Design Guidelines for Capacitive Sensors

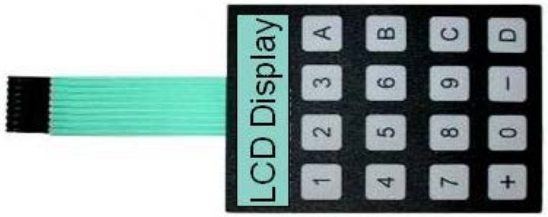
October 2016

SECURE CONNECTIONS
FOR A SMARTER WORLD

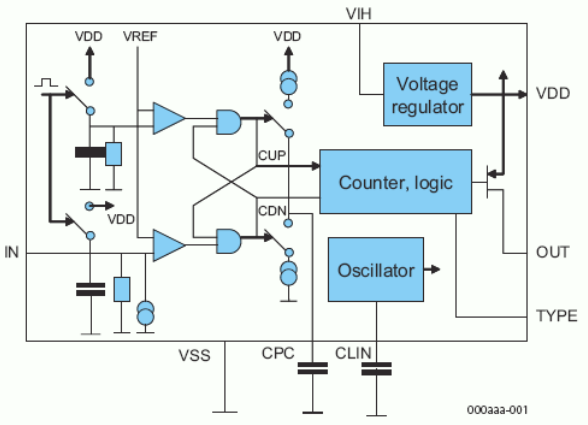
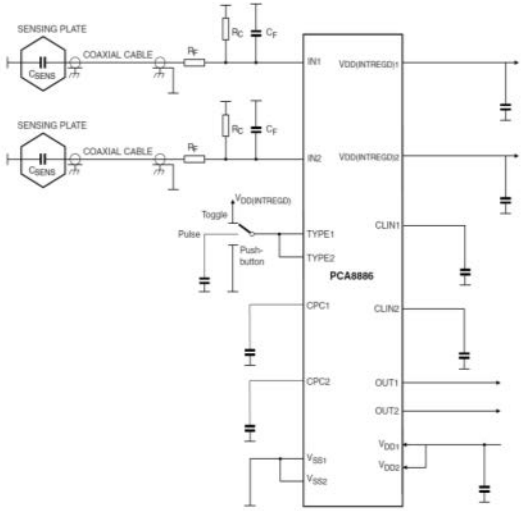
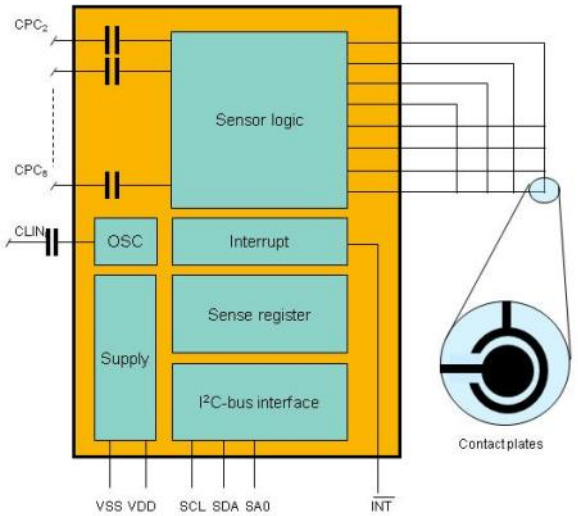
Introduction

Capacitive Sensors Value Proposition

- **Why used?**
  - No contact required (no actual pressing on touch area)
  - Works even when wearing gloves
  - Works in dirty environment (self-calibrating)
  - Works together with any event that generates a pre-defined change in capacitance
- **Where used?**
  - Switches in medical environment
  - Switches for use in explosive environment
  - Sanitary applications like in public rest rooms
  - Mobile applications to detect proximity to the head
  - Keypads
- **Why NXP?**
  - Products are very sensitive, highly configurable and consumes low power



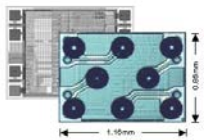
Capacitive Sensor Portfolio

Single Channel	Dual Channel	Eight Channel
		

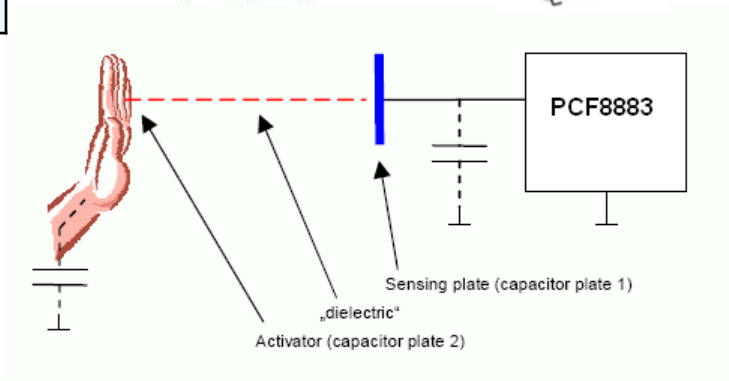
PCF8883
• One input one output
• Does not require a microcontroller
• Available in two packages
  • PCF8883T (SOIC8)
  • **PCF8883US (WLCSP8)**
	PCA8886
	• Two inputs, two outputs
	• Does not require a microcontroller
	• May be used for up to 3 sensors
	• AEC-Q100 compliant
	• Available in TSSOP16 (PCA8886TS/Q900/1)
		PCA8885 and PCF8885
		• 8-Channels
		• Requires a microcontroller
		• May be configured for up to 28 sensors
		• With two devices, user may enable up to 80 sensors
		• Available as both industrial and automotive versions in TSSOP28
		• Industrial version also available in SOIC28 package.

PCF8883: Single-Channel Capacitive Sensor

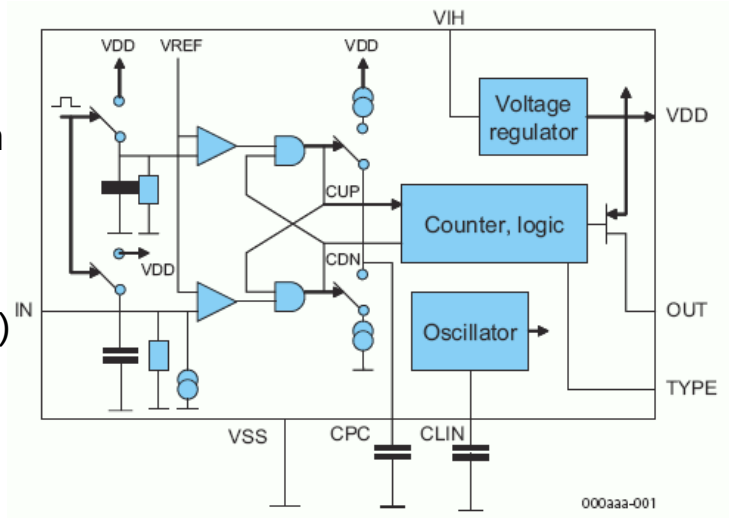
Single-Channel Proximity/Touch Sensor	
PCF8883T	Plastic small outline package, SOIC8
PCF8883US	Wafer level chip-size package, WLCSP8



- Touch/Proximity Switch for User Interface
  - Replacement of mechanical switches
  - No need for mechanical opening or cleaning surface
  - Hygienic aspect
  - Auto (self) calibrating disregards contamination
  - No wear out of contact
  - Single channel device



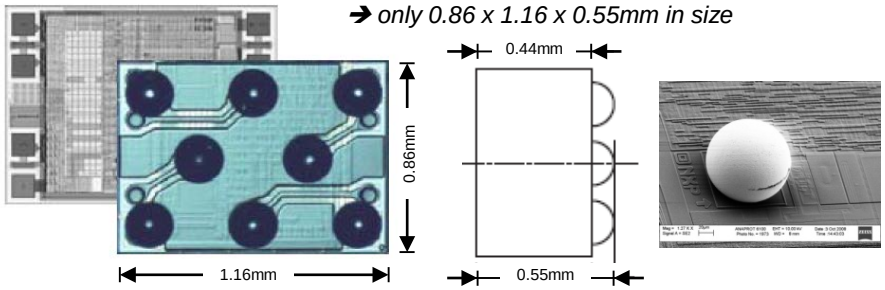
- Superior Device Specification
  - Digital processing method
  - Open-drain output (P-type MOSFET, external load between pin and GND)
  - Output configurable as push-button, toggle or switch
  - Low-power battery operation possible (I_{DD} < 5μA)
  - Extended battery-voltage operating range (2.8V < V_{DD} < 9V)
  - Wide input capacitance range (10pF to 60pF)
  - Adjustable response time and sensitivity
  - Up to 5cm (2”) proximity detection with a 5cm-by-10cm sensor area

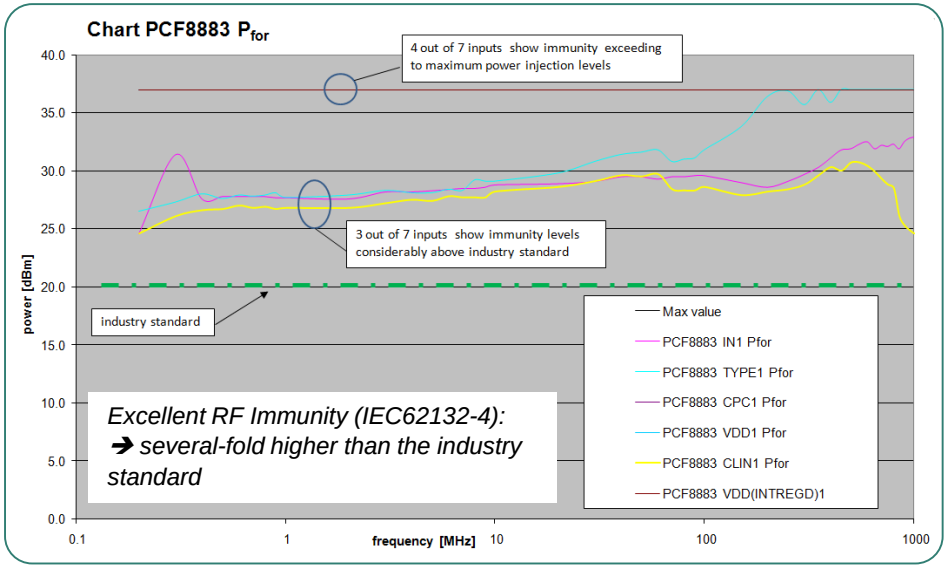


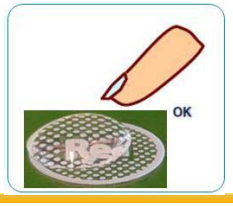
PCF8883: Single-Channel Capacitive Sensor

- *Patented (EDISEN) digital method to detect a change in capacitance on a remote sensing plate.*
  - ➔ *Changes in the static capacitance (as opposed to dynamic capacitance changes) are automatically compensated using continuous auto-calibration.*
- *Auto-calibration filters out contamination on sensor*
  - ➔ *no microcontroller recalibrations necessary*
  - ➔ *water droplets on top of a sensor plate will not cause false switching*
- *Excellent RF Immunity (in accordance with IEC62132-4)*
  - ➔ *The direct RF power injection (DPI) method shows an RF immunity several-fold higher than industry standard*
- *Ultra-low power consumption of 3µA (typ.)*
  - ➔ *¼ of the power consumption of the nearest competitor*
- *Available in Wafer-Level-CSP with bumps:*
  - ➔ *only 0.86 x 1.16 x 0.55mm in size*
  - ➔ *for reflow soldering and in tape and reel*

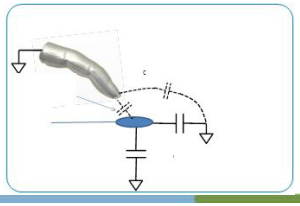
Wafer-Level Chip-Scale Package with Bumps:
➔ *only 0.86 x 1.16 x 0.55mm in size*





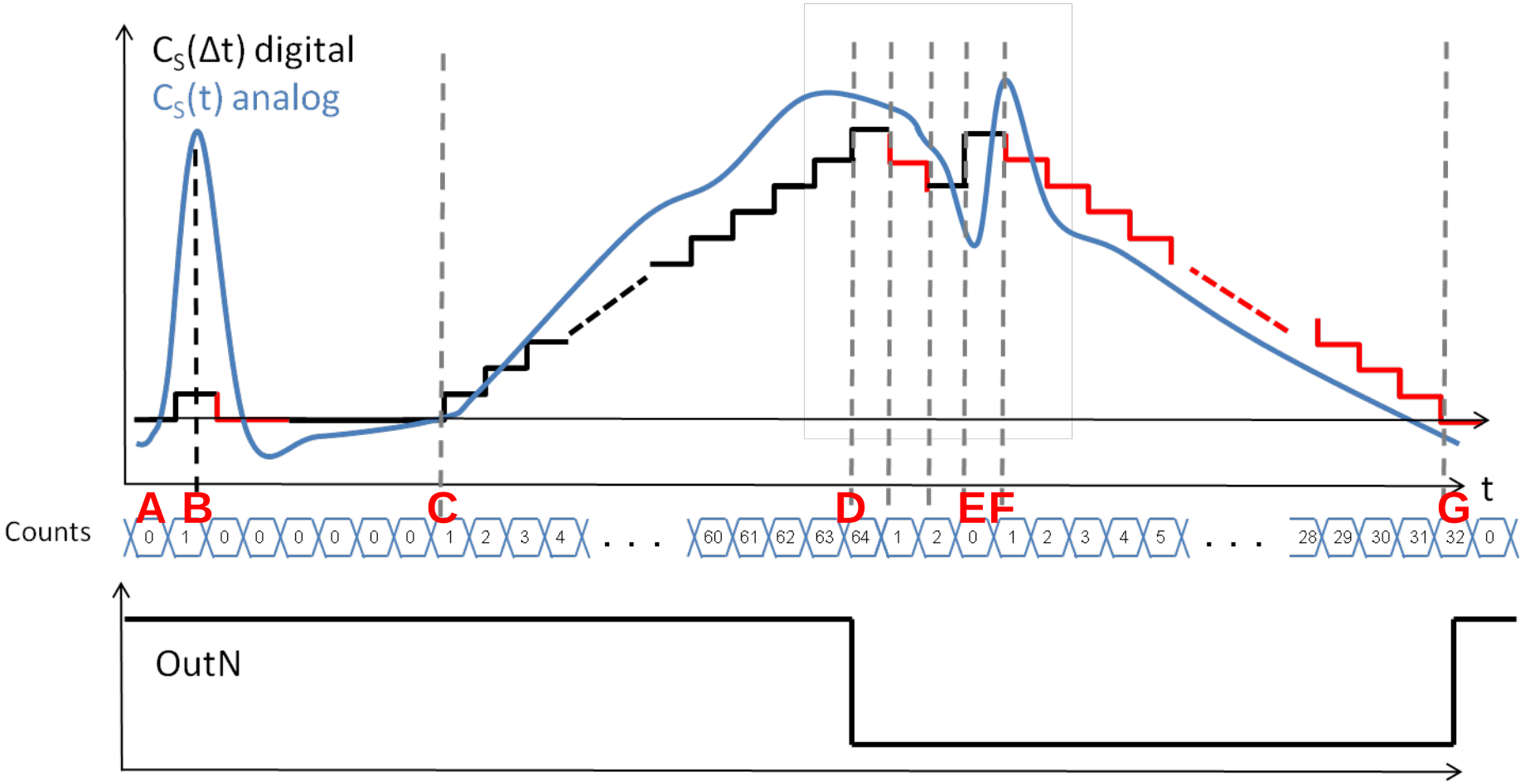


Auto-calibration:
➔*Water droplets on top of the sensor plate will not cause false switching*



Patented (EDISEN) digital method:
➔ *static capacitance changes are filtered out; dynamic capacitance changes are processed*

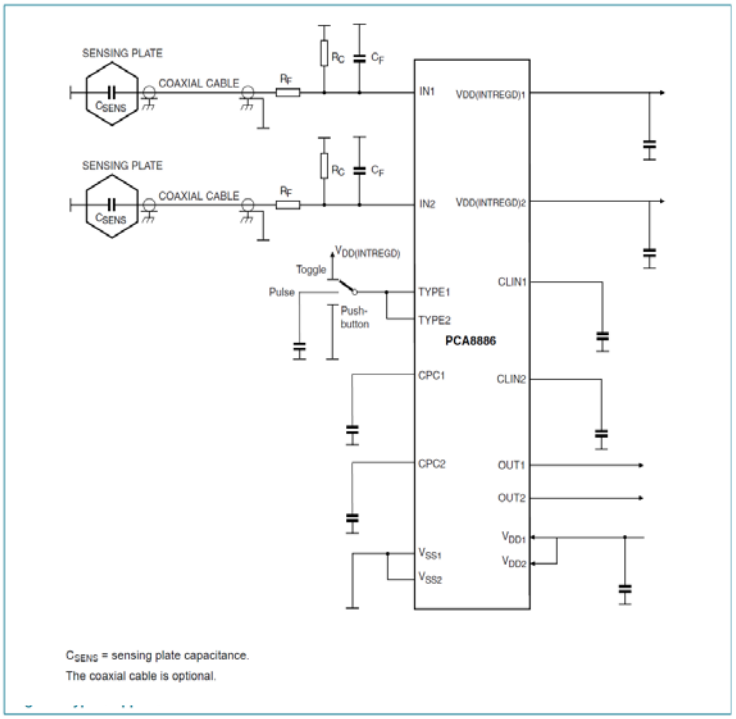
Auto Calibration and Digital Signal Processing in Action

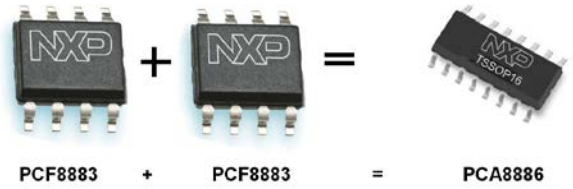


PCA8886: Dual-Channel Capacitive Sensor

Touch Sensor	
PCA8886TS/Q900/1	Self calibrating touch switch, TSSOP16

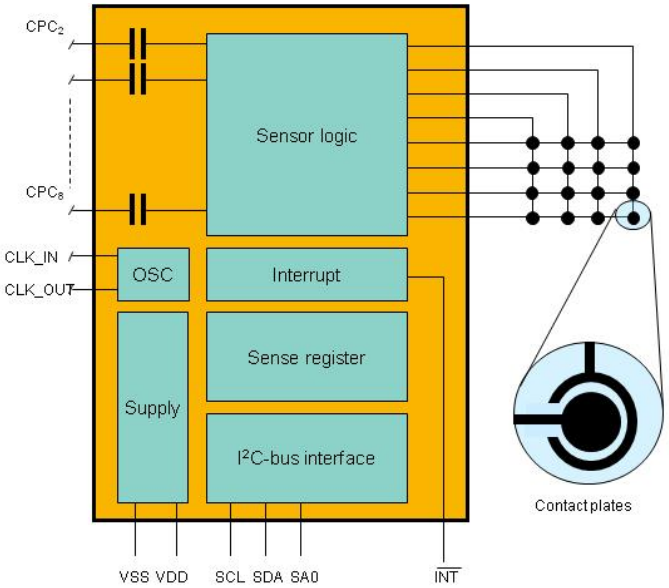
- Features
  - Dynamic proximity switch
  - Adjustable sensitivity
  - Adjustable response time
  - Wide input capacitance range (10pF to 60pF)
  - Automatic calibration
  - Large distance (several meters) between sensing plate and IC is possible
  - Low power consumption (I_{DD} = 6µA)
  - Open-drain output configurable as push-button, toggle, or pulse
  - Extended battery-voltage operating range ($3V < V_{DD} < 9V$)
  - Up to 5cm (2”) proximity detection with a 5cm-by-10cm sensor area
  - **AEC-Q100 Qualified for Automotive Applications**





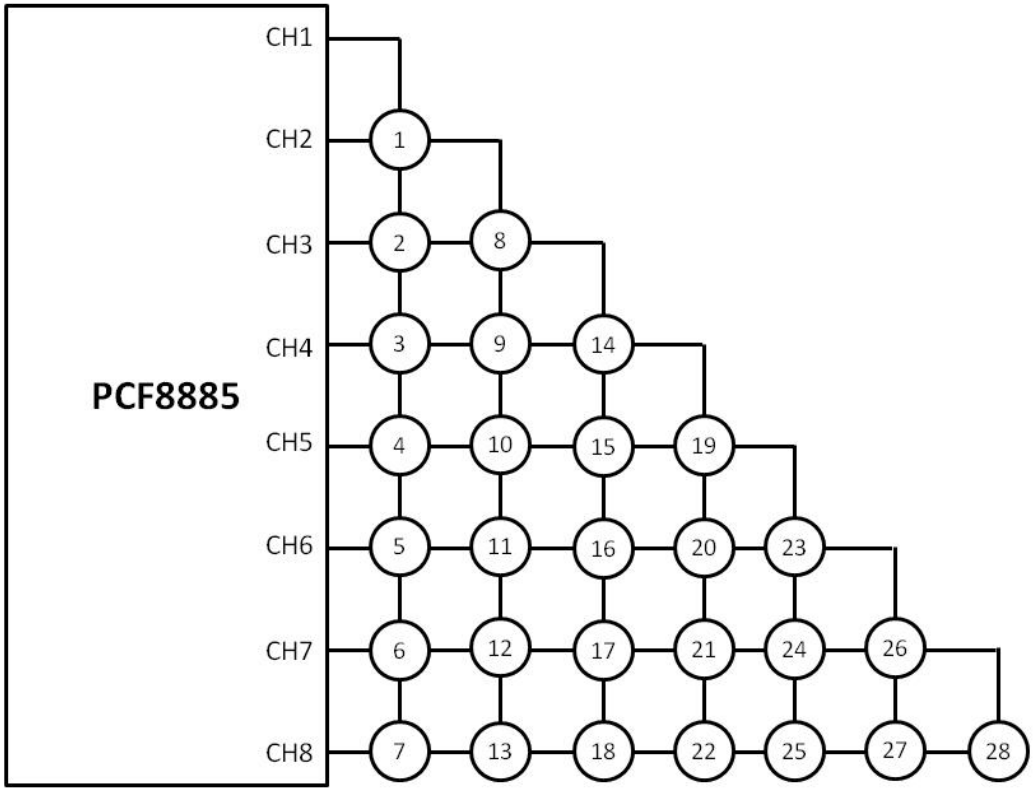
PCF8885: 4x4 Channel Proximity Switch

- Key Features:
  - Based on the PCF8883 algorithm
  - Fm+ I²C-bus (1MHz) interface
  - Supply voltage range: 2.5V < V_{DD} < 5.5V
  - Input capacitance range: 10pF to 40pF
  - Adjustable scanning frequency
  - Channel masking feature
  - Fast start-up mode
  - One sub-address enables 2 devices per bus
  - Sleep mode activated via I²C bus or sleep input
  - Three sensing modes: 1-key, 2-keys and N-keys
  - Two events handling modes; direct and latching modes
  - **AEC-Q100 Qualified for Automotive Applications**



Eight-Channel Capacitive Touch Sensor	
PCF8885T/1	SOIC28; 7.5mm body width
PCF8885TS/1	TSSOP28; 4.4mm body width

PCF8885: Single Device with up to 28-Sensors

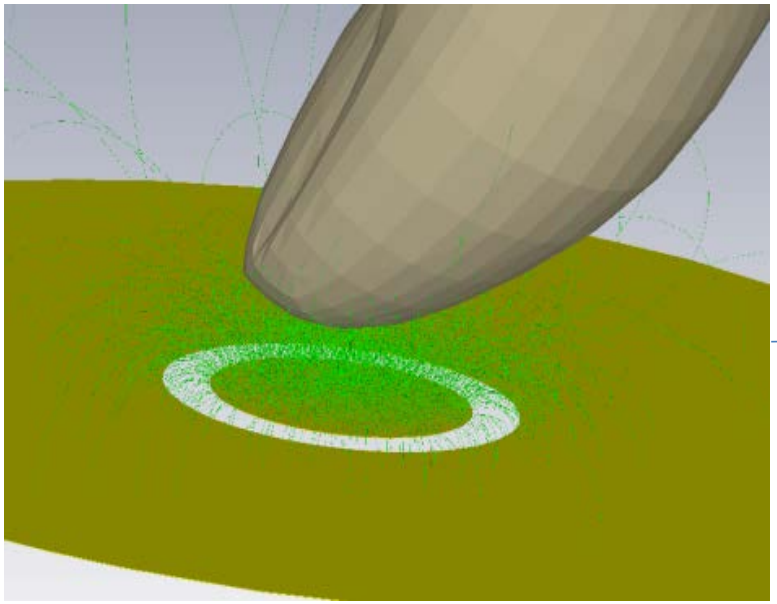


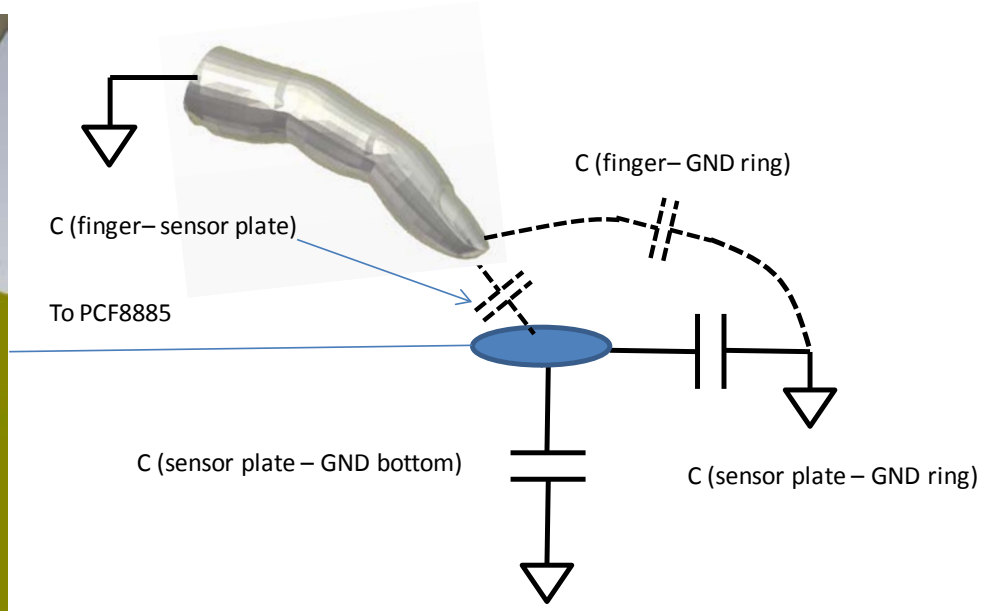
	Inputs							
	b7	b6	b5	b4	b3	b2	b1	b0
1	0	0	0	0	0	0	1	1
2	0	0	0	0	0	1	0	1
3	0	0	0	0	1	0	0	1
4	0	0	0	1	0	0	0	1
5	0	0	1	0	0	0	0	1
6	0	1	0	0	0	0	0	1
7	1	0	0	0	0	0	0	1
8	0	0	0	0	0	1	1	0
9	0	0	0	0	1	0	1	0
10	0	0	0	1	0	0	1	0
11	0	0	1	0	0	0	1	0
12	0	1	0	0	0	0	1	0
13	1	0	0	0	0	0	1	0
14	0	0	0	0	1	1	0	0
15	0	0	0	1	0	1	0	0
16	0	0	1	0	0	1	0	0
17	0	1	0	0	0	1	0	0
18	1	0	0	0	0	1	0	0
19	0	0	0	1	1	0	0	0
20	0	0	1	0	1	0	0	0
21	0	1	0	0	1	0	0	0
22	1	0	0	0	1	0	0	0
23	0	0	1	1	0	0	0	0
24	0	1	0	1	0	0	0	0
25	1	0	0	1	0	0	0	0
26	0	1	1	0	0	0	0	0
27	1	0	1	0	0	0	0	0
28	1	1	0	0	0	0	0	0

- Sensors 1 to 28 are each connected to two channels
  - Sensor 1 is connected to CH1 & CH2
  - Sensor 2 is connected to CH1 & CH3
  - Sensor 8 is connected to CH2 & CH3
- Total of 28 Sensors
- Device should be used in the 2-key mode
- After reading the SENS register, from the two bits set, the user can infer which sensor is touched.

Design Considerations

Design Considerations
Sensor plates





Design Considerations
Steady state capacitance

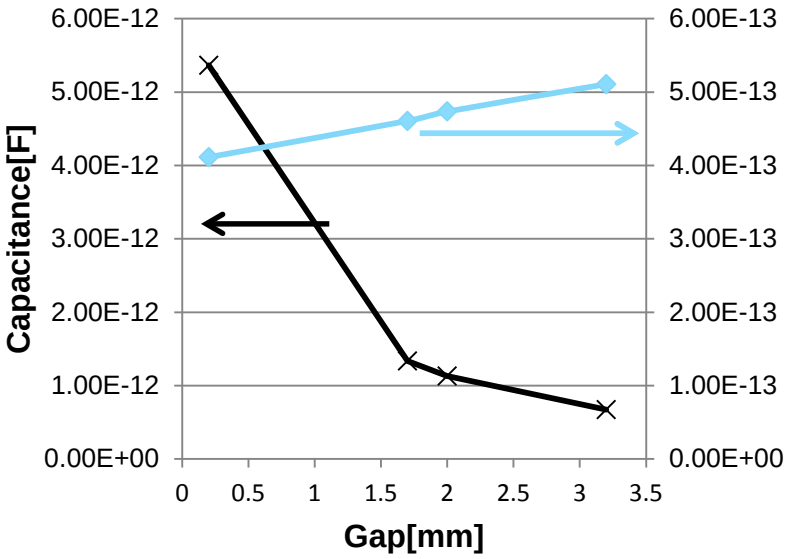
- The steady state capacitance originating from
  - layout
  - slowly changing environmental conditions
  - accumulating dirt and etc….
    will be compensated for by the auto-calibration mechanism
- PCF8883 and PCF8886:
  - 10-60pF
- PCF8885:
  - VDD(INTREGD) =3.0 V 10 - 50 pF
  - VDD(INTREGD) < 3.0 V 10 - 40 pF
- Dynamic capacitance change will be detected
  but at which speed?

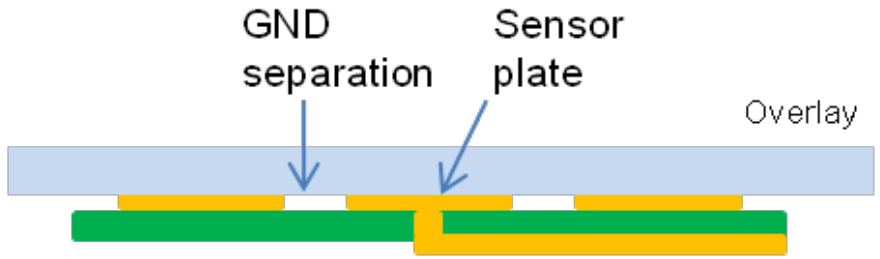
Design Considerations
Approach sensitivity

- *fosc* = 128kHz
- The approach sensitivity can be adjusted for every application with two single configuration commands.
- With m=1 being the default value, the oscillator frequency can be tuned in the range
  0.5 < m < 1.75.
  The clock frequency can be derived as
  fclk = fosc / n
  where n= 1, 4, 16 or 64. Nominal value 16
  ➔ nominal time needed for a capacitive event 64ms

Design Considerations
GND ring

- The thicker overlay the larger GND separation needed
  - Stray capacitance reduced
  - Secondary order, sensor plate – GND capacitance reduced





Design Considerations
Overlay and dielectric constant

$$C_f = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

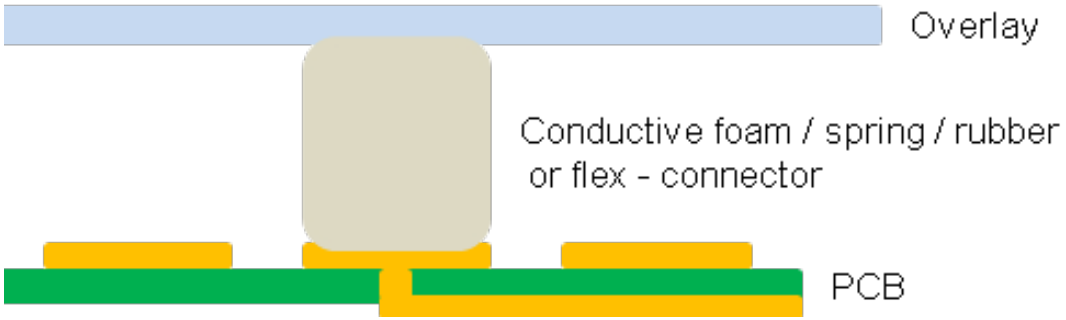
- Capacitance in pF

- free space permittivity $\varepsilon_0 \approx 8.85 \times 10^{-12}$ F·m^{-1} relative permittivity (ε_r) of the media.
- ***A*** is the area of the plates and ***d*** is the thickness of the media

Material	Relative permittivity (ε_r)
Air	1
FR-4	4.7
Glass	5-10
Acrylic	3.1
Water	80
Polycarbonate	3.1

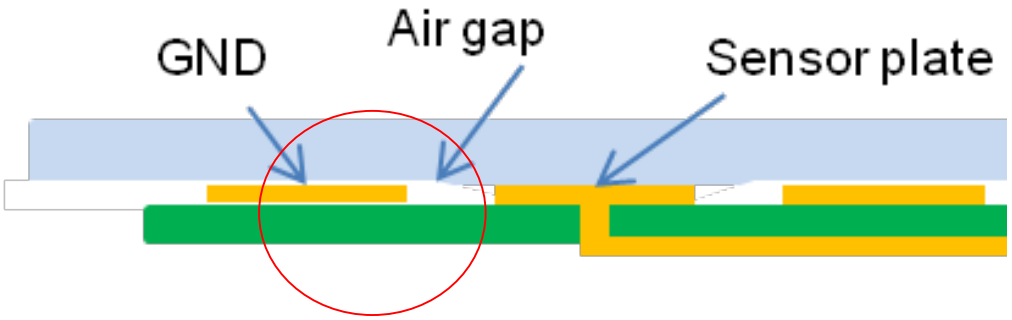
Design Considerations
Air gaps and “extended” sensor plates

- In most applications there is a gap between the PCB and the front panel overlay
- Using a conductive extension creates a robust structure with good sensitivity



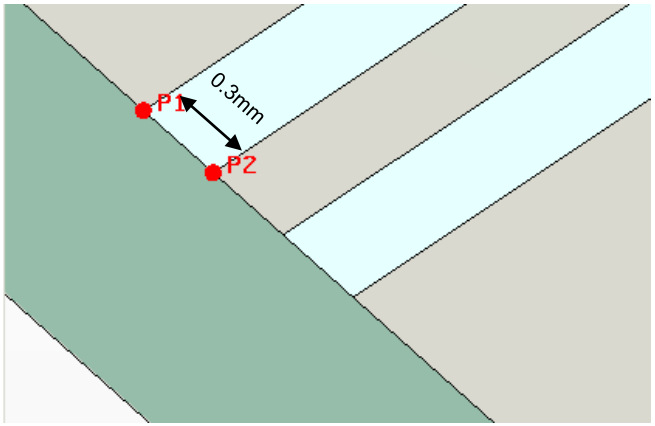
Design Considerations
Further fine tuning – densely placed sensor plates

- Make use of air gaps to reduce stray capacitance
- Improve sensitivity without reducing noise immunity



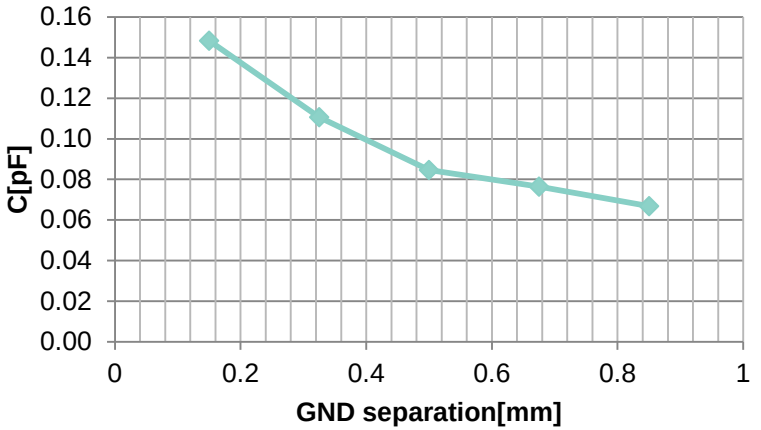
Design Considerations
Traces

- The capacitance of traces important
- Example :
  Gap=Width=0.3mm
  on 1.5mm FR4
  ➔0.12pF / mm



- Gap =0.5mm ➔ 0.09pF /mm
- 100mm ➔ 9pF !

To compare:
A sensor plate with D=10mm on FR4 and GND has 5pF

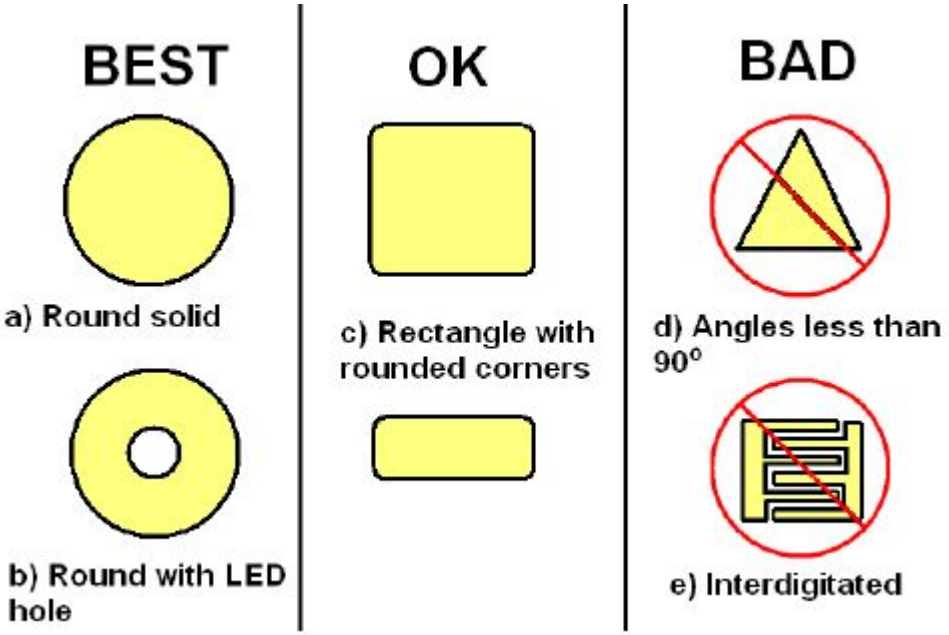


Design Considerations
PCB layout guidelines

- Two-layer board
- hatched ground on top
- all components on the other side
- A hatched ground instead of a solid fill should be provided near the sensors or traces in order to reduce impact of parasitic capacitance
- Solid ground is not recommended around sensor plates

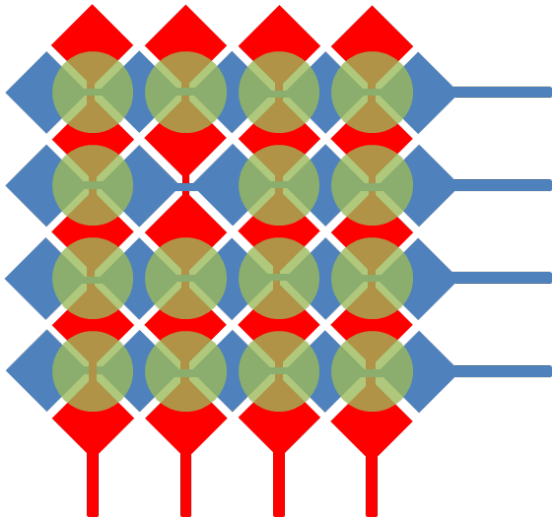
Design Considerations
Button design

- The best shape for buttons is round or oval
- Rectangular shapes with rounded corners are acceptable too
- Sophisticated shapes to be avoided



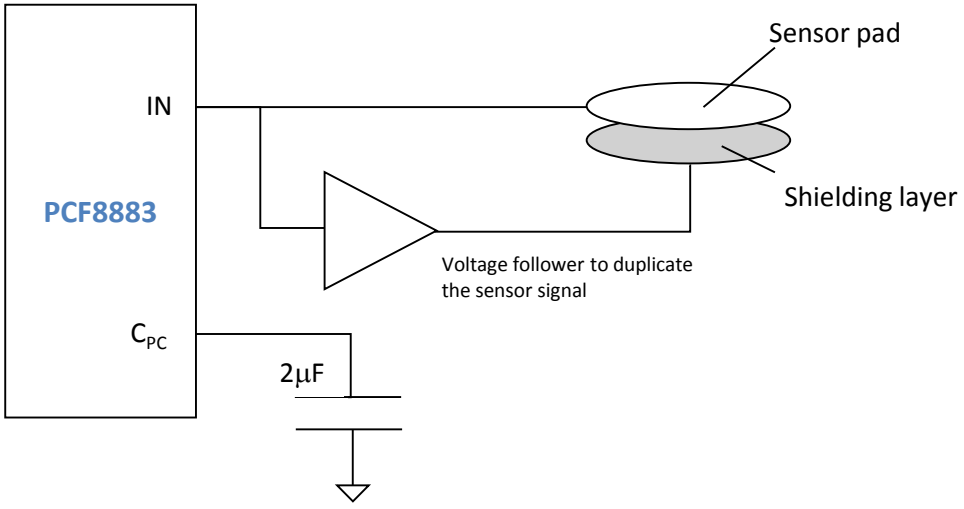
Design Considerations
Key matrix

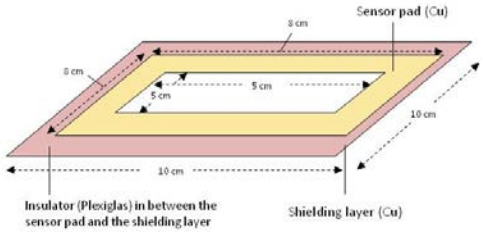
- Dense implementation 4x4 key matrix
- No GND between the rows and columns
- App. 18mm pitch (a standard keyboard)

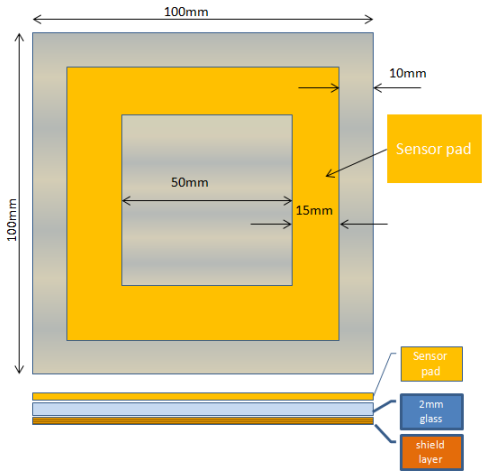


Increasing the Sensing Range

- The sensitivity could be improved by increasing CPC capacitance even beyond the specified 2.5uF. Care must be taken to choose a capacitor with high insulation resistance or low leakage (such as X7R)
- If extreme sensitivity is needed, a polypropylene or polystyrene capacitor can be used (these are large components).
- The sensor pad area is 39 cm^2
  - (8cm x 8cm) – (5cm x 5cm)
- The 5cm x 5cm opening is not necessary. The most critical parameter is the area of the sensor pad.
- The shield layer should be on the "other" side of the sensor pad.
  - It creates a shield against noise from any source behind the sensor pad.
  - It creates a repelling electrical field against the sensor pad







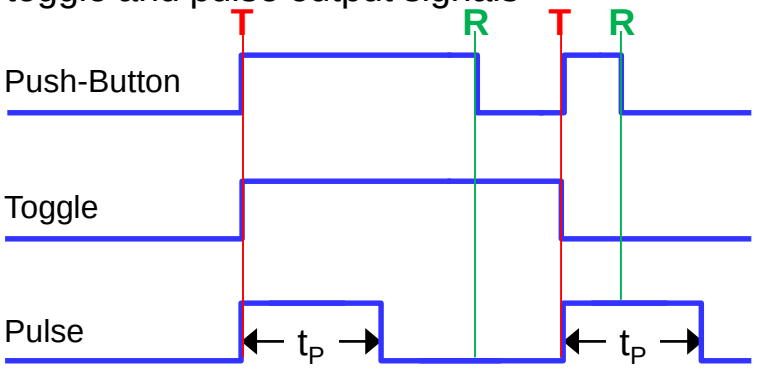
Design Considerations
Summary

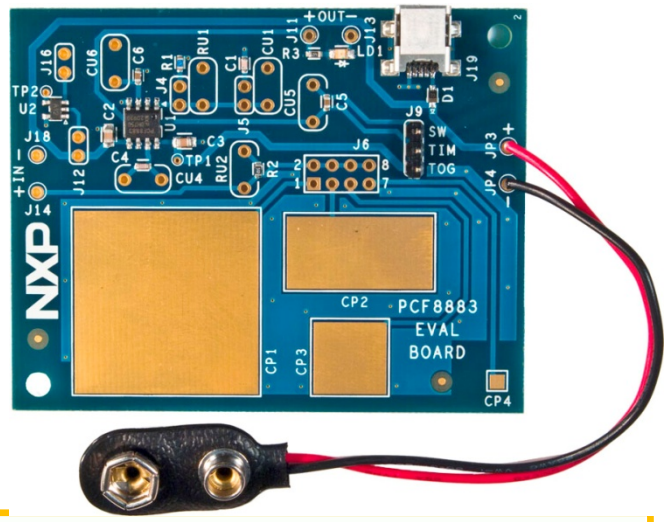
- Maximize sensor plate area for highest sensitivity
- Separation to GND ring kept about 2mm
- Sensor plate Diameter = Overlay thickness + 8 mm
- GND on top layer hatched
- Trace – GND separation should be as small as possible for noise immunity but long traces to be avoided
- Mount controller and all other components on the bottom of the PCB
- Keep signals like I^2C, SPI and other signals with sharp edges at least 4 mm away from the other lines
- If communication signals and sensor signals cross, do that at right angles (90 degrees).

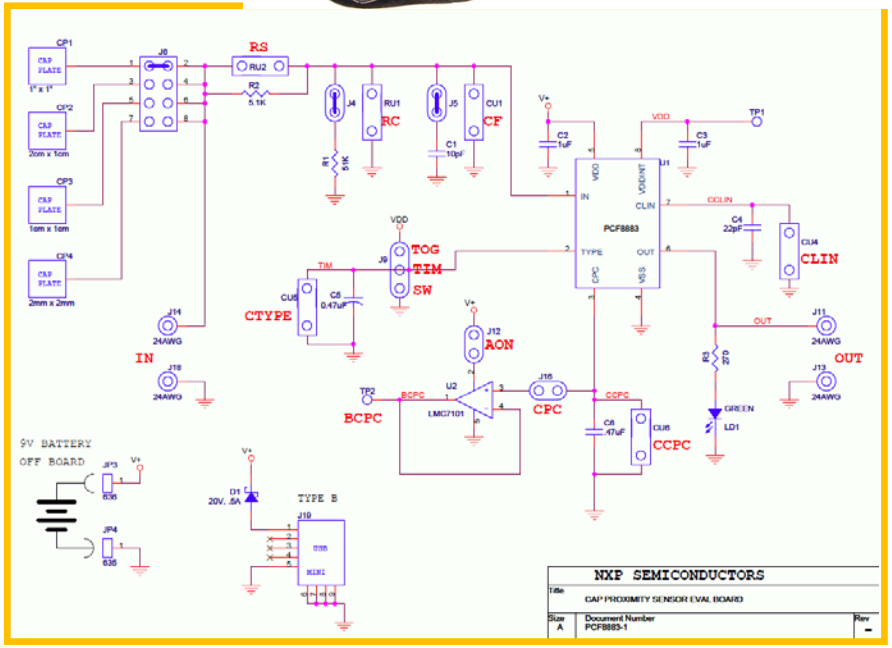
Demo Boards

PCF8883: Evaluation Kit (OM11055)

- Allows tuning of external components
- Inclusion of op-amp allows measuring the voltage on C_{CPC} without disturbing the loop
- Several sensor plate sizes to evaluate
- Power supply via USB or battery (USB cable included)
- Support documents:
  - AN10832: PCF8883 – Capacitive Proximity Switch with Auto-Calibration
  - UM10370: User Manual for the PCF8883 Evaluation Kit OM11055
  - Datasheets: PCF8883, PCA8886
- Reconfigurable TYPE Input to support push-button, toggle and pulse output signals

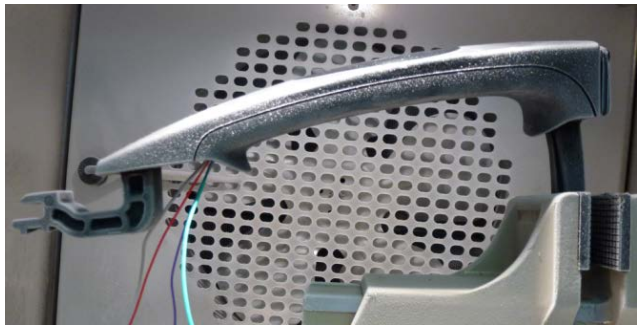


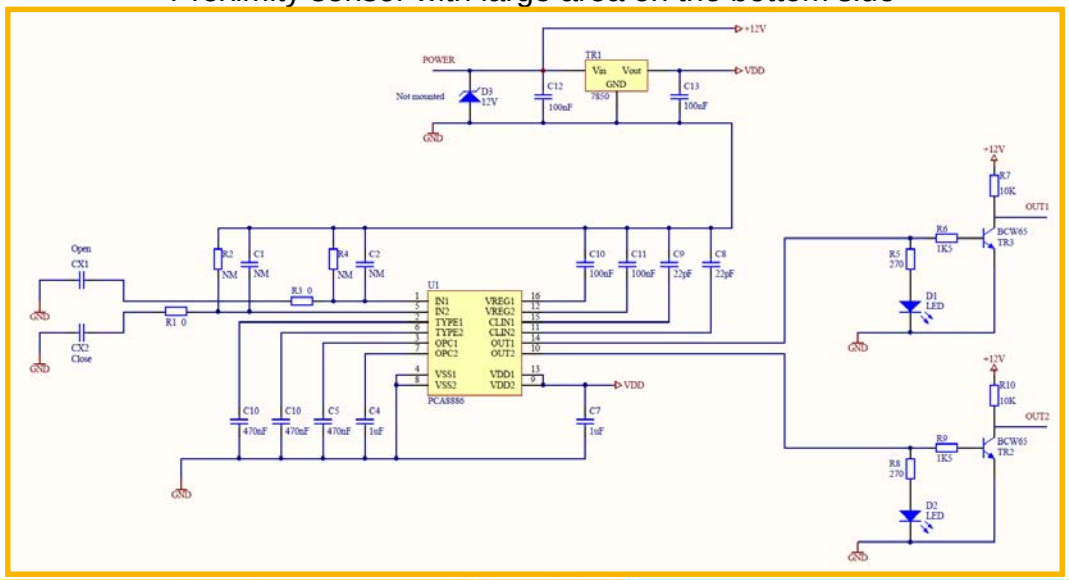




PCA8886: Application Board (OM11052)

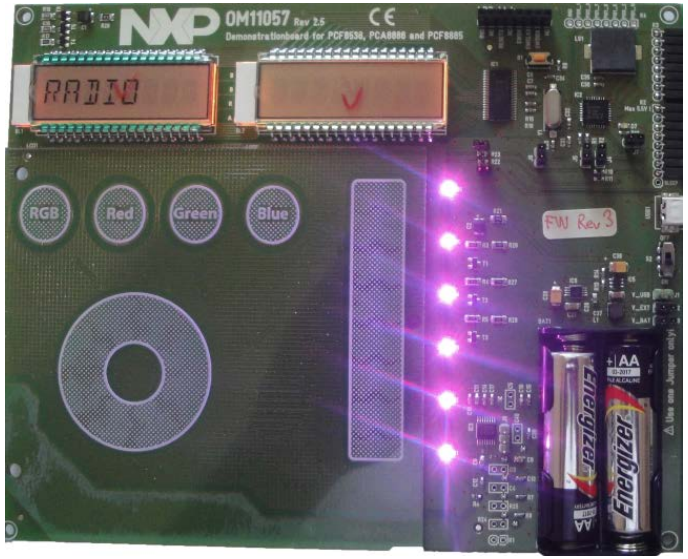
- Detects proximity and touch
- Demonstrates door handle activation with proximity sensing
- Proofs high immunity to environmental changes with measurements performed from -40 °C to +85 °C
  - Operates even with build-up ice on the door handle in the chamber at -40 °C.
  - Operates even with mixture of condensation and ice on the door handle when moved to room conditions.
- Two touch areas are active
  - Touch sensor with small area on the top side
  - Proximity sensor with large area on the bottom side

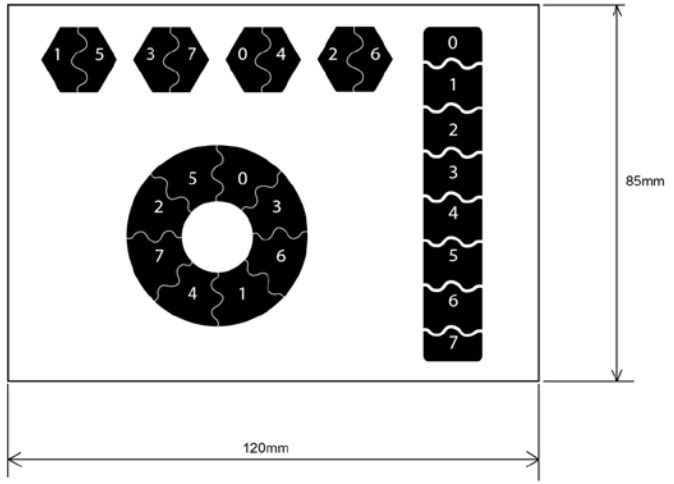




PCF8885 / PCA8886: Evaluation Kit (OM11057)

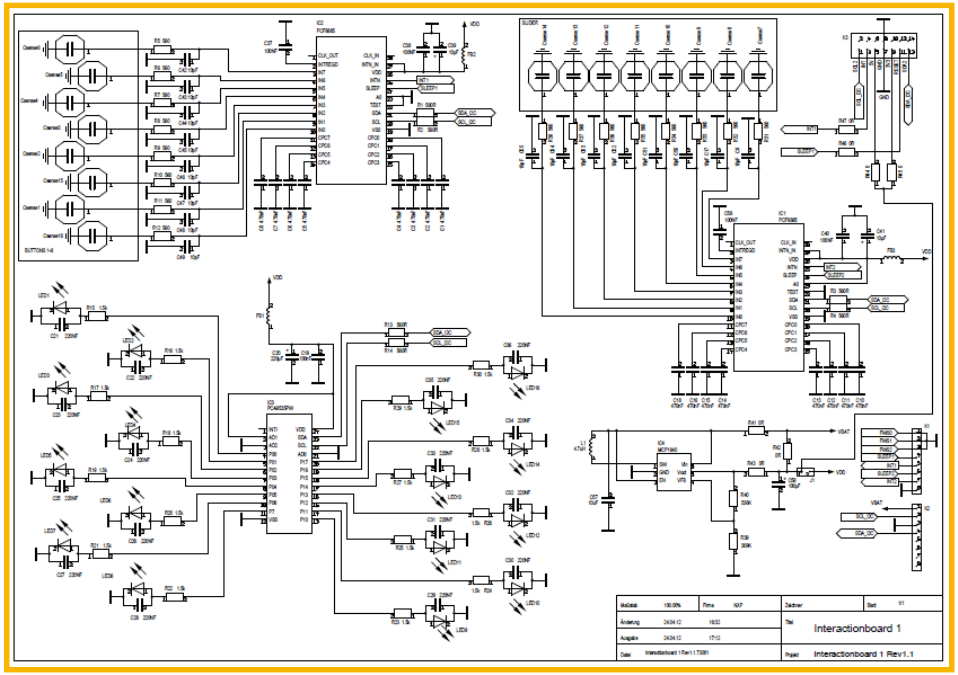
- Demonstrates the use of a single PCF8885 device in a multiplexed mode to achieve up to 28 sensors (19 sensors used on the board)
- Implements four touch buttons, a wheel and a slider
- Operates the PCF8885 in the 2-key mode and use the 2 out-of 8 code to enable 19 different sensor locations (7 for the slider, 8 for the wheel and 4 buttons)
- Enables touch sensitivity through a 3-mm acrylic overlay plate
- Uses the PCA8886 device in a proximity sensor mode to wake up board only when in use and demonstrates power saving features
- Feedback with a piezoelectric sound buzzer
- Feedback with RGB LED's
- Support documents:
  - UM10505: OM11057 Quick Start Guide
  - AN11122: Water and Condensation Safe Touch Sensing with the NXP Capacitive Touch Sensor
  - AN11155: General Design Guidelines for the NXP Capacitive Sensors
  - AN11157: Capacitive Touch Sensing with High EMC Performance
  - Datasheets: PCF8885, PCA8886, PCF8536

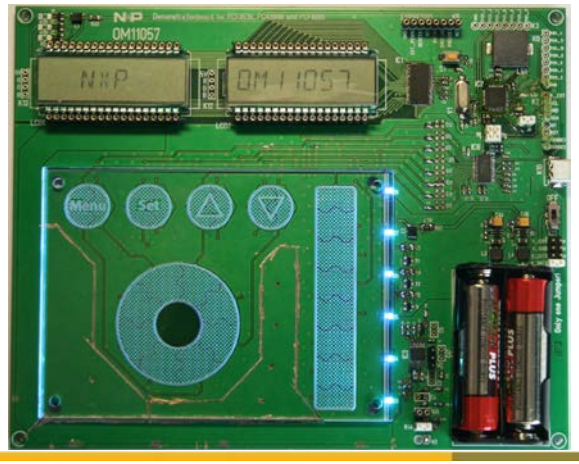


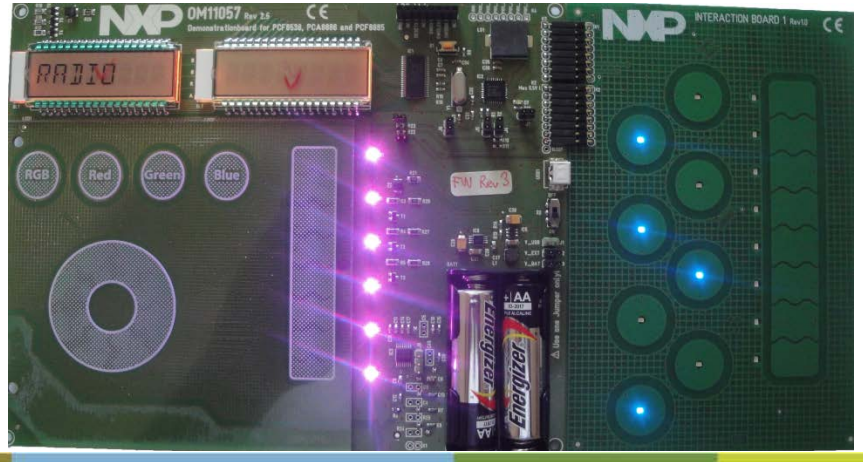


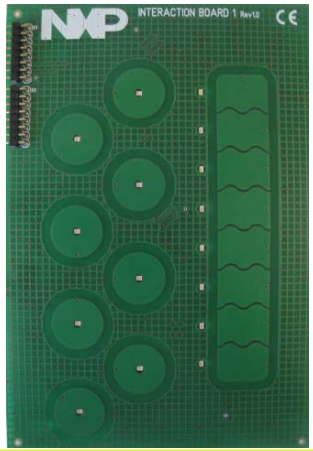
PCF8885 Plug-In Daughter Card (OM11057A)

- Multi-channel capacitive sensor plug-in board with two PCF8885 and one PCA9535 devices
  - One PCF8885 device used for touch buttons
  - One PCF8885 device used for slider
  - PCA9535 device used to drive LED's
- Board plugs into Evaluation kit (OM11057)
- Enables touch sensitivity through a 10-mm thick polycarbonate panel, acrylic overlay plate, or another insulating material
- Connector allows access to VDD, GND, I^2C signals, and interrupt to enable system development and evaluation



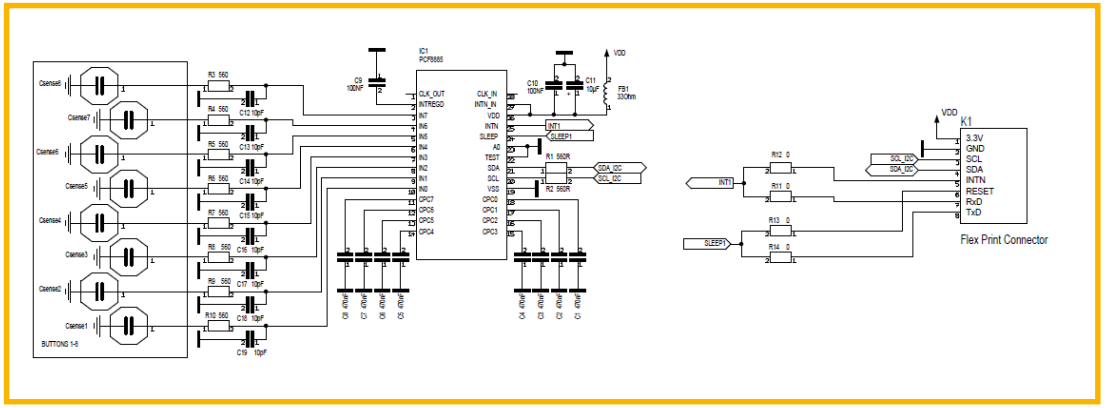


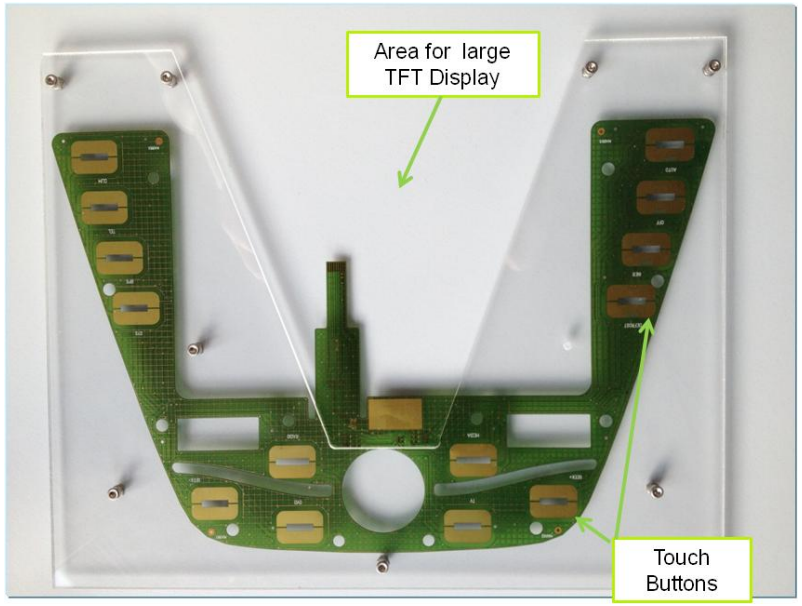


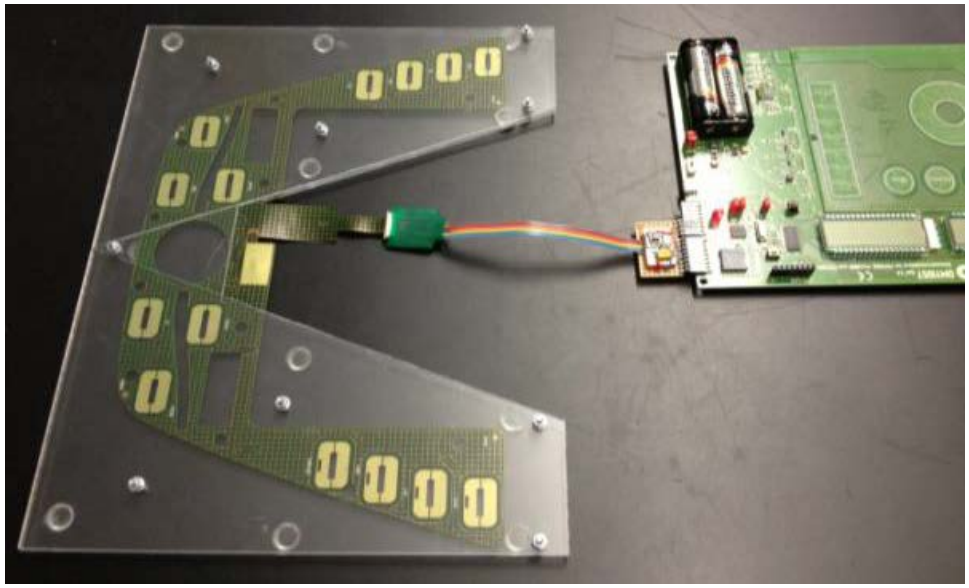


Infotainment Control Panel on Flexprint (OM11057B)

- Flexible board as used in automotive center-stack
  - Car Radios
  - Climate Controls
  - Navigation Systems
- Proofs that sensor areas can be located far away from the PCx8885 circuitry

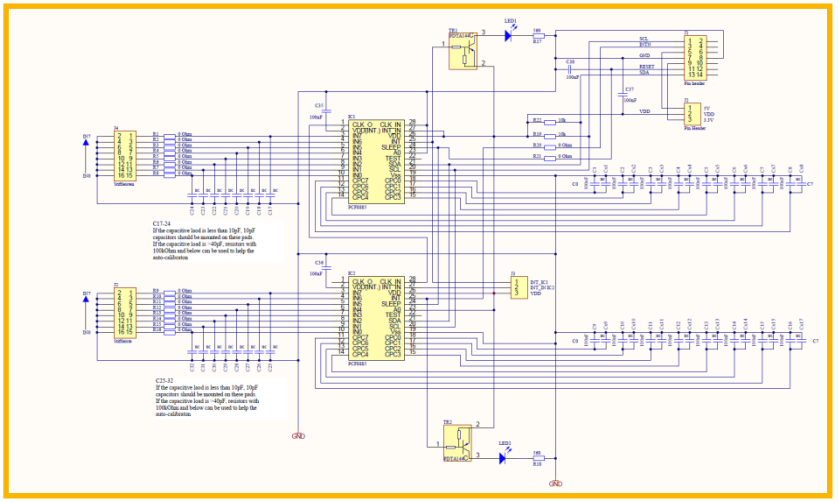


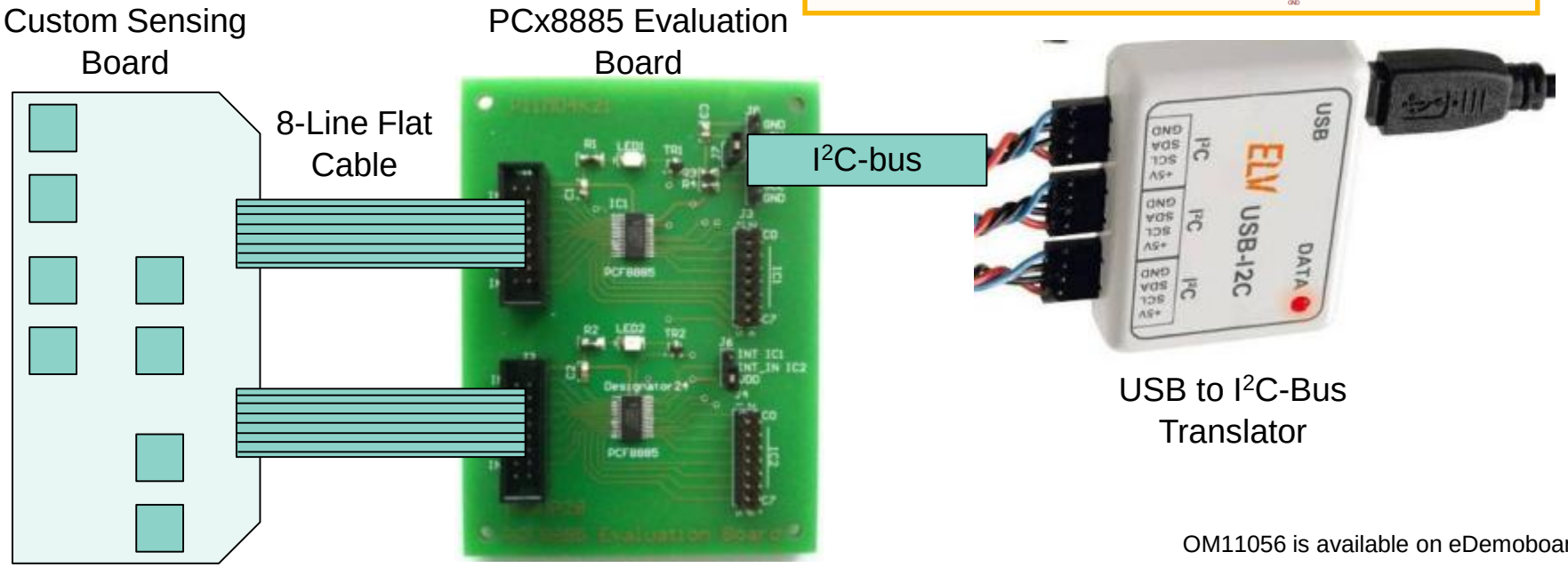




PCx8885: Evaluation Board (OM11056)

- PCF8885 or PCA8885 evaluation board with two TSSOP 28-pin sockets
- Can be directly connected to the I2C-bus and attached to the sensor plates in the customer's application
- Support documents:
  - UM10664: PCA8885 and PCF8885 Evaluation Board OM11056





OM11056 is available on eDemoboard

Reference Videos

- **Introduction to Capacitive Sensors**
  http://www.youtube.com/watch?v=Ga9t-OAJL0g
- **Capacitive Sensors – Quick Learning**
  http://www.youtube.com/watch?v=Wyr8kPUec7k&list=FL8DVBqX6TE7GaSh3daEXurw&index=7
- **Revolutionize Automotive Design with Touch Sensors**
  http://www.youtube.com/watch?v=VC1JlVeXYoI
- **Touch-on-Display Solution**
  http://www.youtube.com/watch?v=3z3JdyRDlZQ
- **Splashing Water During Touch Display Operation**
  http://www.youtube.com/watch?v=K7RZM8fPVlw
- **Robust Capacitive Touch Switches Survive Harsh Environments**
  http://www.youtube.com/watch?v=-0ZivxzYbEI
- **Powering Up and Interfacing with Unit which has Water on Display**
  http://www.youtube.com/watch?v=CT6acNtj-5c
- **Smart Remote Control with Capacitive Sensors**
  http://www.youtube.com/watch?v=0rU3jTwl-z4

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