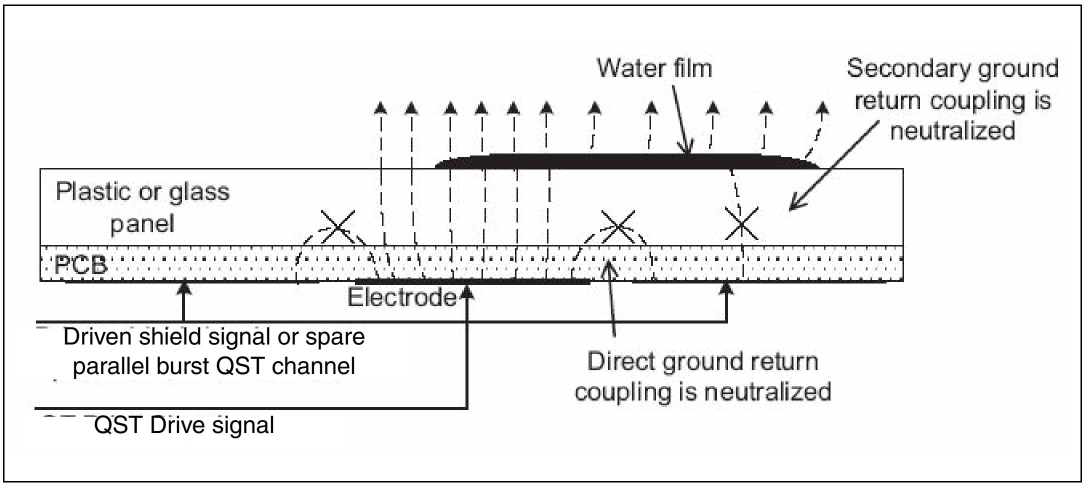


Figure 6 shows how ground planes near electrodes absorb fields making keys less sensitive. They also make the effects of water films dramatically worse by increasing coupling between the electrode and ground (middle). Converting the ground plane into a driven shield improves both problems, but can be expensive to implement (bottom). An extra QST channel from the same burst group on some QST devices can be used to provide an inexpensive driven shield which can also be used to detect and suppress panel wipe-downs. Interestingly, the 'wipedown channel' also can act as a 'driven shield' (*Figure 6*, bottom) which will inherently reduce the effects of water films. This happens when the surrounding 'pour' electrode and the key electrodes are being driven in phase with each other, so that they are equipotential during a burst (see *Section 3.4*). This configuration requires that the QST device has a 'parallel burst' drive: three channels of parallel burst of this device can be used for keys, while the fourth acts as a 'wipedown' and driven shield channel.

AKS™ and water films: Adjacent key suppression (AKS) is a patented QPROX™ method designed to resolve multiple key presses by comparing signal strength changes before making a decision as to which key to report. AKS can also be used to resolve water films that cover two or more keys. Almost always, the touched key has more signal change than secondary keys whose signals are transported via a water film. AKS will choose the only key having the most signal change while suppressing the other keys.

If AKS is used together with a 'wipedown electrode' surrounding the touch keys (see above), then the suppression of wipedown occurs automatically. A touch only on a key is properly recognized, but a touch that contacts both the key and the surrounding wipedown electrode will only result in the 'wipedown output' becoming active even though both are touched. This 'wipedown' output can simply be ignored. An example of this is a modification of *Figure 6*, where the 'ground plane' area is connected instead to a spare QST channel and both channels are then AKS'd together. They do not have to be from the same parallel burst group for this to work, although it is better if they are as this will reduce mutual capacitive loading.

2.5 Interference from other signal traces

Switching signals from other circuits should be routed away from the sense traces and electrodes to prevent interference. If it is unavoidable to have nearby switching signals, the amount of noise coupling can be reduced by running the sense traces and interfering traces on opposite sides of the PCB, and as far away from each other as possible. When these traces need to cross each other they should do so at right angles.

Under no circumstances should a sense trace and a noisy trace run close and parallel to each other. If they must run parallel, a ground trace between them is preferable even though this will cause loading problems and reduced sensitivity (*Section 2.3*). Nor should a noisy trace run near or under an electrode.

See also *Section 4: Electromagnetic compatibility and electrostatic discharge*.

2.6 Component placement

The passive components associated with each sensing channel (such as the Cs reference capacitors and associated resistors) should be placed very near the SNS pins of the IC to assist with EMC compliance (*Figure 4*).

If these parts are placed far from the chip, serious noise problems and instabilities can arise. A common mistake is to place the electrode series resistor (R_S) at the actual key location instead of at the chip. The trace length from the chip to the passive parts is just as important as the distance from the chip to the parts.

Placing the parts close to the chip but having a long set of tracks to the chip negates the desired result, since long tracks act as RF antennas. The resistor R_S acts to reduce RF coupling both in and out of the QST circuit, but it cannot perform this function on RF signals coupled into the chip on a long stretch of PCB trace between the chip and the resistor.

2.7 Trace lengths

Longer electrode traces will have higher C_X capacitive loads than shorter ones, resulting in reduced sensitivity. A circuit with a mixture of trace lengths will therefore have unbalanced key sensitivities from key to key. This can easily be cured by adjusting the design values of C_S on a per-key basis (see *Section 3.1*).

Sense traces that run next to grounds or over ground planes will suffer reduced sensitivity more than those whose path is clear of nearby copper.

2.8 Floating metal

Floating electrical conductors near sense traces or electrodes will pick up the sense fields and re-radiate them. Usually this is highly undesirable as it can cause strange behavior in key detection depending on what the metal is contacting. Touching such nearby floating metal can also cause false key detection.

Floating metal should be connected to AC or DC circuit ground. This can be accomplished by a direct wire connection to power supply common, or by means of a 47nF capacitor back to supply common.

2.9 Electrode leakage currents

QST circuits are sensitive to DC leakage currents, which will cause the sensor to register either higher or lower signal levels than normal. Leakage currents can arise from galvanic conduction between an electrode or its wiring and adjacent metal that is either grounded or at some potential.

A leakage path caused by moisture films contacting the electrode, for example, will cause instabilities in sensing and hence erratic behavior. See also *Section 3.8*.

3 Circuit design

3.1 Balancing key sensitivity

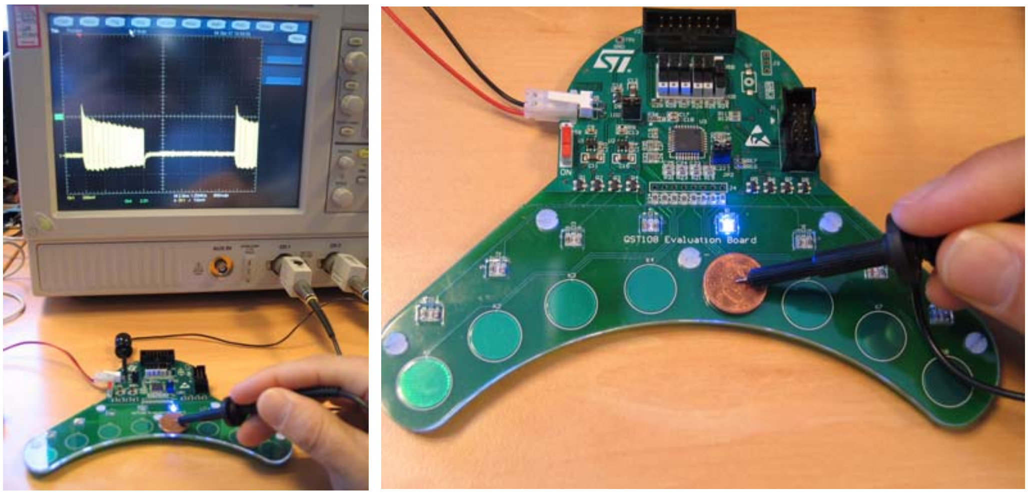
Imbalances in key sensitivity from key to key on a board can be compensated by adjusting the Cs capacitors on a per-key basis. Capacitors are readily obtainable on 20% boundaries, i.e. 10nf, 12nf, 15nf, etc., which is usually sufficient in resolution to adjust the keys. In some cases, it might be necessary to use two capacitors in parallel to achieve the desired Cs value to obtain the desired key sensitivity balance, but this is rare.

3.2 Profiling electrode fields

Capacitive fields can be profiled using a small piece of metal foil or a disk coupled to an oscilloscope probe (*Figure 7*). The foil should be about 8mm in diameter with the user's hand well away from the probe. As the probe is moved across the surface of the key, the signal amplitude can be monitored on the oscilloscope to chart a profile. This gives a reasonably accurate representation of the signals that the chip sees when the panel is touched around the key. Measured pulse amplitude directly correlates with sensitivity.

This measurement method is also very useful to check on the risetime of the QST pulses at the electrode (*Section 3.3*).

Figure 7. Checking key bursts using metal foil or a coin



Note: If a small (8mm) metal disc is used, a profile of the sense field can be plotted vs. position to show finger sensitivity over a key.

3.3 Pulse rise time

Long trace lengths and ground planes (and other signal traces that usually act as an AC ground) add to key C_X capacitance resulting in increased pulse risetime which if too long will reduce key sensitivity and even introduce instability. If the QST pulse is not properly settled, either capacitive loading or the R_S series resistor should be decreased (or both).

The series resistor R_S in line with the electrode acts to increase pulse rise time and to attenuate incoming external interfering fields. R_S should also be near the SNS pins, and its value should be evaluated to be sure that it is the highest value possible without causing signal attenuation.

One way to do this is to check the risetime of the pulses at the electrode with an oscilloscope to be sure they have settled completely before their falling edges; the simplest way to do this without scope probe loading effects is to use a piece of metal foil or copper over the key area as shown in *Figure 7*. This method will display a reduced amplitude signal without being significantly affected by probe capacitance.

As a general rule, the value of R_S should be chosen so that the RC time constant (time from zero to the 0.63 x V_{DD} point on the rising edge) of the pulse is about 1/6th that of the pulse width.

See also *Section 3.2*.

3.4 Driven shields

Long traces and large electrodes increase C_X loading which in turn reduces sensitivity; increasing C_S can compensate for the reduced gain, but the sensor can also become prone to excessive thermal drift.

Where budgets allow, it is possible to use 'driven shield' circuits to eliminate this problem and allow a much lower value of C_S and higher value of R_S (*Figure 8*). Driven shields are a very old concept dating back to the 1960's. The basic idea is to drive neighboring conductors with an exact copy of the QST waveform; this creates an equipotential between the pulse and the neighbor conductor, which in turn causes the neighbor conductor to become non-loading. In theory, a sense trace can be 'wrapped' with a driven shield signal and run forever without loading effects. In practice, the limit is usually under a meter due to ringing and capacitive loading of the driven signal itself.

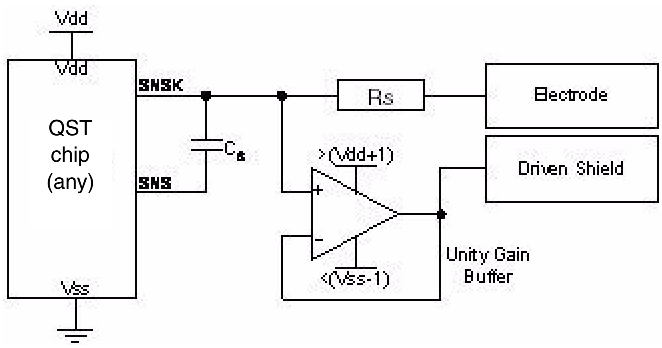
The driven shield should consist of a unity-gain buffer amplifier with a rail-to-rail I/O capability, high slew rate, and very high input impedance and low input current. Very few single-rail amplifiers meet these criteria. Best are op-amps that use split rail power supplies, such as JFET or CMOS input amplifiers. Discrete circuits are also possible. Note that the driven shield signal only has to match the sense signal's AC shape, not its exact DC levels. Each sensing channel requires its own independent driven shield circuit.

Slightly imperfect but still usable driven shields can also be made by turning one channel of a 'parallel burst' into a sacrificial shield driver (*Figure 9*).

Implementing this type of driven shield requires the use of an oscilloscope with a low capacitance FET probe and a willingness to spend a few hours fine-tuning the values of C_S for each channel so that the driven shield has nearly the same waveform as the channel(s) being shielded.

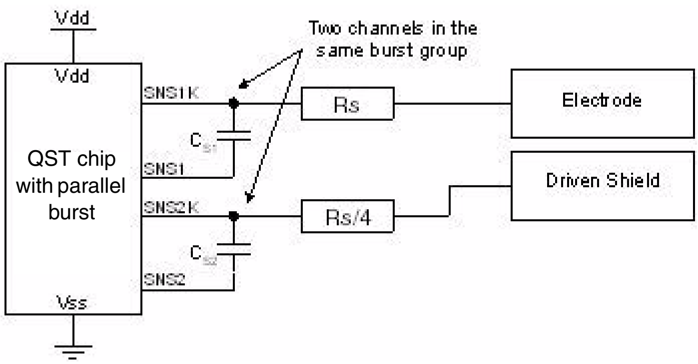
Driven shields can be very useful in suppressing the effects of water films, as described in *Section 2.4* and *Figure 6*. Properly implemented, a driven shield can be used to suppress false keypresses during wet cloth 'wipedown' events as described in *Section 2.4* by also acting as a 'wet cloth detector'.

Figure 8. Driven shield circuit using a buffer amp



The buffer input can also connect to the electrode side of R_S to reduce the slew rate. The buffer needs voltage rails that are somewhat wider than the maximum p-p pulse height in order to drive properly, even if the buffer is advertised as 'rail-to-rail'.

Figure 9. Driven shield using a second QST channel



If a second parallel QST channel is available, it can be used to create an inexpensive driven shield, provided the shape and duration of the waveforms of the two channels are matched by adjusting C_{S1} and C_{S2}. This takes a scope with a FET probe and some patience.

3.5 Multiple QST chips

More than one QST chip can be used in a panel design. If the electrodes or associated sense traces are near each other, they can cross-interfere and generate false detections by beating against each other. Solutions to this problem include making sure the electrodes and traces belonging to adjacent chips are separated by enough distance, or to put ground between these signals, or to synchronize the chips with each other.

3.6 LEDs near keys

Spot indication can be achieved by using LEDs mounted on the PCB near or even in the middle of electrodes. One way to do this is to use 'backfiring' SMT LEDs that shine back through the PCB they are mounted on (*Figure 10*).

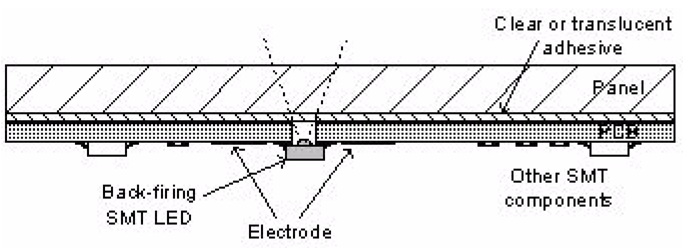
However, LEDs exhibit a substantial change in impedance between their on and off states due to the fact that they are non-linear P-N junction devices. An LED or its traces in close proximity to the electrode wiring will induce a slight increase in apparent C_X when switched on which can falsely trigger a key or make it unstable. Often what happens is that the LED is switched on in response to a touch on the key, the LED node coupling capacitance increases, and as a result the key sticks on.

The easiest solution to this problem is to bypass all switched LED terminals with a non-critical 10nF capacitor to circuit ground (*Figure 11*). The capacitor can be physically located anywhere on the PCB, even far away from the key. The important thing is that the LED node's AC impedance is stabilized as a result of the added capacitor so that the change in node capacitance between floating and driven states has an infinitesimal effect on the sensing channel.

Any LED terminal already connected full time to either V_{CC} or ground, even if through a limiting resistor, does not need such bypassing. LEDs that are constantly driven (i.e. just for constant backlighting) do not normally require bypassing so long as these LEDs are driven before the QST chip gets a chance to calibrate itself on power-up. Multiplexed LEDs usually require bypassing on one terminal, but since multiplex lines drive two or more LEDs, the number of bypass capacitors need not be one per LED; only one capacitor per common drive line is needed.

Other kinds of signal traces that change impedance can also cause false detections; any nearby trace that switches between 'floating' and 'clamped' states will usually cause a slight apparent capacitance change and should be bypassed. Push-pull driven traces, so long as they are never 3-stated, do not require bypassing.

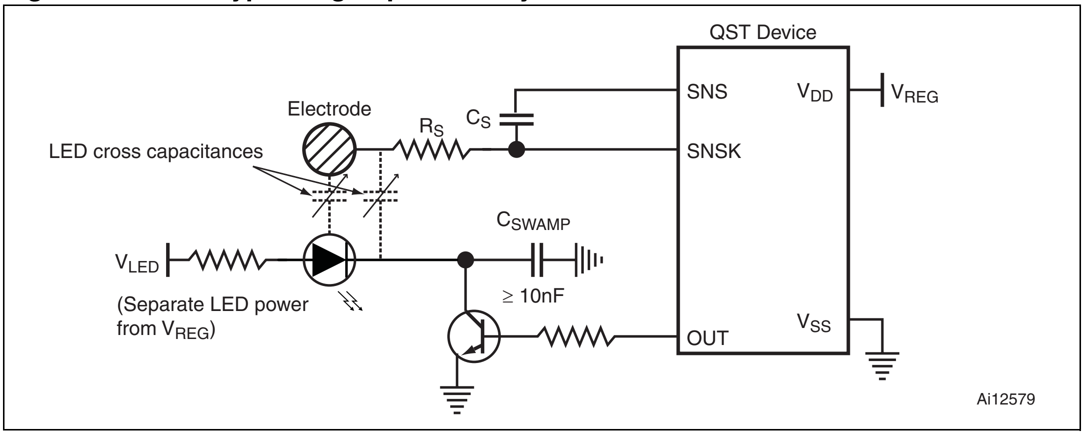
Figure 10. 'Back-firing' touch panel with LEDs



The construction of *Figure 3* can be modified to have back-firing LEDs mounted near or within the electrode areas, so that light emerges through holes in the PCB. This can create the unwanted consequence of 'capacitive interference' between LED wiring and the sensing channels. Fortunately this can be solved with an inexpensive bypass capacitor (*Figure 11*).

LEDs near a key (or its traces) whose terminals can float like this open collector driver require a bypass capacitor from the floating node to ground to swamp the effects of variable cross capacitance. The bypass capacitor (C_{SWAMP}) does not have to be near the LED to be effective.

Figure 11. LED bypassing to prevent key interference



3.7 Power supply considerations

The power supply should be locally regulated and free from spikes, surges or sags due to other loads. In practice, this usually means that the QST circuit should have its own regulator IC. A regulator IC shared with other logic can result in erratic operation and is not advised.

Similarly the regulator should not be used to also power things like LEDs that are switched on or off during operation. Failure to heed the warnings in this section have caused designers many lost hours trying to find the cause of sporadic operation.

LDO regulators are very inexpensive; many are under 0.10 $US in volume. A regulator can be shared among two or more QST devices on one board. One such regulator known to work well with QST chips is the LD2980 from STMicroelectronics.

The power pins should always be bypassed to ground with a ceramic capacitor placed close to the pins of the part with short traces. A common 0.1µF ceramic capacitor of any type is sufficient. Failure to do so can result in device oscillation, high current consumption, erratic operation, and other ills.

3.8 Board cleanliness

Capacitive circuits should be treated as the high sensitivity analog circuits that they are. Residual flux and other contamination can cause serious problems with detection stability over temperature and humidity; rapid heating or cooling of a PCB can cause false detections or loss of sensitivity due to rapid changes in moisture content in the residual flux layer. It is not always obvious that the problem is caused by flux contamination.

Fluxes in particular are hygroscopic, and the moisture contained in these substances has strong effects on the nodes they contact. When dealing with sensitive analog circuits such as QST chips, there is no such thing as 'no clean flux'. Unless the application is truly non-critical, boards should be cleaned of flux after soldering with approved cleaners in an ultrasonic tank followed by a rinse in de-ionized water.

Boards should be dried thoroughly, preferably at an elevated temperature to drive off residual moisture.

Conformal Coating: In the vast majority of cases (i.e. in consumer goods) there is little reason to consider conformal coatings.

However, sometimes electrodes are used in harsh environments, for example in condensing environments or where there are airborne particulates or grease. In these situations conformal coatings are recommended. The worst case is direct water contact on bare metal nodes of the sensor wiring. Conformal coatings such as Parylene are highly effective at protecting QST circuits against moisture effects.

QST chips help to defend against such problems in other ways, for example by using drift compensation to null out the changes due to slow-condensing water films or grime. In some cases, special versions are required to provide accelerated drift compensation. Many QST chips also provide patented adjacent key suppression (AKSTM) to stop false key detections in neighboring keys due to water films. However, these chip features should not be relied upon as a first defense against contamination.

4 Electromagnetic compatibility and electrostatic discharge

4.1 RF susceptibility

Some QST devices feature spread-spectrum operation and are highly robust against external noise sources. Dominant interference points are around the QST device's sampling frequency and harmonics. While spread-spectrum operation and detection integration take care of the majority of these problems, sometimes there are still problems at very high frequencies. These are usually caused by direct coupling of RF fields into the pins of the chip via associated traces. Electrode traces will act as RF antennas at high frequencies.

The influence of external fields at the electrode on the sensor is reduced by means of the resistor R_S and sample capacitor C_S. C_S and R_S form a natural low-pass filter for incoming fields; the roll-off frequency of this network is defined by -

If for example C_S = 22nF and R_S = 10K ohms, the rolloff frequency (f_R) with respect to external fields is 723 Hz, which is much lower than common external noise sources except for power line frequencies. However, R_S and C_S must both be placed very close to the body of the chip so that the traces between them and the chip do not form an antenna at very high frequencies.

Note that protection diodes on the sense lines have a negative effect on RF susceptibility; see *Section 4.2*.

4.2 Electrostatic discharge (ESD) protection

When the electrode is behind glass or plastic, it is extremely difficult to affect or destroy the device via ESD; breakdown voltages of most common panel materials exceed 15kV/mm (*Appendix A*); most plastic panels are over 2mm thick. Further, even if ESD punch-through occurs, the discharge currents are quite weak unless there is a defect in the panel (or if the ESD makes its way around the panel edge). Due to the detection integrator process in all QST chips it is also unlikely that ESD can cause a false detection unless the ESD event lasts several 10s of milliseconds. ESD protection circuitry should only consist of the R_S mentioned in the above sections. R_S will act to limit residual transient currents flowing into the QST chip's pins. The QST pins all contain internal clamp diodes designed specifically to mitigate ESD problems.

QST datasheets sometimes describe diode clamp circuits to shunt aside ESD. These circuits are effective in cases where they are absolutely mandatory, however they also introduce a high degree of RF susceptibility and so should be avoided. Clamp diodes act as RF detectors that convert RF into DC voltages, and thus can cause the circuit to behave erratically. In almost all cases, the better solution is to just use a series R_S resistor close to the QST chip's SNS pins.

The use of bare metal (or thinly coated metal) as an electrode that is directly connected to the chip (even via a resistor) should be avoided.

Appendix A Dielectric properties of common materials

Table 1. Dielectric properties of common materials

	Epsilon	Breakdown voltage	
		V/mil	V/mm
Air	1	30	1.181
Common glass	7.8	200	7.874
Pyrex glass	4.8	335	13.189
Lexan	2.9	400	15.748
Polyethelene	2.3	450	17.717
Polystyrene	2.6	500	19.685
FR-4	5.2	700	27.559
Pexiglass	2.8	450	17.717
PVC, rigid	2.9	725	28.543
Mylar	3	7.500	295.276
Nylon	3.2	407	16.024
Teflon	2.1	1.000	39.370

Revision history

Table 2. Document revision history

Date	Revision	Changes
10-Dec-2007	1	Initial release.

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