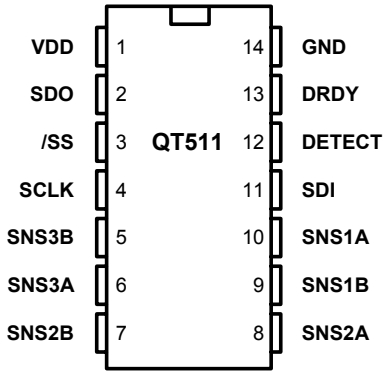
QT511-ISSG

QWHEEL™ TOUCH SLIDER IC

- **Rotary finger-touch 'wheel' slider control**
- **Center-button compatible signal processing**
- **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**
- **Reference design board available**



APPLICATIONS

- **Personal electronics**
- **Appliance controls**
- **Shaft encoders**
- **Automotive controls**

The QT511 QSlide™ IC is a new type of rotary capacitive touch 'slider' sensor IC based on Quantum's patented charge-transfer 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. Generally it can be used to replace any form of rotary knob, through a completely sealed panel.

The device uses a simple, inexpensive resistive sensing element between three connection points. The sense element can be circular or any polygon shape.

The QT511 can report a single rapid touch anywhere along the sense element, or, it can track a finger moving along the wheel surface in real time. The device self-calibrates under command from a host controller.

This device uses three channels of simultaneous sensing across a resistive element to determine finger 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 low emissions.

The output of the QT511 can also be used to create discrete controls in a circle, 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 wheel action and discrete controls can be mixed on a single element, or, the element can be reinterpreted differently at different times, for example when used below 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 QT511 has two enhancements over the QT510. It is significantly more stable with temperature and other environmental influences, and it recognizes a touch in the middle of the wheel as being invalid, which aids considerably in placing a touch button in the center of the wheel. However, unlike the QT510 the QT511 does not have a proximity detection function.

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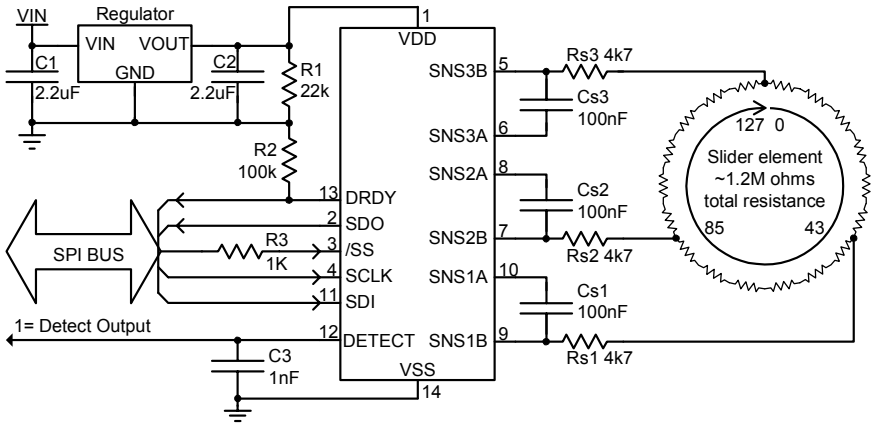
1 Operation

The QT511 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 positional output data is a 7-bit binary number (0...127) indicating angular position.

Like all QProx™ devices, the QT511 operates using bursts of charge-transfer pulses; burst mode permits an unusually high level of control over spectral modulation, power consumption, and response time.

Figure 1-1 QT511 Wiring Diagram



The QT511 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.

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 QT511'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.

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

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

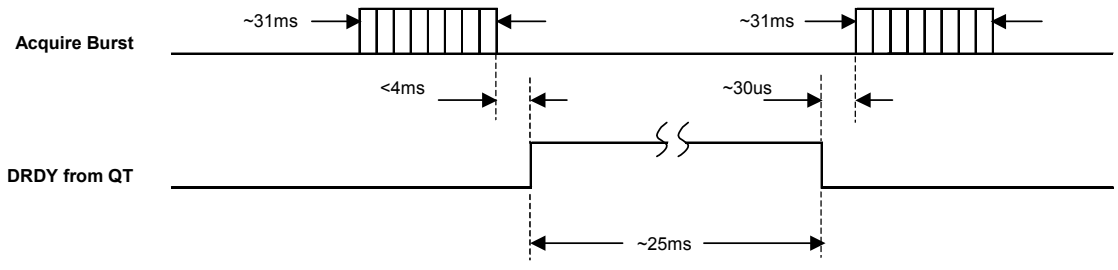


Table 1-1 Pin Descriptions

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 127/0 position (12:00) of wheel
6	SNS3A	I/O	Sense pin (to Cs3)
7	SNS2B	I/O	Sense pin (to Cs2, Rs2); connects to 85 position (8:00) of wheel
8	SNS2A	I/O	Sense pin (to Cs2)
9	SNS1B	I/O	Sense pin (to Cs1, Rs1); connects to 43 position (4:00) of wheel
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. **Note (1)**
13	DRDY	O	Data ready output. Goes high to indicate it is possible to communicate with the QT511. **Note (1)**
14	VSS	Ground	Negative power pin

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

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 QT511 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 QT511, 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 QT511, detection occurs when one or two of the sensing channels becomes unbalanced 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 rotor, 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 QT510 operates.

1.5 Position Data

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

The position data is a 7-bit number (0..127) that is computed in real time; the position number returned is 0 or 127 with position at SNS3, 43 when at SNS1 and 85 at SNS2. The position data will update either with a single rapid touch or will track if the finger is moved along the surface of the element. The position data ceases to be reported when touch detection is no longer sensed.

1.6 Calibration

Calibration is possible via two methods:

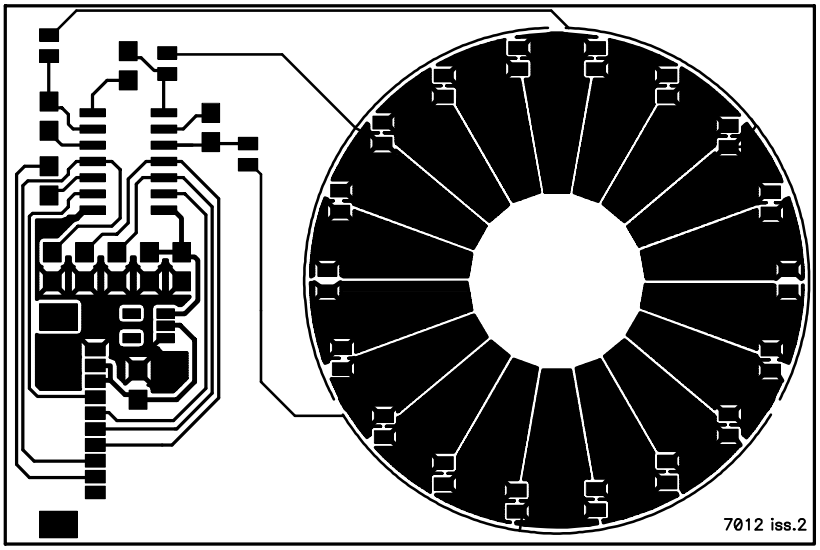
1) Power up or power cycling (there is no reset input).

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.

Figure 1-3 E510 PCB Layout (Applies also to QT511)



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 lowest. The 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 wheel electrode area 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 wheel are inverted and a position is reported as though the wheel 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 it an error is reported, the device should be immediately calibrated again so that the wheel becomes properly functional (Section 3.3.2).

2 Wiring & Parts

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

2.1 Electrode Construction

The wheel 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 diameter and width. Under heavy capacitive loading (for example if the element 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).

There are no known diameter restrictions other than those governed by human factors.

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

Table 1-2 Recommended Cs vs. Materials

Thickness, mm	Acrylic (ε_R =2.8)	Borosilicate glass (ε_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

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, the wheel accuracy will be affected and there could also be missing codes.

2.3 Rs Resistors

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 many cases.

2.4 Power Supply

The usual power supply considerations with QT parts applies also to the QT511. The power should be very clean and come from a separate regulator if possible. This is particularly critical with the QT511 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 QT511 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 QT511 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 QT511 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 QT511, but allow for it to be 'jumpered out'. If in development it is clear that there are no problems with false detection or 'angle noise' even without a regulator just for the QT511, then the regulator can be safely omitted.

2.5 PCB Layout and Mounting

The E510 PCB layout (Figure 1-3) should be followed if possible. 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.

This layout uses 18 copper pads connected with intervening series resistors in a circle. The finger interpolates between the copper pads (if the pads are narrow enough) to make a smooth, 0..127 step output with no apparent stair-casing. The lateral dimension along the centre of each electrode should be no wider than the expected smallest diameter of finger touch, to prevent stair-casing of the position response (if that matters).

Other geometries are possible, for example triangles and squares. The wheel can be made in various diameters up to at least 80mm. The electrode width should be about 12mm wide or more, as a rule.

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 QT511 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 QT511.

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.

3.2.1 /SS Line

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

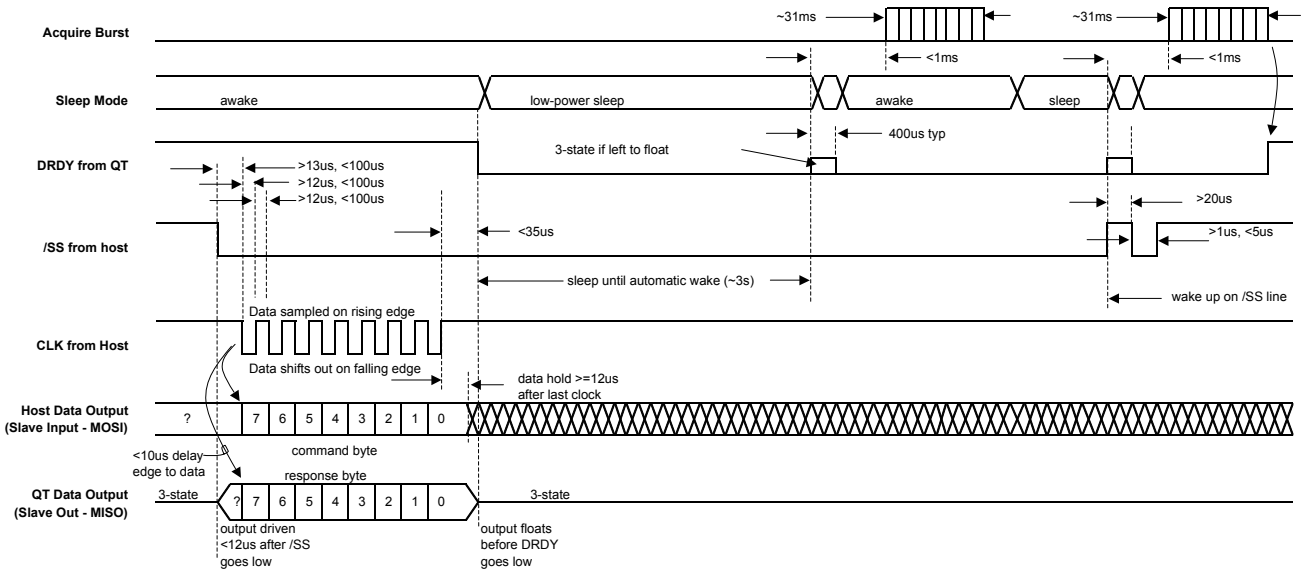
After a shift operation /SS must be pulsed high before being pulsed low for 1-5 µs. This must be a minimum of 35µs after the last clock edge on CLK. The device automatically goes into sleep state during this interval, and wakes again after /SS rises. If /SS is simply held low after a shift operation, 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 ~17Hz rate. In this mode a valid position result can be obtained quickly on demand, and/or one of the two OUT pins 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 10µs 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 700µs before the burst occurring.

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

Figure 3-1 SPI Timing Diagram



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.

3.2.2 DRDY Line

The DRDY line acts primarily as a way to inhibit the host from clocking to the QT511 when the QT511 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 QT511 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 ~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 ~400µs (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 QT511. 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 35µs 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 35µs 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 QT511 will wake up approximately every 3 seconds and burst before going back to sleep. This allows the QT511 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 ~400µs (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 = 1 to indicate QWheel type
= 0 to indicate Linear slider type
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. QT511), and '0' means the device is a linear type (e.g. QT401 or QT411).

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.

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 -

50ms x 10 x 10 = 5.0 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 u nnecessarily 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 QT511. 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 wheel and thereafter removed.

The reported bits are as follows:

Bit 7 = 1 indicates touch;
= 0 indicates no touch
Bit 6 = 1 indicates QWheel type (QT501 or QT511)
= 0 indicates Linear type (QT401 or QT411)
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_5	T_4	T_3	T_2	T_1	T_0

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 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

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

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 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_{DD}. . . . . -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_{DD}, any pin. . . . . infinite
Voltage forced onto any pin. . . . . -0.6V to (Vdd + 0.6) Volts

4.2 Recommended Operating Conditions

V_{DD}. . . . . +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

Vdd = 5.0V, Cs1 = Cs2 = 100nF, 100ms rep rate, Ta = recommended range, all unless otherwise noted

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

4.4 AC Specifications

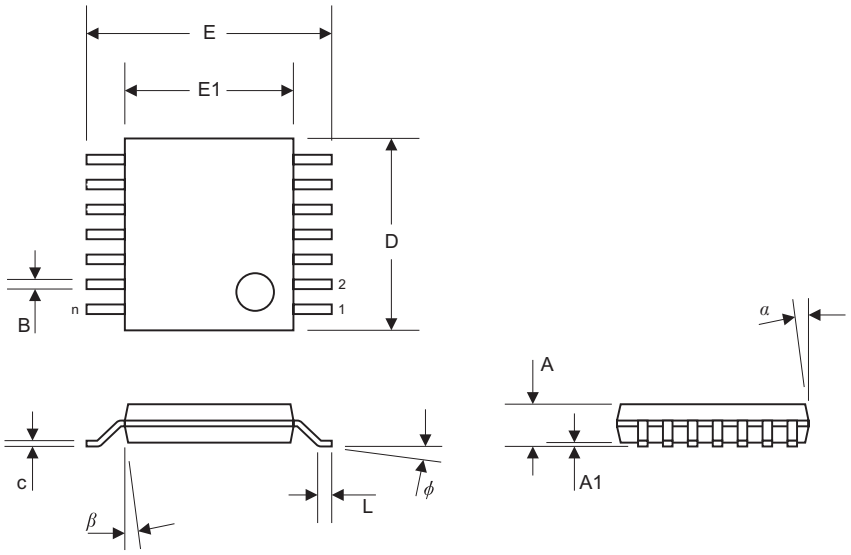
Vdd = 5.0V, Cs1 = Cs2 = 100nF, Ta = recommended range, unless otherwise noted

Parameter	Description	Min	Typ	Max	Units	Notes
T_R	Response time		-		ms	Under host control
S_T	Touch Sensitivity	0.6			pF	Variable parameter under host control
F_{QT}	Sample frequency	92	98	104	kHz	Modulated spread-spectrum (chirp)
T_{BS}	QT Burst spacing	1			ms	
T_D	Power-up delay to operate		550		ms	
F_{SPI}	SPI clock rate	5		37	kHz	

4.5 Signal Processing and Output

Parameter	Description	Min	Typ	Max	Units	Notes
DI	Detection integrator counts		1		counts	Both prox and touch detection
T_P	Threshold, prox	1		63		Host controlled variable
T_T	Threshold, wheel touch	1		63		Host controlled variable
H_P	Hysteresis, prox sensing		0		%	% of threshold setting
H_T	Hysteresis, touch sensing		12.5		%	% of threshold setting
D_R	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	α	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
QT511-ISSG	TSSOP-14	-40^{0}C ~ +85^{0}C	QT511

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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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