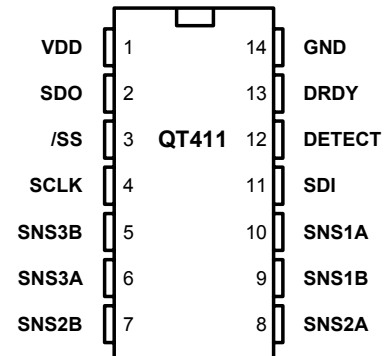


- QT401 QSlide™ enhancement - simplified calibration
- Linear finger-touch capacitive slider control
- Robust Charge-Transfer sensing method
- Extremely simple circuit - no external active components
- SPI slave-mode interface
- Self-calibration and drift compensation
- Spread-spectrum operation for optimal EMC compliance
- 2.5 - 5.5V single supply operation; very low power
- Enhanced power supply & thermal drift rejection
- 14-pin TSSOP Pb-free package
- Compatible with clear ITO over LCD construction
- Inexpensive, simple 1-sided PCB construction possible



## APPLICATIONS

- Personal electronics
- Appliance controls
- Climate controls
- Automotive controls

The QT411 QSlide™ IC is a new type of linear capacitive touch 'slider' sensor IC based on Quantum's patented charge-transfer ('QT') methods. This unique IC allows designers to create speed or volume controls, menu bars, and other more exotic forms of human interface on the panel of an appliance or personal electronic device. Generally it can be used to replace any form of linear control, through a completely sealed panel.

The device uses a simple, inexpensive resistive sensing element between four connection points. The sense element can be a straight line or curved. The device can report a single rapid touch anywhere along the sense element, or, it can track a finger moving along the sensing surface in real time.

This device uses three channels of synchronous sensing across a resistive element to determine touch position, using mathematical analysis. A positional accuracy of 5% (or better) is relatively easy to achieve. The acquisitions are performed in a burst mode which uses proprietary spread-spectrum modulation for superior noise immunity and ultra-low RF low emissions.

The output of the QT411 can also be used to create discrete controls buttons in a line, by interpreting sets of number ranges as buttons. For example, the number range 0..19 can be button A, 30..49 button B, 60..79 button C etc. Continuous slider action and number-range based discrete control points can be mixed on a single element, or, the element can be reinterpreted differently at different times, for example when used adjacent to or on top of an LCD to act as a menu input device that dynamically changes function in context. The device is compatible with ITO (Indium Tin Oxide) overlays on top of various displays or simply to provide for a backlighting effect.

The QT411 is significantly more stable with temperature and other environmental influences than the QT401 which it is designed to replace. In particular it can tolerate extreme temperature swings without false detection or shifts in reported touch position. Also it does not require special calibration of the endpoints of the slider area. However, unlike the QT401 the QT411 does not have a proximity detection function.

# 1 Operation

The QT411 uses a SPI slave mode interface for control and data communications with a host controller. Acquisition timings and operating parameters are under host control; there are no option jumpers and the device cannot operate in a stand-alone mode.

The output data is a 7-bit binary number (0...127) indicating angular position.

Like all QProx™ devices, the QT411 operates using bursts of charge-transfer pulses; burst mode permits an unusually high level of control over spectral modulation, power consumption, and response time.

The QT411 modulates its bursts in a spread-spectrum fashion in order to heavily suppress the effects of external noise, and to suppress RF emissions.

## 1.1 Synchronized Mode

Refer also to Figure 3-1, page 6.

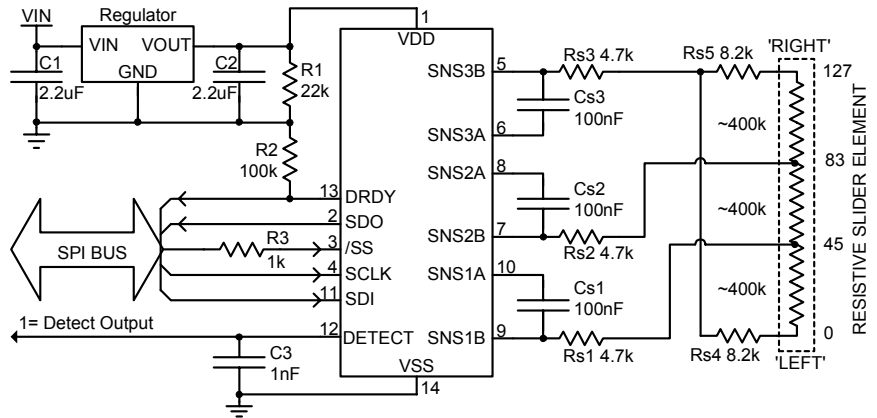
Sync mode allows the host device to control the repetition rate of the acquisition bursts, which in turn govern response time and power consumption.

In sync mode, the device will wait for the SPI slave select line /SS to fall and rise and will then do an acquisition burst; actual SPI clocks and data are optional. The /SS pin thus becomes a 'sync' input in addition to acting as the SPI framing control.

Within 35µs of the last rising edge of CLK, the device will enter a low power sleep mode. The rising edge of /SS must occur after this time; when /SS rises, the device wakes from sleep, and shortly thereafter does an acquisition burst. If a more substantial sleep time is desired, /SS should be made to rise some delay period later.

By increasing the amount of time spent in sleep mode, the host can decrease the average current drain at the expense of response time. Since a burst typically requires 31ms (at 3.3V, reference circuit), and an acceptable response time might be ~100ms, the power duty cycle will be 31/100 or 31% of peak current.

Figure 1-1 QT411 Wiring Diagram



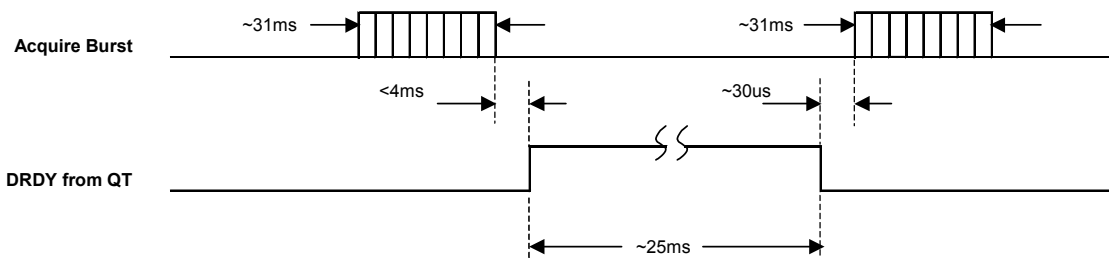
If power is not an issue the device can run constantly under host control, by always raising /SS after 35µs from the last rising edge of CLK. Constant burst operation can be used by the host to gather more data to filter the position data further to suppress noise effects, if required.

Synchronized mode also allows the host device to control the rate of drift compensation, by periodically sending a 'drift' command to the device.

**Mains Sync:** Sync mode can and should be used to sync to mains frequency via the host controller, if mains interference is possible (ie, running as a lamp dimmer control). The host should issue SPI commands synchronously with the mains frequency. This form of operation will heavily suppress interference from low frequency sources (e.g. 50/60Hz), which are not easily suppressed using spread-spectrum pulse modulation.

**Cross-talk suppression:** If two or more QT411's are used in close proximity, or there are other QTouch™ type device(s) close by, the devices can interfere strongly with one another to create position jitter or false triggering. This can be suppressed by making sure that the devices do not perform acquisition bursts at overlapping times. The host controller can make sure that all such devices operate in distinctly different timeslots, by using a separate /SS line for each part.

Figure 1-2 Free-Run Timing Diagram ( /SS = high )



**Table 1-1 Pin Descriptions**

PIN	NAME	TYPE	DESCRIPTION
1	VDD	Power	Positive power pin (+2.5 .. +5V)
2	SDO	O	Serial data output
3	/SS	I	Slave Select pin. This is an active low input that enables serial communications
4	SCLK	I	Serial clock input. Clock idles high
5	SNS3B	I/O	Sense pin (to Cs3, Rs3); connects to both slider ends, each via separate additional 8.2K ohm resistors
6	SNS3A	I/O	Sense pin (to Cs3)
7	SNS2B	I/O	Sense pin (to Cs2, Rs2); connects to 66% point (from left) of slider
8	SNS2A	I/O	Sense pin (to Cs2)
9	SNS1B	I/O	Sense pin (to Cs1, Rs1); connects to 33% point (from left) of slider
10	SNS1A	I/O	Sense pin (to Cs1)
11	SDI	I	Serial data input
12	DETECT	O	Active high touch detected. May be left unconnected. <b>Note (1)</b>
13	DRDY	O	Data ready output. Goes high to indicate it is possible to communicate with the QT411. <b>Note (1)</b>
14	VSS	Ground	Negative power pin

**Note (1):** Pin floats ~400µs after wake from Sleep mode.

## 1.2 Free-Run Mode

If /SS stays high, the device will acquire on its own repetitively after a timeout of about 30ms (Figure 1-2). In this mode, the DETECT pin can be used to wake up the host when it goes high upon touch.

In free-run mode, the device does not sleep between bursts. In this mode the QT411 performs automatic drift compensation at the maximum rate of one count per 120 acquisition burst cycles, or about one count every 7 seconds without host intervention. It is not possible to change this setting of drift compensation in Free-Run mode. See also Section 3.3.3.

## 1.3 Sleep Mode

After an SPI transmission, the device will enter a low power sleep state; see Figure 3-1, page 6, and Section 3.2.4, page 7 for details. This sleep state can be extended in order to lower average power, by simply delaying the rise of /SS.

Coming out of sleep state when /SS is pulsed, the DETECT and DRDY pins will float for ~400µs. It is recommended that the DRDY pin be pulled to Vss with a resistor and DETECT by bypassed with a capacitor to avoid false signalling if they are being monitored during this time; see Section 1.4.

Note: Pin /SS clamps to Vss for 250ns after coming out of sleep state as a diagnostic pulse. To prevent a possible pin drive conflict, /SS should either be driven by the host as an open-drain pull-high drive (e.g. with a 100K pullup resistor), or there should be a ~1K resistor placed in series with the /SS pin. See Figure 1-1.

**Note that activity on SCLK** will also wake the QT411, which in turn will then wait for the /SS to rise. For lowest possible operation in Sleep mode, do not pulse on SCLK until after /SS goes low.

## 1.4 DETECT Output Pin

This pin drives high when touch is detected and the chip is reporting an angular position. This condition is also found as bit 7 in the standard response.

This output will float for ~400µs during wake from Sleep mode (see Section 1.3). It is recommended that the DETECT pin (if it is used) be shunted to ground with a 1nF capacitor to hold

its state during the 400µs float interval when emerging from Sleep.

Note that in the QT411, detection occurs when one or two of the sensing channels becomes imbalanced with respect to the other channel(s). A touch at one position will always cause such an imbalance. However, a signal change that is balanced among all 3 channels will not cause a detection. For example, if a book is placed on top of the slider element, the channels will all change in the same way and as a result, detection will be suppressed. This feature is significantly different from the way the QT401 operates.

## 1.5 Position Data

The position value is internally calculated and can be accessed only when the sensor is touched (Detect pin high).

**Direction convention:** 'Left' is defined as the side closest to the connection made by SNS1, and 'Right' is defined as the side closest to the SNS2 connection. The ends are both connected to SNS3, each via a resistor which allows the chip to identify left and right as separate positions. See Figure 1-1.

The use of the terms 'left' and 'right' should not be interpreted to mean the device can only be used in one orientation. In fact the strip can be oriented backwards, vertically, or at any angle.

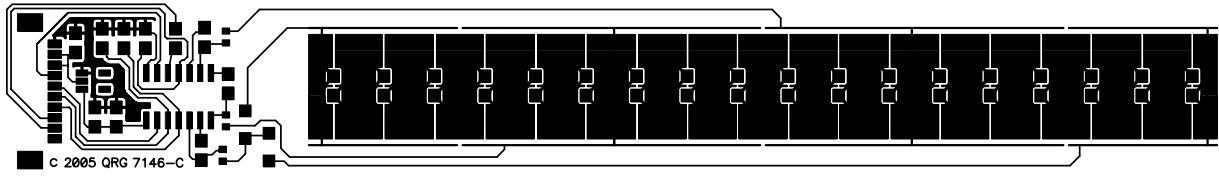
The position on the left end reports as 0, while the position at the right reports as 127. The device reports 45 when touched at the SNS1 node and 83 at SNS2. The position data is a 7-bit number (0..127) that is computed in real time and is returned via a status command.

**End stops:** The QT411 defines end zones of the slider element as saturated 'end stops', which consist of fixed regions where only a reading of '0' or '127' is returned. This is to allow robust position detection of these important locations, so that it is easy for a user to select 'full off' and 'full on'. The left slider end allocates 10% of the slider's length to location '0', and the right end similarly allocates 10% of the slider's length to location '127'. Only the center 80% of the slider's length will track changes in touch position in the range of 1..126.

The position data will update either with a single rapid touch or will track if the finger is moved along the surface of the

**Figure 1-3 Conventional PCB Layout (1-sided)**

*Copper side faces away from the panel; the bare side is glued to the inside of the product.*



element. The position data ceases to be reported when touch detection is no longer sensed.

### 1.6 Calibration

Calibration is possible via two methods:

- 1) Power up or power cycling (there is no reset input).
- 2) On command from the host via the SPI port (Command 0x01: see Section 3.3.2).

The calibration period requires 10 burst cycles, which are executed automatically without the need for additional SPI commands from the host. The spacing between each Cal burst is 1ms, and the bursts average about 31ms each, i.e. the Cal command requires ~325ms to execute. The power up calibration has 6 extra bursts to allow for power supply stabilization, and requires a total of ~550ms to begin normal operation.

Calibration should be performed when there is no hand proximity to the element, or the results may be in error. Should this happen, the error flag (bit 1 of the standard response, see Section 3.3) will activate when the hand is withdrawn. In most cases this condition will self-correct if drift compensation is used, and it can thus be ignored. See Section 1.9 below.

Note: During calibration, the device cannot communicate. DRDY will remain low during this interval.

### 1.7 Sensitivity Setting

The sensitivity of the slider area to finger detection is dependent on the values of the three Cs capacitors (Section 2.2) and the threshold setting (Section 3.3.5). Larger values of Cs increase sensitivity and also reduce granularity (missing codes), at the expense of higher power consumption due to longer acquisition bursts.

The threshold setting can be used to fine tune the sensitivity of the sensing element. When setting the threshold, use the smallest finger size for which detection is desired (normally a 6mm diameter spot), and probe at one of the two center connection points where sensitivity is weakest. The linear stretches between connection points are generally slightly higher in sensitivity due to the collection of charge from two channels.

A 'standard finger' probe can be made by taking a piece of metal foil of the required diameter, gluing it on the end of a cylinder of sponge rubber, and connecting it to ground with a wire. This probe is pressed against the panel centered on one of the middle two connection points; the threshold parameter is iterated until the sensor just detects. It is important to push the probe into the panel quickly and not let it linger near the

electrode afterwards, so that the drift compensation mechanism does not artificially create a threshold offset during the iteration process. Between threshold changes, the probe must be removed to at least 100mm from the panel.

### 1.8 Drift Compensation

The device features an ability to compensate for slow drift due to environmental factors such as temperature changes or humidity. Drift compensation is performed under host control via a special drift command. See Section 3.3.3 for further details.

### 1.9 Error Status

An error flag status is provided via a special command. An error can only occur when a finger was touching the sensing strip during power-on or recalibration, and then removed. In this sequence of events, the finger is 'calibrated away' and is not recognized as a touch. When the finger is removed, the signals from the device are inverted and a position is reported as though the strip has been touched. However, this position report is in error.

After any calibration event (i.e. a power-on cycle or a CAL command) the next detection event should be checked to see if it is in error by using the special error command. If an error is reported, the device should be immediately calibrated again to restore normal function (Section 3.3.2).

## 2 Wiring & Parts

The device should be wired according to Figure 1-1. An examples of a PCB layout is shown in Figure 1-3.

### 2.1 Electrode Construction

The strip electrode should be a resistive element of between 200K to 500K ohms (400K nominal target value) between each set of connection points, of a suitable length and width. Under heavy capacitive loading (for example if the element

**Table 1-2 Recommended Cs vs. Materials**

Thickness, mm	Acrylic ( $\epsilon_R=2.8$ )	Borosilicate glass ( $\epsilon_R=4.8$ )
0.4	10nF	5.6nF
0.8	22nF	10nF
1.5	47nF	22nF
2.5	100nF	39nF
3.0	-	47nF
4.0	-	100nF

must be placed immediately over a ground plane within a millimeter), the resistance might need to be lowered. Observe the sensing pulses for flatness on their tops in the middle of a segment using a small coin and scope probe to make sure the pulses fully settle before the falling edge (see app note AN-KD02 Figure 7).

The electrode can be made of a series chain of discrete resistors with copper pads on a PCB, or from ITO (Indium Tin Oxide, a clear conductor used in LCD panels and touch screens) over a display. Thick-film carbon paste can also be used, however linearity might be a problem as these films are notoriously difficult to control without laser trimming or scribing.

The linearity of the sensing strip is governed largely by the linearity and consistency of the resistive element. Position accuracy to within 5% is routinely achievable with good grade resistors and a uniform construction method.

## 2.2 Cs Sample Capacitors

Cs1, Cs2 and Cs3 are the charge sensing sample capacitors; normally they are identical in nominal value. They should be of type X7R dielectric.

The optimal Cs values depend on the thickness of the panel and its dielectric constant. Lower coupling to a finger caused by a low dielectric constant and/or thicker panel will cause the position result to become granular and more subject to position errors. The ideal panel is made of thin glass. The worst panel is thick plastic. Granularity due to poor coupling can be compensated for by the use of larger values of sample capacitors.

A table of suggested values for no missing position values is shown in Table 1-2. Values of Cs smaller than those shown in the table can cause skipping of position codes. Code skipping may be acceptable in many applications where fine position data is not required. Smaller Cs capacitors have the advantage of requiring shorter acquisition bursts and hence lower power drain.

Larger values of Cs improve granularity at the expense of longer burst lengths and hence more average power.

Cs1, Cs2 and Cs3 should be X7R type, matched to within 10% of each other (ie, 5% tolerance) for best accuracy. The PCB reference layout (Figure 1-3) is highly recommended. If the Cs capacitors are poorly matched, position accuracy will be affected and there could also be missing codes.

## 2.3 Rs Resistors

See Figure 1-1. Rs1, Rs2, and Rs3 are low value (typically 4.7K) resistors used to suppress the effects of ESD and assist with EMC compliance. They are optional in most cases.

In addition, there are two 8.2K resistors required to split channel SNS3B into the two constituent ends. These two resistors should be placed close to the ends of the slider strip.

## 2.4 Power Supply

The usual power supply considerations with QT parts applies also to the QT411. The power should be very clean and come from a separate regulator if possible. This is particularly critical with the QT411 which reports continuous position as opposed to just an on/off output.

A ceramic 0.1µF bypass capacitor should be placed very close to the power pins of the IC.

**Regulator stability:** Most low power LDO regulators have very poor transient stability, especially when the load transitions from zero current to full operating current in a few microseconds. With the QT411 this happens when the device comes out of sleep mode. The regulator output can suffer from hundreds of microseconds of instability at this time, which will have a negative effect on acquisition accuracy.

To assist with this problem, the QT411 waits 500µs after the 400µs taken to come out of sleep mode before acquiring to allow power to fully stabilize. This delay is not present before an acquisition burst if there is no preceding sleep state.

Use an oscilloscope to verify that Vdd has stabilized to within 5mV or better of final settled voltage before a burst begins.

The QT411 has specially enhanced power supply rejection built in. This means that it is often possible to share the regulator with other circuits. However, it is always advised to be sure that Vdd is free from spikes and transients, and is filtered sufficiently to prevent detection problems.

During development it is wise to first design a regulator onto the PCB just for (and next to) the QT411, but allow for it to be 'jumped out'. If in development it is clear that there are no problems with false detection or 'angle noise' even without a separate regulator for the QT411, then the regulator can be safely omitted.

## 2.5 PCB Layout and Mounting

One form of PCB layout is shown in Figure 1-3. This is a 1-sided board; the blank side is simply adhered to the inside of a 2mm thick (or less) control panel. Thicker panels can be tolerated with additional position error due to capacitive 'hand shadow' effects and will also have poorer EMC performance.

The Figure 1-3 layout uses a series copper pads connected with intervening series resistors in a row. The total resistance between any two connection points can be in the range of 100K to 500K, with ~400K being a suitable target value. Resistance values at the higher end of this range will generate more sensitivity provided there is no ground plane close underneath the electrode strip.

A human finger interpolates between the copper pads (if the pads are narrow enough) to make a smooth output with no apparent steps. The lateral dimension along the centre of each electrode should be no wider than the expected smallest diameter of finger touch, to prevent stepping of the position response (if it matters).

It is also possible create an interleaved electrode array with only 3 resistors between each channel's connection point on the strip. Interleaving eliminates stepping while reducing the number of required resistors. Consult Quantum for further details.

Resistive inks (such as ITO, Agfa Orgacon™ etc.) can also be used if the resistance between connection points is in the recommended range.

The electrode strip can be made in various lengths up to at least 80mm. The electrode width should be about 12mm wide or more, as a rule. The strip can also be an arc or other irregular shape. For a 360 degree wheel, use the QT511 or consult Quantum for other options.



The SMT components should be oriented perpendicular to the direction of bending so that they do not fracture when the PCB is flexed during bonding to the panel.

Additional ground area or a ground plane on the PCB will compromise signal strength and is to be avoided. A single sided PCB can be made of FR-2 or CEM-1 for low cost.

**‘Handshadow’ effects:** With thicker and wider panels an effect known as ‘handshadow’ can become noticeable. If the capacitive coupling from finger to electrode element is weak, for example due to a narrow electrode width or a thick, low dielectric constant panel, the remaining portion of the human hand can contribute a significant portion of the total detectable capacitive load. This will induce an offset error, which will depend on the proximity and orientation of the hand to the remainder of the element. Thinner panels and those with a smaller diameter will reduce this effect since the finger contact surface will strongly dominate the total signal, and the remaining handshadow capacitance will not contribute significantly to create an error offset.

**PCB Cleanliness:** All capacitive sensors should be treated as highly sensitive circuits which can be influenced by stray conductive leakage paths. QT devices have a basic resolution in the femtofarad range; in this region, there is no such thing as ‘no clean flux’. Flux absorbs moisture and becomes conductive between solder joints, causing signal drift and resultant false detections or temporary loss of sensitivity. Conformal coatings will trap in existing amounts of moisture which will then become highly temperature sensitive.

The designer should specify ultrasonic cleaning as part of the manufacturing process, and in extreme cases, the use of conformal coatings after cleaning.

## 2.6 ESD, EMC and Related Issues

Please refer to Quantum app note AN-KD02 for further information on ESD and EMC matters.

## 3 Serial Communications

The serial interface is a SPI slave-only mode type which is compatible with multi-drop operation, i.e. the MISO pin will float after a shift operation to allow other SPI devices (master or slave) to talk over the same bus. There should be one dedicated /SS line for each QT411 from the host controller.

A DRDY (‘data ready’) line is used to indicate to the host controller when it is possible to talk to the QT411.

### 3.1 Power-up Timing Delay

Immediately after power-up, DRDY floats for approximately 20ms, then goes low. The device requires ~525ms thereafter before DRDY goes high again, indicating that the device has calibrated and is able to communicate.

From power up to first communication, allow a total of 550ms in startup delay.

### 3.2 SPI Timing

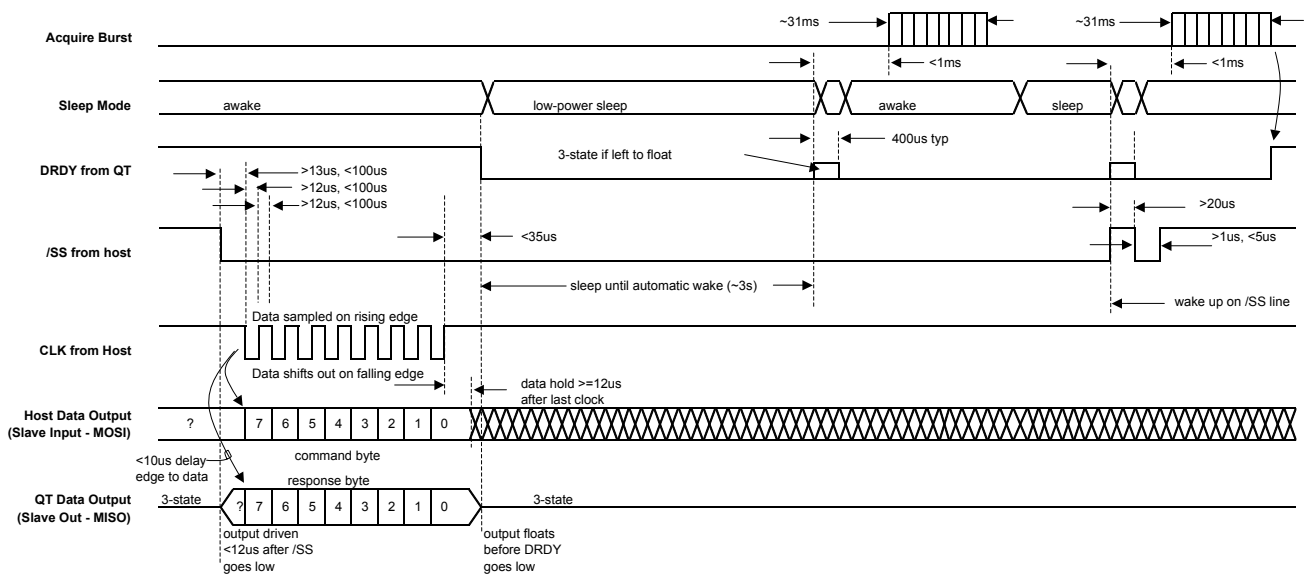
The SPI interface is a five-wire slave-only type; timings are found in Figure 3-1. The phase clocking is as follows:

Clock idle:	High
Data out changes on:	Falling edge of CLK from host
Input data read on:	Rising edge of CLK from host
Slave Select /SS:	Negative level frame from host
Data Ready DRDY:	Low from QT inhibits host
Bit length & order:	8 bits, MSB shifts first
Clock rate:	5kHz min, 40kHz max

The host can shift data to and from the QT on the same cycle (with overlapping commands). **Due to the nature of SPI, the return data from a command or request is always one SPI cycle behind.**

An acquisition burst always happens about 920µs after /SS goes high after coming out of Sleep mode. SPI clocking lasting more than 15ms can cause the chip to self-reset.

Figure 3-1 SPI Timing Diagram



### 3.2.1 /SS Line

/SS acts as a framing signal for SPI data clocking under host control. See Figure 3-1.

After a shift operation /SS must be pulsed high before being pulsed low for 1-5  $\mu$ s. This must be a minimum of 35 $\mu$ s after the last clock edge on CLK. The device automatically goes into sleep state during this interval, and wakes again after /SS rises. If /SS is simply held low after a shift operation, the device will remain in sleep state up to the maximum time shown in Figure 3-1. When /SS is pulsed, another acquisition burst is triggered.

If /SS is held high all the time, the device will burst in a free-running mode at a  $\sim$ 17Hz rate. In this mode a valid position result can be obtained quickly on demand, and/or the DETECT pin can be used to wake the host. This rate depends on the burst length which in turn depends on the value of each Cs and load capacitance Cx. Smaller values of Cs or higher values of Cx will make this rate faster.

**Dummy /SS Burst Triggers:** In order to force a single burst, a dummy 'command' can be sent to the device by pulsing /SS low for 10 $\mu$ s to 10ms; this will trigger a burst after the rising edge of /SS without requiring an actual SPI transmission. In order to ensure the sampling capacitors have enough time to discharge after a short /SS pulse, DRDY is held high for approximately 700 $\mu$ s before the burst occurring.

After the burst completes, DRDY will rise again to indicate that the host can get the results.

Note: Pin /SS clamps to Vss for 250ns after coming out of sleep state as a diagnostic pulse. To prevent a possible pin drive conflict, /SS should either be driven by the host as an open-drain pull-high drive (e.g. with a 100K pullup resistor), or there should be a  $\sim$ 1K resistor placed in series with the /SS pin.

### 3.2.2 DRDY Line

The DRDY line acts primarily as a way to inhibit the host from clocking to the QT411 when the QT411 is busy. It also acts to signal to the host when fresh data is available after a burst. The host should not attempt to clock data to the QT411 when DRDY is low, or the data will be ignored or cause a framing error.

On power-up, DRDY will first float for about 20ms, then pull low for  $\sim$ 525ms until the initial calibration cycle has completed, then drive high to indicate completion of calibration. The device will be ready to communicate in typically under 600ms (with Cs1 = Cs2 = Cs3 = 100nF).

While DRDY is a push-pull output; however, this pin floats after power-up and after wake from Sleep mode, for  $\sim$ 400 $\mu$ s (typical at Vdd = 3.3V). It is desirable to use a pulldown resistor on DRDY to prevent false signalling back to the host controller; see Figure 1-1 and Section 1.3.

### 3.2.3 MISO / MOSI Data Lines

MISO and MOSI shift on the falling edge of each CLK pulse. The data should be clocked in on the rising edge of CLK. This applies to both the host and the QT411. The data path follows a circular buffer, with data being mutually transferred from host to QT, and QT to host, at the same time. However the return data from the QT is always the standard response byte regardless of the command.

The setup and hold times should be observed per Figure 3-1.

### 3.2.4 Sleep Mode

Please refer to Figure 3-1, page 6.

The device always enters low-power sleep mode after an SPI transmission (Figure 3-1), at or before about 35 $\mu$ s after the last rising edge of CLK. Before entering sleep mode, the device will lower DRDY. If another immediate acquisition burst is desired, /SS should be pulsed at least 35 $\mu$ s after the last rising edge of CLK. To prolong the sleep state, it is only necessary to pulse /SS after an even longer duration. During this time, the QT411 will wake up approximately every 3 seconds and burst before going back to sleep. This allows the QT411 to compensate for thermal changes.

Changes on CLK will also cause the device to wake, however the device will not cause an acquire burst to occur if /SS has also gone low and high again.

In sleep mode, the device consumes only a few microamps of current. The average current can be controlled by the host, by adjusting the percentage of time that the device spends in sleep.

The delay between the wake signal and the following burst is 1ms max to allow power to stabilize. The DETECT and DRDY lines will float for  $\sim$ 400 $\mu$ s (typical at Vdd = 3.3V) during wake from Sleep mode; see Section 1.3 for details.

After each acquisition burst, DRDY will rise again to indicate that the host can do another SPI transmission.

## 3.3 Commands

Commands are summarized in Table 3-1. Commands can be overlapped, i.e. a new command can be used to shift out the results from a prior command.

All commands cause a new acquisition burst to occur when /SS is raised again after the command byte is fully clocked.

**Standard Response:** All SPI shifts return a 'standard response' byte which depends on the touch detection state:

**No touch detection:** Bit 7 = 0 (0= not touched)  
Bit 6 = 0 to indicate linear type sensor  
= { 1 to indicate wheel chip }  
Bits 5, 4, 3, 2: unused (report 0)  
Bits 1, 0 reserved (report 0 or 1)

**Is touch detection:** Bit 7 = 1 (1= is touched)  
Bits 0..6: Contains calculated position

Note that touch detection calculated position is based on the results of the prior burst, which is triggered by the prior /SS rising edge (usually, from the prior command, or, from a dummy /SS trigger).

Bit 6 indicates the type of device: '1' means that the device is a wheel (e.g. QT501 or QT511), and '0' means the device is a linear type (e.g. QT411, or QT401).

There are 5 commands as follows.

#### 3.3.1 0x00 - Null Command

7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0

The Null command will trigger a new acquisition (if /SS rises), otherwise, it does nothing. The response to this command is the Standard Response byte, returned on the next SPI shift.

**TABLE 3-1 - Command Summary**

Hex	Command	What it does
0x00	Null	Shift out data; cause acquire burst (if /SS rises again)
0x01	Calibrate	Force recalibration of reference; causes 10 sequential bursts Power up default value = calibrated
0x03	Drift Comp	Drift compensation request; causes acquire burst. Max drift rate is 1 count per ten 0x03 commands.
0x04	Error Status	On the following SPI shift, returns the error status of the part; causes acquire burst. See Section 3.3.4.
0x8T	Threshold	Set touch threshold; causes acquire burst. Bottom 6 bits ('T') are the touch threshold value. (10TT TTTT) Power up default value = 10

This command is predominant once the device has been calibrated and is running normally.

**3.3.2 0x01 - Calibrate**

7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	1

This command takes ~325ms @ 3.3V to complete.

0x01 causes the device to do a basic recalibration. After the command is given the device will execute 10 acquisition bursts in a row in order to perform the recalibration, without the need for /SS to trigger each of the bursts. The host should wait for DRDY to rise again after the calibration has completed before shifting commands again.

**This command should be given if there is an error reported via the 0x04 command.**

On power-up the device calibrates itself automatically and so a 0x01 command is not required on startup.

The response to this command is the Standard Response byte, returned on the next SPI shift. During calibration, device communications are suspended.

**3.3.3 0x03 - Drift Compensate**

7	6	5	4	3	2	1	0
0	0	0	0	0	0	1	1

0x03 causes the sensor to perform incremental drift compensation. This command must be given periodically in order to allow the sensor to compensate for drift. The more 0x03 commands issued as a percentage of all commands, the faster the drift compensation will be.

The 0x03 command must be given 10 times in order for the device to do one count of drift compensation in either direction. The 0x03 command should be used in substitution of the Null command periodically.

**Example:** The host causes a burst to occur by sending a 0x00 Null command every 50ms (20 per second). Every 10th command the host sends is a 0x03 (drift) command.

The maximum drift compensation slew rate in the reference level is -

$$50\text{ms} \times 10 \times 10 = 5.0 \text{ seconds}$$

The actual rate of change of the reference level depends on whether there is an offset in the signal with respect to the reference level, and whether this offset is continuous or not.

It is possible to modulate the drift compensation rate dynamically depending on circumstances, for example a significant rate of change in temperature, by varying the mix of Drift and Null commands.

If the Drift command is issued while the device is in touch detection (ie bit 7 of the Standard Response byte =1), the drift function is ignored.

Drift compensation during Free-Run mode is fixed at 6, which results in a maximum rate of drift compensation rate of about 3secs / count; see Section 1.2.

The drift compensation rate should be made slow, so that it does not interfere with finger detection. A drift compensation rate of 3s ~ 5s is suitable for almost all applications. If the setting is too fast, the device can become unnecessarily desensitized when a hand lingers near the element. Most environmental drift rates are of the order of 10's or 100's of seconds per count.

The response to this command is the Standard Response byte, returned on the next SPI shift.

**3.3.4 0x04 - Error Status**

7	6	5	4	3	2	1	0
0	0	0	0	0	1	0	0

This command is used to read the current status of the device. In particular it is used to detect if there is a sensing error caused by a calibration or power-on at a bad time, ie when a finger is on the sensing strip and thereafter removed.

The reported bits are as follows:

- Bit 7 = 1 indicates touch;  
= 0 indicates no touch
- Bit 6 = 0 indicates Linear type (QT401 or QT411)  
= 1 indicates Wheel type (QT510 or QT511)
- Bits 5, 4, 3, 2: unused (0)
- Bit 1 = 1 if calibration error
- Bit 0 reserved (reports 0 or 1)

All bits except Bit 1 can be safely ignored.

The status byte should be read the first time there is a detection just after a power-on reset or after a 0x01 calibration. If Bit 1 = 1, there was a calibration error and the device should be immediately calibrated again using the 0x01 command. After the second calibration it should be checked yet again (and so on) until there is no error.

If there is no error according to the sequence of the above paragraph, it is not required to read this byte again.

The error byte is returned on the following SPI shift.



### 3.3.5 0x8T - Set Touch Threshold

7	6	5	4	3	2	1	0
1	0	T <sub>5</sub>	T <sub>4</sub>	T <sub>3</sub>	T <sub>2</sub>	T <sub>1</sub>	T <sub>0</sub>

The lower 6 bits of this command (T5..T0) are used to set the touch threshold level. Higher numbers are less sensitive (ie the signal has to travel further to cross the threshold).

Operand 'T' can range from 0 to 63. Internally the number is multiplied by 4 to achieve a wider range. 0 should never be used.

This number is normally set to 10, more or less depending on the desired sensitivity to touch and the panel thickness. Touch detection uses a hysteresis value equal to 12.5% of the threshold setting.

Both the touch bit (bit 7) in the standard response and the DETECT pin will go high if this threshold is crossed. The DETECT pin can be used to indicate to the host that the device has detected a finger, without the need for SPI polling. However the /SS line must remain high constantly so that the device continues to acquire continuously, or /SS has to be at least pulsed regularly for this to work.

The response to this command is the Standard Response byte, returned on the next SPI shift.

**0x8T power-up default setting: 10**

### 3.4 SPI - What to Send

The host should execute the following commands after powerup self-cal cycle has completed (assuming a 50ms SPI repetition rate):

1. 0x01 - Basic calibration (optional as this is done automatically on power-up)
2. 0x8T - Set touch threshold (optional)
3. An endlessly repeating mixture of:
  - a. 0x00 (Null) - all commands except:
  - b. 0x03 (Drift compensate) - replace every nth Null command with 0x03 where typically, n = 10
  - c. 0x04 (Error status) - use after any detection just after a calibration or power-up to see if there is a calibration error.

Note: the Null can be replaced by an empty /SS pulse if there is no need for fast updates.

## 4.1 Absolute Maximum Specifications

Operating temperature range, Ta	-40°C to +85°C
Storage temperature range, Ts	-55°C to +125°C
V <sub>DD</sub>	-0.5 to +7.0V
Max continuous pin current, any control or drive pin	±20mA
Short circuit duration to ground, any pin	infinite
Short circuit duration to V <sub>DD</sub> , any pin	infinite
Voltage forced onto any pin	-0.6V to (V <sub>DD</sub> + 0.6) Volts

## 4.2 Recommended Operating Conditions

V <sub>DD</sub>	+2.5 to 5.0V
Supply ripple+noise	5mV p-p max
Cs1, Cs2, Cs3	100nF
Cs1, Cs2, Cs3 relative matching	±5%
Output load, max.	±0.5mA

## 4.3 DC Specifications

V<sub>DD</sub> = 5.0V, Cs1 = Cs2 = 100nF, 100ms rep rate, Ta = recommended range, all unless otherwise noted

Parameter	Description	Min	Typ	Max	Units	Notes
I <sub>DD5P</sub>	Peak supply current		0.75	1.5	mA	@ 5V
I <sub>DD3P</sub>	Peak supply current		0.45	0.6	mA	@ 3V
I <sub>DD5A</sub>	Average supply current		180		µA	@ 5V
I <sub>DD3A</sub>	Average supply current		110		µA	@ 3V
V <sub>DDS</sub>	Supply turn-on slope	100			V/s	Required for proper startup and calibration
V <sub>IL</sub>	Low input logic level			0.8	V	
V <sub>HIL</sub>	High input logic level	2.2			V	
V <sub>OL</sub>	Low output voltage			0.6	V	4mA sink
V <sub>OH</sub>	High output voltage	V <sub>DD</sub> -0.7			V	1mA source
I <sub>IL</sub>	Input leakage current			±1	µA	
A <sub>R</sub>	Acquisition resolution			7	bits	

## 4.4 AC Specifications

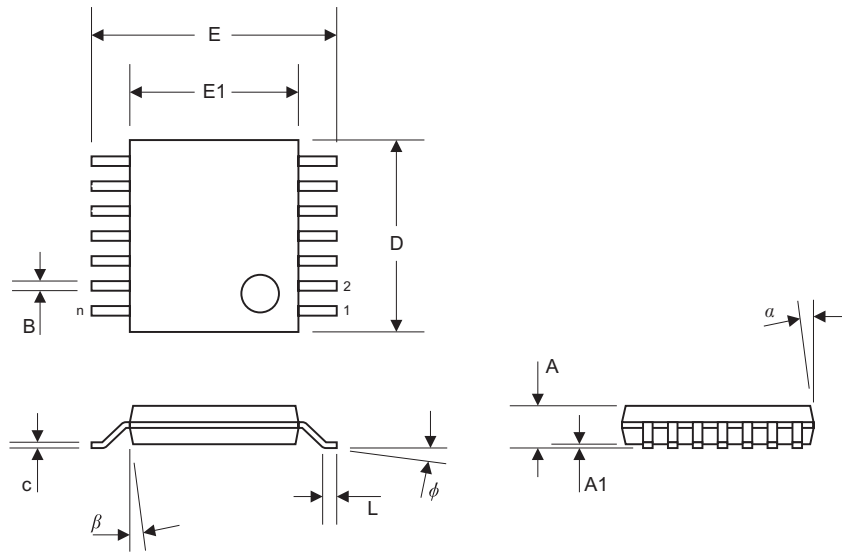
V<sub>DD</sub> = 5.0V, Cs1 = Cs2 = 100nF, Ta = recommended range, unless otherwise noted

Parameter	Description	Min	Typ	Max	Units	Notes
T <sub>R</sub>	Response time		-		ms	Under host control
S <sub>T</sub>	Touch Sensitivity	0.6			µF	Variable parameter under host control
F <sub>QT</sub>	Sample frequency	92	98	104	kHz	Modulated spread-spectrum (chirp)
T <sub>BS</sub>	QT Burst spacing	1			ms	
T <sub>D</sub>	Power-up delay to operate		550		ms	
F <sub>SPI</sub>	SPI clock rate	5		37	kHz	

## 4.5 Signal Processing and Output

Parameter	Description	Min	Typ	Max	Units	Notes
D <sub>I</sub>	Detection integrator counts		1		counts	Both prox and touch detection
T <sub>P</sub>	Threshold, prox	1		63		Host controlled variable
T <sub>T</sub>	Threshold, wheel touch	1		63		Host controlled variable
H <sub>P</sub>	Hysteresis, prox sensing		0		%	% of threshold setting
H <sub>T</sub>	Hysteresis, touch sensing		12.5		%	% of threshold setting
D <sub>R</sub>	Drift compensation rate			±10	%	% of bursts; host controlled
L	Position linearity		±3		%	Depends on element linearity, layout

## 4.6 TSSOP Package



Units		INCHES			MILLIMETERS		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		14			14	
Pitch	p		0.026			0.65	
Overall Height	A			0.043			1.10
Standoff	A1	0.002	0.004	0.006	0.05	0.10	0.15
Overall Width	E	0.246	0.251	0.256	6.25	6.38	6.50
Moulded Package Width	E1	0.169	0.173	0.177	4.30	4.40	4.50
Moulded Package Length	D	0.193	0.197	0.201	4.90	5.00	5.10
Foot Length	L	0.020	0.024	0.028	0.50	0.60	0.70
Foot Angle		0	4	8	0	4	8
Lead Thickness	c	0.004	0.006	0.008	0.09	0.15	0.20
Lead Width	B	0.007	0.010	0.012	0.19	0.25	0.30
Mould Draft Angle Top	alpha	0	5	10	0	5	10
Mould Draft Angle Bottom		0	5	10	0	5	10

## 4.7 Ordering Information

PART NO.	PACKAGE	TEMP RANGE	MARKING
QT411-ISSG	TSSOP-14	-40°C ~ +85°C	QT411



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## Corporate Headquarters

1 Mitchell Point  
Ensign Way, Hamble SO31 4RF  
Great Britain  
Tel: +44 (0)23 8056 5600 Fax: +44 (0)23 80565600

**[www.qprox.com](http://www.qprox.com)**

## North America

651 Holiday Drive Bldg. 5 / 300  
Pittsburgh, PA 15220 USA  
Tel: 412-391-7367 Fax: 412-291-1015

This device covered under one or more of the following United States and corresponding international patents: 5,730,165, 6,288,707, 6,377,009, 6,452,514, 6,457,355, 6,466,036, 6,535,200. Numerous further patents are pending which may apply to this device or the applications thereof.

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*Development Team: Martin Simmons, Matthew Trend*