QMatrix™ Technology White Paper

Overview

QMatrix devices are digital charge-transfer (QT) ICs designed to detect touch using a scanned, passive matrix of electrode sets to achieve a large number of touch keys driven by a single chip. This configuration leads to a high pin count efficiency in the sensing chip and allows for a small number of connections between the chip and the key matrix, when compared with sensing technologies such as QTouch which require one sensing connection for each key. These devices achieve the lowest possible cost per key possible with the lowest parts count. In volume, these devices achieve chip costs below $0.05 per key. In addition, this configuration has certain properties which make them intrinsically resistant to environmental drift, water films, and radio interference.

QMatrix circuits offer tremendous signal-to-noise ratios, high levels of immunity to moisture films, extreme levels of temperature stability, superb low power characteristics, ease of wiring, and small IC package sizes for a given key count, For these reasons, QMatrix circuits are highly prized for automotive, kitchen appliance, and mobile applications.

QT chips contain the full drive, receive, and processing logic; only a few inexpensive passive parts are additionally required.

Quantum patented this technology in 1999; first applications were in kitchen appliances, notably in GE Appliance's Monogram kitchen appliance series. The technology has been extended to include matrix based touch screens, the first use of which is found on the landmark Whirlpool USA's Velos™ Speedcook microwave oven series, marketed since January 2006.

The basic benefits of QMatrix technology can be summarized as:

- High key-count to chip pin-count efficiency
- Low parts count
- Easy to wire
- Compatible with inexpensive 1-sided PCB materials
- Temperature stability
- Naturally moisture suppressing
- Highly immune to external RF fields
- Low power modes
- Can be used to make clear touch screens
- Very low cost per key

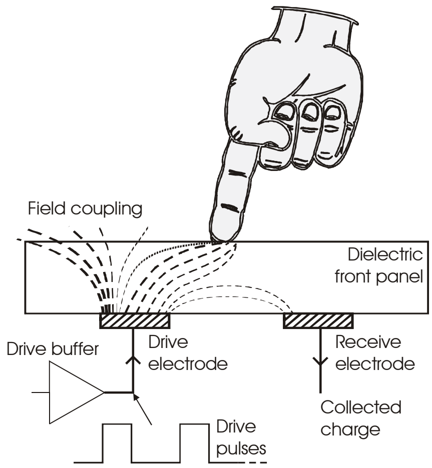

Fig. 1 - QMatrix™ field flow between electrodes. Touch absorbs the field, reducing collected charge.

QMatrix Theory

Each sensing electrode pair contains a field drive electrode and a receive electrode (Fig. 1). The emitting electrode is driven as a digital burst of logic pulses; the receive electrode normally collects most of the charge that is coupled from the emitting electrode via the overlying dielectric front panel.

This field coupling is attenuated by human touch, since the human body conducts away a portion of the fields which arc through the front panel; the absorbed part of the field is re-radiated by the human body back to the product via various capacitive paths.

Signal that couples through the mutual capacitance of the electrode structure is collected onto a sample capacitor which is switched by the chip synchronously with the drive pulses (Fig. 2). A burst of pulses is used to improve the signal to noise ratio; the number of pulses in each burst also affects the gain of the circuit, since more pulses will result in more collected charge and hence more signal. By modifying the burst pulse length, the gain of the circuit can be easily changed to suit various key sizes, panel materials, and panel thicknesses.

After the burst completes, the charge on the sample capacitor is converted using a slope conversion resistor which is driven high, and a zero crossing is detected to

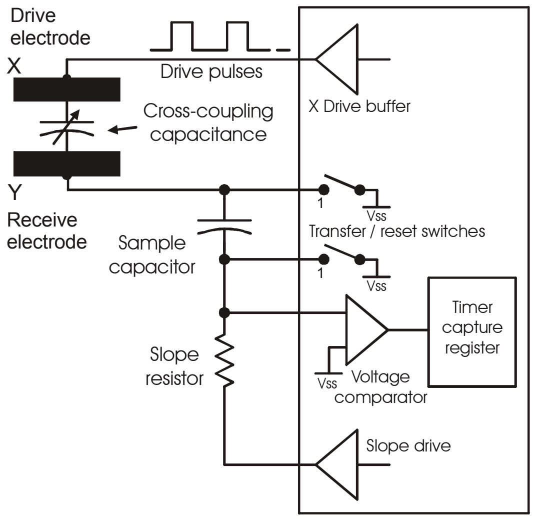

Fig. 2 - QMatrix dual-slope circuit. The pulses generate the first slope - a staircase on the sample capacitor, induced via electrode charge cross coupling. After the burst, the slope resistor is switched high to ramp the sample capacitor until a zero crossing is achieved to null its charge. The slope time required to obtain the zero crossing is the signal result. The dual-slope nature of these circuits makes them extremely stable over wide operating temperatures.

result in a timer value which is proportional to the X-Y electrode charge coupling which also reflects charge absorption caused by finger touches. Finger touches absorb charge, so the measured signal *decreases* with touch. The burst phase causes the charge on the sample capacitor to ramp in a negative direction, and the slope conversion causes a ramp in the positive direction on the capacitor; the net effect is that the conversion process is 'dual slope', and is largely independent of the value of the sample capacitor and is highly stable over time and temperature.

Moisture suppression: The matrix approach offers two moisture suppression attributes not found in any other capacitive method. First, the presence of a localized water film (such as condensation, mist, or droplets) will induce only a slight *increase* in signal coupling. Since touch induces a decrease in signal, the contributions to signal coupling caused by moisture are in the 'wrong' direction and thus do not cause false detections. Second, the presence of larger moisture films which can conduct charge away are also suppressed by the use of narrow 'gate times' which restrict the charge capture to a narrow time window just after the pulse edge. Since a water film can be modeled as a distributed RC network with a time-dependent characteristic, narrow gate times (on the order of a microsecond or less) heavily suppress the effects of a water film's signal potential reduction, further reducing the chances of a false detection.

Thus, QMatrix circuits naturally suppress water films making it ideal for moist environments.

RF interference rejection: Because both electrodes are always connected to a low impedance circuit, and due to the fact that their electric fields are closed and self-shielding, keys do not respond well to external interference. In addition, all QMatrix devices use spread-spectrum technology which is highly effective at suppressing both radiated emissions and external fields susceptibility.

Control panels made with this technology routinely pass susceptibility tests exceeding field strengths of 20V/m.

Matrix Layout and Design

A matrix of many keys is formed by using multiple X drive and Y receive lines, with key electrode sets attached at the intersections. Keys are scanned sequentially in time, in the same way an electromechanical keyboard is scanned. QMatrix electrodes can sense through any dielectric, e.g. glass or plastic, up to thicknesses of 50mm or more depending on the electrode size and burst length (gain) setting.

Arbitrary key size, placement: Key placement is entirely arbitrary and keys can be located anywhere on a panel; they do not have to be configured as a rectangular array as shown. Key signals do not cross-interfere, and as a result they can be placed immediately next to each other without problems. Electrodes are also immune to adjacent grounded metal, and electrodes can even be placed within a millimeter of an underlying chassis or ground plane. Both the X and Y lines are highly resistant to the

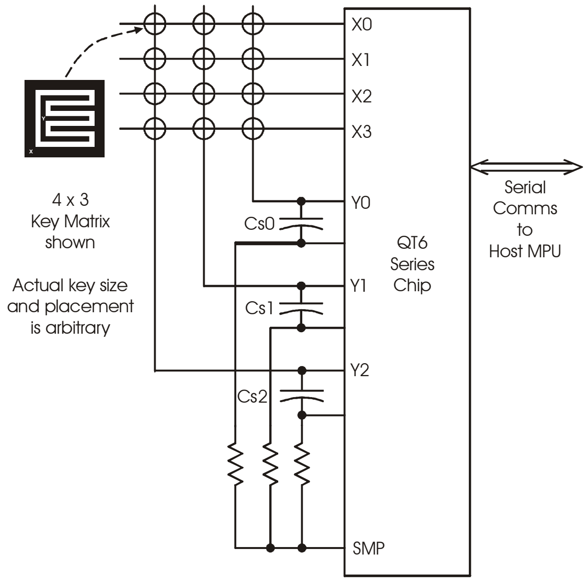

Fig. 3 - Wiring of a QMatrix circuit. An electrode set is wired at each X-Y intersection, achieving high IC pin efficiencies.

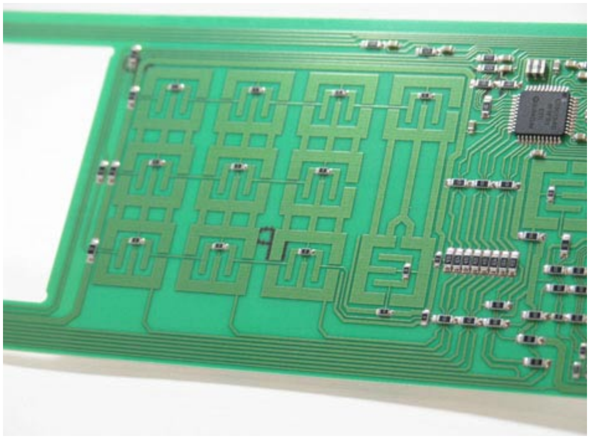

Fig. 4 - Example QT6-family QMatrix design using inexpensive 1-sided CEM-1 PCB material; the sensing fields 'back-fire' through the PCB, adhesive layer, and front panel with plenty of signal strength. Zero-ohm jumpers are used for crossovers.

Fig. 5 - QMatrix keyboard implemented using silver traces on a PET-film. This 64-ley layout has only 16 interconnects (8X + 8Y lines).

effects of ground planes and adjacent conductors, however too much ground around the Y lines can absorb some of the received charge and reduce gain, so there are practical limits to Y line capacitive loading.

Key sizes, shapes and placement are almost entirely arbitrary; sizes and shapes of keys can be mixed within a single panel of keys and can vary by a factor of 20:1 in surface area. The sensitivity of each key can be set individually via commands over a serial port. Electrode design is discussed in more detail in Quantum application note AN-KD01.

Material options: The electrodes are defined as 2-part interleaved electrodes of almost any conductive material, like etched PCB copper or silver or carbon ink. The electrodes are most conveniently fashioned on a conventional PCB or FPCB which is glued to the rear of the control panel. The signals are so strong and reliable that the chip, circuit, and electrodes can be placed all on the same layer on the side of the PCB facing away from the touch surface; in this way, a very inexpensive 1-sided punched CEM-1 PCB can be used, which is usually less than half the price of FR-4. As shown in Fig. 4, zero-ohm jumpers can be used to implement crossovers at negligible cost. An industrial sheet adhesive is used to bond the PCB to the rear of the front panel.

Another inexpensive option is to use a punched PET film with screened silver on both sides to create a matrix electrode layer. A tail allows the film to plug in to a controller PCB with the QMatrix chip and circuit (Fig. 5).

Fully internal signal processing: QMatrix chips contain all the signal filtering, debounce logic, and automatic drift compensation required for decades of reliable operation. Many of these devices contain FMEA (Failure Modes and Effects Analysis) self-checking routines, to report back any circuit failures such as shorts and opens for fail-safe operation, making them highly prized for cooking and automotive applications.

Design Diagnostics: Uniquely, QMatrix devices output actual key signals and diagnostics in real time that can be viewed on any PC via a USB interface using QmBtn software, which can be downloaded for free from the Quantum website. The ability to observe actual key signals in real time adds a high degree of confidence to designs.

Lighted and backlighted keys are always of interest to designers. LEDs can be placed in the middle of QMatrix keys simply by creating an opening in the PCB and working the drive/receive electrodes around a surface mount LED and its pads and wiring. This can even be done on a single-sided PCB. Clear conductors such as Orgacon™ from Agfa N.V as well as printable ITO can be used to create clear, backlightable discrete keys when printed onto a clear substrate such as PET film. The film is laminated on to the rear of the front panel using a clear, readily obtainable adhesive sheet. A PCB with LEDs placed behind this layer creates the required back illumination. Light guides and diffusers can be used to make the backlighting more even.

Touchscreens: Special variants of QMatrix devices (consult Quantum) can also drive clear capacitive touchscreens fashioned from 1 or 2 layers of ITO (Indium Tin Oxide on PET film; Fig. 6). A single QMatrix chip can drive both conventional keys and the touchscreen film in unison, creating a seamless interface to a host microcontroller for the entire front panel. The ITO film wires into the scanning matrix and provides a large number of discrete keys over an LCD display. The Whirlpool Velos™ oven uses this method behind a solid, unbroken sheet of curved glass to create a spectacular design. Touchscreens made in this way are impossible to damage and have very high transparency compared to resistive screens.

Proximity sensing limitations: Due to the closed nature of the fields between the electrodes these devices are not well suited to proximity sensing applications unless large, spaced apart electrodes are used to allow the fields to migrate deeper into free space in front of the panel. QTouch devices are generally better at sensing proximity to longer ranges since their fields project better into space. However unlike QTouch technology, QMatrix electrodes are much more tolerant of stray capacitance to ground planes and other nearby traces.

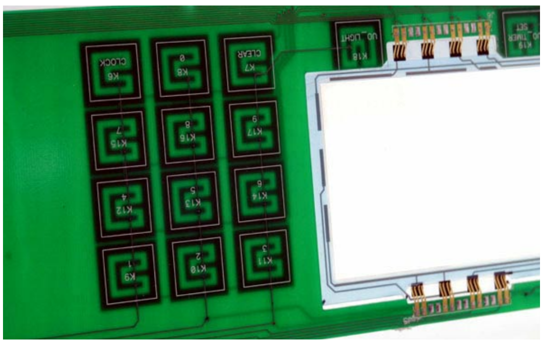

Fig. 6 - QMatrix Button + Touchscreen Design. A single custom QT6 chip drives both the PCB electrodes as well as those on the clear ITO film.

Fig. 7 - Whirlpool Velos™ oven with a single-chip QMatrix part driving 21 conventional touch keys plus 10 clear ITO-film buttons to create an LCD touchscreen. This design uses a 1-layer CEM-1 PCB for very low cost.

Device Specifics

Quantum QT6xxxx series devices are all QMatrix ICs, and are available from 16 to 64 keys, with all but one device, the QT60645, using the dual-slope acquisition method. The middle three digits indicate the key count capacity of the device, while the ending digit indicates a variation code. QT60160 and QT60240 in particular are designed for very low cost, but do not have FMEA (safety self-test) capability; they are best suited to portable applications such as MP3 players, mobile phones, non-cooking appliances such as washing machines and the like. These two devices also employ I2C interfaces as opposed to the SPI interface found on most other QMatrix parts.

All QMatrix devices feature patented AKS™ (Adjacent Key Suppression™) which allows keys to be tightly packed onto keyboards yet properly resolve touch ambiguities associated with finger touches overlapping multiple keys. AKS resolves inadvertent multiple key touches by analyzing the signal strengths from all keys at the moment of touch. AKS can also be used to suppress 'head and pocket detection' which occurs when a portable device, such as a mobile phone, is held to the user's head, or placed in the user's pocket. To do this, a 'guard key' is strategically placed near to the keypad; a trigger of this guard key can be used to suppress any or all of the other keys so that false touches are suppressed. AKS is also useful to suppress water films on a panel surface.

Customization: Over half of all QMatrix devices sold are customized to suit specific applications. The process of customization is made easier due to the fact that these chips have microcontroller cores with Flash memory. Quantum parts starting with 'QT6C' are custom devices, and are not detailed on the Quantum website.

QMatrix Applications

Since introduction in 1999, the primary use of QMatrix devices has been in the kitchen appliance sector, with major customers including GE Appliances, Whirlpool, Miele and Electrolux. The vast majority of these have been higher keycount devices such as the QT60326 or custom derivations. Increasing interest in touchscreens has been generated following the introduction of the Whirlpool Velos™ Speedcook microwave oven (Fig. 7) which is based on a QT6 family device, and a large number of new touchscreen designs using this technology are set to appear on the market.

Design wins have been achieved in mobile and other portable applications with QMatrix devices; this interest has been fueled by the technical superiority of this technique over older technologies as well as the drive to reduce package size, yet achieve high key counts. There have also been design wins in the automotive sector due to the industrial-grade robustness of the technology over extreme environmental conditions.

Derivations of this technology have also been implemented for linear sliders, wheels, and X-Y touchpads; consult Quantum for further details.

QMatrix™ technology is covered by US Patent 6,452,514 and corresponding foreign patents, and can only be obtained from Quantum or its licensees. QMatrix is a trademark of QRG Ltd. UK.

Fig. 8 - Quantum sells QMatrix demo boards such as this E6240 unit, to allow user evaluation of the technology. This board demonstrates the ability of QT6 family devices to sense a wide variety of key sizes and layouts. These boards also work with QmBtn PC software for complete visualization of the signals in real time.