AN529

Capacitive Sensing Through Long Wires

1. Relevant Devices

C8051F70x, C8051F71x, C8051f8xx, and C8051F99x.

2. Supporting Documentation

- AN367: Understanding Capacitive Sensing Signal to Noise Ratios and Setting Reliable Thresholds
- AN447: Printed Circuit Design Notes for Capacitive Sensing with the CS0 Module

3. Introduction

One of the problems that developers face when implementing capacitive sensors is the varied length of the traces that connect the sensing device and the capacitive sensor.

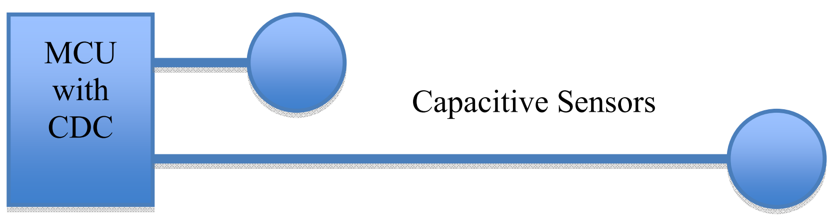

Figure 1. Capacitive Sensing MCU with Two Capacitive Sensors

The layout shown in Figure 1presents two major design challenges: the interference susceptibility of the antenna-like trace and the unwanted capacitance of the trace itself. This application note addresses these concerns with a combination of physical design and compensation algorithms.

4. Applications

The challenge of long capacitive sensing traces can appear in numerous applications. Suppliers of capacitive to digital converters (CDC) almost universally recommend very short connection traces with a centrally located MCU. However, applications such as a car dashboard may require multiple devices interconnected with a digital communications link to span the HMI region of a center console. The cost of multiple devices and the complexity of coordinating/communicating the system seem unnecessary.

The gain control feature in the Silicon Labs F70x/71x and F99x devices enables the CDC to take capacitive measurements on sensors even when long traces add many pF of capacitance to the measurement. Gain control provides the developer with the ability to sense capacitances from 0 to 500 pF. However, the longer the trace, the more susceptible the system becomes to interference. Common sources of interference include:

- human touch near the trace rather than at the intended sensor
- electrical interference from nearby communications traces
- interference from nearby capacitive sensing traces

One possible solution is to shield the long sensing trace(s) with a ground shield—similar to coaxial cable. However, surrounding a trace with a ground shield will increase the capacitance of the trace. Additionally, adding a surrounding ground shield to PC board-based solutions is impractical.

A more practical alternative to using a ground shield is to use a second capacitive sensing line to eliminate the effects of interference through a common-mode measurement system. Figure 2 depicts a CDC connected to two separate capacitive sensing traces. Assuming that these are 28 gauge twisted wires with some rubber shrink tubing and that one of them ends in a loop while the other stops short of the loop.

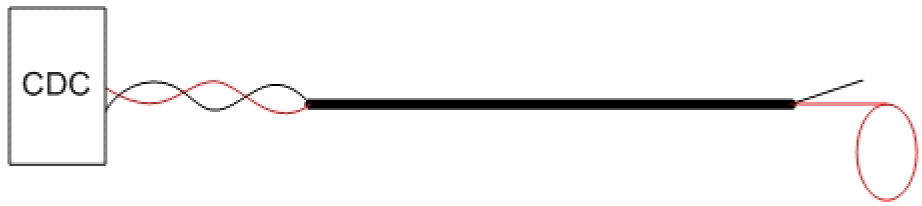

Figure 2. Common-Mode Noise Cancellation

We can also assume the CDC only measures one element at a time and that the block contains an analog mux and control logic to switch between the two. The CDC will measure the capacitance of one element and then the other. The capacitance of both is stored in RAM for future comparison.

If a user places a finger on the loop of the longer trace, the added capacitance of the human body to ground causes the CDC to sense an increase in capacitance on the longer element. However, a touch to the loop causes virtually no change of the capacitance of the shorter element when compared to the initial reading stored in RAM.

When a user touches any point along the twisted line pair, both elements see a roughly equal increase in capacitance. Because the increase in capacitance on both elements is equal, the common mode value remains unchanged.

In the case where the user grips the wire and then presses on the loop with a finger, the hand grabbing the tubing will cause both elements to increase in capacitance, while the finger pressing on the loop will increase the capacitance of only the longer element indicating a positive press.

The table below shows possible measured capacitance values for a system with two channels connected to a sensor as shown in Figure 2.

Table 1. Comparison of Results

Touch	None	Loop Touch	Shrink Tube Touch	Both Tube/Loop
Long trace	100 pF	104 pF	106 pF	110 pF
Short trace	95 pF	95 pF	101 pF	101 pF
Difference	5 pF	9 pF	5 pF	9 pF

In the example above there is a 5 pF delta between the two elements in its static no-touch condition. When the loop is touched the difference between the two elements increases to 9 pF. And when only the shrink tube is touched it returns to a difference of 5 pF. When both the tube and loop are touched the total capacitance difference rises again to 9 pF, indicating that a valid touch condition has occurred.

The effects of noise as a source of interference can be minimized by employing this twisted element pair in designs. If the hand gripping the wire in the example above were replaced with digital communications traces running near the two wires, the two elements will "pick up" signal from the communications lines. This reception occurs because the two elements are substantially similar in construction. However, as long as the lines are kept away from the loop, the system will see the interference on both elements and ignore the interferer.

While the simple example made use of twisted wires a more practical implementation would be two PC board traces running side-by-side to a sensor pad. This technique is suitable for many applications.

Another example of this technique can be applied to liquid level sensing. Figure 3 depicts two different scenarios for measuring the level of a non-conductive container filled with a conductive fluid. The yellow bars are the equivalent of the conductive traces on a PC board or flex circuit.

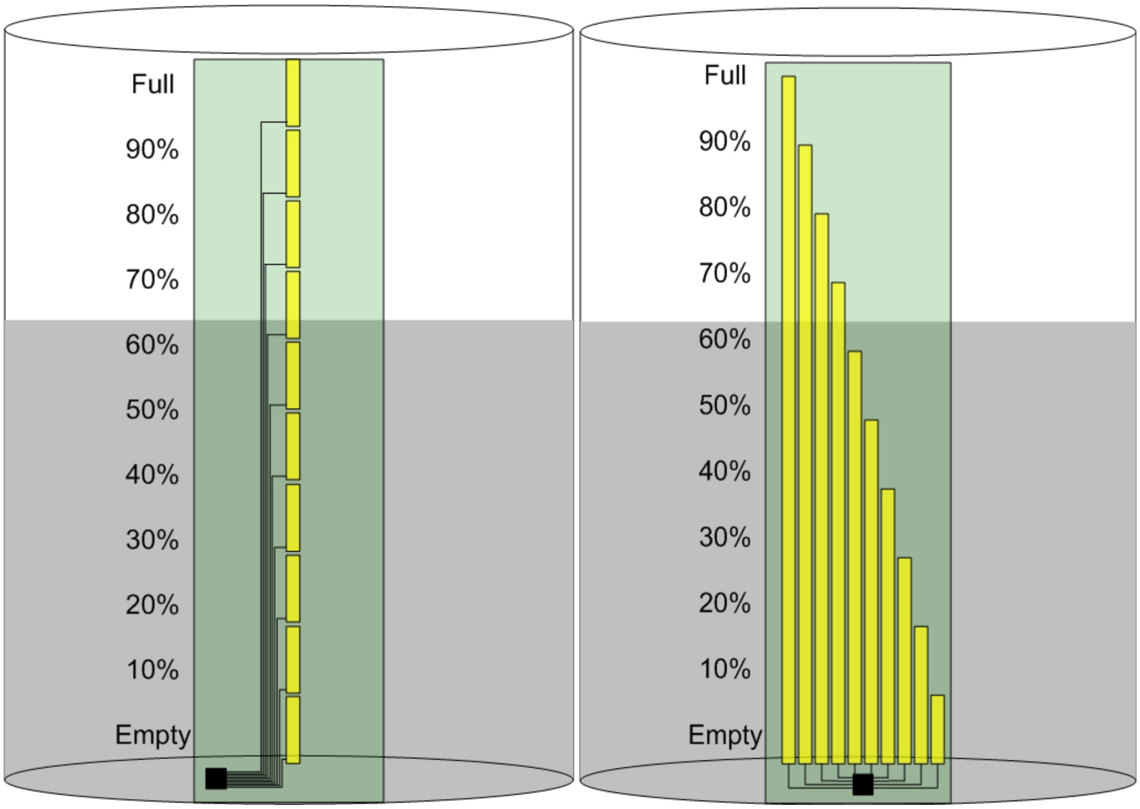

Figure 3. Liquid Level Capacitive Sensing

In the example on the left, each element serves as a common-mode element for its neighbor. When the longest element on the left is measured, its neighbor to the right can provide a common-mode cancellation for that portion that overlaps such that only the top portion of the left-most element is effectively monitored. The technique would involve a round-robin measurements system as the two elements to measure are cascaded from left to right. The example on the right identifies an alternate approach whereby the traces to the sensor pads are much less capacitive to the liquid and remain common until reaching the sensor element.

For the liquid level sensing technique, the size, shape, connection points, and application of the conductive sensors should be optimized while taking into account the conductivity of the fluid, the dielectric and thickness of the container, and the desired accuracy and resolution of the measurement.

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