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Touch Sensing

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Minds in Motion

Agenda

- Overview of Touch sensing Application
- Foundation of System-Level
- MSP430 Implementation
- Keys, Sliders & Demo
- Summary

Applications of Touch sensing

- Alternative to mechanical switches
  - Low cost
  - Longer life
- Flexible user interface
  - Simple buttons
  - Multi-position sliders
- Adaptable
- Useful in…
  - Consumer electronics
  - Appliances
  - Residential control

- …and almost anywhere a switch is currently use

Touch Sensing Overview

- Different technologies
  - Optical, Resistive, Capacitive, Strain…
- All detect change in system
- Optical
  - Expensive
  - Complex system design
- Resistive
  - Require sensor material that changes R when touched
  - Relatively low cost, but is an additional element to the BOM
- Capacitive
  - Can be implemented on PCB directly
  - Flexible sensor size & shape
  - Cost is a function of the PCB and any externals needed

Capacitive Methods

- Charge transfer technology
  - Quantum Research Group patented solution
  - Fixed function ICs that measure charge transfer from one sensor C to another
  - Stimulus signal and measurement integrator
- Capacitive measurement via ADC
  - Stimulus signal impacts capacitive sensor element, resulting voltage is measured by ADC
  - ADI implementation using a 16-bit Sigma-Delta to perform C-to-Digital conversion
- Relaxation Oscillator
  - Creates oscillator dependent on sensor C variation & measures frequency
- RC Charge/Discharge
  - Using high frequency clock, times charge and/or discharge times for sensor element with varying C

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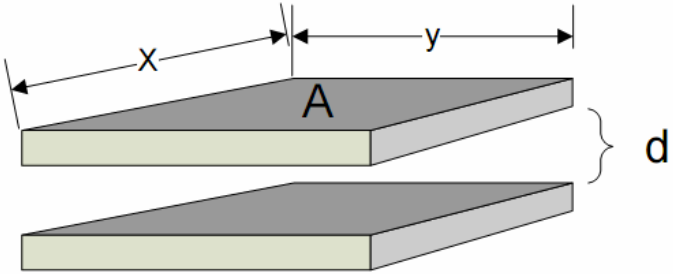
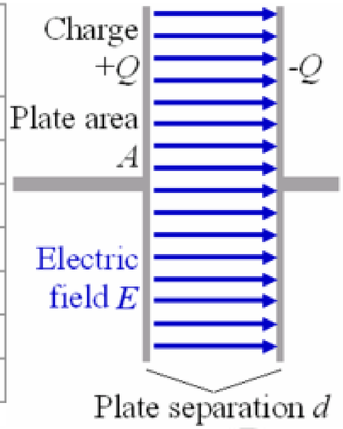
Capacitive Fundamentals

- Base capacitance created by PCB mechanics
- Capacitance change due to changing parasitics Finger touch proximity (or conductive other source)
- Minimize base capacitance Limit parasitics Limit sensor size
- Maximize impact of change Match sensor & finger areas for greatest delta-C Minimize distance between sensor and finger
- Sensitivity



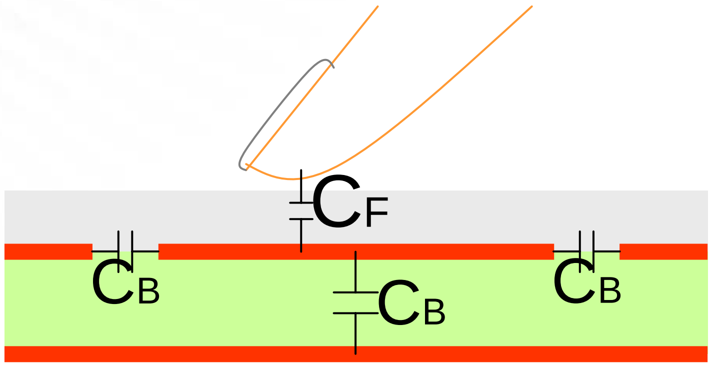
$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

Material	*Dielectric Constant* (ε_r)
Vacuum	1 (by definition)
Air	1.00054
Polyethylene	2.25
Paper	3.5
Pyrex glass	4.7
Rubber	7
Silicon	11.68



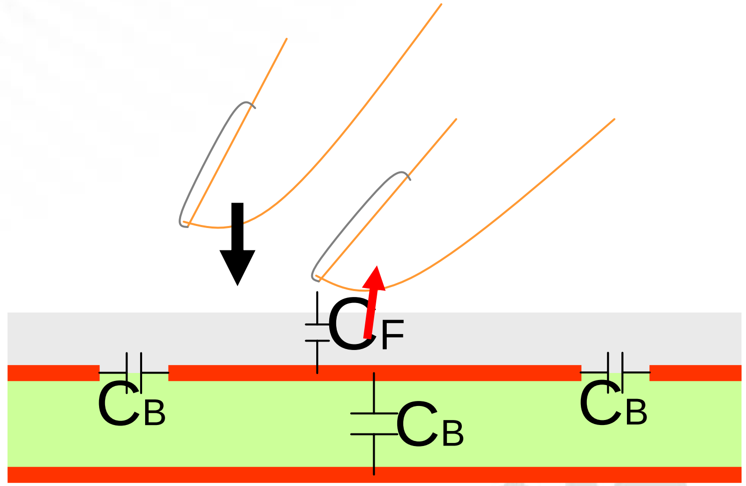
Capacitive PCB Sensor

- Copper pour on PCB makes a good sensor element
- ~10-20mil spacing between sensor & adjacent elements
- Size pads to maximize finger overlap for max delta C
- Simple pads can also be good sliders
- For true sliders, sizing pads such that more than one is touched at a time helps determine position



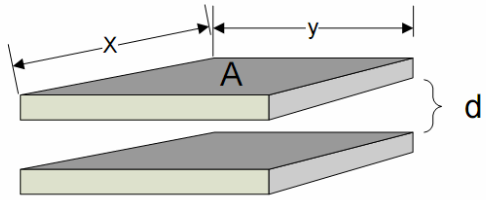
What Happen When You “TOUCH”

- Before you touch, PCB has its own C, we call $C_{B(Base)}$
- When you touched, $C_{T(Total)} = C_{F(Finger)} + C_{B(Base)}$



Consider your PCB

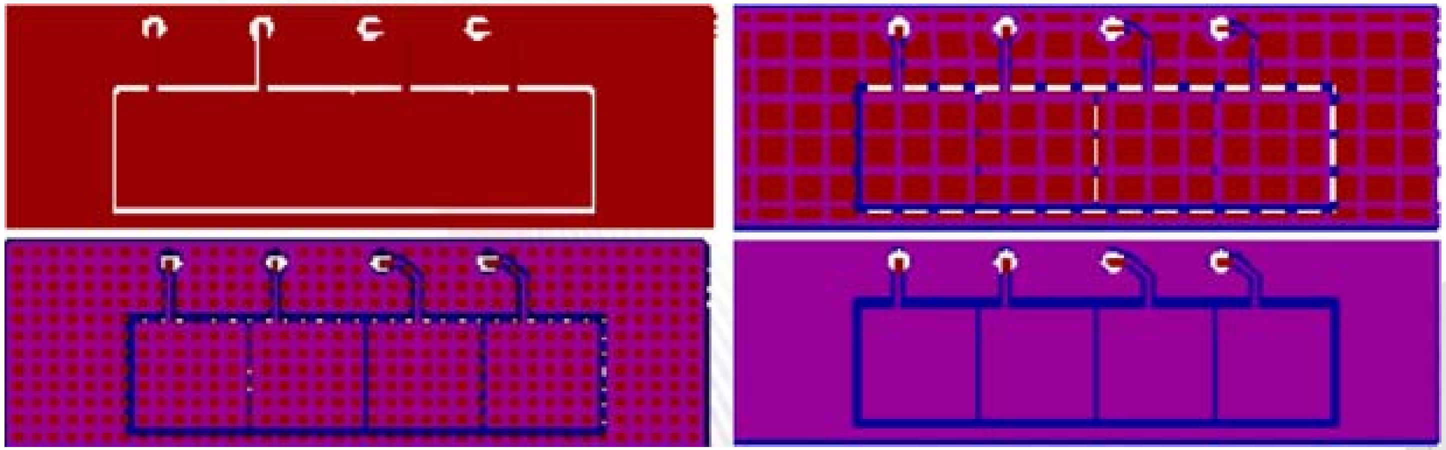
- Material and thickness matters
  - Goal 1: Small base C
  - Goal 2: Stable base C
- As d decreases, the base capacitance increase
- For a given sensor size and insulator thickness, the delta C created by a touch is fairly constant
- This change is a smaller percentage of the base C as d goes down
- Thinner PCBs require more care in insulator selection and thickness



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

Layout and Grounding

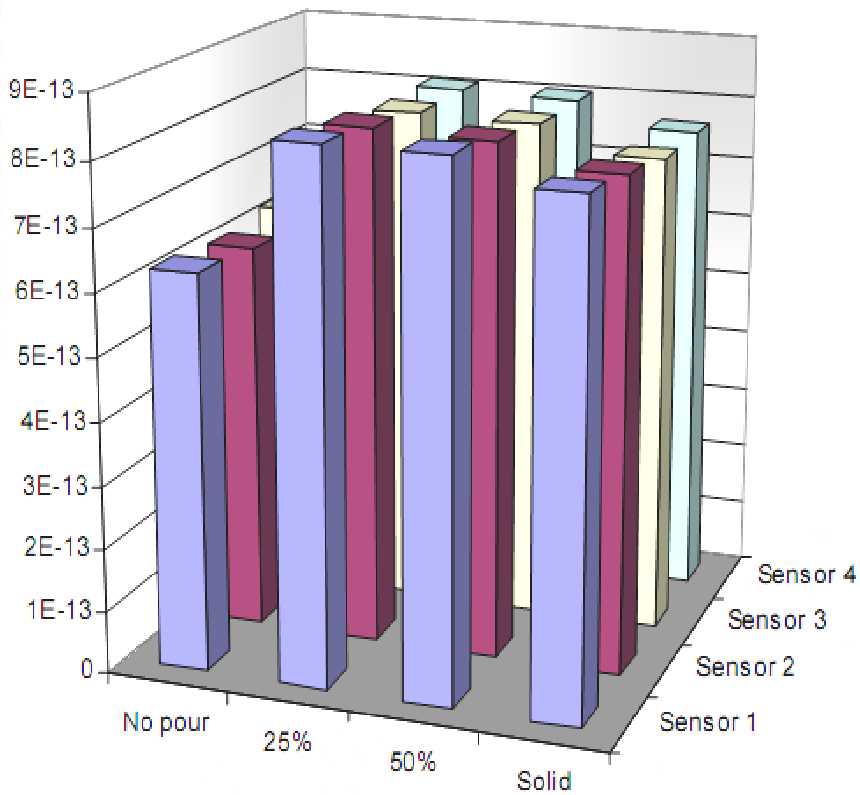
- Minimize noise & signal coupling with solid ground pour on sensor side of PCB
- Hatch pour underneath sensors if possible
  - Solid pour ok for noise, but increases base capacitance (larger A)
  - No pour has no increase in base capacitance but no noise benefits
  - A hatch of 50% is a good compromise



Sensors & Ground

- Tradeoff between PCB ground pour under sensors and sensitivity
- No Pour
  - Low base C
  - Small delta C
- 25-75%
  - Base C increases
  - Larger delta C
- Solid Pour
  - Large base C
  - Harder to influence change = lower delta C

Delta C vs. Pour
(8x8mm sensor on 1.5mm FR4)

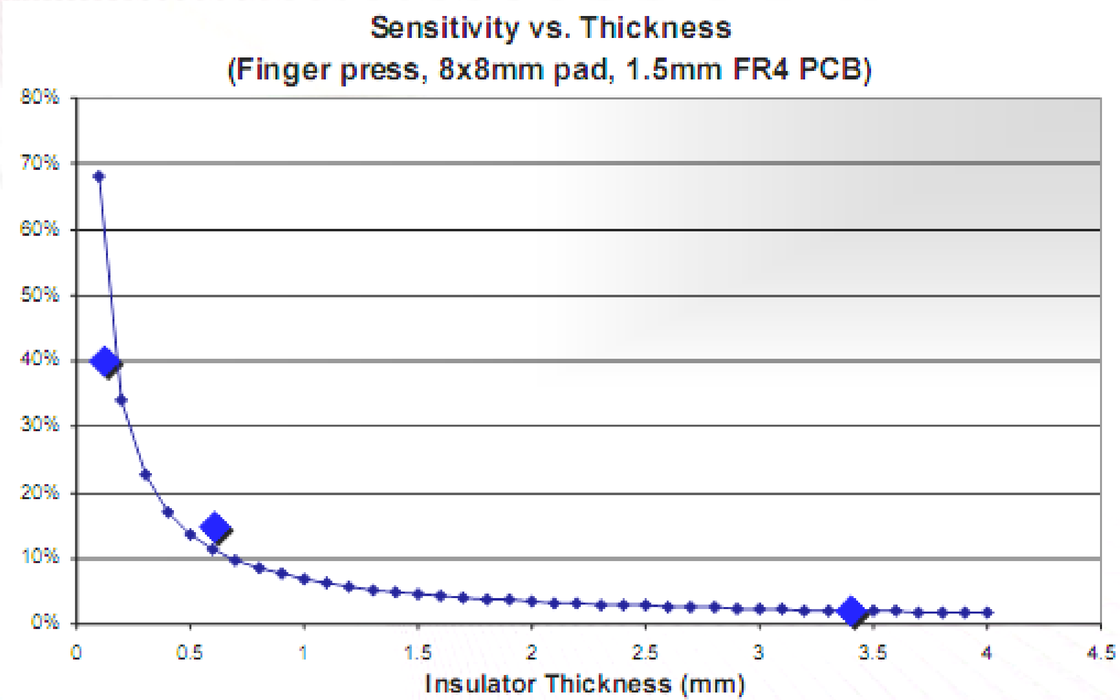


Insulators & Assembly

- An insulator is usually needed between PCB and user
- Insulator material must be non-conductive
- Thin is better
  - C is inversely proportional to the distance between the conductors
- No air should be present between insulator and the sensors on the PCB
  - C is proportional to the dielectric constant
- Use adhesives to secure sensor and insulator
  - Nonconductive adhesives, air-free
  - Those which tolerate temperature and humidity changes well are recommended

Insulator Spacing

- Achievable sensitivity is inversely proportional to insulator thickness



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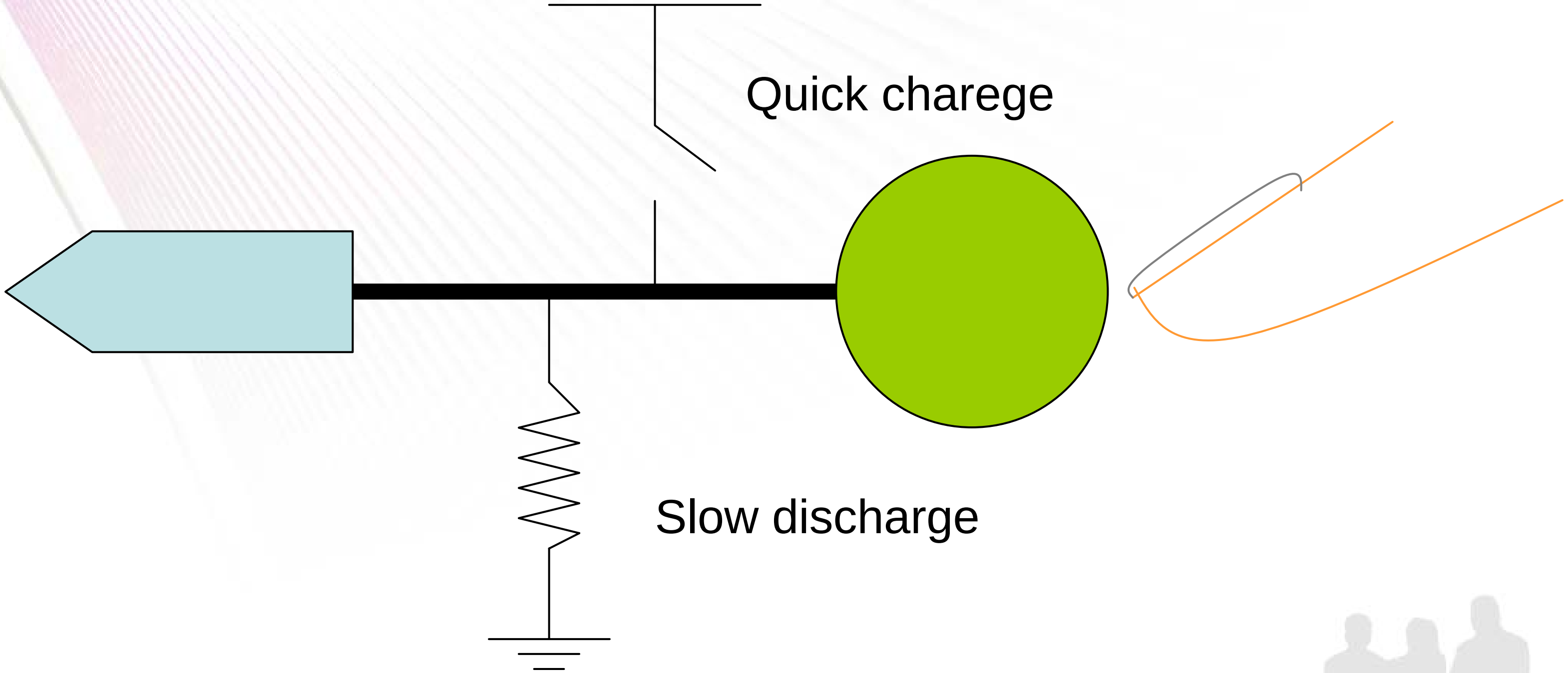
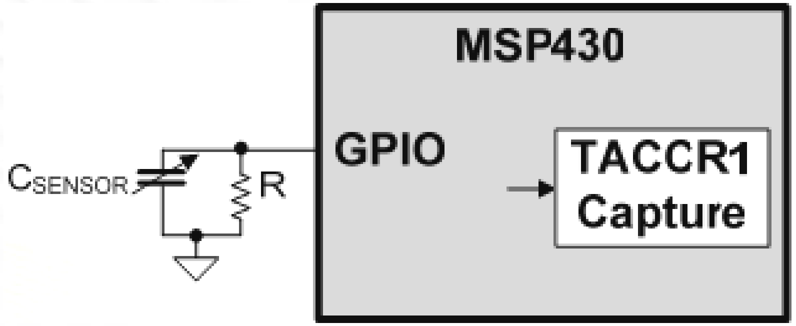
Before We Talking about RC

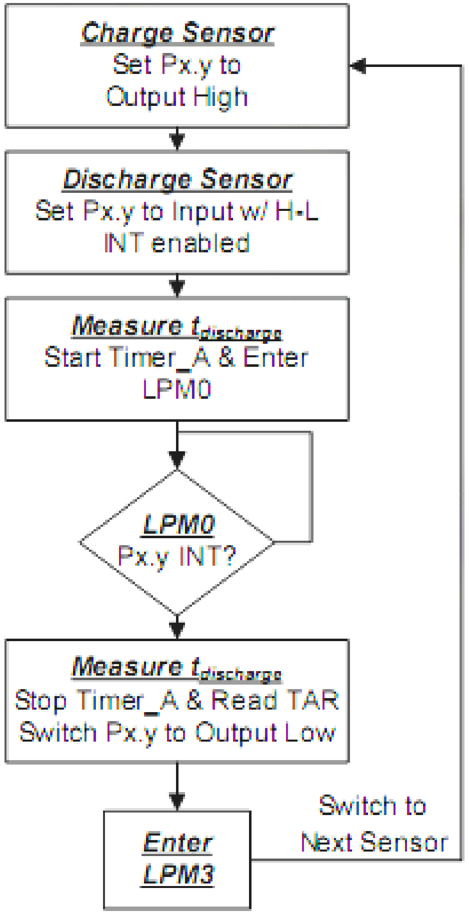


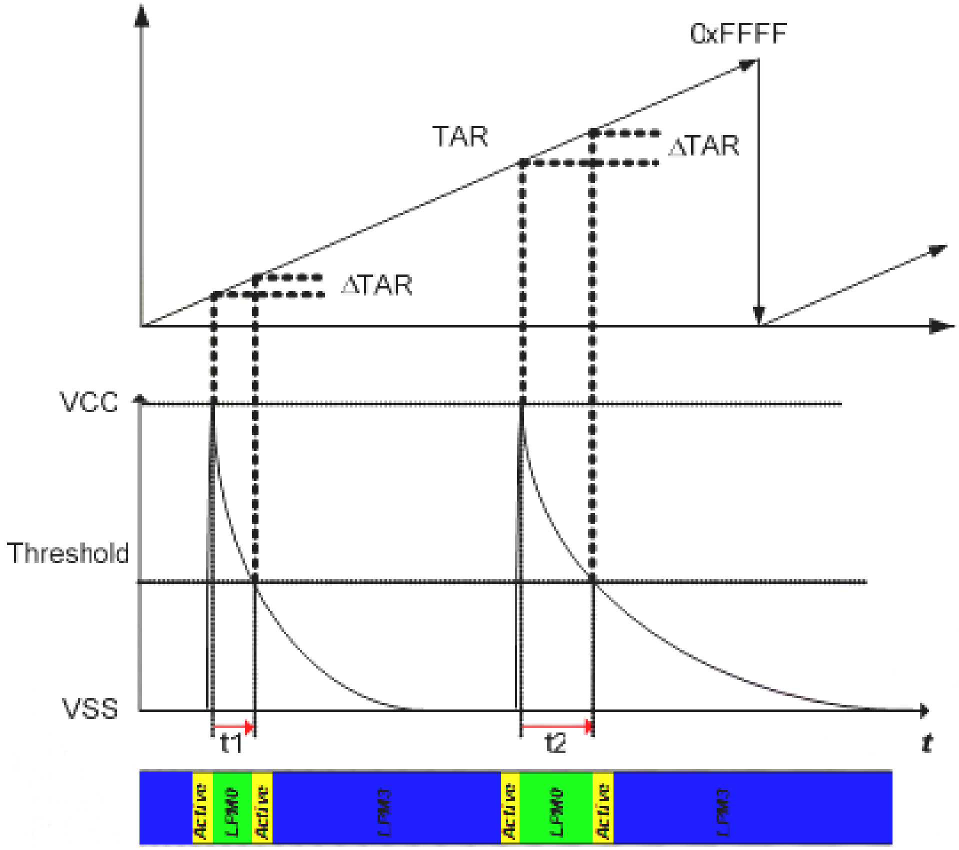
RC System Overview

- RC discharge time measured using interrupt on GPIO
- P1.x/P2.x GPIOsused
- Port pin used to charge sensor cap and measure discharge time
  - GPIO = Output high (charge C)
  - GPIO = Input (discharge C)
  - GPIO INT on low threshold
- Timer_A used to measure discharge time of C_sensor



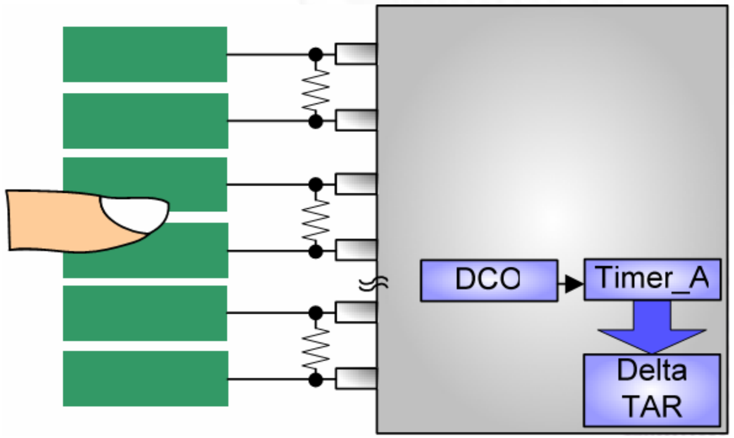
RC Measurement Cycle

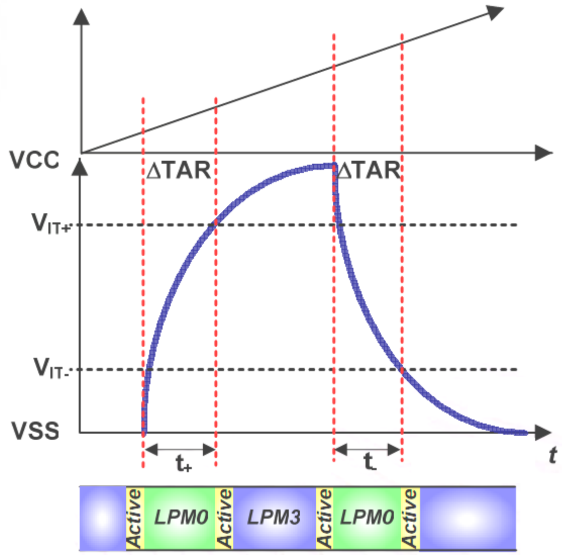




RC Optimizations

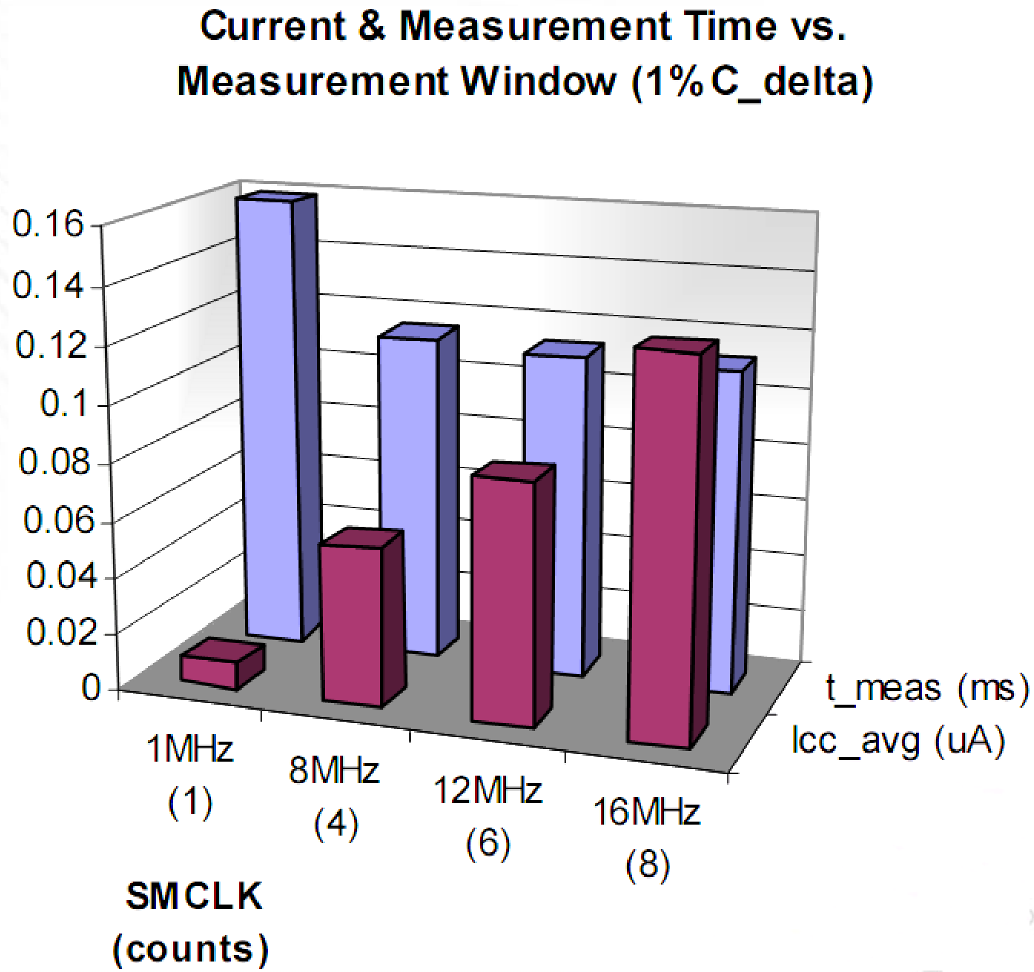
- Two sensor elements can share a single R
- Each sensor can be charged, then discharged for an average result: better noise rejection





RC Current Consumption

- t_measure is constant: ~2*t_RC_charge
  - R = 5.1Mohm
  - Counts TACLK
- Average Icc depends on
  - Tau = RC
  - DCO current consumption
- Set TACLK for adequate counts for application
  - Bigger delta C, lower f_DCO can be used
  - Design to fewest counts needed for lowest current



RC System Care about

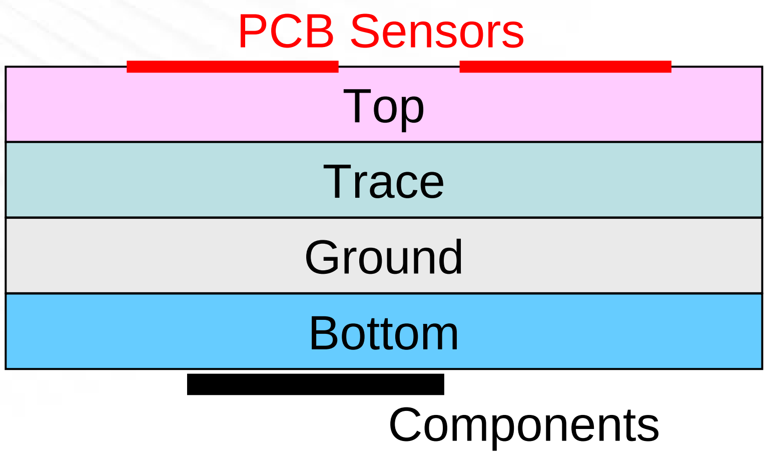
- Requires interrupt enabled GPIO for measurement
- One pin per sensor, shared resistor per two sensors
- R is Mohm's (5.1M)
  - With pF C, large R required for a measurable charge/discharge time
- Low pin leakage of MSP430 ideal for the methodology
- Noise rejection aided by charge/discharge average
- Measurement window is fixed by RC charge/discharge time: high freq reference clock needed to "count"
- Measurement counts dependent on Vcc & Temp (DCO)

Use MSP430 increase the performance

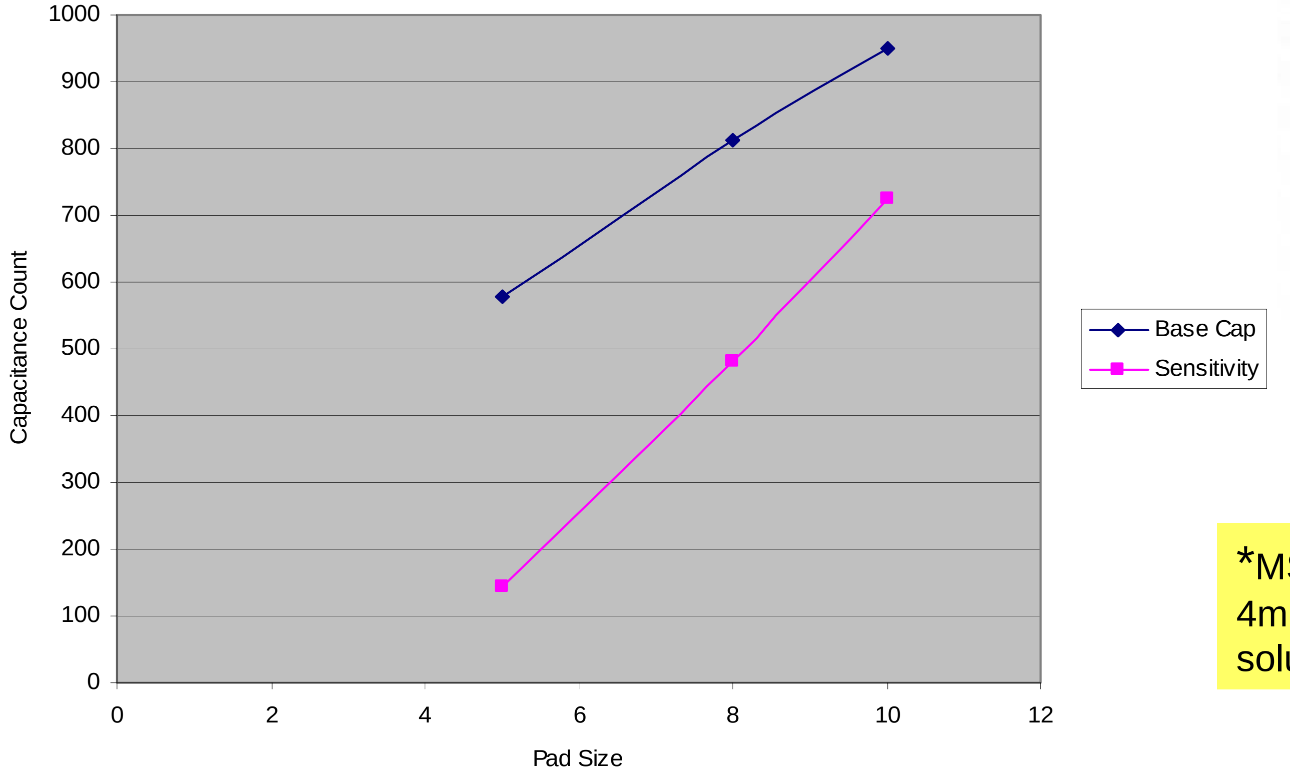
- Multi **layer** PCB design.
- Which **size** of pad could get better performance?
- The **clearance** to the ground?
- **Overlay** material?
- **ESD**!
- **Noise**

4 Layer PCB Consider

- No air gap should between PCB sensors and overlay material.
- Keep out the trace clean under sensors
- Reduce the traces capacitive influence each other.

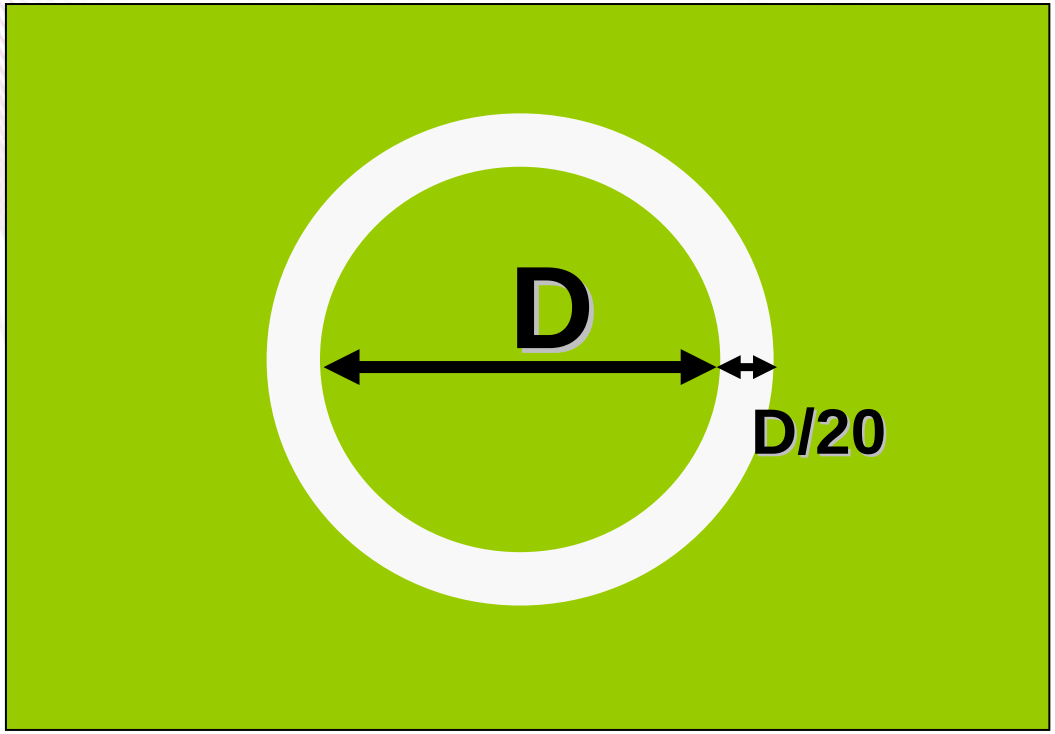


Size does matter(Pad and chip)



*MSP430 smallest package only 4mm x 4mm,suitable for any solution.

D/20 for Clearance



Overlay Material & ESD

Material	εr (dielectric constant)
Air	1.0
Glass	7.6 to 8.0
Mylar	3.2
ABS	3.8 to 4.5
Wood	1.2 to 2.5

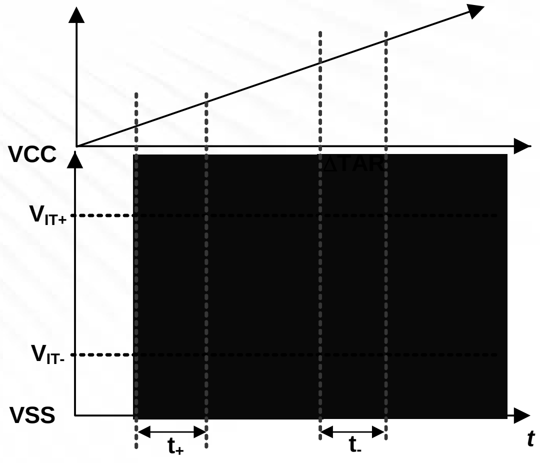
*Higher dielectric materials give better capacitive coupling

Material	Minimum thickness for ESD protection
FR-4	0.4 mm
Kapton	0.04mm
Acrylic	0.9mm
Polycarbonate	0.8mm
Glass	1.5mm
ABS	0.8mm

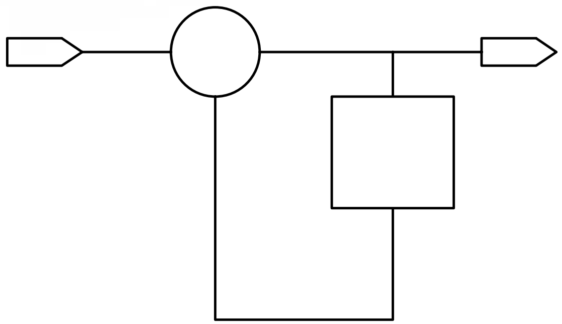
* minimum thickness to avoid 12KV damage through

Improve Noise Immunity and Sensitivity

- Pseudo differential measurement

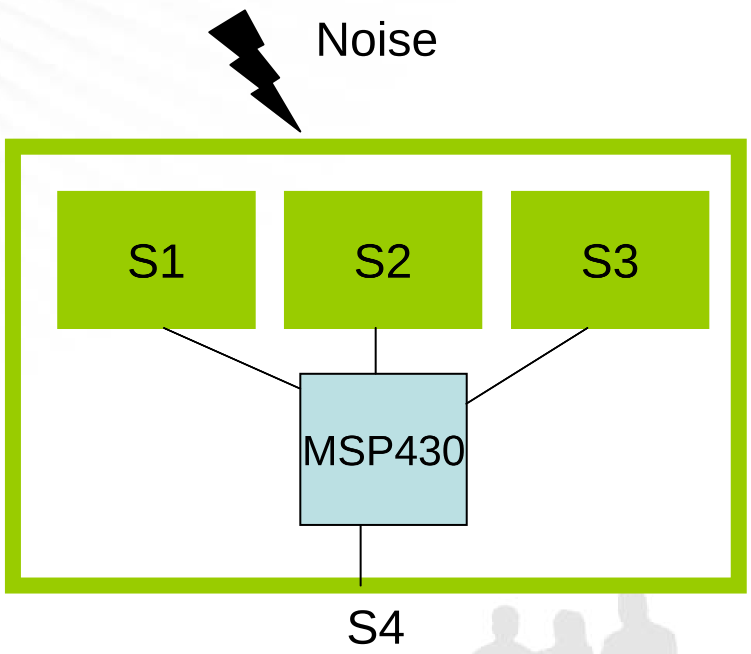


- Software low pass filter



Noise Detect Layout

- In some applications, you can add a “layout” guard-ring sensor, to detect and software remove-able the back or front side noise.



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Touch Sensor care about

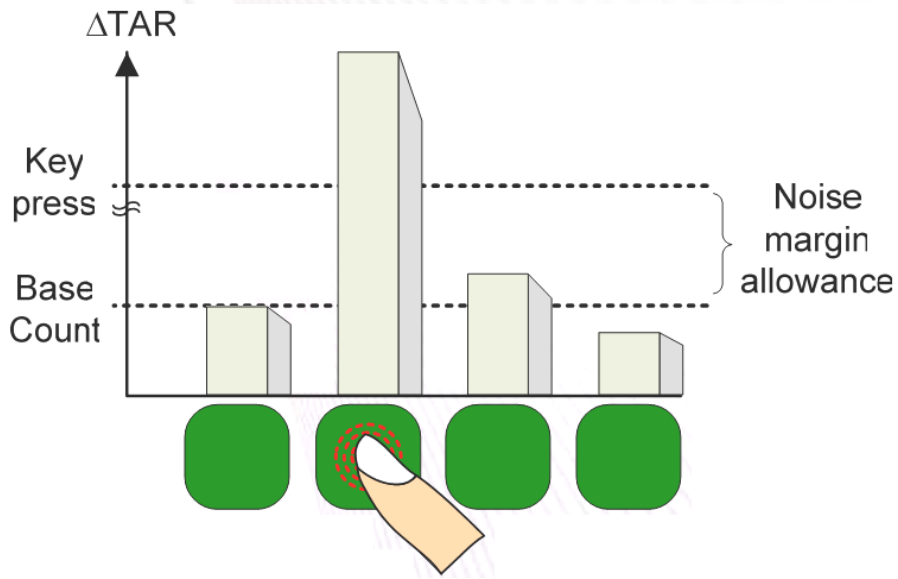
- What is the application:
  - A switch replacement?
  - Position detection? (e.g. slider)
- Threshold: Establish a "usable" limit
  - Can it be reached?
  - Enough noise margin?
  - Tolerant to manufacturing changes?
- Filtering: Noise coupling
  - Given large R in RC method, noise can easily couple in
  - Multi-result averaging: RC charge/discharge method
- Tracking: Baseline capacitance can shift
  - Periodically adjust base capacitance count set-point
  - Take care to exclude a "Touched" sensor result from any tracking algorithm

Tracking C Base

- **C_base measurement result can change over time**
  - Humidity effects
  - Temperature
  - Component tolerances
  - Voltage drift
- **Failure to track this change adequately can result in false key events or inability to detect events**
- **Algorithm basics:**
  - Adjust for a decreasing C rapidly, e.g. on each measurement, since this is not a function of sensor excitation
  - Adjust for increasing C very slowly as this may be due to a finger hovering over a key, not just C_base drift
  - Exclude an increasing C adjustment when any keys are pressed as it may be caused by the user, not C_base drift

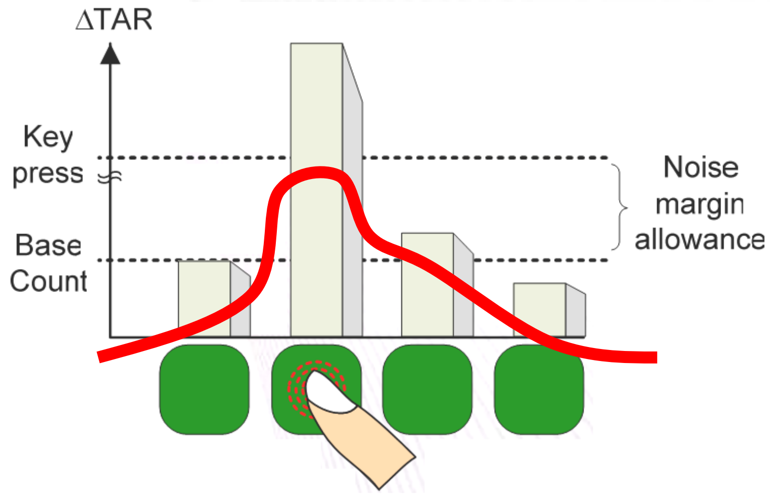
Key Press Detection

- Measurement Flow
  - Step 1: Establish a base count measurement
  - Step 2: Set a key press count threshold
  - Step 3: Scan keys
- Set detection threshold ~50% of maximum count delta expected from the given implementation



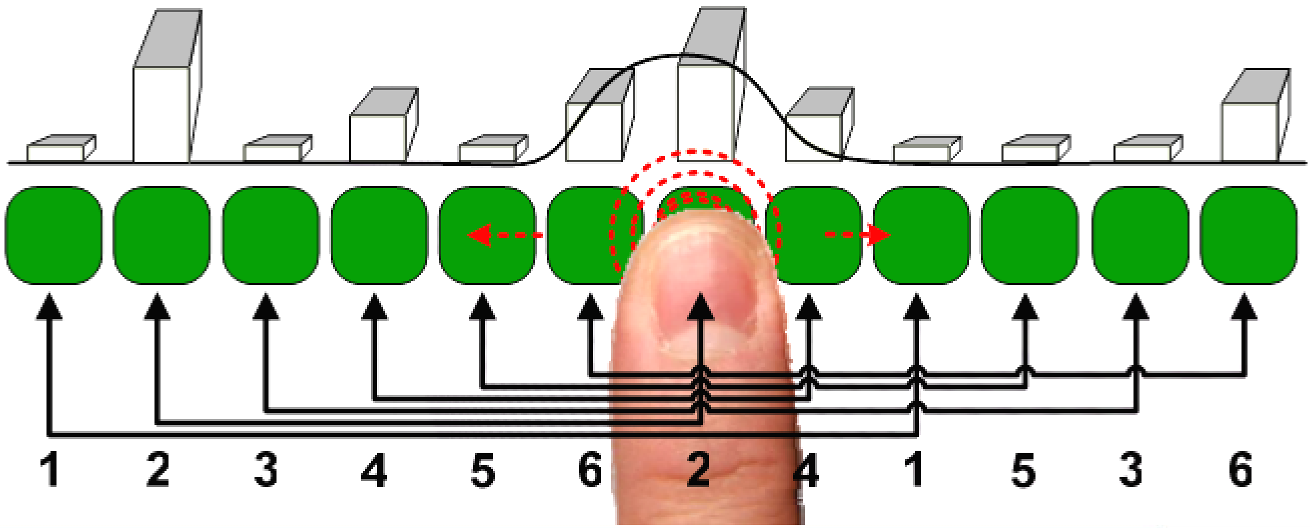
Slider Scan Method

- Measurement Flow
  - Step 1: Establish a base count measurement
  - Step 2: Set a key press count threshold
  - Step 3: Scan keys
  - Step 4: Calculate position based on counts for each key
- Apply linear weighting algorithm
- Filter noise counts for jitter-free operation



Multiplex Sliders

- Multiplex sensors for better pin: sensor ratio
  - Increases base capacitance
  - Measured delta C will be lower
- Mux for unique pattern for each position
- Multiple sensors should be excited for proper location & direction detection



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Summary

- Capacitive touch sensing can be an attractive option
  - ..for existing switch replacement
  - .. and more: potentiometer replacement, multi-position switches
- MSP430 RC Method
  - Can be implemented on any MSP430
  - Up to 16 independent sensors (16 interruptible GPIOs)
  - Single external R per two sensors Sensitivity limited by on-chip max clock frequency, fixed measurement time
  - Lowest power implementation

Thanks!

Reference Data:

1)MSP430 ATC2006,Enabling Capacitive Touch Sensing with MSP430

2) http://en.wikipedia.org/wiki/Capacitive

3) Value Provider International Corp. Cap Sensing EVM.

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