- **Less expensive than many mechanical switches**
- **Projects a 'touch button' through any dielectric**
- **100% autocal for life - no adjustments required**
- **No active external components**
- **Piezo sounder direct drive for 'tactile' click feedback**
- **LED drive for visual feedback**
- **2.5 ~ 5V single supply operation**
- **10μA at 2.5V - very low power drain**
- **Toggle mode for on/off control (via option pins)**
- **10s or 60s auto-recalibration timeout (via option pins)**
- **Pulse output mode (via option pins)**
- **Gain settings in 3 discrete levels**
- **Simple 2-wire operation possible**
- **HeartBeat™ health indicator on output**
- **Pb-Free packages**

	QT110	
Vdd	1	8	Vss
Out	2	7	Sns2
Opt1	3	6	Sns1
Opt2	4	5	Gain
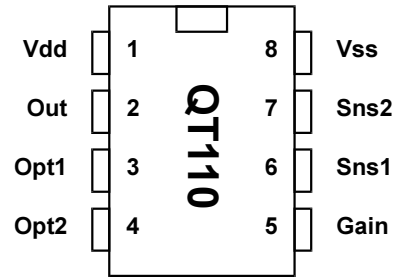
APPLICATIONS -

- Light switches
- Appliance control
- Access systems
- Elevator buttons
- Industrial panels
- Security systems
- Pointing devices
- Consumer electronics

The QT110 charge-transfer ("QT'") sensor IC is a self-contained digital IC used to implement near-proximity or touch sensors. It projects sense fields through almost any dielectric, like glass, plastic, stone, ceramic, and wood. It can also turn small metal-bearing objects into intrinsic sensors, making them respond to proximity or touch. This capability coupled with an ability to self-calibrate continuously leads to entirely new product concepts.

The QT110 is designed specifically for human interfaces, like control panels, appliances, toys, lighting controls, or anywhere a mechanical switch or button may be found; they may also be used for some material sensing and control applications provided that the presence duration of objects does not exceed the recalibration timeout interval.

A piezo element can also be connected to create a feedback click sound.

This IC requires only a common inexpensive capacitor in order to function. Average power consumption is under 20μA in most applications, allowing battery operation.

The QT110 employs digital signal processing techniques pioneered by Quantum, designed to make it survive real-world challenges, such as 'stuck sensor' conditions and signal drift. Sensitivity is digitally determined for the highest possible stability. No external active components are required for operation.

The device includes several user-selectable built-in features. One, toggle mode, permits on/off touch control for example for light switch replacement. Another makes the sensor output a pulse instead of a DC level, which allows the device to 'talk' over the power rail, permitting a simple 2-wire twisted-pair interface. Quantum's unique HeartBeat™ signal is also included, allowing a host controller to continuously monitor sensor health.

By using the charge transfer principle, the QT110 delivers a level of performance clearly superior to older technologies in a highly cost-effective package.

AVAILABLE OPTIONS (Pb-FREE)

T$_A$	SOIC	8-PIN DIP
0°C to +70°C	-	QT110-DG
-40°C to +85°C	QT110-ISG	-

QUANTUM

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1 - OVERVIEW

The QT110 is a digital burst mode charge-transfer (QT) sensor designed specifically for touch controls; it includes all hardware and signal processing functions necessary to provide stable sensing under a wide variety of changing conditions. Only a few low cost, non-critical discrete external parts are required for operation.

Figure 1-1 shows the basic QT110 circuit using the device, with a conventional output drive and power supply connections. Figure 1-2 shows a second configuration using a common power/signal rail which can be a long twisted pair from a controller; this configuration uses the built-in pulse mode to transmit output state to the host controller (QT110 only).

1.1 BASIC OPERATION

The QT110 employs low duty cycle bursts of charge-transfer cycles to acquire its signal. Burst mode permits power consumption in the low microamp range, dramatically reduces EMC problems, and yet permits excellent response time. Internally the signals are digitally processed to reject impulse noise, using a 'consensus' filter which requires four consecutive confirmations of a detection before the output is activated.

The QT switches and charge measurement hardware functions are all internal to the QT110 (Figure 1-3). A single-slope switched capacitor ADC includes both the required QT charge and transfer switches in a configuration that provides direct ADC conversion. Vdd is used as the charge reference voltage.

Larger values of Cx cause the charge transferred into Cs to rise more rapidly, reducing available resolution; as a minimum resolution is required for proper operation, this can result in dramatically reduced apparent gain.

The IC is highly tolerant of changes in Cs since it computes the signal threshold level ratiometrically. Cs is thus non-critical and can be an X7R type. As Cs changes with temperature, the internal drift compensation mechanism also adjusts for the drift automatically.

Piezo sounder drive: The QT110 can drive a piezo sounder after a detection for feedback. The piezo sounder replaces or augments the Cs capacitor; this works since piezo sounders are also capacitors, albeit with a large thermal drift coefficient. If C_{piezo} is in the proper range, no additional capacitor is required. If C_{piezo} is too small, it can simply be 'topped up' with a ceramic capacitor in parallel. The QT110 drives a ~4kHz signal across SNS1 and SNS2 to make the piezo (if installed) sound a short tone for 75ms immediately after detection, to act as an audible confirmation.

Option pins allow the selection or alteration of several other special features and sensitivity.

Figure 1-1 Standard mode options

OUTPUT = DC
TIMEOUT = 10 Secs
TOGGLE = OFF
GAIN = HIGH
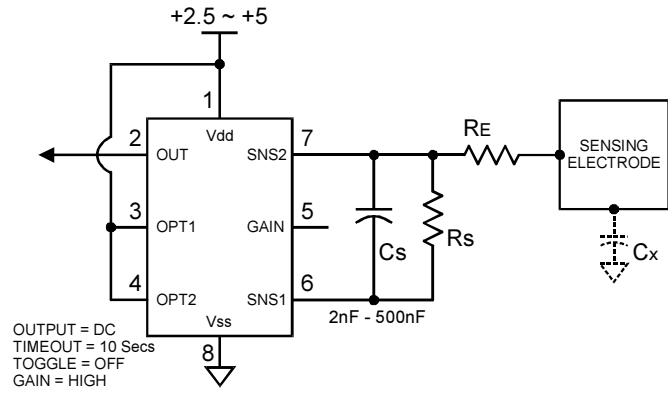
1.2 ELECTRODE DRIVE

The internal ADC treats Cs as a floating transfer capacitor; as a direct result, the sense electrode can in theory be connected to either SNS1 or SNS2 with no performance difference. However, the noise immunity of the device is improved by connecting the electrode to SNS2, preferably via a series resistor Re (Figure 1-1) to roll off higher harmonic frequencies, both outbound and inbound.

In order to reduce power consumption and to assist in discharging Cs between acquisition bursts, a 470K series resistor Rs should be connected across Cs (Figure 1-1).

The rule Cs >> Cx must be observed for proper operation. Normally Cx is on the order of 10pF or so, while Cs might be 10nF (10,000pF), or a ratio of about 1:1000.

It is important to minimize the amount of unnecessary stray capacitance Cx, for example by minimizing trace lengths and widths and backing off adjacent ground traces and planes so as keep gain high for a given value of Cs, and to allow for a larger sensing electrode size if so desired.

The PCB traces, wiring, and any components associated with or in contact with SNS1 and SNS2 will become touch sensitive and should be treated with caution to limit the touch area to the desired location.

1.3 ELECTRODE DESIGN

1.3.1 ELECTRODE GEOMETRY AND SIZE

There is no restriction on the shape of the electrode; in most cases common sense and a little experimentation can result in a good electrode design. The QT110 will operate equally well with long, thin electrodes as with round or square ones; even random shapes are acceptable. The electrode can also be a 3-dimensional surface or object. Sensitivity is related to electrode surface area, orientation with respect to the object being sensed, object composition, and the ground coupling quality of both the sensor circuit and the sensed object.
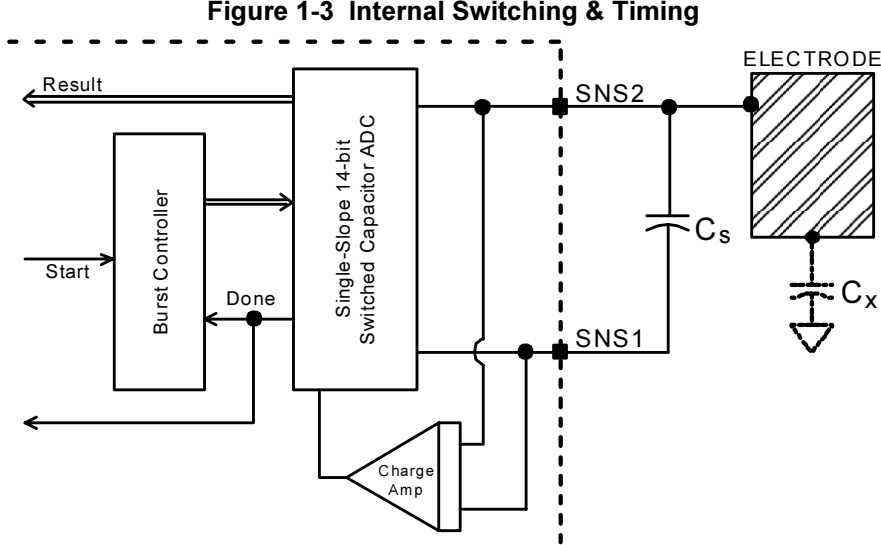
1.3.2 KIRCHOFF'S CURRENT LAW

Like all capacitance sensors, the QT110 relies on Kirchoff's Current Law (Figure 1-5) to detect the change in capacitance of the electrode. This law as applied to capacitive sensing requires that the sensor's field current must complete a loop, returning back to its source in order for capacitance to be sensed. Although most designers relate to Kirchoff's law with regard to hardwired circuits, it applies equally to capacitive

Figure 1-2 2-wire operation, self-powered
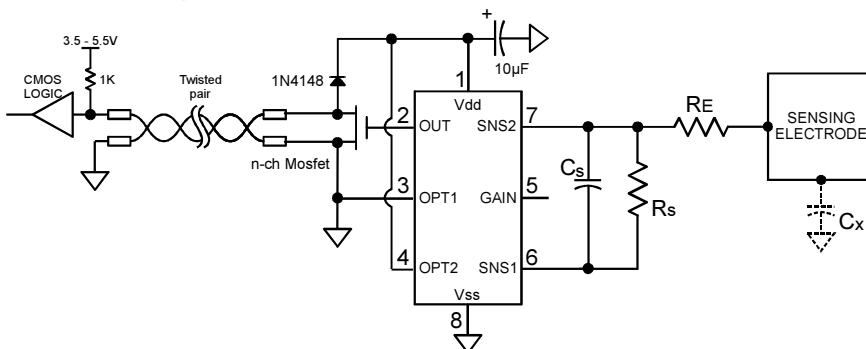
field flows. By implication it requires that the signal ground and the target object must both be coupled together in some manner for a capacitive sensor to operate properly. Note that there is no need to provide actual hardwired ground connections; capacitive coupling to ground (Cx1) is always sufficient, even if the coupling might seem very tenuous. For example, powering the sensor via an isolated transformer will provide ample ground coupling, since there is capacitance between the windings and/or the transformer core, and from the power wiring itself directly to 'local earth'. Even when battery powered, just the physical size of the PCB and the object into which the electronics is embedded will generally be enough to couple a few picofarads back to local earth.

Figure 1-3 Internal Switching & Timing

1.3.3 VIRTUAL CAPACITIVE GROUNDS

When detecting human contact (e.g. a fingertip), grounding of the person is never required. The human body naturally has several hundred picofarads of 'free space' capacitance to the local environment (Cx3 in Figure 1-3), which is more than two orders of magnitude greater than that required to create a return path to the QT110 via earth. The QT110's PCB however can be physically quite small, so there may be little 'free space' coupling (Cx1 in Figure 1-3) between it and the environment to complete the return path. If the QT110 circuit ground cannot be earth grounded by wire, for example via the supply connections, then a 'virtual capacitive ground' may be required to increase return coupling.

A 'virtual capacitive ground' can be created by connecting the QT110's own circuit ground to:

- A nearby piece of metal or metallized housing;
- A floating conductive ground plane;
- Another electronic device (to which its might be connected already).

Free-floating ground planes such as metal foils should maximize exposed surface area in a flat plane if possible. A square of metal foil will have little effect if it is rolled up or crumpled into a ball. Virtual ground planes are more effective and can be made smaller if they are physically bonded to other surfaces, for example a wall or floor.

1.3.4 SENSITIVITY

The QT110 can be set for one of 3 gain levels using option pin 5 (Table 1-1). If left open, the gain setting is high. The sensitivity change is made by altering the numerical threshold level required for a detection. It is also a function of other things: electrode size, shape, and orientation, the composition and aspect of the object to be sensed, the thickness and composition of any overlaying panel material, and the degree of ground coupling of both sensor and object are all influences.

Gain plots of the device are shown on page 9.

The Gain input should never be tied to anything other than SNS1 or SNS2, or left unconnected (for high gain setting).
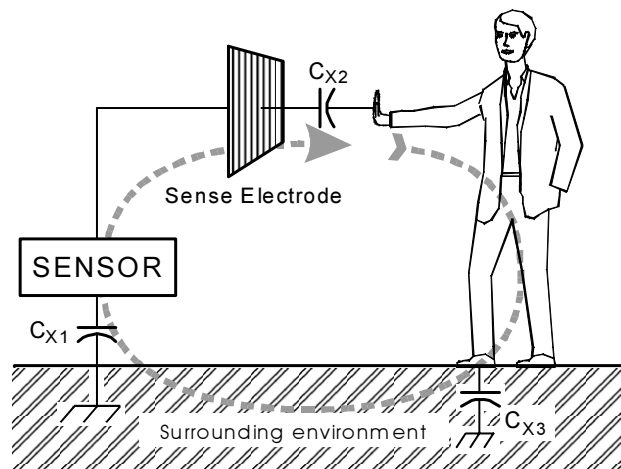
Table 1-1 Gain Strap Options

Gain	Tie Pin 5 to:
High	Leave open
Medium	Pin 6
Low	Pin 7

In some cases it may be desirable to increase sensitivity further, for example when using the sensor with very thick panels having a low dielectric constant.

Sensitivity can often be increased by using a bigger electrode, reducing panel thickness, or altering panel composition to one having a higher dielectric constant. Increasing electrode size can have diminishing returns, as high values of Cx will reduce sensor gain.

Increasing the electrode's surface area will not substantially increase touch sensitivity if its diameter is already much larger in surface area than the object being detected. Metal areas near the electrode will reduce the field strength and increase Cx loading and are to be avoided for maximal gain.

Ground planes around and under the electrode and its SNS trace will cause high Cx loading and destroy gain. The possible signal-to-noise ratio benefits of ground area are more than negated by the decreased gain from the circuit, and so ground areas around electrodes are discouraged. Keep ground, power, and other signals traces away from the electrodes and SNS wiring.

The value of Cs has a minimal effect on sensitivity with these devices, but if the Cs value is too low there can be a sharp drop-off in sensitivity.

Figure 1-5 Kirchoff's Current Law

2 - QT110 SPECIFICS

2.1 SIGNAL PROCESSING

The QT110 processes all signals using a number of algorithms pioneered by Quantum. The algorithms are specifically designed to provide for high 'survivability' in the face of all kinds of adverse environmental changes.

2.1.1 DRIFT COMPENSATION ALGORITHM

Signal drift can occur because of changes in Cx and Cs over time. It is crucial that drift be compensated for, otherwise false detections, non-detections, and sensitivity shifts will follow. Cs drift has almost no effect on gain since the threshold method used is ratiometric. However Cs drift can still cause false detections if the drift occurs rapidly.

Drift compensation (Figure 2-1) is performed by making the reference level track the raw signal at a slow rate, but only while there is no detection in effect. The rate of adjustment must be performed slowly, otherwise legitimate detections could be ignored. The QT110 drift compensates using a slew-rate limited change to the reference level; the threshold and hysteresis values are slaved to this reference.

Once an object is sensed, the drift compensation mechanism ceases since the signal is legitimately high, and therefore should not cause the reference level to change.

The QT110's drift compensation is 'asymmetric': the reference level drift-compensates in one direction faster than it does in the other. Specifically, it compensates faster for decreasing signals than for increasing signals. Increasing signals should not be compensated for quickly, since an approaching finger could be compensated for partially or entirely before even touching the sense pad. However, an obstruction over the sense pad, for which the sensor has already made full allowance for, could suddenly be removed leaving the sensor with an artificially elevated reference level and thus become insensitive to touch. In this latter case, the sensor will compensate for the object's removal very quickly, usually in only a few seconds.

2.1.2 THRESHOLD CALCULATION

Sensitivity is dependent on the threshold level as well as ADC gain; threshold in turn is based on the internal signal reference level plus a small differential value. The threshold value is established as a percentage of the absolute signal level. Thus, sensitivity remains constant even if Cs is altered dramatically, so long as electrode coupling to the user remains constant. Furthermore, as Cx and Cs drift, the threshold level is automatically recomputed in real time so that it is never in error.

The QT110 employs a hysteresis dropout below the threshold level of 50% of the delta between the reference and threshold levels.

The threshold setting is determined by option jumper; see Section 1.3.4.

2.1.3 MAX ON-DURATION

If an object or material obstructs the sense pad the signal may rise enough to create a detection, preventing further operation. To prevent this, the sensor includes a timer which monitors detections. If a detection exceeds the timer setting, the timer causes the sensor to perform a full recalibration. This is known as the Max On-Duration feature.

After the Max On-Duration interval, the sensor will once again function normally, even if partially or fully obstructed, to the best of its ability given electrode conditions. There are two nominal timeout durations available via strap option: 10 and 60 seconds. The accuracy of these timeouts is approximate.

2.1.4 DETECTION INTEGRATOR

It is desirable to suppress detections generated by electrical noise or from quick brushes with an object. To accomplish this, the QT110 incorporates a detect integration counter that increments with each detection until a limit is reached, after which the output is activated. If no detection is sensed prior to the final count, the counter is reset immediately to zero. In the QT110, the required count is 4.

The Detection Integrator can also be viewed as a 'consensus' filter, that requires four detections in four successive bursts to create an output. As the basic burst spacing is 75ms, if this spacing was maintained throughout all 4 counts the sensor would react very slowly. In the QT110, after an initial detection is sensed, the remaining three bursts are spaced about 20ms apart, so that the slowest reaction time possible is 75+20+20+20 or 135ms and the fastest possible is 60ms, depending on where in the initial burst interval the contact first occurred. The response time will thus average about 95ms.

2.1.5 FORCED SENSOR RECALIBRATION

The QT110 has no recalibration pin; a forced recalibration is accomplished only when the device is powered up. However, the supply drain is so low it is a simple matter to treat the entire IC as a controllable load; simply driving the QT110's Vdd pin directly from another logic gate or a microprocessor port (Figure 2-2) will serve as both power and 'forced recal'. The source resistance of most CMOS gates and microprocessors is low enough to provide direct power without any problems. Almost any CMOS logic gate can directly power the QT110.

A 0.01uF minimum bypass capacitor close to the device is essential; without it the device can break into high frequency oscillation.

Option strap configurations are read by the QT110 only on powerup. Configurations can only be changed by powering the QT110 down and back up again; again, a microcontroller can directly alter most of the configurations and cycle power to put them in effect.

2.2 OUTPUT FEATURES

The devices are designed for maximum flexibility and can accommodate most popular sensing requirements. These are selectable using strap options on pins OPT1 and OPT2. All options are shown in Table 2-1.

OPT1 and OPT2 should never be left floating. If they are floated, the device will draw excess power and the options will not be properly read on powerup. Intentionally, there are no pullup resistors on these lines, since pullup resistors add to power drain if the pin(s) are tied low.
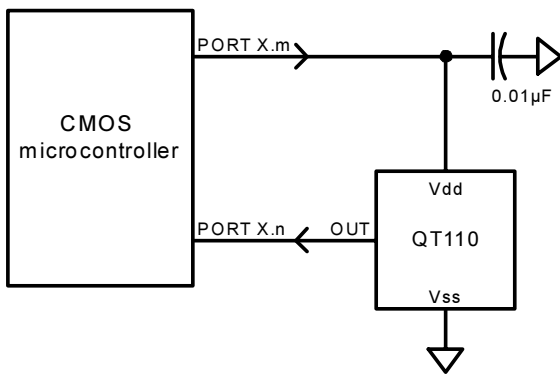
2.2.1 DC MODE OUTPUT

The output of the device can respond in a DC mode, where the output is active-low upon detection. The output will remain active for the duration of the detection, or until the Max

Figure 2-1 Drift Compensation
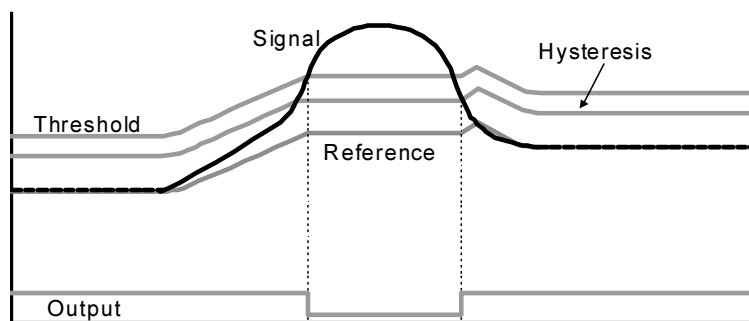
Figure 2-2 Powering From a CMOS Port Pin

Figure 2-3 Damping Piezo Clicks with Rs

On-Duration expires, whichever occurs first. If the latter occurs first, the sensor performs a full recalibration and the output becomes inactive until the next detection.

In this mode, two Max On-Duration timeouts are available: 10 and 60 seconds.

2.2.2 TOGGLE MODE OUTPUT
This makes the sensor respond in an on/off mode like a flip flop. It is most useful for controlling power loads, for example in kitchen appliances, power tools, light switches, etc.

Max On-Duration in Toggle mode is fixed at 10 seconds. When a timeout occurs, the sensor recalibrates but leaves the output state unchanged.

Table 2-1 Output Mode Strap Options

	Tie Pin 3 to:	Tie Pin 4 to:	Max On-Duration
DC Out	Vdd	Vdd	10s
DC Out	Vdd	Gnd	60s
Toggle	Gnd	Gnd	10s
Pulse	Gnd	Vdd	10s

2.2.3 PULSE MODE OUTPUT
This mode generates a negative pulse of 75ms duration with every new detection. It is most useful for 2-wire operation, but can also be used when bussing together several devices onto a common output line with the help of steering diodes or logic gates, in order to control a common load from several places.

Max On-Duration is fixed at 10 seconds if in Pulse output mode.

Note that the beeper drive does not operate in Pulse mode.

2.2.4 PIEZO ACOUSTIC DRIVE
A piezo drive signal is generated for use with a piezo sounder immediately after a detection is made; the tone lasts for a nominal 95ms to create a 'tactile feedback' sound.

The sensor drives the piezo using an H-bridge configuration for the highest possible sound level. The piezo is connected across pins SNS1 and SNS2 in place of Cs or in addition to a parallel Cs capacitor. The piezo sounder should be selected to have a peak acoustic output in the 3.5kHz to 4.5kHz region.

Since piezo sounders are merely high-K ceramic capacitors, the sounder will double as the Cs capacitor, and the piezo's metal disc can even act as the sensing electrode. Piezo transducer capacitances typically range from 6nF to 30nF in value; at the lower end of this range an additional capacitor should be added to bring the total Cs across SNS1 and SNS2 to at least 10nF, or possibly more if Cx is above 5pF
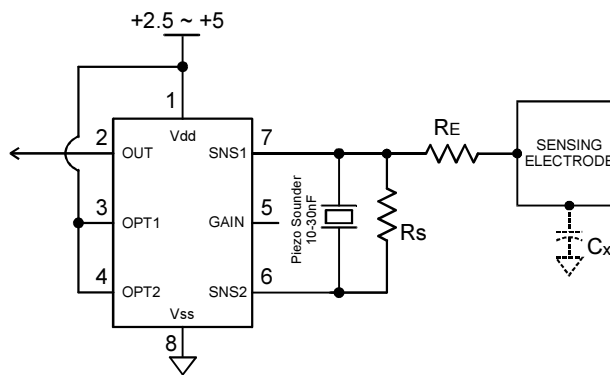
Piezo sounders have very high, uncharacterized thermal coefficients and should not be used if fast temperature swings are anticipated, especially at high gains. They are also generally unstable at high gains; even if the total value of Cs is largely from an added capacitor the piezo can cause periodic false detections.

The burst acquisition process induces a small but audible voltage step across the piezo resonator, which occurs when SNS1 and SNS2 rapidly discharge residual voltage stored on the resonator. The resulting slight clicking sound can be greatly reduced by placing a 470K resistor Rs in parallel with the resonator; this acts to slowly discharge the resonator, attenuating of the harmonic-rich audible step (Figure 2-3).

Note that the piezo drive does not operate in Pulse mode.

2.2.5 HEARTBEAT™ OUTPUT
The output has a full-time HeartBeat™ 'health' indicator superimposed on it. This operates by taking 'Out' into a 3-state mode for 350µs once before every QT burst. This output state can be used to determine that the sensor is operating properly, or, it can be ignored using one of several simple methods.

The HeartBeat indicator can be sampled by using a pulldown resistor on Out, and feeding the resulting negative-going pulse into a counter, flip flop, one-shot, or other circuit. Since Out is normally high, a pulldown resistor will create negative HeartBeat pulses (Figure 2-4) when the sensor is not detecting an object; when detecting an object, the output will remain active for the duration of the detection, and no HeartBeat pulse will be evident.

If the sensor is wired to a microcontroller as shown in Figure 2-5, the controller can reconfigure the load resistor to either ground or Vcc depending on the output state of the device, so that the pulses are evident in either state.

Electromechanical devices will usually ignore this short pulse. The pulse also has too low a duty cycle to visibly activate LED's. It can be filtered completely if desired, by adding an RC timeconstant to filter the output, or if interfacing directly and only to a high-impedance CMOS input, by doing nothing or at most adding a small non-critical capacitor from Out to ground (Figure 2-6).

2.2.6 OUTPUT DRIVE
The QT110's output is active low ; it can source 1mA or sink 5mA of non-inductive current.

Care should be taken when the IC and the load are both powered from the same supply, and the supply is minimally regulated. The device derives its internal references from the power supply, and sensitivity shifts can occur with changes in Vdd, as happens when loads are switched on. This can induce detection 'cycling', whereby an object is detected, the load is turned on, the supply sags, the detection is no longer sensed,

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