Application notes for the Microdul MS888x capacitive switches

Contents

Introduction

The MS8883, MS8885 & MS8886 ICs are a family of capacitive switches that use a particular mixed-signal technique to evaluate a change of capacitance on the sensor inputs.

The **MS8883** is a single channel switch, which can be operated stand-alone. Between the MS8883A and the MS8883C there is a minor functional difference, which is described in the datasheets, and which is irrelevant for these application notes.

The **MS8886** is a dual-channel switch, consisting of two identical MS8883 channels.

The **MS8885** is an 8-channel switch. Among other features, the MS8885 provides a serial I²C interface for readout of switch states and for extended configuration options, like matrix keyboard support, channel masking, clock setting and others.

All three circuits are based on the same sensing principle. Therefore they all share the same properties of sensing performance, sensitivity and touch behaviour. The following notes equally apply to all three circuits in most respects, with the exception of the sampling frequency setting, which is different for the MS8885.

In order to use these switches, the first steps are to define the electrode shape and size, the materials to be used, the desired switching distance from the sensing electrode and the desired switching characteristic.

This application note helps with the optimisation of the switching performance in a particular product.

Typical application circuits

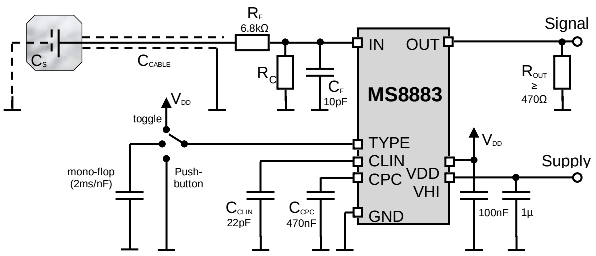

Figure 1: Typical application of the MS8883A

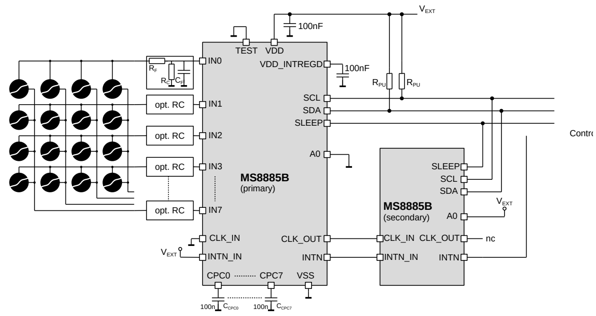

Figure 2: Typical application of MS8885B

It is essential to have the datasheets handy. These can be downloaded from www.microdul.com

External components

R_F, C_F

These two elements form an R-C filter at the sensor input, which increases noise immunity. The typical values are R_F = 6.8 kΩ and C_F = 10 pF. An additional effect of R_F is the improved robustness to electrostatic discharges. This filter is optional.

C_F, R_C

Besides the filtering aspect, C_F also plays a role in the definition of the operating point of the capacitive switch. If the total input capacitance is too low, capacitor C_F is required. On the other side, if the input capacitance exceeds the allowed range, R_C can be employed. Details on the correct dimensioning of C_F or R_C are given in the section 'Operating point optimisation' below.

C_{CPC}

This capacitor is the main sensitivity defining component. Details on the correct dimensioning of C_{CPC} are given in the section 'Sensitivity optimisation' below.

C_{CLIN}

This capacitor defines the sampling frequency of the capacitive switches MS8883 & MS8886. This in turn defines the dynamic behaviour of the switch. Details on the correct dimensioning of C_{CLIN} are given in the section 'Switching dynamics' below.

Generally, to get started with a new application design it is suggested to use the typical values for all these components, as specified in the corresponding datasheets.

Description of sensing principle

Sensing architecture

The discharge time t_{SENS} on input IN attached to the sensing electrode capacitance C_{IN} + C_S is compared to the discharge time t_{REF} of an internal RC timing element. Both R-C timing circuits are periodically charged to VDD via a MOS switch and then discharged via a resistor to ground (GND).

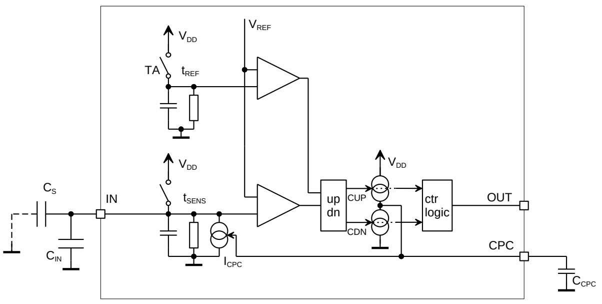

Figure 3 Sensing architecture of the MS888x family

The discharge time t_{SENS} at the sensor input depends on the parasitic input capacitance C_{IN}, the measured capacitance C_S and the internal discharge current I_{CPC}. The current I_{CPC} is defined by the voltage at the CPC pin. The circuit regulates the voltage V_{CPC} in a feedback loop, such that an equilibrium state is reached where the two discharge times t_{REF} and t_{SENS} are equal. The V_{CPC} voltage therefore directly reflects the total capacitance seen at the sensor input pin IN.

The V_{CPC} voltage is regulated by depositing or removing charge units on the capacitor C_{CPC} depending on the comparison result of the discharge times. Every time $t_{SENS} > t_{REF}$ is detected, a pulse will be given on CUP and a charge will be deposited on C_{CPC}. The voltage on C_{CPC} and the discharge current I_{CPC} therefore rise, and at the next sampling event t_{SENS} will be reduced. The opposite happens if $t_{SENS} < t_{REF}$ is detected.

If C_S is changing, the discharge time t_{SENS} also changes. The feedback mechanism will then slowly adjust the voltage V_{CPC} until the discharge times are equal again.

Auto-calibration

If the input capacitance changes slowly, the voltage V_{CPC} will track the changes in real. This behaviour represents the auto-calibration property of the circuit. The circuit will not switch.

Counting principle & switching

If the input capacitance changes quickly and sufficiently, the slow auto-calibration will lag behind. It will take time to reach the equilibrium again. During this time a continuous sequence of pulses in the same direction on CUP ($t_{SENS} > t_{REF}$) or on CDN ($t_{SENS} < t_{REF}$) will be produced.

If a sufficient number of pulses in the CUP direction caused by an increase of C_S is observed, a touch is detected and the output OUT is set high. The number of required consecutive pulses on CUP is 64 (except for the MS8883C with pin MODE=1, where the required count is 32).

If the sensor is in switched-on state, and the triggering object is removed, C_S will be reduced. After 32 consecutive CDN pulses, the output will be switched off.

It is important to note, that a consecutive count of 64 or 32 pulses in the same direction are required to cause successful switching. If the sequence is disturbed by any opposite pulse, the counter is reset and the counting has to start at 0 again.

Electrode and dielectric design

Basic information

The MS888x family only uses a single electrode to detect an approaching or touching object (eg. a finger). This electrode should consist of a single conducting 'object' connected to the sensor input pin IN. It will mostly consist of a metal plate or foil, or a copper area on a PCB. However any conducting shape can be employed as a sensing electrode.

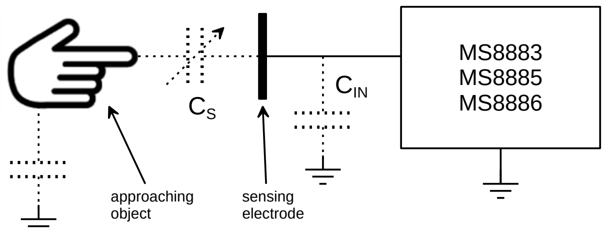

Figure 4 Important capacitances in the system

Together with the approaching object, the sensing electrode forms a capacitor C_S, whose dynamically changing value is detected by the sensor. The approaching object should never make direct contact with the sensing electrode. This would prevent the proper operation of the sensor. For this reason, an isolating dielectric layer is required on top of the sensing electrode. Often the sensing electrode is placed behind a plastic panel in the application.

Total input capacitance

Besides the measured C_S between the approaching object and the sensing electrode, there is a capacitance C_{IN} that always exists between the sensing electrode and ground. The value of this parasitic capacitance is defined by the size of the sensing electrode, nearby grounded objects (PCB ground, grounded metal construction) and the length and properties of the connecting cable (coaxial, flat ribbon, PCB trace). This capacitance is usually not well defined and can vary due to manufacturing tolerances.

The MS888x family of capacitive switches automatically compensate the value of C_{IN} with the auto-calibration mechanism. For a proper operating point of the sensor, the total input capacitance C_{IN} must be within the allowed range (see datasheet).

Operating point optimisation

As described in section ‘Sensing architecture’ above, the input capacitance C_{IN} translates into a voltage V_{CPC}. If the input capacitance C_{IN} is outside the allowed range, the resulting V_{CPC} will also be outside of its allowed operating range and switching will not be possible.

If this is the case the operating point must be corrected by bringing V_{CPC} into the allowed range. Two cases must be differentiated:

> **$V_{CPC} > V_{CPC,MAX}$**: The input capacitance C_{IN} and hence the discharge time t_{SENS} are too large and cannot be compensated by the feedback loop. In this case the discharge time must be reduced by reducing C_{IN} or by adding a pull-down resistor R_C at the sensor input. R_C can have values in the range of 5 kΩ to 50 kΩ.
>
> **$V_{CPC} < V_{CPC,MIN}$**: The input capacitance C_{IN} and hence the discharge time t_{SENS} are too small and cannot be compensated by the feedback loop. In this case the discharge time must be increased by adding additional capacitance C_F to the sensor input.

In both cases, the target is to bring the V_{CPC} voltage into its allowed operating range, preferably to a value of approximately $V_{DD}/2$.

Measurement of V_{CPC}

In order to optimise the operating point, the voltage V_{CPC} must be measured. This voltage is very sensitive to leakage currents. Measuring V_{CPC} directly with a simple voltage meter or with a scope probe having an input resistance of typically 1 to 10 MΩ will disturb the voltage and the equilibrium will be lost.

The voltage can be measured using:

- a multi-meter with GΩ high-impedance input mode
- an active oscilloscope probe with a high impedance input
- an operational amplifier buffer, as employed on the MS8883A evaluation board.

Sensitivity

Sensitivity factors

As described above, the input capacitance C_{IN} translates into a voltage V_{CPC} in equilibrium.

An approaching object will induce an additional capacitance C_S, which adds to C_{IN}. Therefore the V_{CPC} voltage will be increased by the auto-calibration mechanism to a voltage of $V_{CPC} + \Delta V_{CPC}$. To produce the voltage difference, a number N of fixed charge units ΔQ have to be deposited on C_{CPC} with $N = C_{CPC} * \Delta V_{CPC} / \Delta Q$. If N > 64 the sensor may ideally switch on. The larger N is, the more secure is the switching, and the more sensitive is the sensor.

Therefore N must be increased for increased switching sensitivity. This can be achieved in two ways:

- Increasing the value of C_{CPC}
- Increasing ΔV_{CPC} which is equivalent to increasing C_S (larger sensor area, thinner dielectric)

Sensitivity optimisation

It is suggested to start the application design with the standard values for the components. In most cases the standard value of C_{CPC} allows for proper switching.

If no switching is observed at all, the design is not sensitive enough. Either the electrode and dielectric design must be adjusted or the C_{CPC} capacitance must be increased.

If switching is too sensitive (switching occurs at a distance, switching occurs due to smaller objects that should not be detected), the C_{CPC} capacitance should be reduced.

C_{CPC} capacitor

Increasing the C_{CPC} capacitance above the maximum value specified in the datasheet is possible. However unreliable switching or an inability to switch off may occur.

In any case a low leakage X7R type ceramic capacitor should be use, which can be bulky for large values.

Sensor electrode size

The sensitivity can also be increased by increasing the sensor electrode area. The optimal size of the electrode is similar to the size of the approaching object (finger).

Essentially there is no limitation on the form or design of the sensor electrode. The sensor electrode can take any form as long as the required sensitivity can be obtained. Oval or round areas are recommended since they have the least edge effects.

Dielectric stack

The dielectric stack encompasses everything between the sensor electrode and the triggering object.

Often it is not possible to increase the sensor electrode size due to mechanical constraints in the application. In this case sensitivity can be increased by reducing the thickness of the dielectric layer(s), or by changing the material of the dielectric to a higher permittivity. The achieved capacitance is proportional to the permittivity of the dielectric.

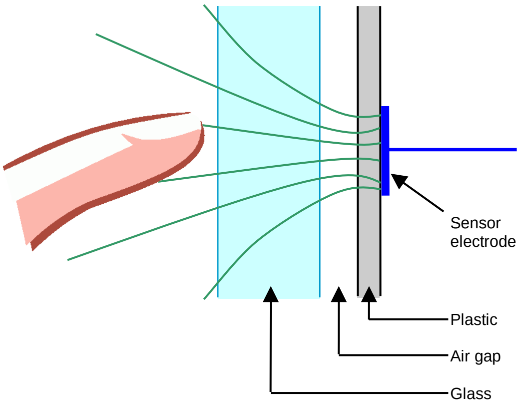

Figure 5 Example of dielectric stack

Figure 5 shows an example application. The sensor electrode is mounted behind 10mm thick glass, a 3mm air gap and 2mm thick plastic. The relative permittivity ε_r of the most commonly applied dielectrics are:

- Glass: 6-8
- FR4 PCB: ~4
- Plastic: 2-4
- Air: 1

Air gaps should be avoided if possible in all applications. They severely reduce the sensitivity due to their low permittivity.

Switching dynamics

Sampling frequency

The capacitor C_{CLIN} (MS8883, MS8886) respectively the register CLKREG (MS8885) define the sensor sampling frequency. The nominal sampling frequency is 1 kHz.

The reaction time of the sensor becomes faster when the sampling frequency is increased since the necessary number of comparisons is reached in less time. On the other hand, this also means that the sensor self-calibrates to environmental changes more quickly, with the result that a slow moving object will no longer cause the sensor to switch.

It is also important to note that the device power consumption increases when the sampling frequency increases.

Perceived sensitivity

Different sampling rates contribute to a different perceived sensitivity, even if the sensor electrode size and C_{CPC} capacitor are the same.

A low sampling rate can lead to switching with a slowly moving object. At a higher sampling rate the same slow object would not cause switching due to the faster auto-calibration. Thus the lower sampling rate results in a higher perceived sensitivity.

External influences

Ground near sensor

The presence of ground (earth) influences capacitive sensing. Figure 6 shows the expected fields with and without neighbouring grounds.

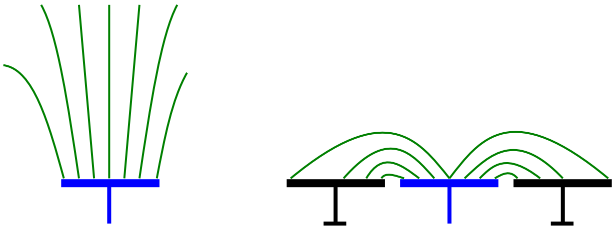

Figure 6: Influence of grounds

The electric field takes the shortest path to ground. The presence of the ground flattens the field and therefore shortens the switching distance and sensitivity in comparison to the example without a nearby ground.

Additionally it has to be considered, that the neighbouring grounds represent additional capacitance in the system that the device has to compensate.

Dirt and humidity, ambient temperature

Over time dirt can accumulate on the dielectric. In a humid environment, water can condensate on the dielectric. Temperature variations can lead to small mechanical deformations due to the thermal expansion of the materials composing the application. All these are slow effects and they can cause changes in the input capacitance of the sensor.

The auto-calibration feature of the MS888x family automatically compensates all these environmental variations. The sensor remains equally sensitive at all times.

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Mechanical tolerances

Mechanical tolerances of the fabrication process and the used materials will result in slightly different absolute sensor capacitance for each device.

The auto-calibration feature of the MS888x family automatically compensates these tolerances. At power-up the sensor will automatically find its equilibrium. There is no calibration required.

Common mode noise

Common mode noise manifests itself as a disturbance between the triggering object and the sensor electrode. Common mode noise is usually generated by low-cost switching power supplies or comes from the power line. It is normally not significant in handheld battery powered applications.

The MS888x sensing principle is sensitive to common mode noise in the frequency range of approximately 50 kHz to 1 MHz. The noise is directly coupling to the sensor electrode. A disturbance during the sampling pulses can lead to a wrong decision of the comparators (Figure 3), which in turn will reset the counter.

The requirement of 64 consecutive counts to switch on, guarantees that no false detections will occur even in a noisy environment. On the other side this mechanism may prevent the circuit from intended switching, if the common mode noise level is too high.

The capacitive compromise

A capacitive switch is always a compromise. A fixed-threshold capacitive device must be initially calibrated and will only function with one set of materials and over a particular distance. Dirt, humidity and temperature changes can impair and even prevent correct function.

The auto-compensating switches MS8883, MS8885 & MS8886 adjust themselves continuously to the environment. They will only switch, when the capacitance changes dynamically and the change is sufficiently large. Very slow changes on the other side will be neutralised by the compensation.

More information: https://www.microdul.com/en/standardprodukte/capacitive-switches/

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