AUTOMOTIVE TOUCH SENSE SOLUTION

DECEMBER 2019

- Introduction
- NXP Touch Sense Solution
- Hand-on:S32K144 multi-pad keypad solution with slider
- Conclusion

Introduction

- Motivation & Opportunities
- Touch keyboard design
- Touch Sense MCU
- Measuring electrode capacitance

Where Can Touch Sense Wins?

- Keyboards:
  - S32K, S12ZVL
- Steering wheel “Hands OFF detection”:
  - S32K
- Automotive Door Handle:
  - S12ZVL

Picture source: www.audi.com

Anything Special Where Can Touch Sense Wins?

- Mechatronics & Control in single unit

- Panoramatic sun roof

Picture source: www.google.com

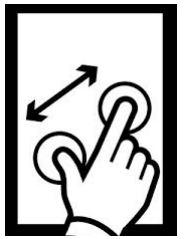
Current GPIS Touch Sense Solution Focus Application

What we focus on:

- Mechanical button replacement
- Single-point Touch (self-capacitance)
- Typical applications:
  - Steering switches & hands-off detection
  - Seat control
  - Interior light
  - Door handle
  - Buttons, switches, knobs, sliders

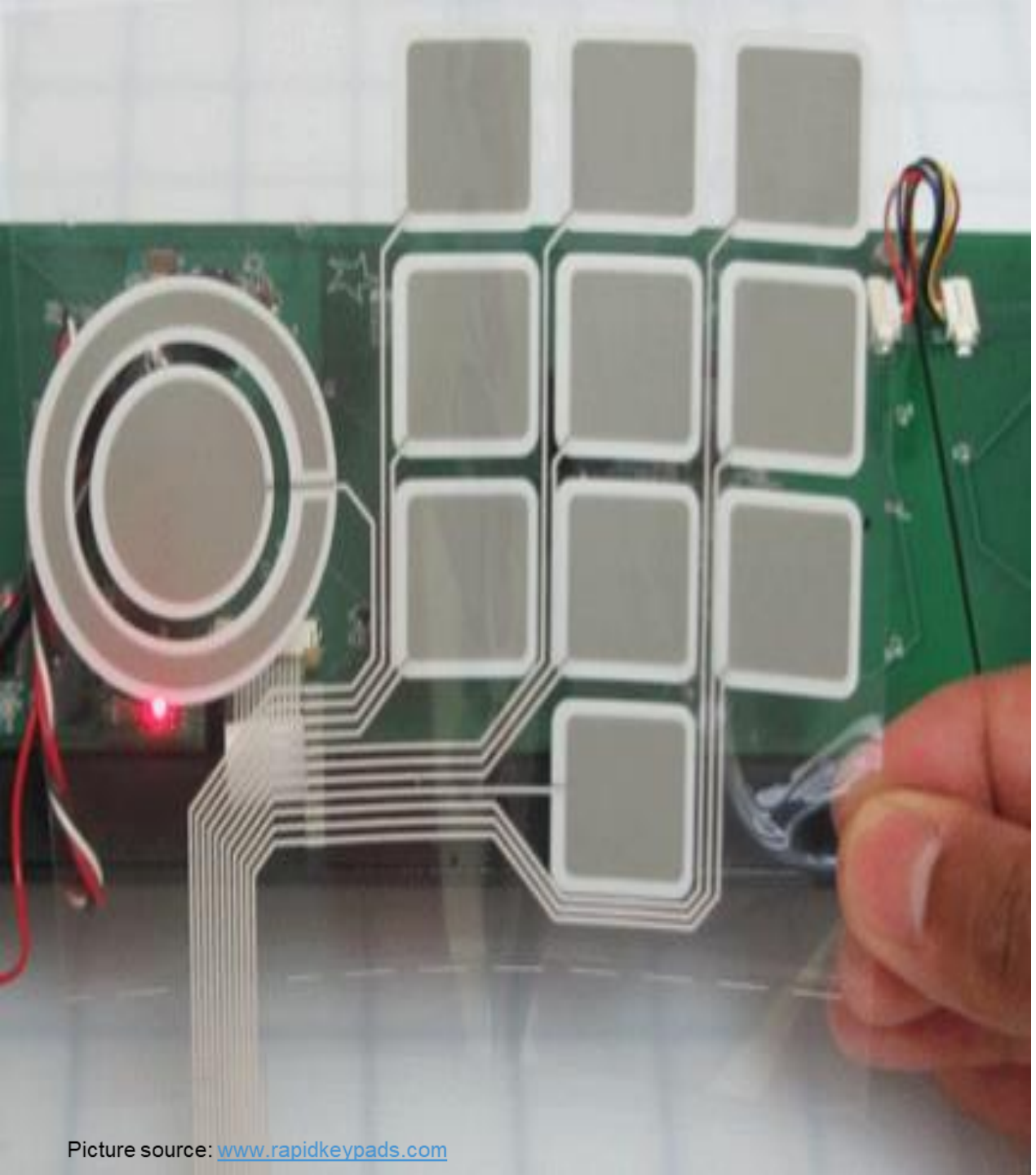
What we NOT focus on:

- Multi-point Touch (e.g. pinch and zoom)
- Mutual capacitance
- Gesture detect
- Haptic feedback
- Touch screen & display



TOUCH KEYBOARD DESIGN

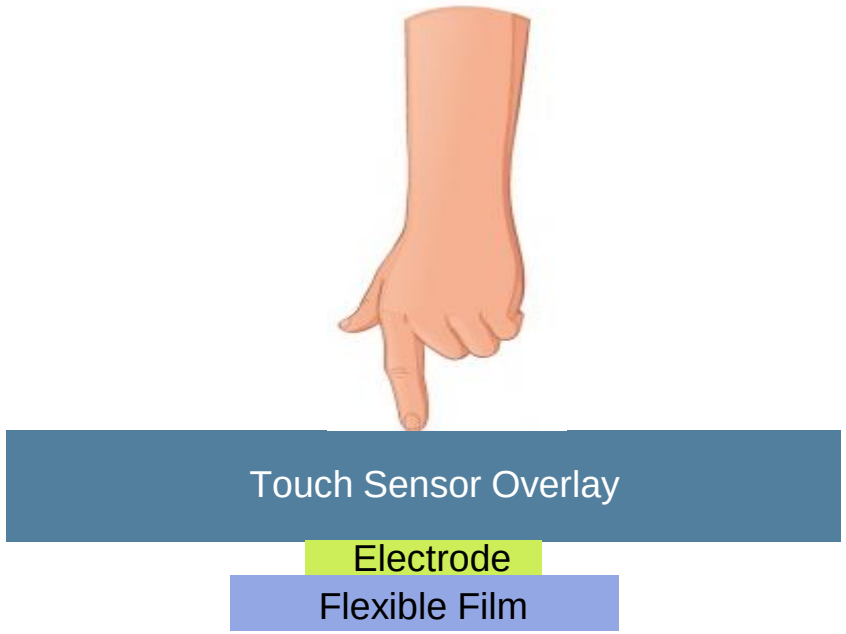
Touch Sensor Design

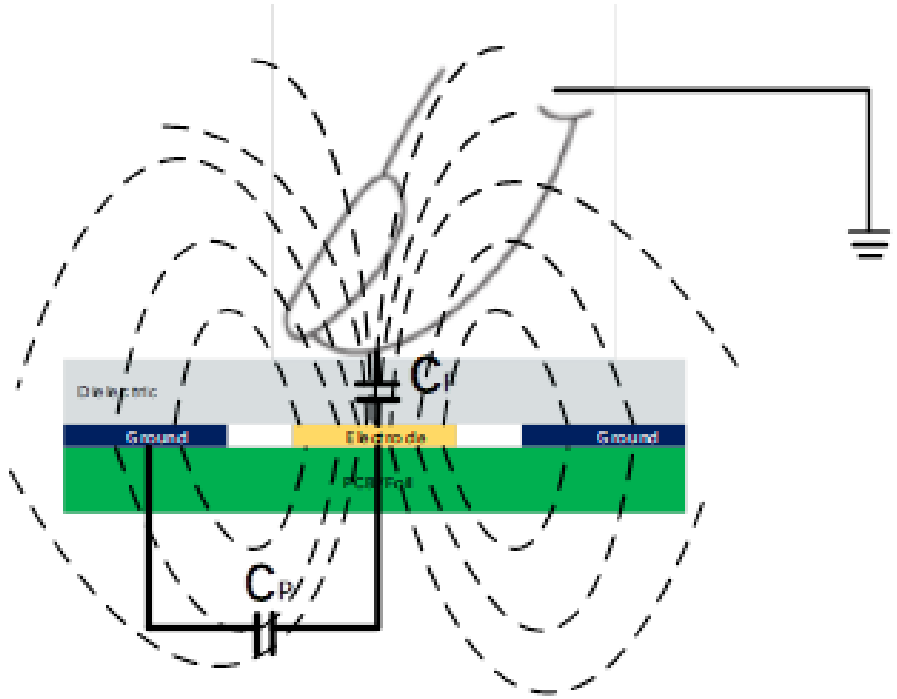


Picture source: www.rapidkeypads.com

- Flexible film with printed touch sensor pads
- Overlay material glass, wood, plastic of various thickness

Touch Keyboard In Detail





- Measure electrode self-capacitance change

- When touching keyboard plastic cover, the electrode capacitance increases by:
  - Typ. 2%
  - Equals to roughly 0.1pF

$$C_F = \frac{\varepsilon_0 \varepsilon_r A}{D}$$

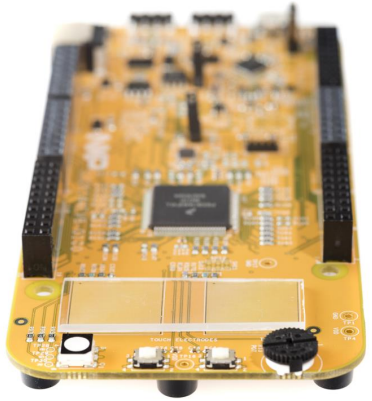
Picture source: www.freepik.com

TOUCH SENSE MCU

Goal

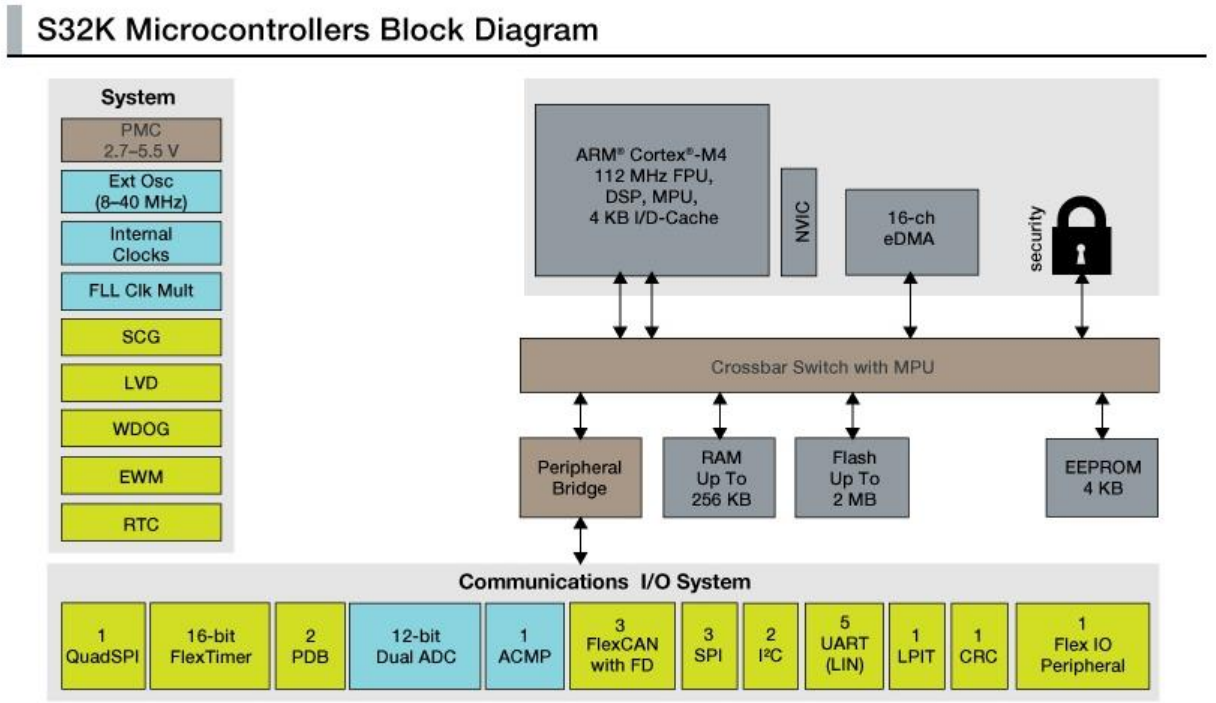
- **Enable general purpose S32K and S12ZVL MCUs for touch sense application:**
  - Developed electrode sensing method

- **Using NXP tool chain**:
  - S32K144EVB Q100
  - S32DS
  - FreeMASTER



Why is S32K Good Fit?

- 32Bit
- Scalable family
- Safety (ASIL B)
- Security
- Connectivity



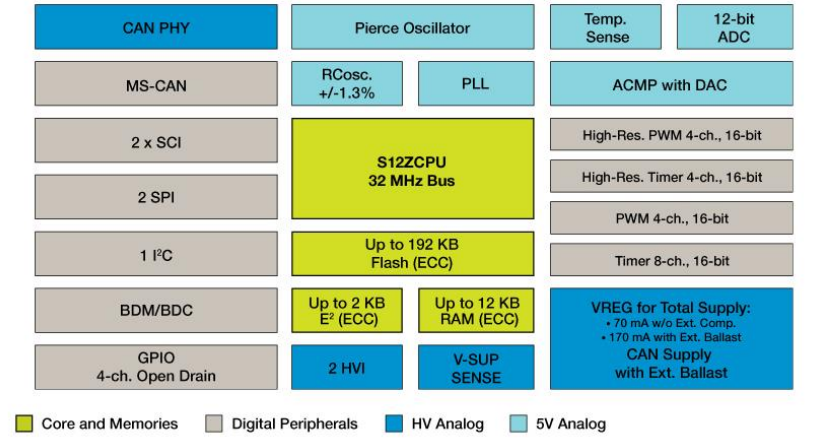
- Medium and large keypads (up to 50 electrodes)
- Steering wheel hands OFF detection (HOD)

Why is S12ZVL and S12ZVC Good Fit?

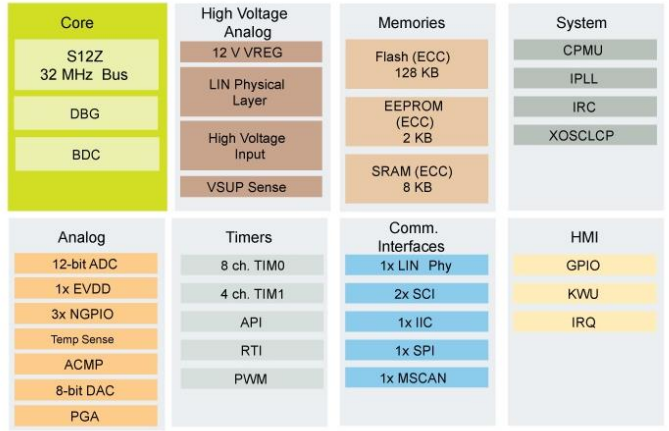
- 16Bit
- Scalable family
- Connectivity
- System in Package

S12 MagniV Mixed-Signal MCU for CAN Applications Block Diagram Close

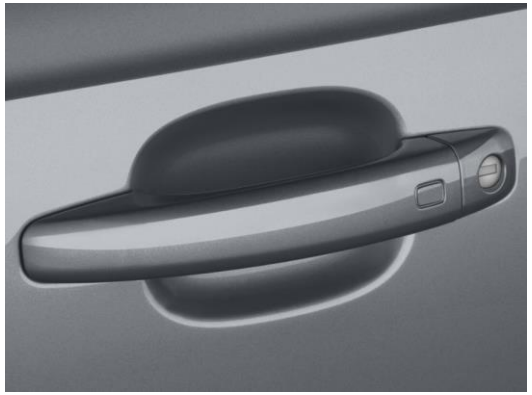
S12ZVC Family Block Diagram



S12 MAGNIV MIXED-SIGNAL MCU FOR LIN APPLICATIONS BLOCK DIAGRAM Close



- Small keypads
- Door handle



MEASURING ELECTRODE CAPACITANCE

Method

- **Developed for general purpose MCUs**

- **What it does?**
  - Converting electrode capacitance to voltage
  - ADC samples voltage

- **Legal:**
  - NXP patent US9823798B2

(12) **United States Patent**
Cholasta

(10) **Patent No.: US 9,823,798 B2**
(45) **Date of Patent: Nov. 21, 2017**

(54) **CAPACITIVE SENSOR DEVICE AND METHOD OF OPERATION**

(71) Applicant: **FREESCALE SEMICONDUCTOR, INC.**, Austin, TX (US)

(72) Inventor: **Petr Cholasta**, Hutisko-Solanec (CZ)

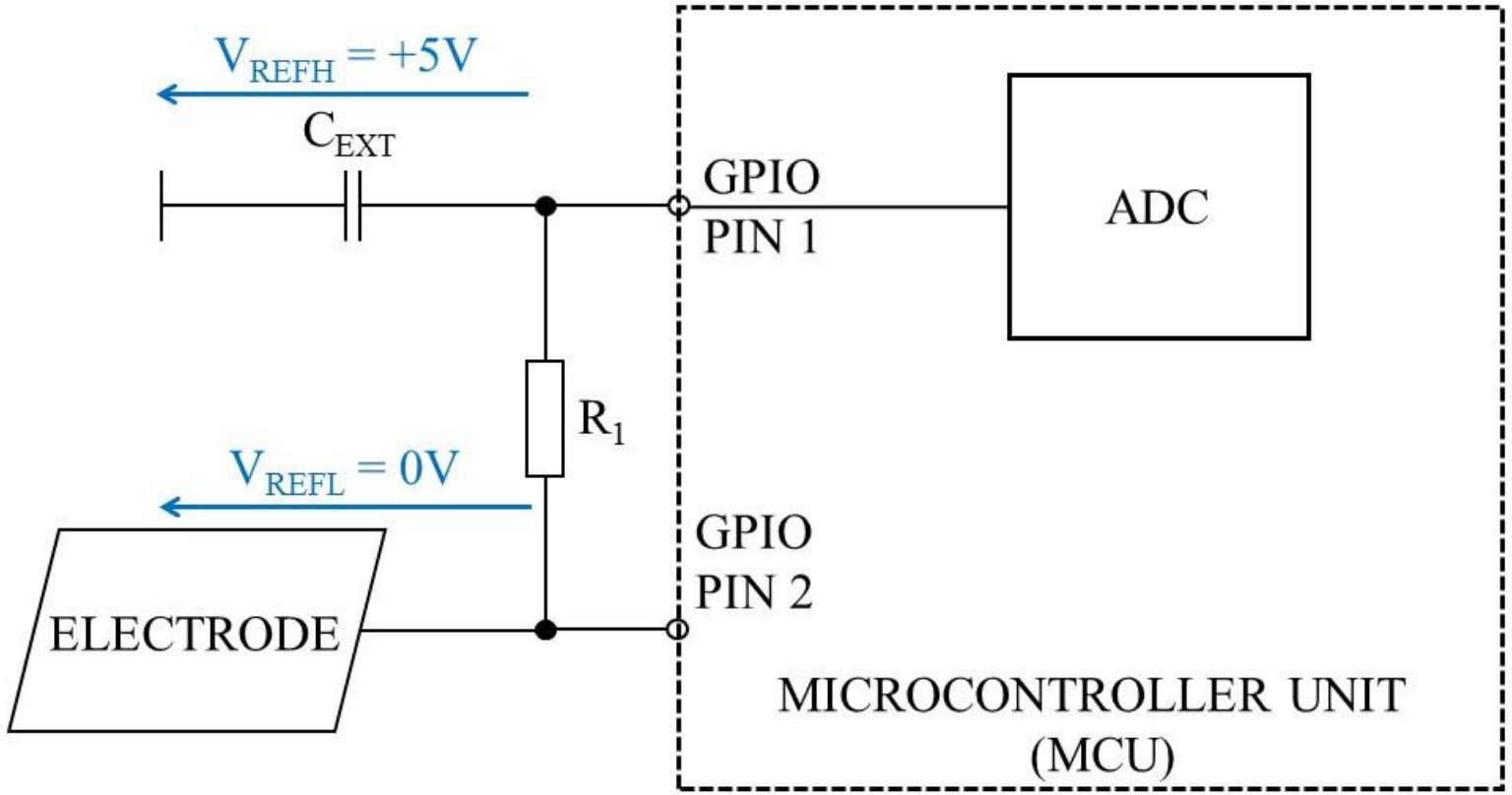
(73) Assignee: **NXP USA, Inc.**, Austin, TX (US)

(56) **References Cited**

U.S. PATENT DOCUMENTS

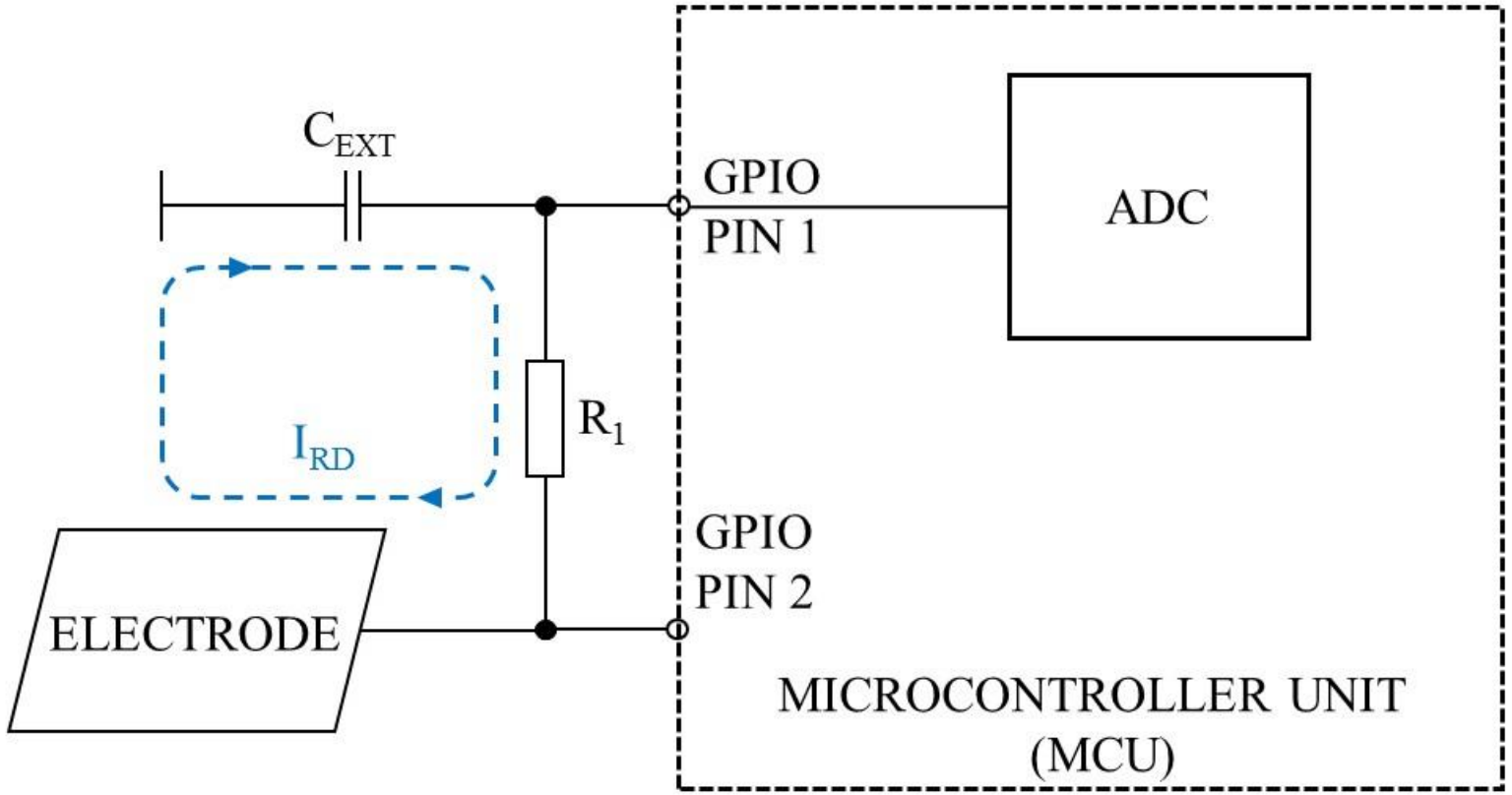
2009/0224776	A1*	9/2009	Keith	H03K 17/962 324/686
2010/0181180	A1	7/2010	Peter	
2011/0073383	A1*	3/2011	Simmons	H03K 17/962 178/18.06
2013/0088377	A1*	4/2013	Lundstrum	H03M 1/1245 341/172

Step 1 – Charge Distribution



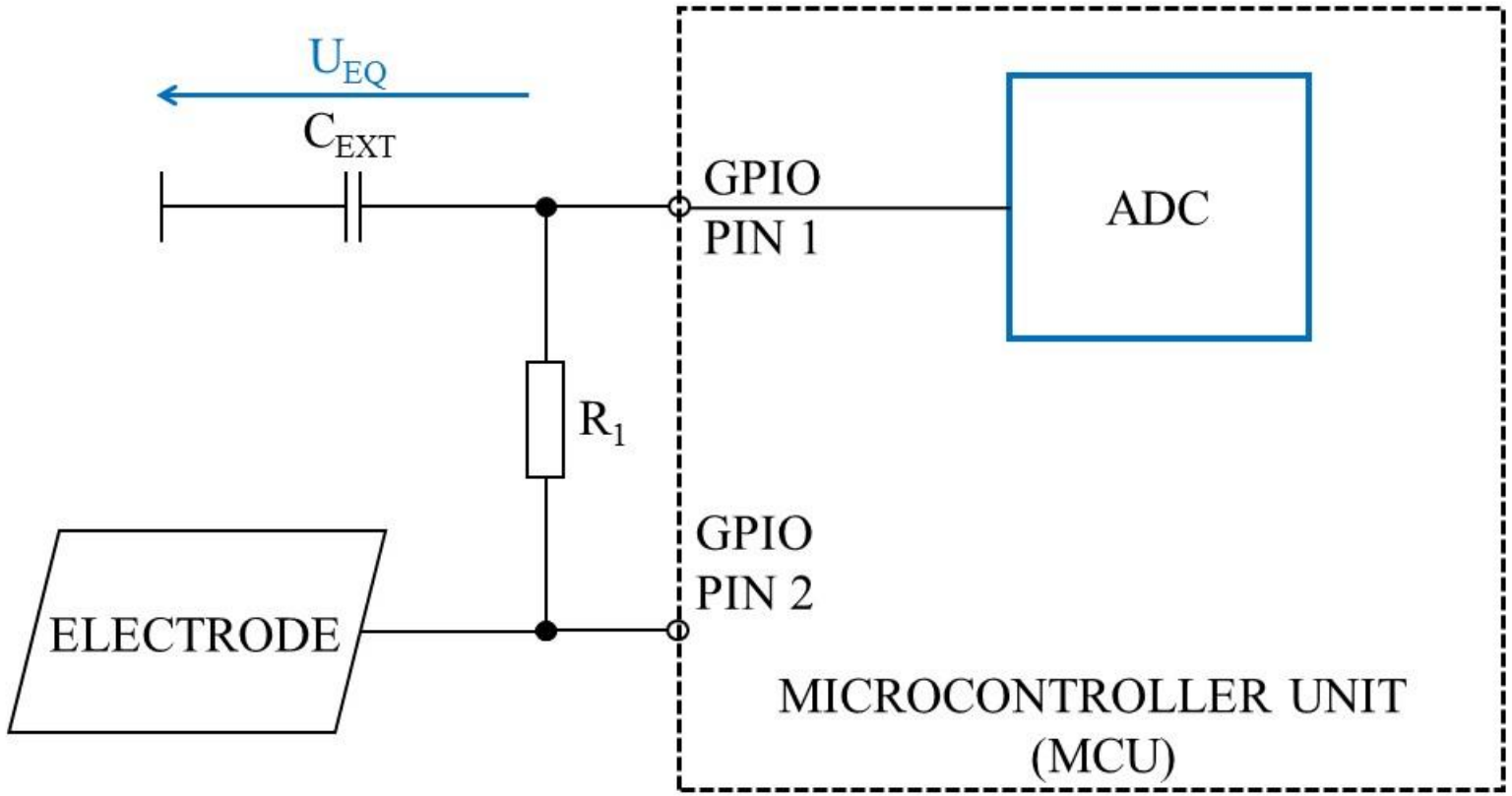
- GPIO PIN 1:
  - Output
  - Driving ADC V_{REFH}
  - Typically +5V
- GPIO PIN 2:
  - Output
  - Driving ADC V_{REFL}
  - Typically 0V
- GPIO PIN 1 and PIN2 share the same MCU port

Step 2 – Charge Redistribution



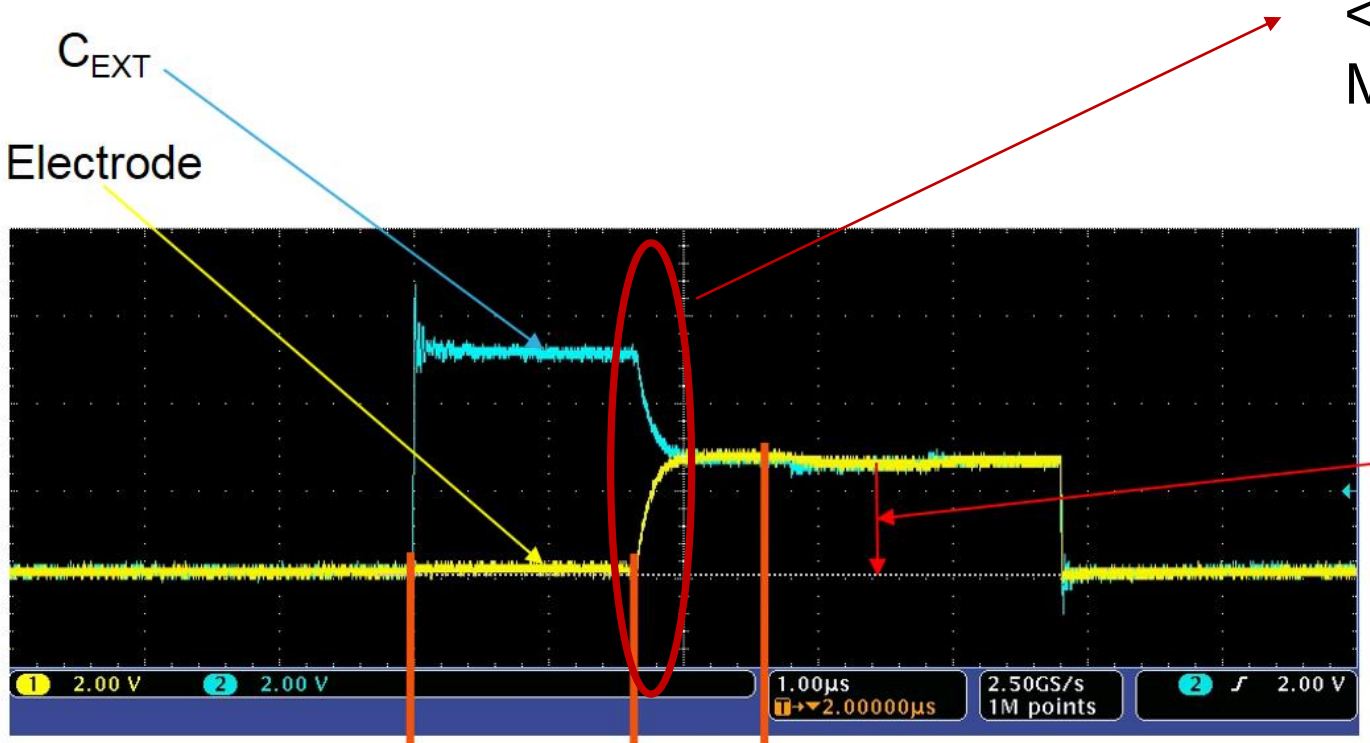
- GPIO PIN 1:
  - Input
  - ADC input
- GPIO PIN 2:
  - Input
  - GPIO input

Step 3 – Equivalent Voltage Digitalization

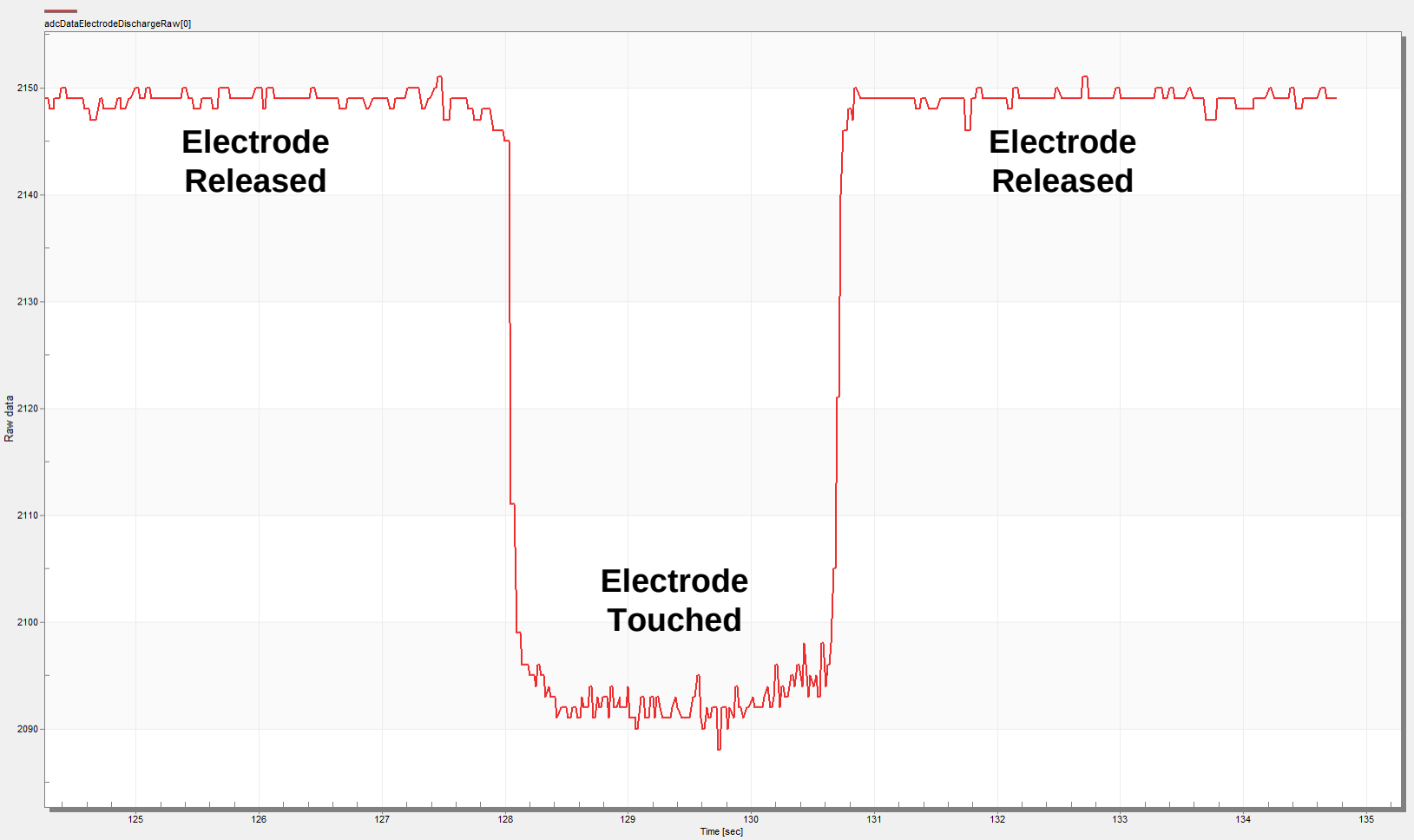


- U_{EQ} ADC conversion

Electrode an C_{EXT} Signal Shapes

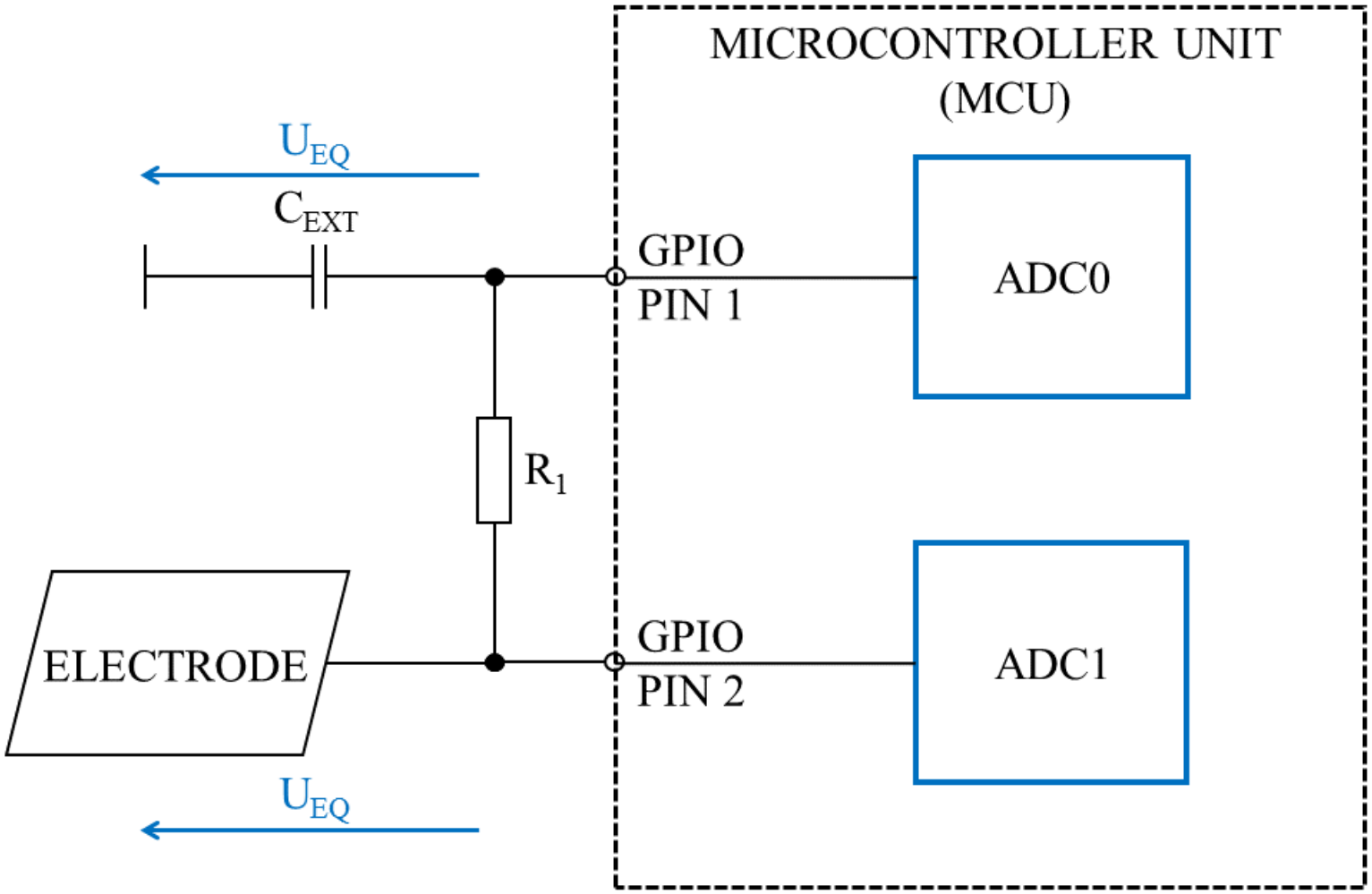


Touching the Electrode



- Repeating periodically typ. 30ms
- Touch and release voltage difference equals 60mV

Do You Need a Redundancy?



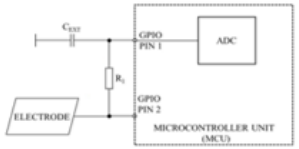
- U_{EQ} ADC0 and ADC1 conversion
- 2x independent conversion results
- Cext can be replaced by trace
- GPIO PIN 1 and PIN2 share the same MCU port(MCU Pins Configuration Tool)

MCU Pins Configuration Tool

MCU			DEBUG, POWER SUPPLY, COMMUNICATION								ELECTRODES	
Select MCU	Select Package	CONFIRM MCU	Debug interface	SBC	SPI module	LIN	LIN module	CAN	CAN module	CONFIRM	Select port	No.of electrodes
S32K144	LQFP-100		SWD	Yes	SPI0	1 LIN		1 CAN			PTA	8
		UNLOCK MCU	Occupied pins:		Occupied pins:	Occupied pins:	LPUART0	Occupied pins:	CAN0	RESET		SORT BY PORT
		CLEAR ALL	~~No.: 96 - PTC4~~		~~No.: 21 - PTD16~~	~~No.: 29 - PTC3~~	LPUART1	~~No.: 8 - PTE5~~	CAN1	DEFAULT		PAIR THE PINS
			~~No.: 98 - PTA4~~		~~No.: 22 - PTD15~~	~~No.: 30 - PTC2~~	LPUART2	~~No.: 9 - PTE4~~	CAN2			
					~~No.: 27 - PTB5~~							
					~~No.: 28 - PTB4~~							

Quick User guide

1. Select MCU, package, debug interface etc. – just follow the green lighted box or button!
2. Each touch sense electrode requires a pair of pins, both with GPIO functionality and one with ADC functionality.In addition, both pins must share a common port.



3. For the number of available electrodes in your configuration, please refer to cell "M3". For port-specific number of electrodes please select port. Use *Sort by port* or *pair the pins* buttons at your will.
4. Happy pin pairing. :-)

REMAINING Pins for Pin1-ADC functionality

Pin Number	Pin Name	DEFAULT	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7

REMAINING Pins for Pin2-GPIO functionality

Pin Number	Pin Name	DEFAULT	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7

PAIRED Pins, each pair = one electrode(touch sense pad)

Pin Number	Pin Name	DEFAULT	ALT0	ALT1	ALT2	ALT3	ALT4	ALT5	ALT6	ALT7
57	PTA7	ADC0_SE3	ADC0_SE3	PTA7	FTM0_FLT2		RTC_CLKIN		LPUART1_RTS	
62	PTA17	DISABLED		PTA17	FTM0_CH6	FTM3_FLT0	EWM_OUT_b			
58	PTA6	ADC0_SE2	ADC0_SE2	PTA6	FTM0_FLT1	LPSPI1_PCS1			LPUART1_CTS	
88	PTA14	DISABLED		PTA14	FTM0_FLT0	FTM3_FLT1	EWM_IN		FTM1_FLT0	
72	PTA3	ADC1_SE1	ADC1_SE1	PTA3	FTM3_CH1	LPI2C0_SCL	EWM_IN	FXIO_D5	LPUART0_TX	
89	PTA13	DISABLED		PTA13	FTM1_CH7	CAN1_TX			FTM2_QD_PHA	
73	PTA2	ADC1_SE0	ADC1_SE0	PTA2	FTM3_CH0	LPI2C0_SDA	EWM_OUT_b	FXIO_D4	LPUART0_RX	
90	PTA12	DISABLED		PTA12	FTM1_CH6	CAN1_RX			FTM2_QD_PHB	
78	PTA1	ADC0_SE1/CMP0	ADC0_SE1/CMP0	PTA1	FTM1_CH1	LPI2C0_SDAS	FXIO_D3	FTM1_QD_PHA	LPUART0_RTS	TRGMUX_OUT0
91	PTA11	DISABLED		PTA11	FTM1_CH5		FXIO_D1	CMP0_RRT		
79	PTA0	ADC0_SE0/CMP0	ADC0_SE0/CMP0	PTA0	FTM2_CH1	LPI2C0_SCLS	FXIO_D2	FTM2_QD_PHA	LPUART0_CTS	TRGMUX_OUT3
92	PTA10	JTAG_TDO/noetm_TRACE_SWO		PTA10	FTM1_CH4		FXIO_D0			JTAG_TDO/noetm_TRACE_SWO
82	PTA16	ADC1_SE13	ADC1_SE13	PTA16	FTM1_CH3	LPSPI1_PCS2				
99	PTA9	DISABLED		PTA9	LPUART2_TX	LPSPI2_PCS0	FXIO_D7	FTM3_FLT2	FTM1_FLT3	
83	PTA15	ADC1_SE12	ADC1_SE12	PTA15	FTM1_CH2	LPSPI0_PCS3	LPSPI2_PCS3			
100	PTA8	DISABLED		PTA8	LPUART2_RX	LPSPI2_SOUT	FXIO_D6	FTM3_FLT3		

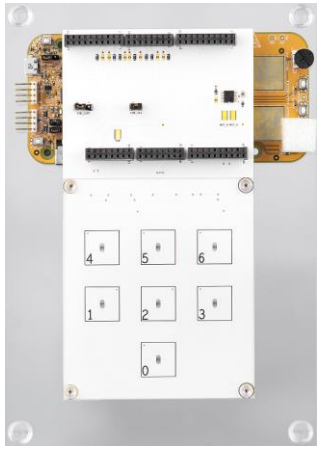
NXP Touch Sense Solution

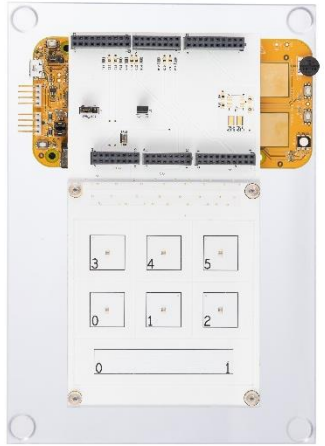
- Demo board & features
- Low power consideration
- Touch Sense MCU
- Measuring electrode capacitance

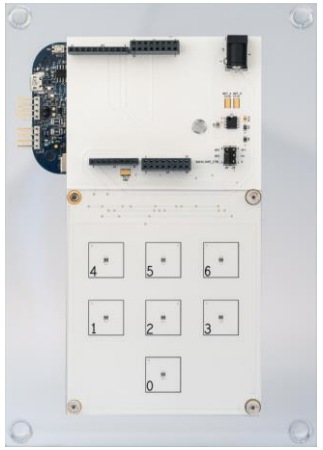
Demos

- S32K144EVB Q100 2pad solution
  - Small keypad solution

- S32K144 & S12ZVLA128 multi-pad keypad
  - Medium and Large keypad solution w/o slider







- S32K144 steering wheel hands OFF detection

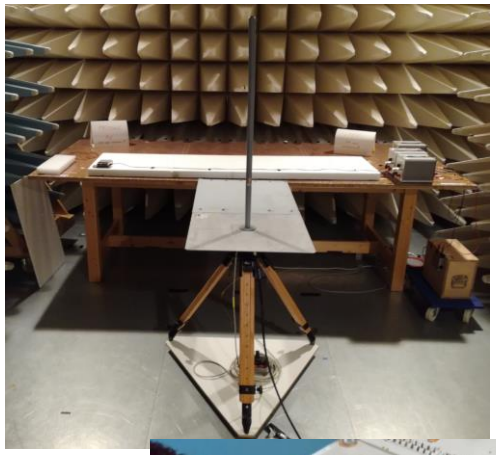
1. Sensitivity tuned for 2mm plastic glass overlay on a top of the electrodes （3mm available）
2. haptic feedback H-bridge driver is placed at the top right PCB corner
3. the SH circuit brake can be used to disconnect the PCB keyboard and connect the custom board
4. Proximity can achieve 10cm

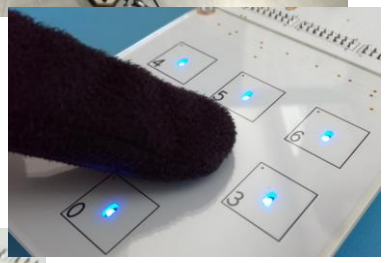
- MCU average current consumption vs. reaction time:
  1. **S32K1 70uA / 90ms (EGS used)**
  2. **S12ZVL 220uA / 120ms(EGS used)**
- Flash Usage :
  1. **S32K1:20kB**
  2. **S12ZVL: 8kB**

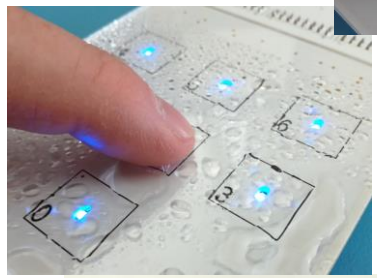
参考设计	是否使能 EGS	功耗情况(uA)
7pad keypad	ON	65
	OFF	126
6pad keypad with slider	ON	68
	OFF	170
2pad EVB	OFF	62

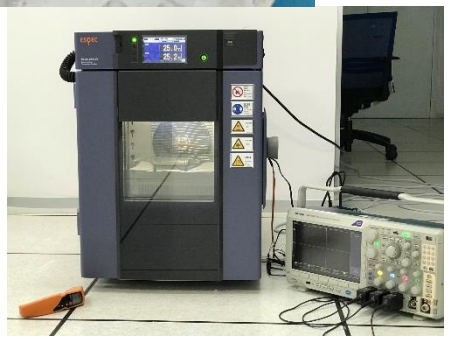
Test Summary

- EMC, EMI, ESD tests follow Jaguar-Landrover standards:
  - EMC: RE310 (CISPR 25, ed 3 based)
  - EMI: RI112 (ISO 11452-4 based), RI114 (ISO 11452-2 based) and RI115 (ISO 11452-9 based), Florescent lamp, Mobile phone in-call
  - ESD: CI280 (ISO 10605 based)
- Gloves test with plastic, rubber and winter gloves
- Water test with drops and spray
- Temperature test range from -40°C to +105°C







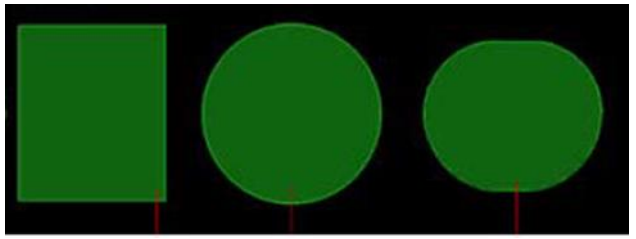


MEDIUM AND LARGE KEYPADS SOLUTION

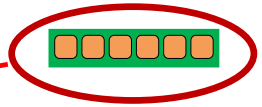
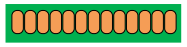
HARDWARE DESIGN

The design of pad

- Key
  - Random
  - The size of key is recommended that not lower than 0.8cm×0.8cm，Normal is 1.5x1.5
  - The distance of 2 key is almost 2~3 times than the height of overlay (The mutual touch is not in the solution, If you want to use 2keys to detect 1 event . The FreeMASTER can be the good tool.



➢ Slider

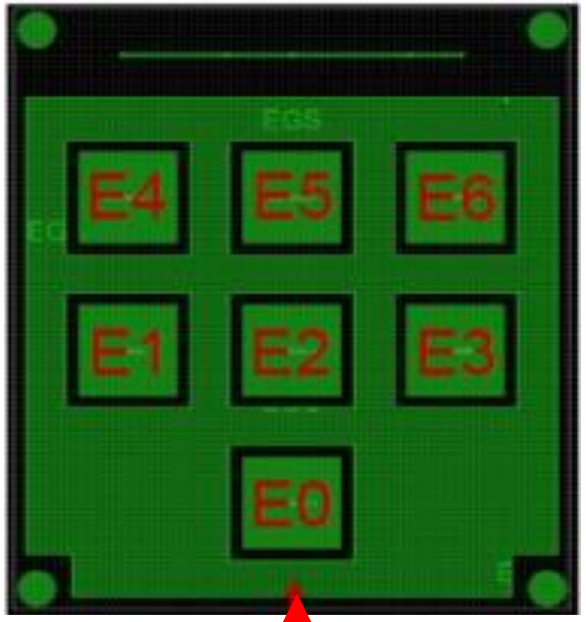
构造方式	样式	常用场景	布局注意	描述	缺点
数个按键电极		低分辨率	与单独按键一致		大多数情况触摸发生在单一按键，位置变化只能在两个按键电极之间被检测
数个小尺寸按键电极		较高分辨率	1)减小单一按键宽度（约为长度的一半） 2)按键间间距 0.25mm~1mm	同一时间有两个或三个按键被按下可线性检测手指滑动	滑条较长时需要的按键数也较多，可能会有按键检测延迟
军徽章		较低分辨率	两个电极间距大于 1.3mm 则与数个按键电极相似但位置变化检测相较于后者线性度更高	线性度介于第一种与第二种之间	位置检测的灵敏度相较于第二种较差，但所需按键电极更少
人形		1)电极自身灵敏度较好 2)较高分辨率	1）同一时间触控能确保至少有两个电极被同时触摸 2）按键间间距 0.25mm~1mm 1）较短滑条只需两个按键电极，较大滑条可适当增加电极	具有较高的灵敏度	滑条过大会导致基础电容过大，单个按键检测灵敏度受影响
楔形		1)高分辨率 2)硬件资源受限	2）按键间间距 0.25mm~1mm，若滑条过长间距加大到 0.5mm~1.5mm，转角直径 2mm（可降低对 ESD 的敏感） 3）交错长度 8mm~60mm，宽度方向单个区域为 12mm	若不考虑 EMI 灵敏度非常高，通过软件进行区域划分	EMI 与软件区域划分相关

HAVC

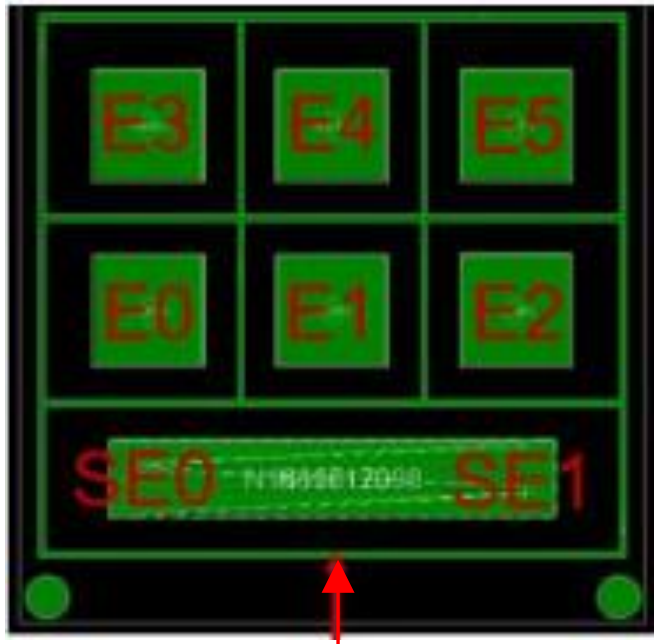
Demo

➢ Proximity electrode

- The distance of proximity is the same as the diagonal of it without filter



接触感应电极



接触感应电极

Hardware Checklist

a. 1 key need 2 pins & 2 pins must be shared the same port(Use the configuration tools supported by NXP)

b. The external resistor and capacity is needed on the protype. The recommend value is 4.7kohm and 4.7pf, The range of resistor is from 1k -10k, The range of capacity is from 1pf -10pf(VDDA/2 for the reference). C0g or np0 is enough.

c. Distance between 2 pad is 2-3 times than overlay height (FreeMASTER needed)

d. The width is limited in 5-7mil and 5mil is better.

e. For the clearance. Pls leave the minimal of 10mil (much more is better) between 2 parallel traces. But the end of sensor. The bottleneck mode connection is needed.

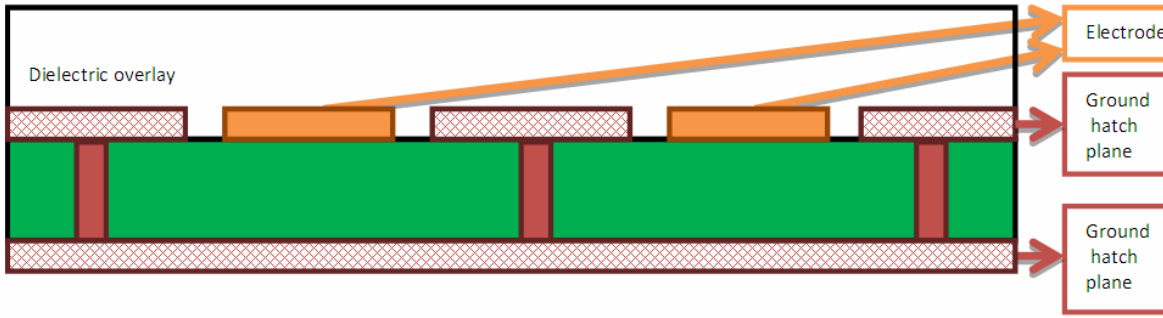
f. Component/traces must not near and opposite to the touch pad

g. surface mount is recommended and through hold is not

h. LEDs &LCDs should be reverse mounted. Drills a hole on the pad and let light transfer.

i. For two room placement The sensing circuitry room must avoid parasitic capacitance.

Hardware Checklist



j. Do not use filled ground planes underneath electrodes area, In case a ground plane is needed, make sure it is not filled

k. Use X-hatch pattern underneath the electrodes area and The X-hatch pattern recommended is round 20%, which defines the line width as minimum as possible with the line spacing proximate to 50 mils.

l. When there is enough space between electrodes it is recommended to also include a grounded hatch between the electrodes.(additional noisy mask)

m. Make sure no signals that are not touch sensing run parallel to the touch sensing signals. If signals need to go through the touch sensing traces, have them go in a different layer and perpendicular. Make sure to fill in ground between groups of traces (analog, digital, and touch), if possible, fill in ground between touch sensing traces.

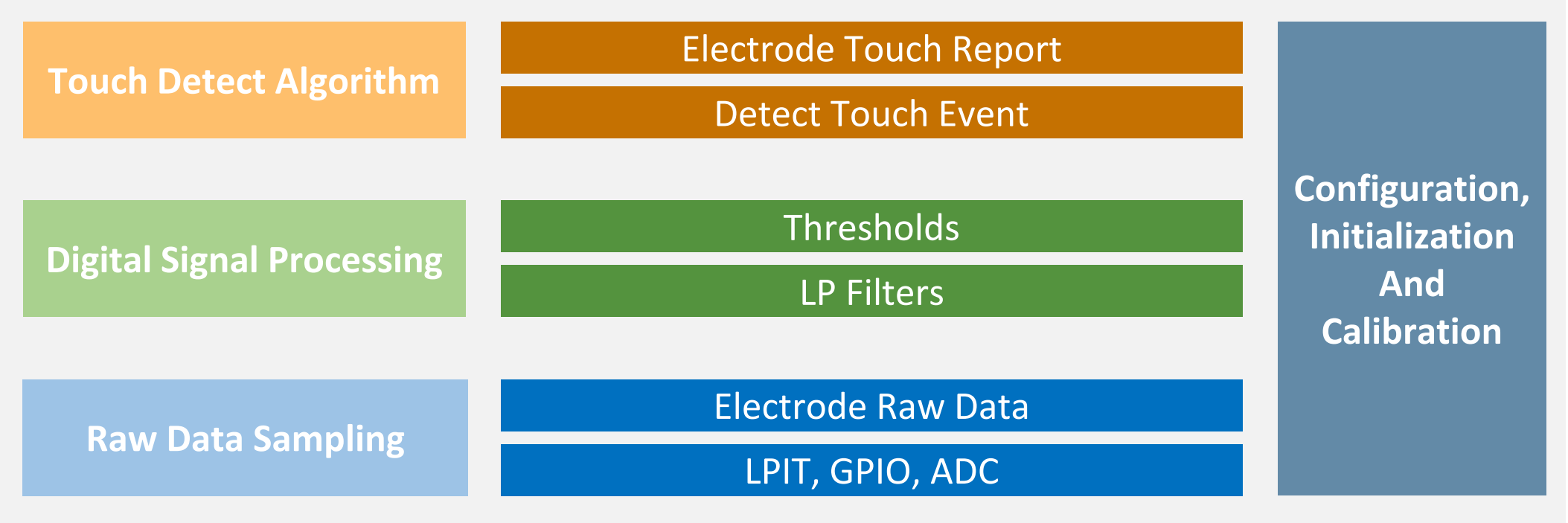
n. Short traces (< 5 in. from electrode to MCU, ideally < 2 in.)

o. Overlay material is not conductor. If you want accurate resolution. Conductive rubber is recommended.

SOFTWARE

- LAYERING
- ALGORITHMS

Software Layers



Raw Data Sampling

- Task:
  - Deliver electrode raw data:
    - Converting electrode capacitance to equivalent voltage
    - Equivalent voltage sampled by ADC
  - Build an application EMI:
    - Electrode repetitive sampling
    - Averaging

- Deliverable:
  - Electrode raw data (electrode capacitance converted to digital value)
  - Electrode raw data available for custom operation

Digital Signal Processing

- Task:
  - Enhance EMI (improve electrode signal S/N ratio):
    - Filter the electrode raw data by LP filter
  - Build immunity to electrode environment change (humidity and temperature)
    - Establish system baseline using very slow LP filter
    - Set the thresholds relatively to system baseline

- Deliverable:
  - Electrode raw data with improved S/N ratio
  - Electrode touch and release thresholds with an environment compensation included

Filter

滤波器种类	处理噪声类型	参数	其他
一阶 IIR 滤波器	高频噪声		低通滤波器会降低响应时间例程中参数在感应时间 30ms 及 1Hz 截止频率条件下设置，为了确保滤波器良好的效果，小数点后至少保留 15 位
DC Tracker 滤波器	长期环境噪声	ELEC_DCTRACKER_FILTER_FACTOR_IDLE ELEC_DCTRACKER_FILTER_FACTOR_ACTIVE SLIDER_ELEC_DCTRACKER_FILTER_FACTOR_IDLE SLIDER_ELEC_DCTRACKER_FILTER_FACTOR_ACTIVE	设置参数在 1 到 8 之间，其中 8 代表最慢更新速
Jittering	周期性扫描电极导致的谐波干扰噪声	NUMBER_OF_JITTERING_BITS	此滤波器通过遮掩掉原始数据的低 2 到 8 位来计算的随机数来随机延迟采样时间。更改 JITTERING 定义来开启滤波器，JITTERING_OPTION 1 表示在进定时器中断时延迟 JITTERING_OPTION 2 表示两个极采样之间加入随机延迟
Frequency Hopping	电极感应频率噪声及其谐波噪声	ELECTRODES_SENSE_PERIOD_FH FH_DCTRACKER_FILTER_FACTOR	30ms 扫描后开启 LPIT,并在 330us 后激发对所有按键的第二次扫描，触摸必须经过周期和频率来进行确认 通过定义 FREQUENCY_HOPPING 来开启此滤波器 ELECTRODES_SENSE_PERIOD_FH 定义 LPIT 定时时间 FH_DCTRACKER_FILTER_FACTOR 能降低因为频繁进电极扫描而导致 DC Tracker 滤波器的更新速度
Decimation	脉冲噪声	DECIMATION_STEP DF_DCTRACKER_FILTER_FACTOR	此滤波器实质为用于限制脉冲干扰的低摆率限制器，可通过定义 DECIMATION_FILTER 来开启此滤波器。根据与扫描的原始数据比较后对数据进行加法 DECIMATION_STEP 处理，这需要较快的采样率，经过此滤波器处理后的数据作为低通滤波器的输入。此滤波器也会导致电极较快的感应，也会造成 DCtracker 更新的频繁，因此通过设置 DF_DCTRACKER_FILTER_FACTOR 能降低因为频繁进电极扫描而导致 DC Tracker 滤波器的更新速度

Touch Detect Algorithm

- Task:
  - Touch sense application user interface
    - Detect and report electrode touch or release
    - If more than single electrode touched, the fastest touched electrode wins

- Deliverable:
  - Electrode touch or release event report

Algorithm Flow

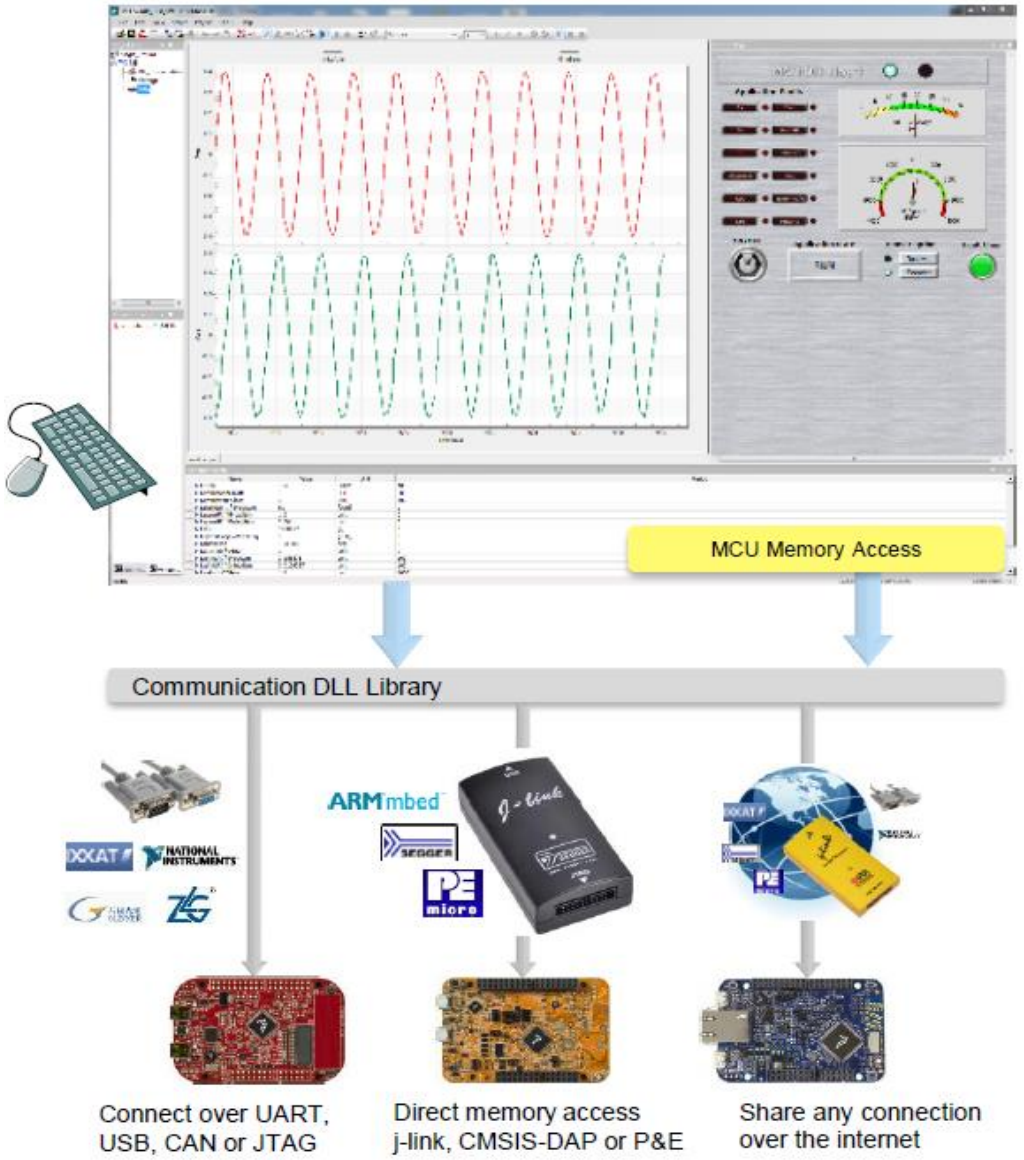
- MCU periodically wakes-up from low power mode:
  - Repeat:
    - Converting electrode capacitance to voltage
    - ADC samples voltage
  - Calculate electrode signal average value
  - Signal filtering by DC tracker (baseline) and IIR1 LP filter
  - Set electrode touch and release thresholds relative to baseline
  - Compare IIR1 signal to thresholds
  - Evaluate electrode touch or release event
  - MCU enters low power mode

Software

- FreeMASTER – application parameters tuning tool
- Electrode raw data available for custom operation
- Configurable to operate customer hardware design

FreeMASTER intro

- **What is FreeMASTER**
  - Runtime configuration & tuning tool for embedded software applications
  - Graphical Control Panel
  - Data Capture tool, interface to custom processing in Matlab, Excel etc.
- **What do we do with FreeMASTER?**
  - **Connect**: to target MCU over UART, CAN,BDM, JTAG
  - **Monitor**: Read & show variables in run-time
  - **Control**: Set variables, send commands
  - **Share**: Enable Excel, Matlab or a script engine to add hardware to the control loop



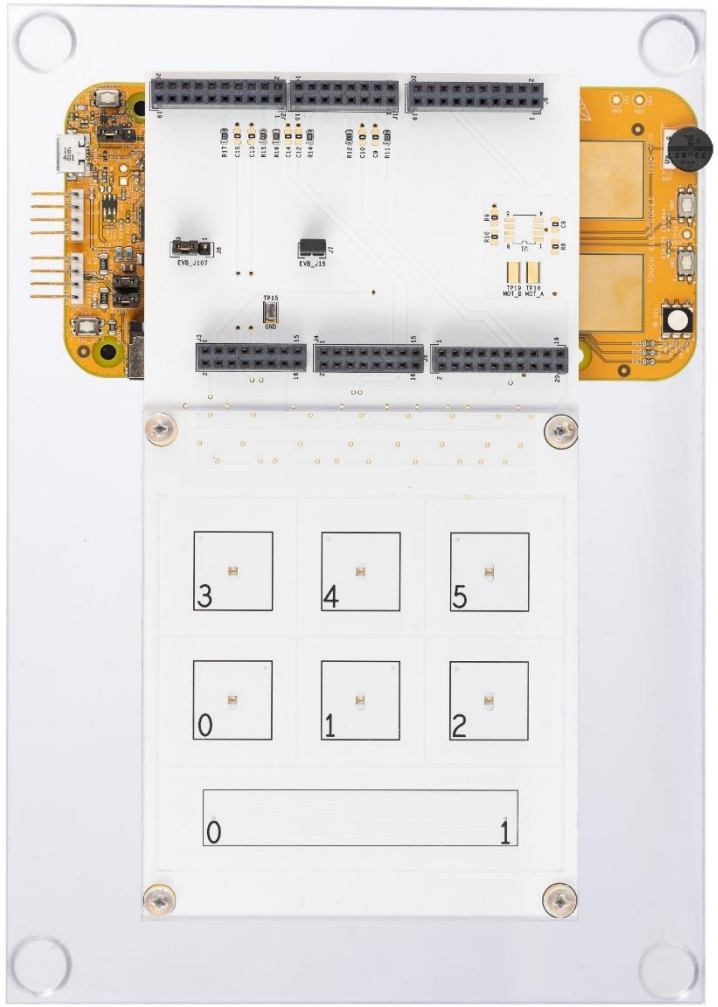
Hand-on:S32K144 multi-pad keypad solution with slider

- Introduction
- Installation and setup
- Pre-configuring the slider application
- Real-time debugging with Freemaster – slider tuning

INTRODUCTION TO THE SLIDER APPLICATION

BRIEF WALKTHROUGH

S32K144 Multi-Pad Keypad Solution with Slider: Use Case 1



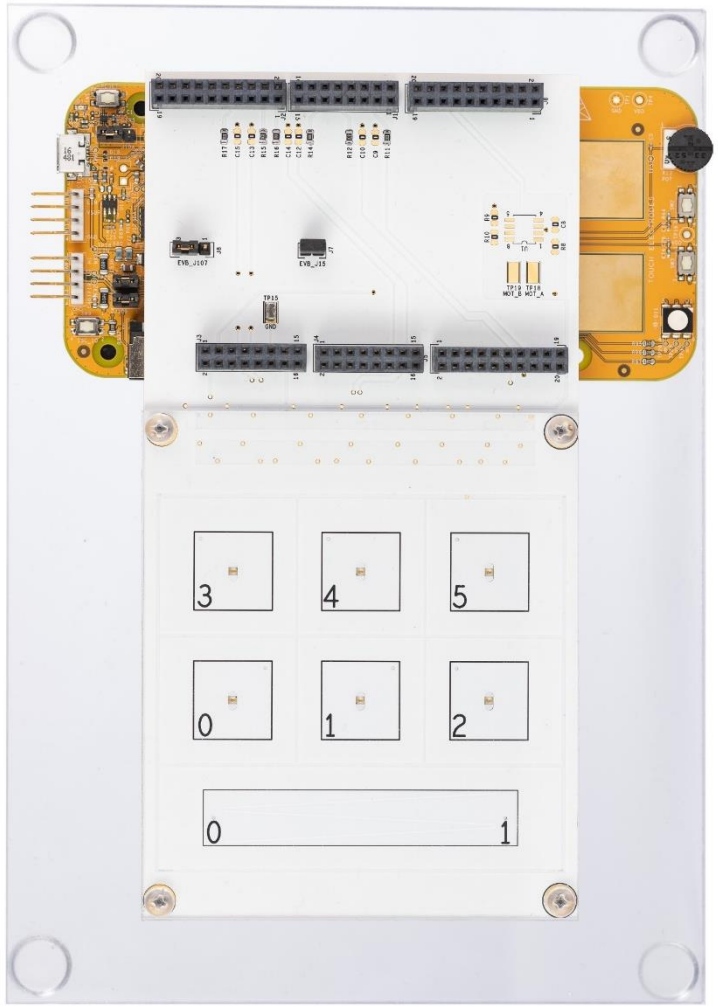
- Features:
  - 6 touch buttons with 2mm plastic overlay on electrodes
  - 5 position 60mm slider consisting of 2 electrodes with 2mm plastic overlay
  - Backlight
  - Immunity: Sustain florescent lamp ON (EMI)

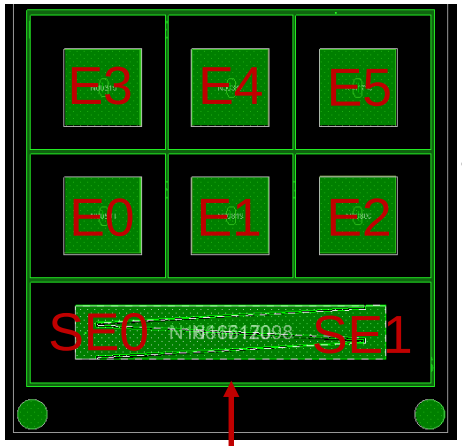
- Performance:
  - Low Power Operation: Periodically wake-up MCU (each 30ms) by on-chip timer to sense electrodes and process data to detect touch or release events
  - Response time 30ms / Reaction time 90ms
  - MCU 160uA average current consumption, when searching touched electrode (E0, E1, E2, E3, E4, E5, SE0, SE1). Backlight OFF
  - MCU 22mA average current consumption, when electrode touch detected. Backlight ON. The touch event is displayed by on board RGB LED
  - If more than single touch button electrode touched, the fastest touched electrode wins
  - If slider touched, on board RGB LED displays detected finger position
  - Touch buttons have bigger priority than slider for on board RGB LED displaying

Use Case 1 Configuration

- Response time: 30ms
- Number of touch button electrodes: 6 electrodes
- Number of slider electrodes: 2 electrodes
- Number of slider positions: 2 to 8 (5 is optimal)
- Wake-up electrode: NO EGS
- All electrodes pre-sampling: 1 sample
- Touch button electrode sampling in row & average:
  - When all touch button electrodes released: 4 samples
  - When any touch button electrode touched: 16 samples
- Slider electrodes sampling in row & average:
  - When slider electrodes released: 4 samples
  - When slider electrodes touched: 32 samples
- Filter IIR1, ft = 1Hz
- DC Tracker filter response: 1 step / second
- Thresholds touch, release:
  - Touch buttons: 22 / 20
  - Slider electrodes: 17
- Compiler GCC, -O3 alternative
- Backlight PWM duty cycle: 30%
- Backlight ON period: 3s

S32K144 Multi-Pad Keypad Solution with Slider: Use Case 3





EGS
Electrode Global Sense

- Features:
  - 6 touch buttons with 2mm plastic overlay on electrodes
  - 5 position 60mm slider consisting of 2 electrodes with 2 mm plastic overlay
  - >4.5mm spacing between En (E0 to E5), SEn (SE0 to SE1) and EGS
  - Backlight
  - Immunity: Sustain florescent lamp ON (EMI)
- Performance:
  - Low Power Operated: Periodically wake-up MCU (each 30ms) by on-chip timer to sense electrodes and process data to detect touch or release events
  - Response time 30ms / Reaction time 90ms
  - MCU 70uA average current consumption, when all electrodes released (EGS & En & SEn)
  - MCU 350uA average current consumption, when searching touched electrode (E0, E1, E2, E3, E4, E5, SE0, SE1)
  - MCU 22mA average current consumption, when electrode touch detected. The touch event is displayed by on board RGB LED
  - If more than single electrode touched, the fastest touched electrode wins
  - If slider touched, on board RGB LED displays detected finger position
  - Touch buttons have bigger priority than slider for on board RGB LED displaying

Use Case 3 Configuration

- Response time: 30ms
- Number of touch button electrodes: 6 electrodes
- Number of slider electrodes: 2 electrodes
- Number of slider positions: 2 to 8 (5 is optimal)
- Wake-up electrode: YES EGS
- All electrodes pre-sampling: 1 sample
- Touch button electrode sampling in row & average:
  - When wake up electrode EGS released: 4 samples
  - When wake up electrode EGS touched: 16 samples
- Slider electrodes sampling in row & average:
  - When wake up electrode EGS released: 4 samples
  - When wake up electrode EGS touched: 32 samples
- Filter IIR1, ft = 1Hz
- DC Tracker filter response: 1 step / second
- Thresholds touch, release:
  - Touch buttons: 22 / 20
  - Slider electrodes: 17
- Compiler GCC, -O3
- Backlight PWM duty cycle: 30%
- Backlight ON period: 3s

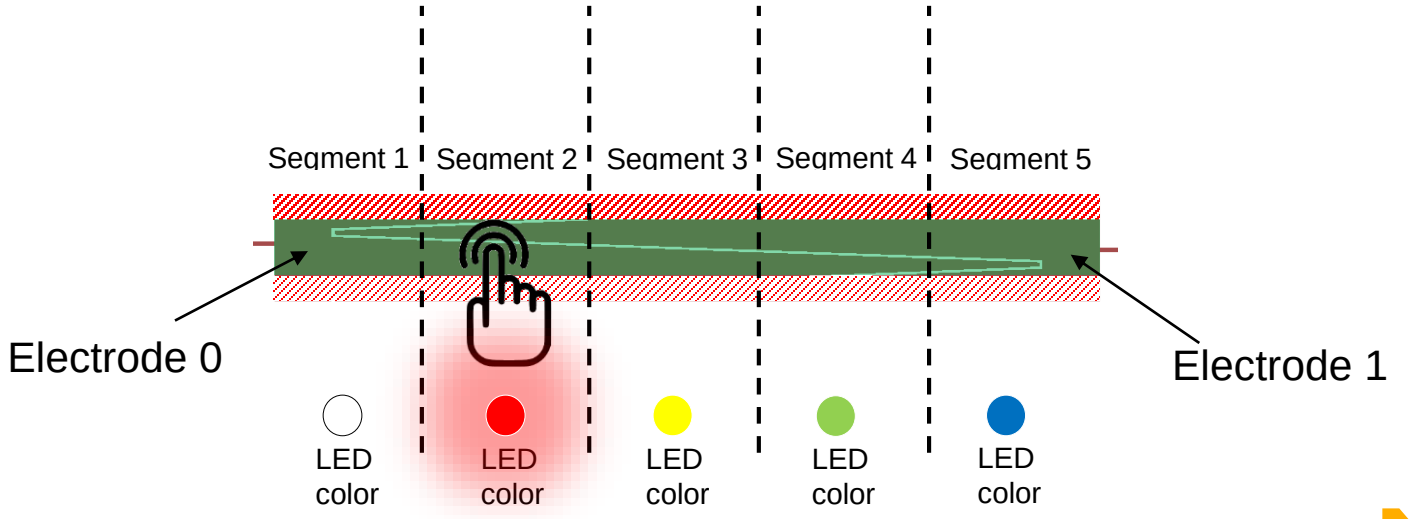
Introduction to slider application

- Slider HW - 2 copper electrodes
  - Slider resolution 50 steps
- By software divided into insensitive and sensitive area

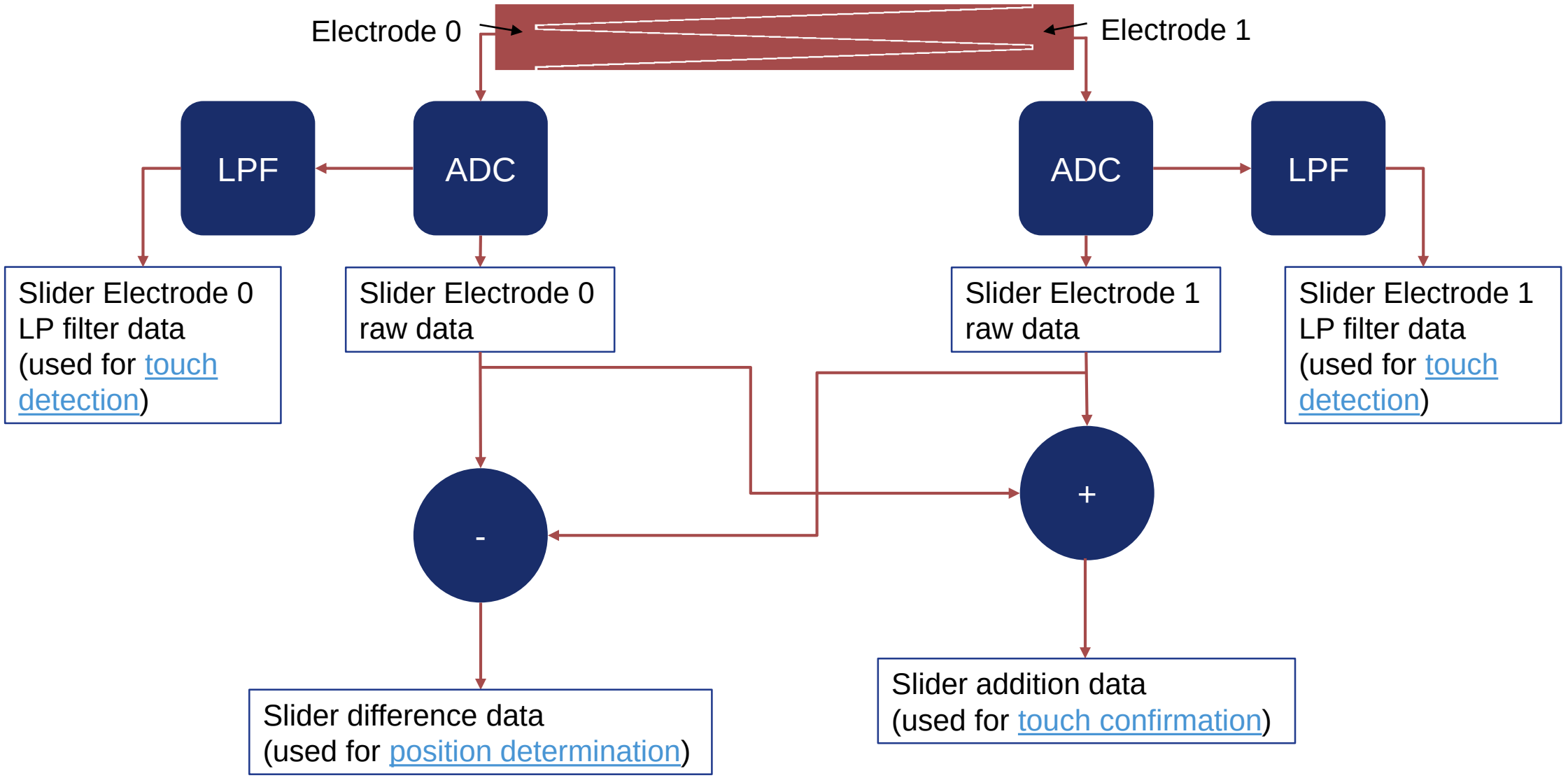
Insensitive area

Sensitive area

- Also by software divided into chosen number of virtual segments
  - Segments boarders are „slider difference data thresholds“
  - Shining on board LED color indicates position of the finger
  - 5 segments represent typical HVAC fan speed control application

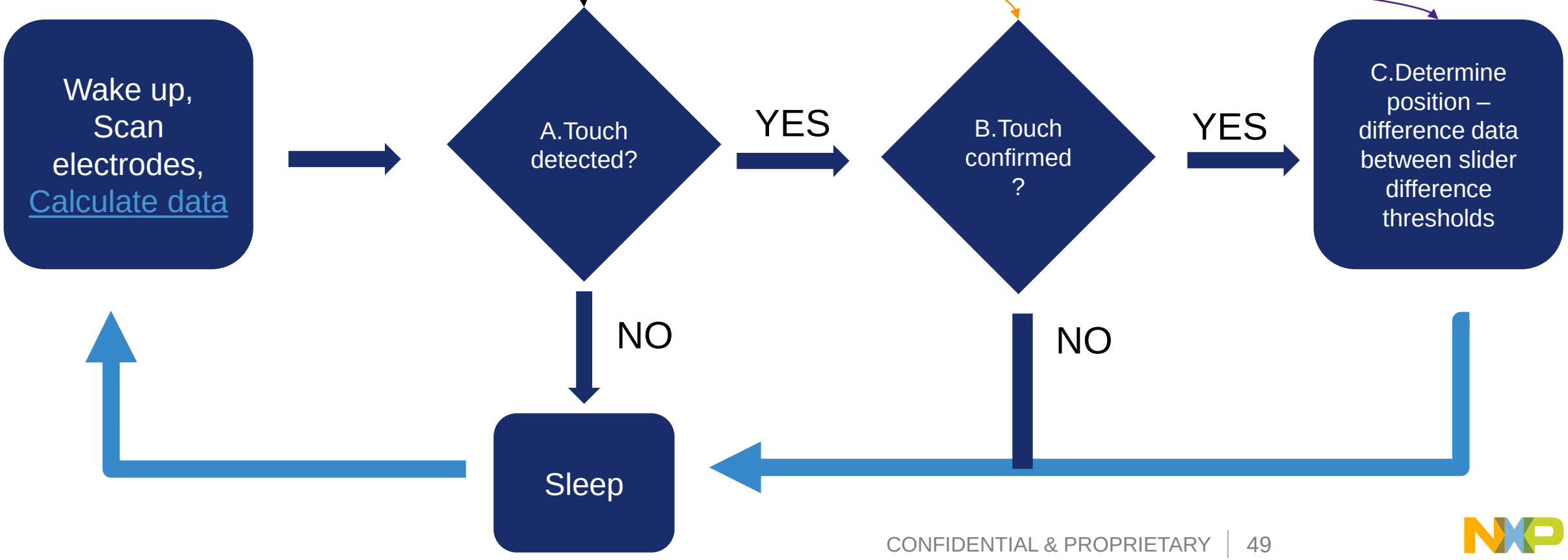


Slider application data

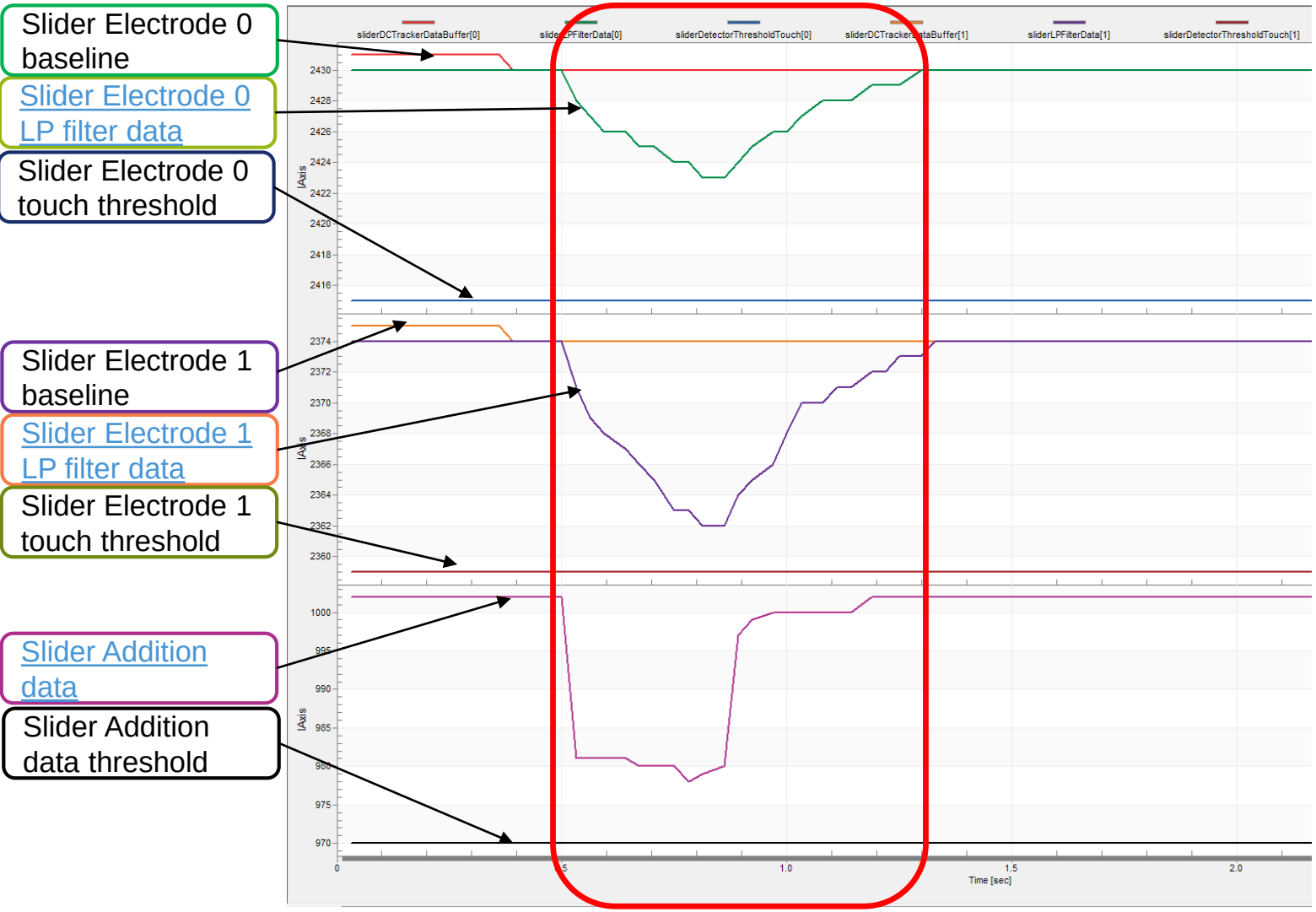


Simplyfied TS slider application Flowchart

- 3 steps of touch evaluation:
  - A. Touch detection
  - B. Touch confirmation
  - C. Position determination

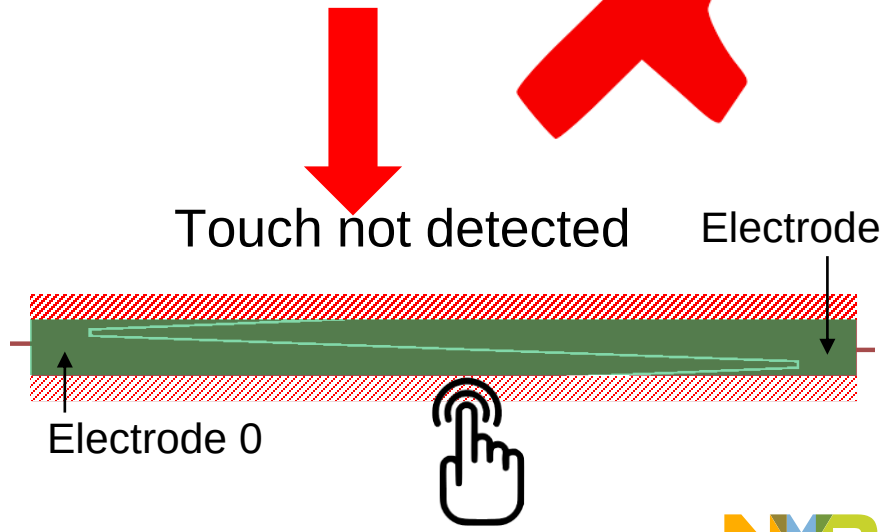


Touch detection and confirmation: Touch not detected

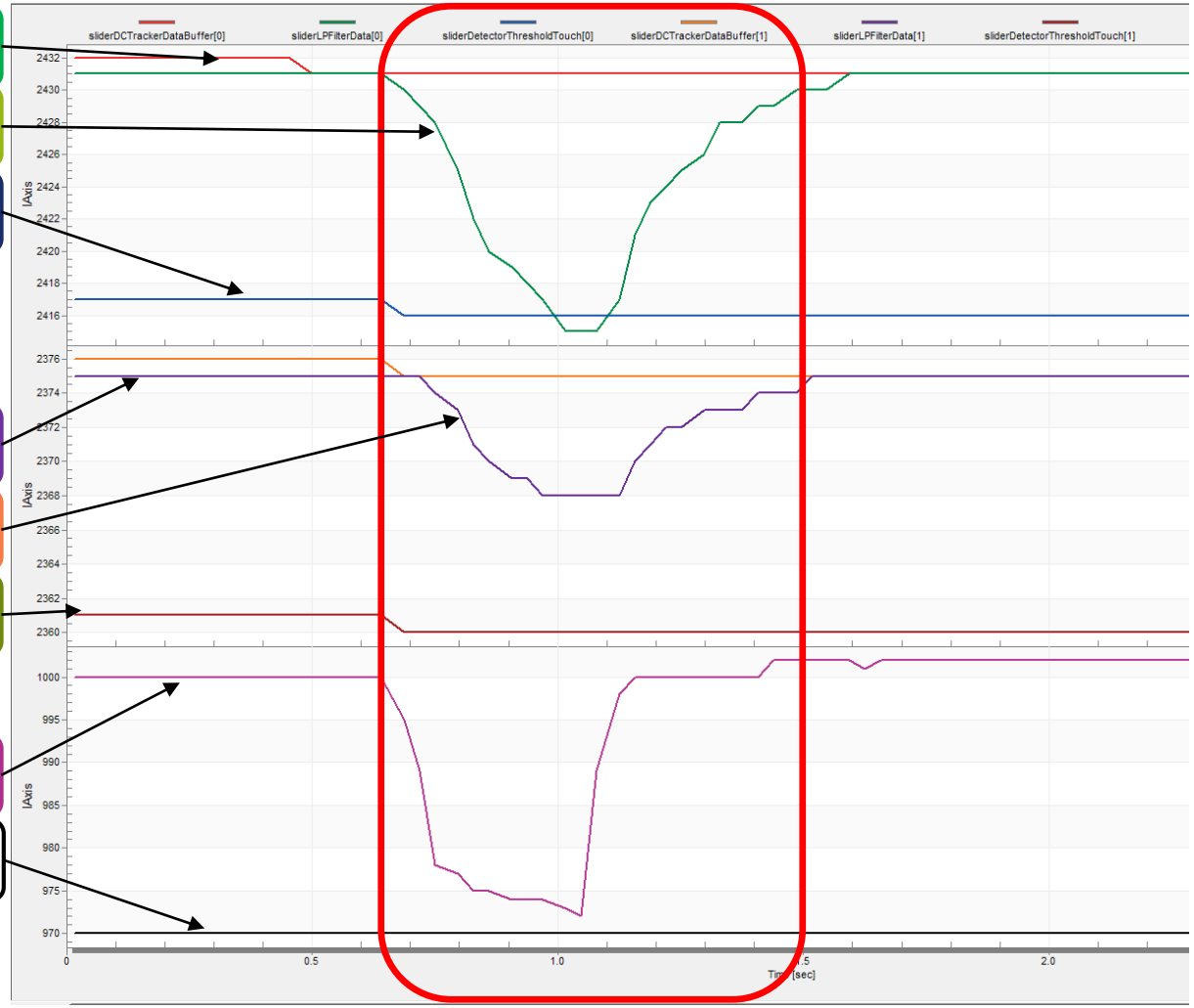


- LP filter data dropped below touch threshold at Electrode 0 OR Electrode 1?

- Addition data dropped below addition data threshold?



Touch detection and confirmation: Touch detected, but not confirmed



Slider Electrode 0 baseline

Slider Electrode 0 LP filter data

Slider Electrode 0 touch threshold

Slider Electrode 1 baseline

Slider Electrode 1 LP filter data

Slider Electrode 1 touch threshold

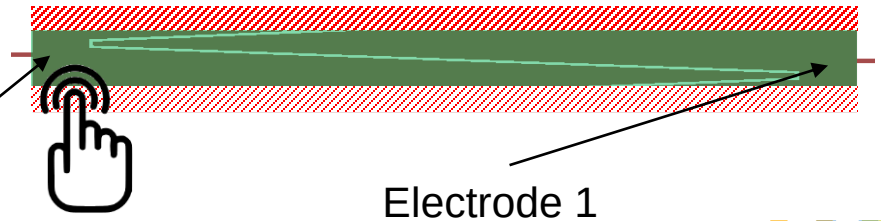
Slider Addition data

Slider Addition data threshold

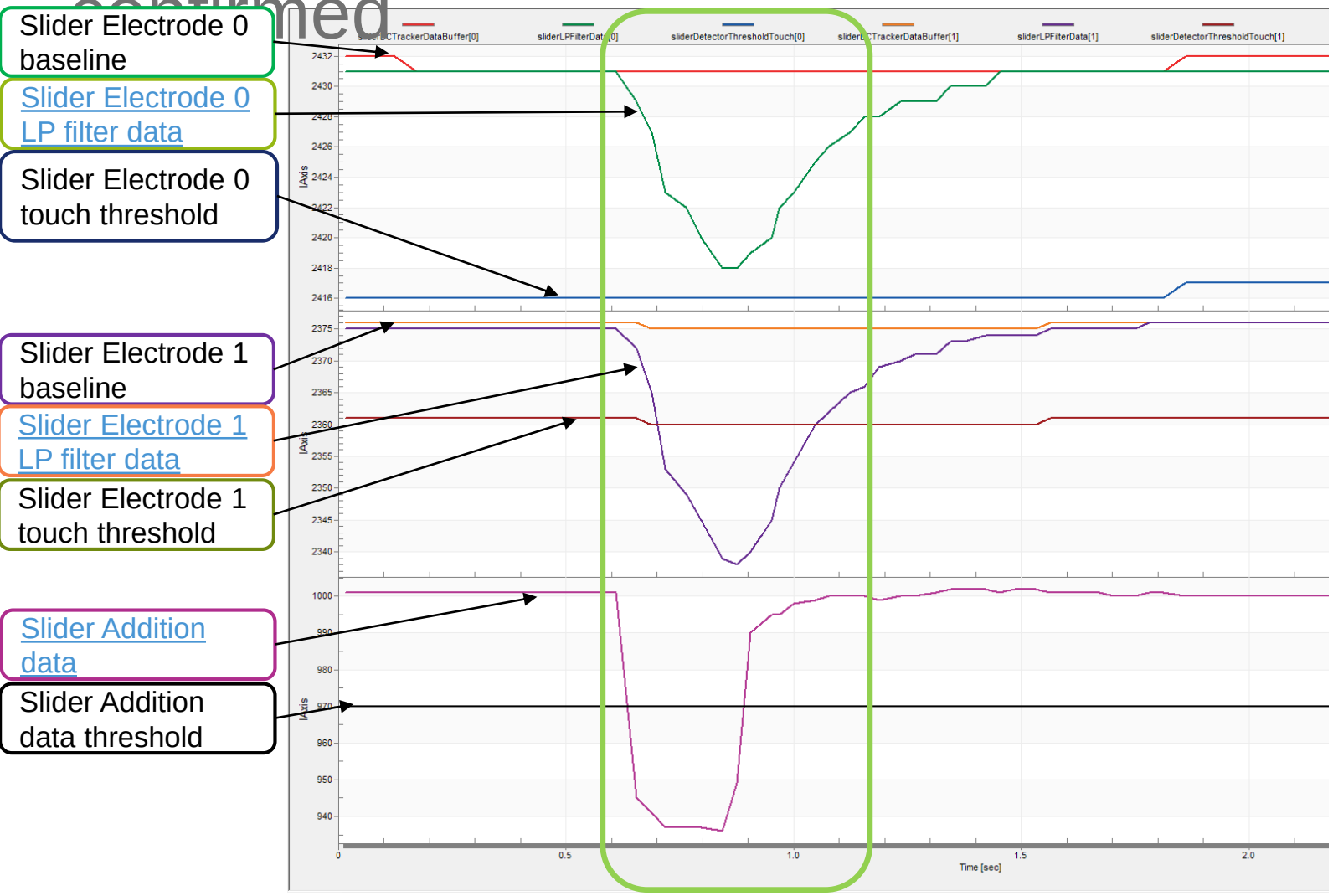
- LP filter data dropped below touch threshold at Electrode 0 OR Electrode 1?

- Addition data dropped below addition data threshold?

Touch detected, but not confirmed

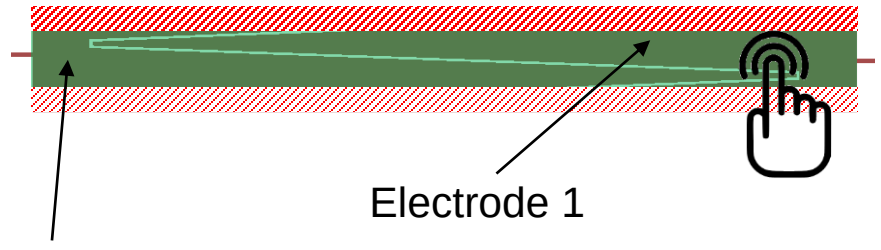


Touch detection and confirmation: Touch detected and confirmed



- LP filter data dropped below touch threshold at Electrode 0 OR electrode 1?
- Addition data dropped below addition data threshold?

Touch detected and confirmed



Position determination on 5 segment slider (HVAC

Slider Resolution – 50 steps (sliderAbsoluteRawData)

- Slider difference data shifted into sliderAbsoluteRawData and filtered for 50 steps resolution demonstration

INSTALLATION AND SETUP

STEP BY STEP INSTALATION GUIDE

STEP 1: Download and install required software

- Download and install following software tools:

⮋ S32 Design Studio IDE for Arm® based MCUs

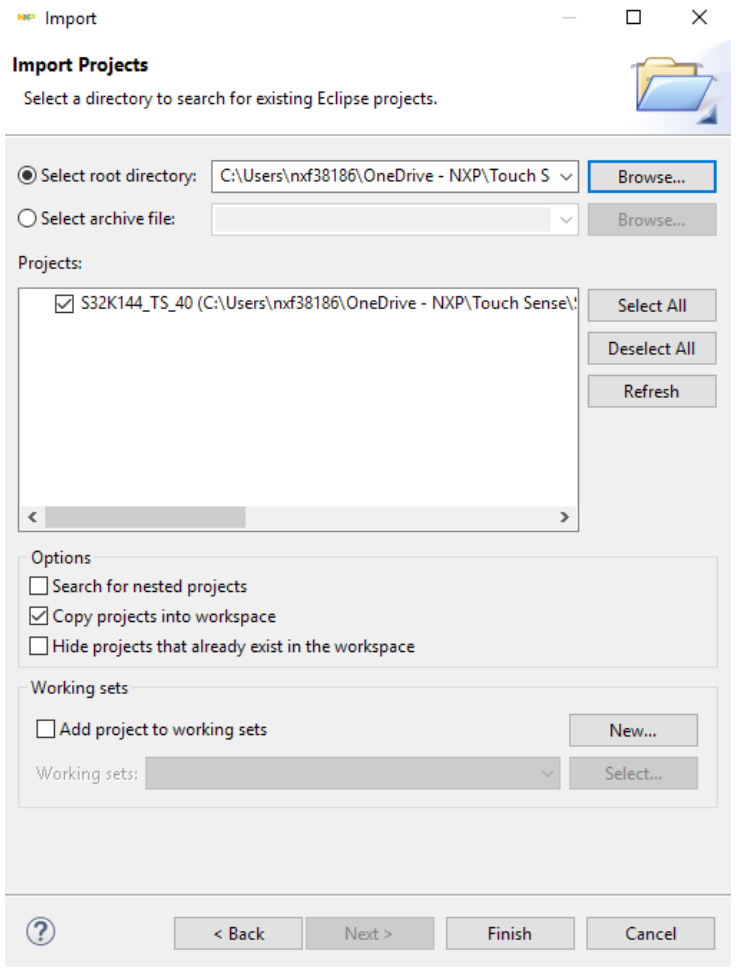
⮋ FreeMASTER Run-Time Debugging Tool

⮋ Touch Sense software package:

”S32K144_TS_40_COMMON_TOUCH_SENSE_SOFTWARE_SOLUTION.exe”

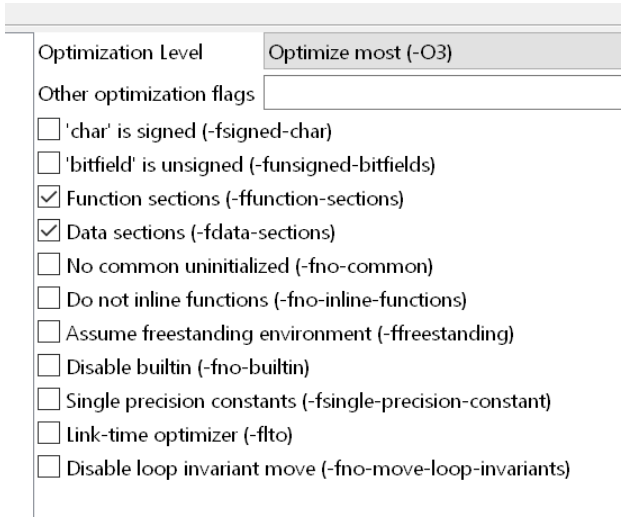
STEP 2: Importing project into S32 Design Studio

1. Run the S32DS and Import installed project “S32K144_TS_50” in S32DS
   - File → Import → Existing projects into Workspace

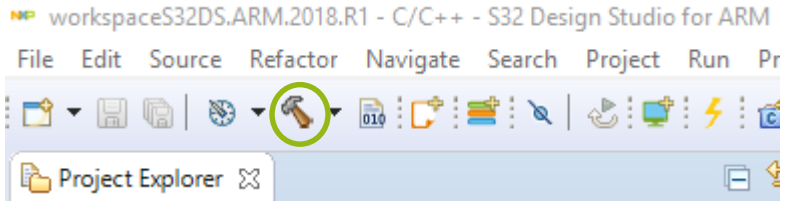


STEP 3: Building project in S32 Design Studio

1. Check compiler optimization -O3
   - Right-click imported project in Project explorer section → Properties → C/C++ Build → Settings → Tool Settings card → Standard S32DS C Complier → Optimization

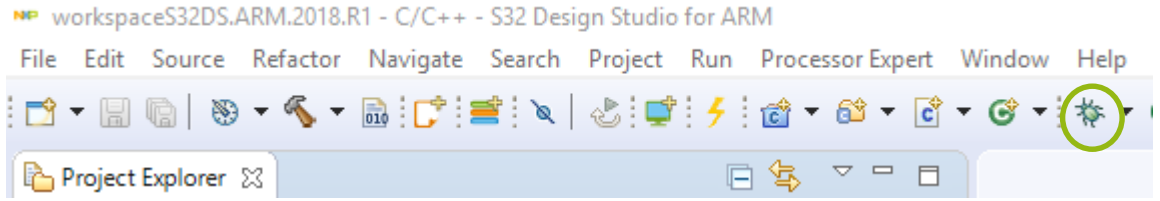


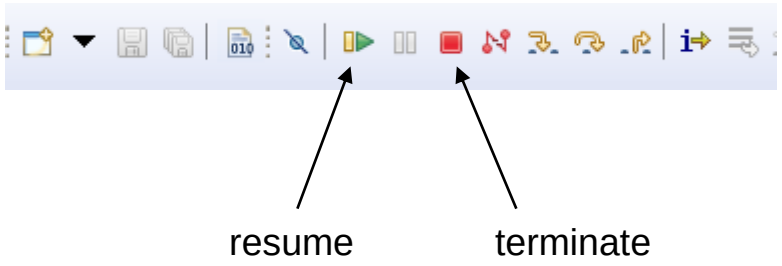
2. Click on hammer icon in toolbar to Build project



STEP 4: Connect S32K144EVB_Q100 board & Debug

1. Connect PC and S32K144EVB_Q100 board with USB cable
2. Download code in S32K144EVB_Q100 board MCU using on-board OPENSDA interface – click on bug icon in toolbar and select S32K144_TS_50_Debug configuration
3. If the debug was succesful, resume and then terminate the debug session



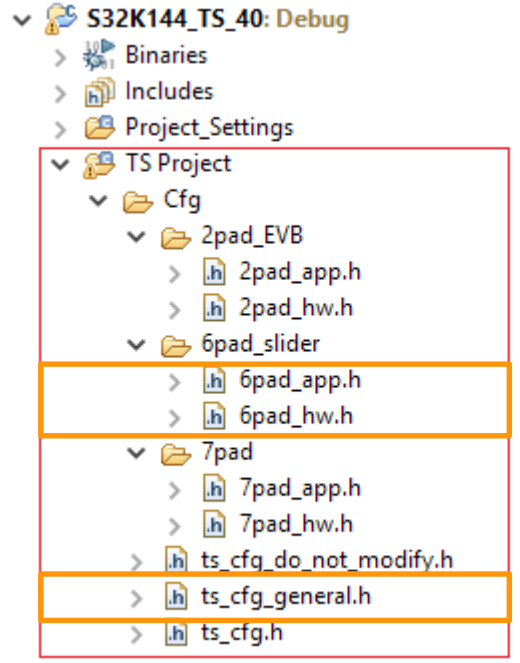


PRE-CONFIGURING THE SLIDER APPLICATION

STEP BY STEP GUIDE THROUGH THE
PROJECT HEADER FILES

STEP 5: Software configuration files

- The Touch Sense software is common for all reference designs boards
- Chosen reference design board must be selected in software configuration files
- Software configuration files are located in „Cfg“ folder

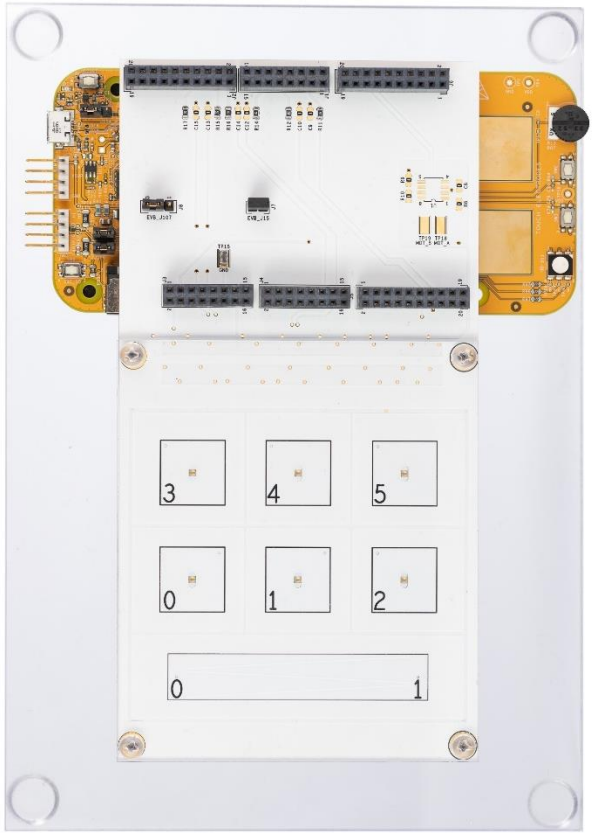


- General configuration file for reference design selection
  - ts_cfg_general.h

- Slider configuration files:
  - 6pad_hw.h
  - 6pad_app.h

STEP 5: Reference design board selection (ts_cfg_general.h)

- **`#define REFERENCE_DESIGN_BOARD S32K144_6PAD_KEYPAD_SLIDER`**
  - Selects S32K144 6pad keypad with slider – the only reference design providing slider application
  - After reference design board selection (modification):
    - Clean the project: Right-click imported project in Project explorer section
    → Clean Project
    - Rebuild indexing: Right-click imported project in Project explorer section
    → Index → Rebuild
    - Build project: Right-click imported project in Project explorer section
    → Build Project



STEP 6: Slider Enable (6pad_hw.h)

- **`#define SLIDER_ENABLE SLIDER_YES`**
  - Enables slider application
  - The slider consists of two electrodes

- **`#define SLIDER_ENABLE SLIDER_NO`**
  - Slider application not used

STEP 7: HW Slider electrodes defines (6pad_hw.h)

- There are following defines for each slider electrode to configure:

```
#define SLIDER_ELEC#_ADC
#define SLIDER_ELEC#_ADC_CHANNEL
#define SLIDER_ELEC#_PORT
#define SLIDER_ELEC#_GPIO
#define SLIDER_ELEC#_ELEC_GPIO_PIN
#define SLIDER_ELEC#_CEXT_GPIO_PIN
```

- And conditions for these defines are:
  - ADC modules used for Electrode 0 and 1 can be different or the same (e.g. ADC0 or ADC1)
  - All GPIO pins used for Electrode 0 and Electrode 1 must be on the same port (e.g. PORTB)

STEP 8: Slider sensing cycles per sample (6pad_app.h)

- **`#define NUMBER_OF_ELECTRODE_SENSING_CYCLES_PER_SAMPLE_SLIDER_IDLE X`**
  - When slider or wake-up EGS electrode is released (idle), one (averaged) slider sample is calculated from this “X” number of sensing (ADC) cycles
  - By default:

    ```
    #define NUMBER_OF_ELECTRODE_SENSING_CYCLES_PER_SAMPLE_SLIDER_IDLE 4
    ```

  - If “X” is increased → better EMI resistance when EGS electrode is released, higher power consumption

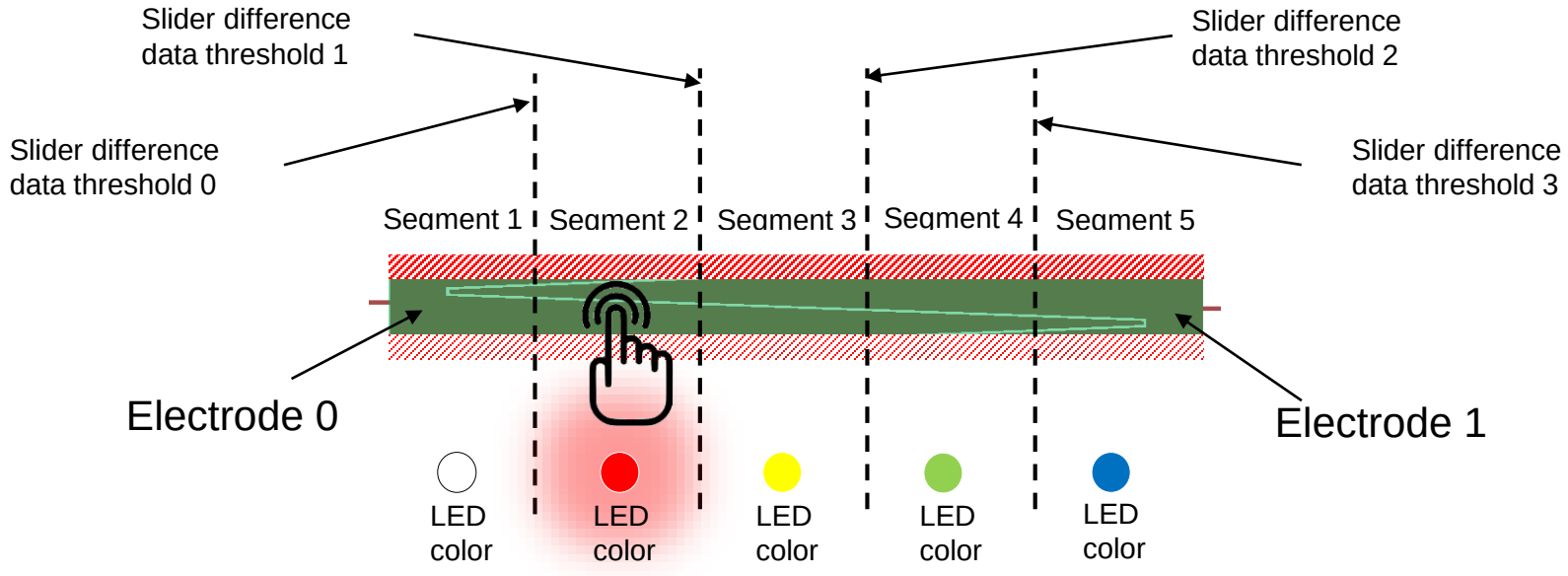
- **`#define NUMBER_OF_ELECTRODE_SENSING_CYCLES_PER_SAMPLE_SLIDER_ACTIVE Y`**
  - When slider or wake-up EGS electrode is touched (active), one (averaged) slider sample is calculated from this “Y” number of sensing(ADC) cycles
  - By default:

    ```
    #define NUMBER_OF_ELECTRODE_SENSING_CYCLES_PER_SAMPLE_SLIDER_ACTIVE 32
    ```

  - If “Y” is increased → better EMI resistance when proximity EGS electrode is touched, higher power consumption

STEP 9: Slider segments (6pad_app.h)

- **`#define NUMBER_OF_SLIDER_SEGMENTS X`**
  - "X" should be a number from 2 to 8 (5 is optimal)
  - The slider area is divided into defined number of virtual segments
  - Each segment is enclosed between two virtual slider difference data thresholds
  - Position of the finger is qualified as a number of touched segment and indicated as LED color



REAL-TIME DEBUGGING WITH FREEMASTER - SLIDER TUNING

STEP BY STEP GUIDE TO THE FINALIZATION OF THE SLIDER APPLICATION

Finalizing Slider application configuration (6pad_app.h) tuning in FreeMASTER

- The remaining defines to be configured in file “ts_slider_cfg_app.h” after visualizing the slider behavior in FreeMASTER are:

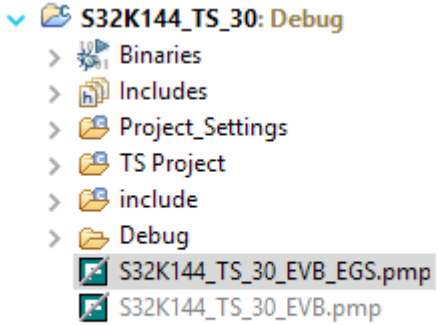
```
#define SLIDER_ADDITION_DATA_THRESHOLD_DEFAULT
#define NUMBER_OF_HYSTERESIS_BLIND_POINTS
#define AUTO_DIFF_THRESHOLDS_GEN
#define NUMBER_OF_MAXIMAL_OBSERVED_DIFFERENCE
#define NUMBER_OF_MINIMAL_OBSERVED_DIFFERENCE
```

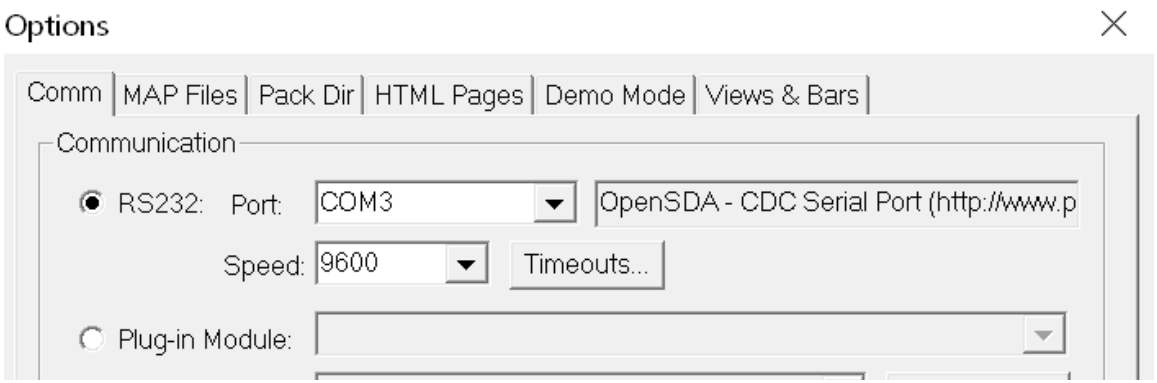
- The idea is:
  1. Temporary modify a variable in FreeMASTER to see how the slider behaves
  2. Then go to “ts_slider_cfg_app.h ” and modify variable related `#define`
  3. Build and Debug the project again
  4. Now the variable is loaded as defined after power up/reset

STEP 10: FreeMASTER connection setup

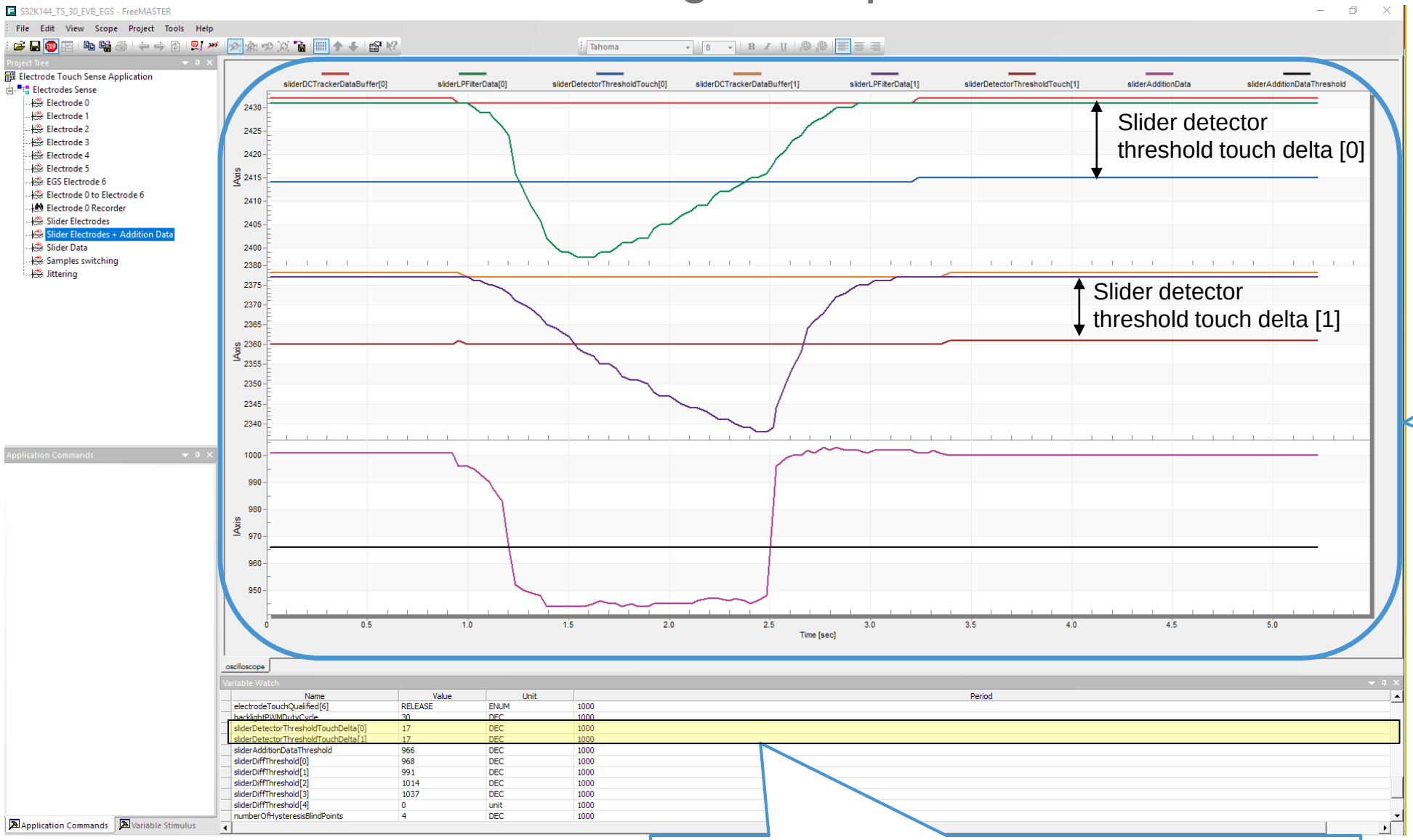
1. Build and Debug the project after previous configuration changes
2. Open the FreeMASTER project
   - If Wake up electrode is planned to be used, open the _EGS FreeMASTER project
3. Establish communication
   - Project →Options →Comm bookmark → Port with OpenSDA

4. Start communication





STEP 11: FreeMASTER slider tuning – Scope: Slider EL. + Add. data



Variable Display

Modify these 2 variables to temporary change the electrodes touch threshold (touch detection)

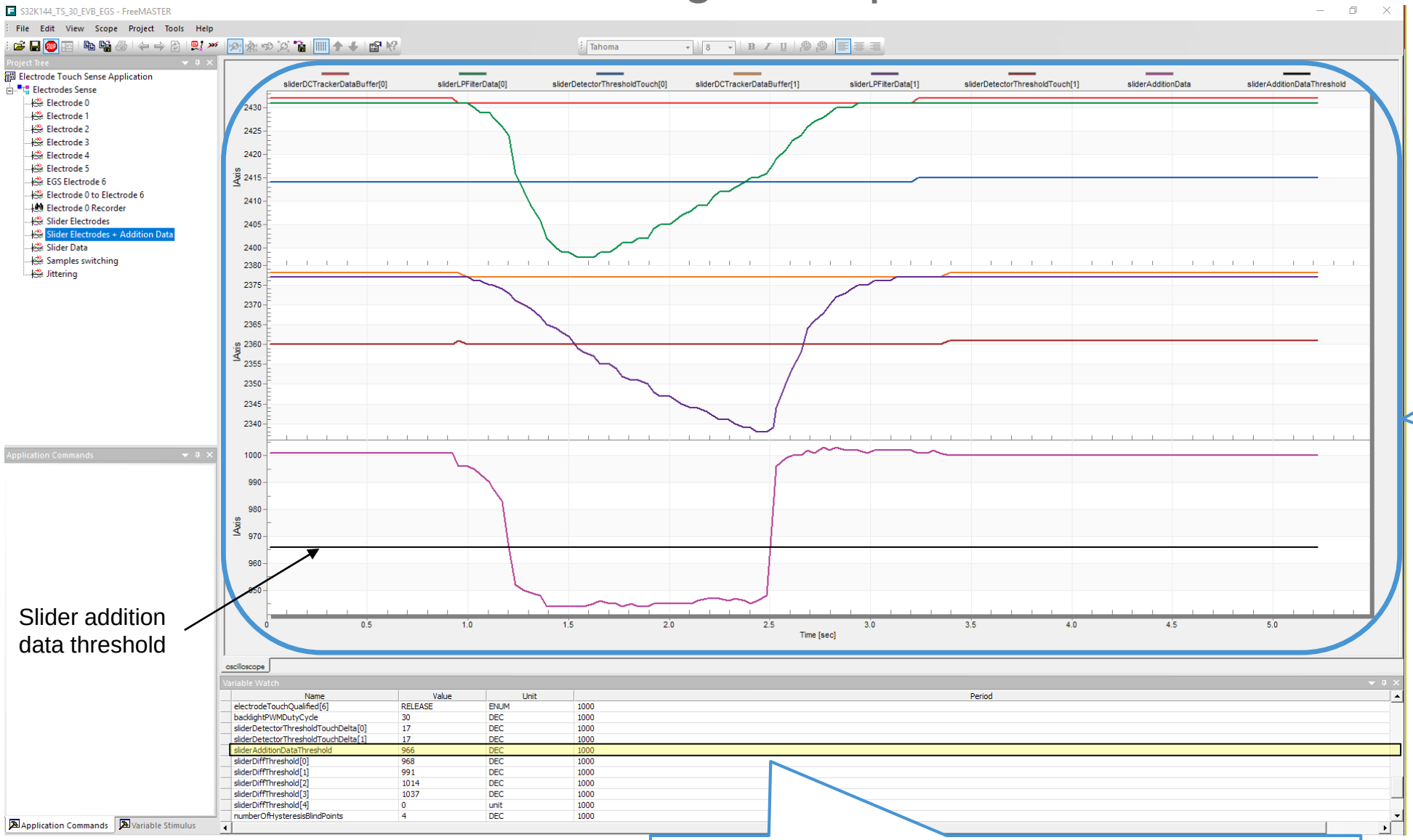
STEP 11: Slider electrodes touch threshold (6pad_app.h)

- **`#define SLIDER_ELEC#_TOUCH_THRESHOLD_DELTA X`**
  - Touch threshold delta (“X”) – number of points under the electrode DCtracker baseline which the slider raw data must drop below in order to detect touch
  - (“X”) is typically from 8 to 22
  - By default:

```
#define SLIDER_ELEC0_TOUCH_THRESHOLD_DELTA          17
#define SLIDER_ELEC1_TOUCH_THRESHOLD_DELTA          17
```

- Changing the touch threshold delta updates the touch threshold in variable display in FreeMASTER

STEP 12: FreeMASTER slider tuning – Scope: Slider EL. + Add. data



Slider addition data threshold

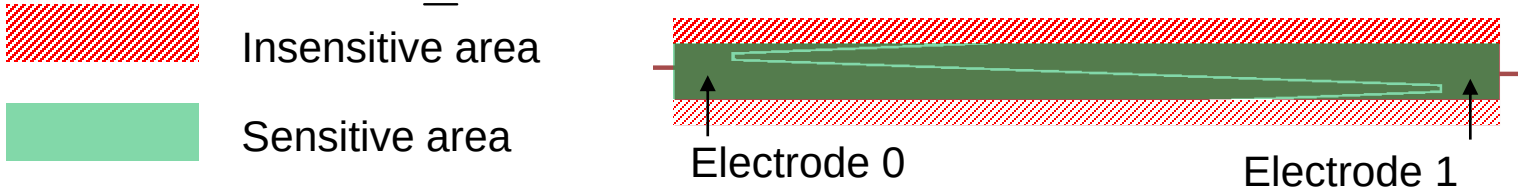
Variable Display

Modify to change the slider addition threshold (touch confirmation)

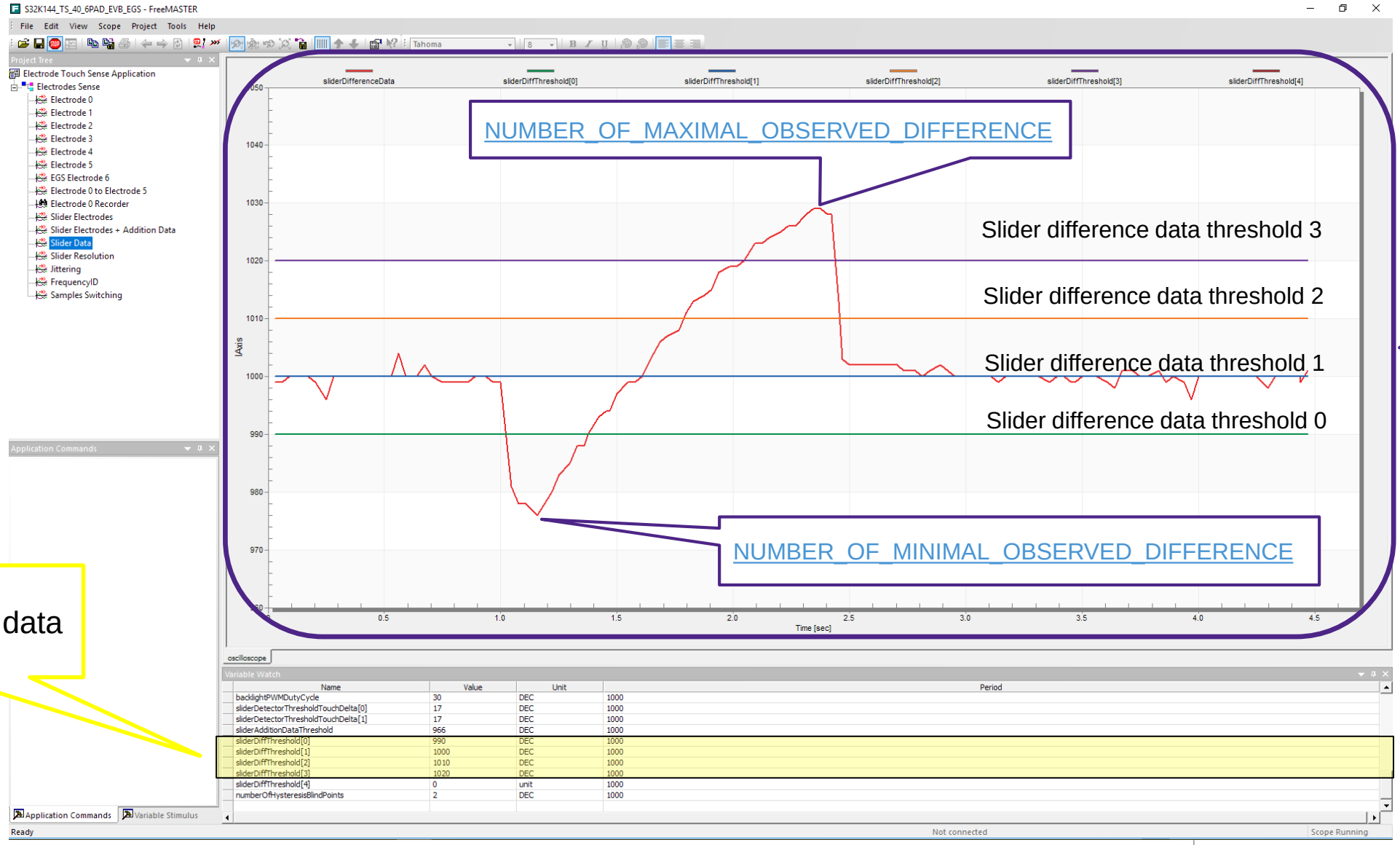
STEP 12: Slider addition data threshold (6pad_app.h)

- **#define SLIDER_ADDITION_DATA_THRESHOLD_DEFAULT X**
  - Protects from unwanted position variation in case of transverse finger movement
  - Causes the insensitive slider area around the slider edges (by software)
  - (“X”) here stands for slider addition data threshold
  - (“X”) is a number (threshold) which the slider addition data must drop below in order to confirm touch
  - By default:

```
#define SLIDER_ADDITION DATA THRESHOLD DEFAULT        966
```



STEP 13: FreeMASTER slider tuning – Scope: Slider Data



Variable Display

Modify non-zero slider difference data thresholds

STEP 13: Manual slider difference data thresholds (6pad_app.h)

- Slider difference data thresholds can be created either manually or automatically based on: #define AUTO_DIFF_THRESHOLDS_GEN

- **`#define AUTO_DIFF_THRESHOLDS_GEN 0`**
  - Slider difference data thresholds manually set – define (hardcode) each manually
  - The number of difference data thresholds to be defined depends on number of slider segments defined in STEP 9
  - e.g. :

```
#define SLIDER_DIFF_THRESHOLD0 990
#define SLIDER_DIFF_THRESHOLD1 1000
#define SLIDER_DIFF_THRESHOLD2 1010
```

STEP 13: Automatic slider difference data thresholds (6pad_app.h)

- Slider difference data thresholds can be created either manually or automatically based on # define AUTO_DIFF_THRESHOLDS_GEN

- **`#define AUTO_DIFF_THRESHOLDS_GEN 1`**
  - Software creates equally distributed slider difference data thresholds across the difference data range
  - In FreeMASTER scope Slider Data observe and then in (ts_slider_cfg_app.h) define following:

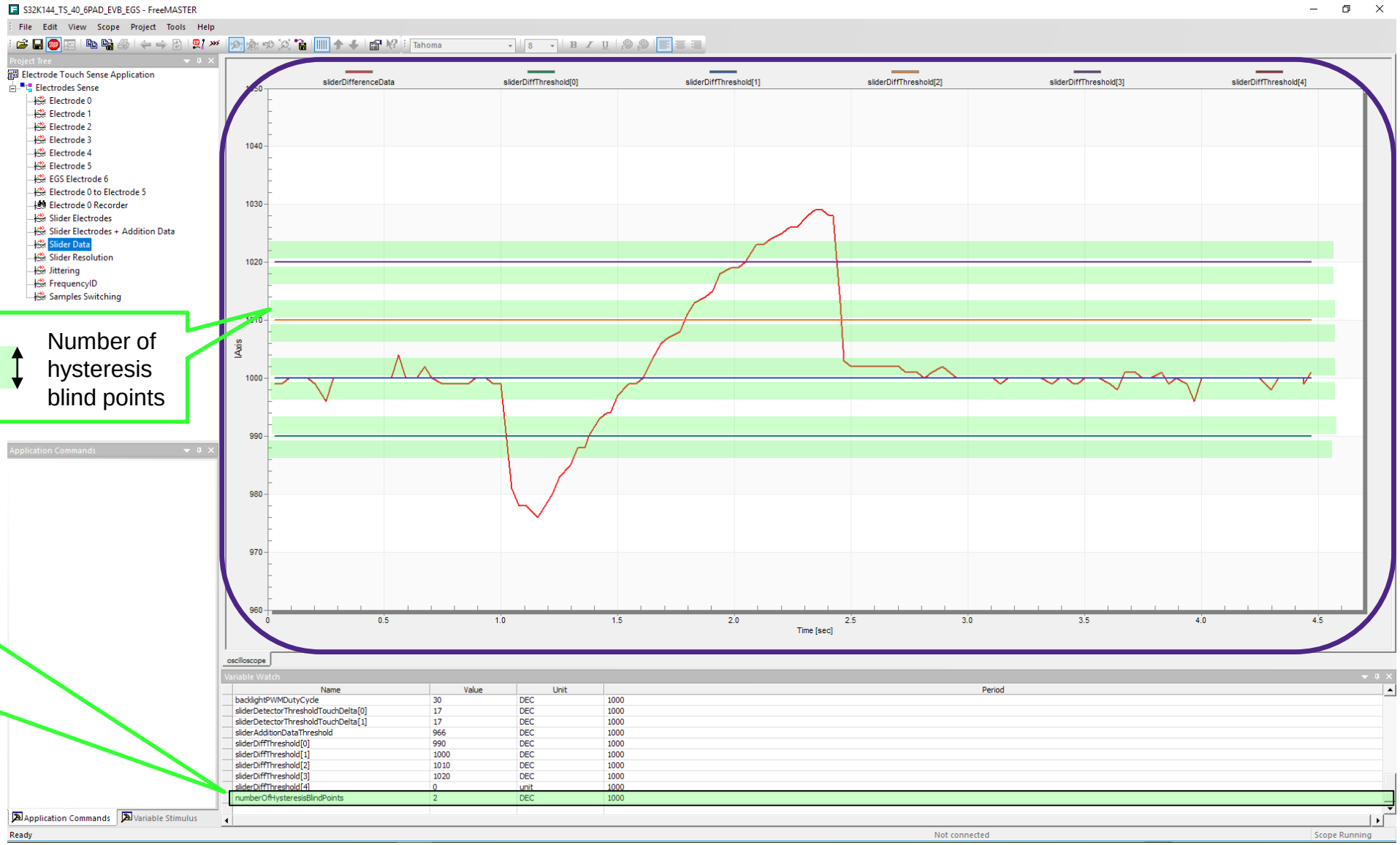
```
#define NUMBER_OF_MINIMAL_OBSERVED_DIFFERENCE X
```

    - (“X”) here stands for minimum of difference data when moving finger across the slider
    - By default: `#define NUMBER_OF_MINIMAL_OBSERVED_DIFFERENCE 980`

```
#define NUMBER_OF_MAXIMAL_OBSERVED_DIFFERENCE Y
```

    - (“Y”) here stands for maximum of difference data when moving finger across the slider
    - By default: `#define NUMBER_OF_MAXIMAL_OBSERVED_DIFFERENCE 1030`

STEP 14: FreeMASTER slider tuning – Scope: Slider Data



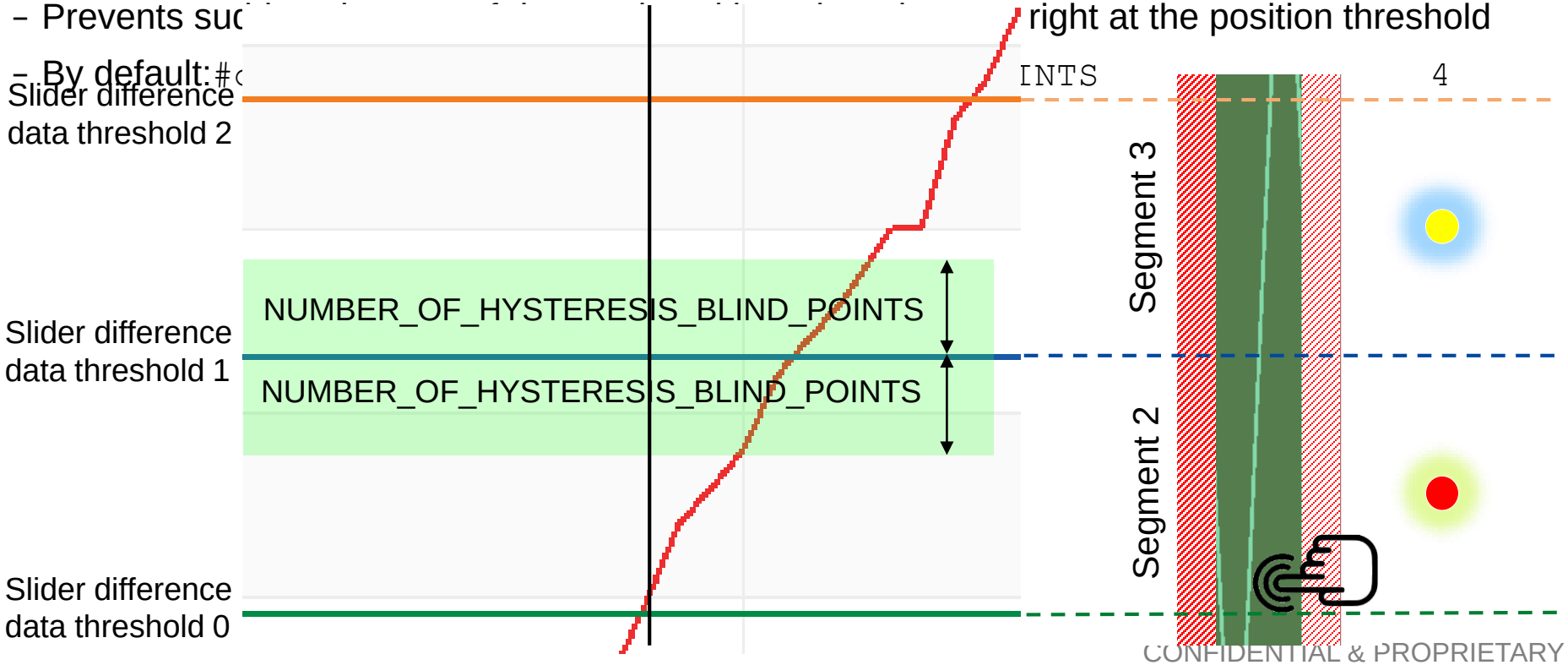
Number of hysteresis blind points

Modify to change the sensitivity around slider difference data thresholds

Variable Display

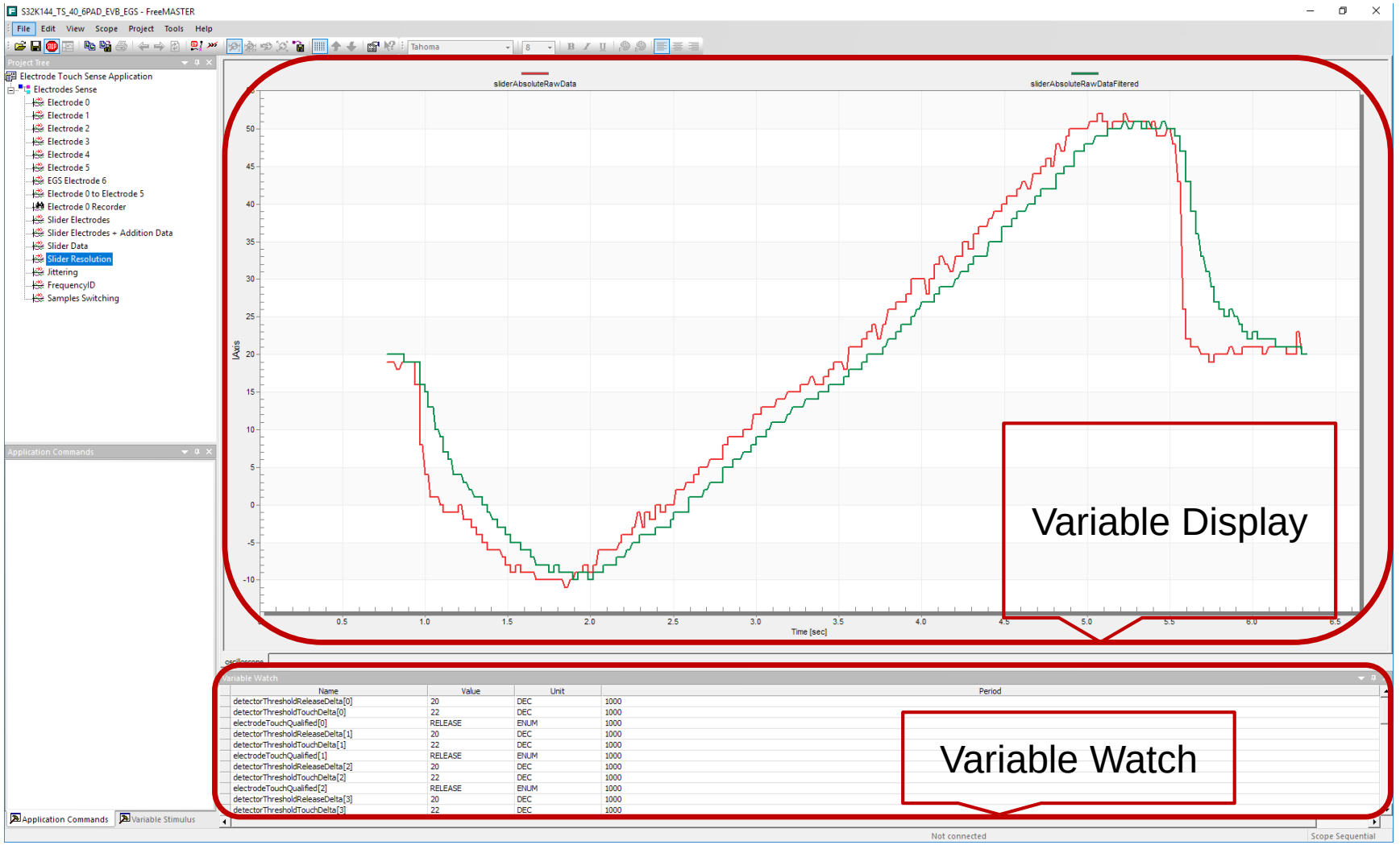
STEP 14: Slider hysteresis (6pad_app.h)

- **`#define NUMBER_OF_HYSTERESIS_BLIND_POINTS X`**
  - (“X”) here stands for hysteresis blind points
  - (“X”) means the number of points of slider difference data above and below each slider difference data threshold, where the slider is unwilling to change the qualified position
  - Prevents sud[illegible] right at the position threshold
  - By default: #d[illegible]INTS 4



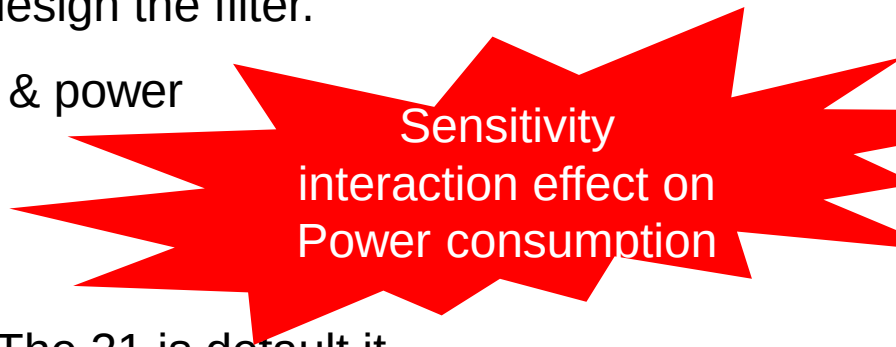
STEP 15: Slider Resolution demonstration – Scope: Slider Resolution

- Slider difference data shifted into sliderAbsoluteRawData and filtered for 50 steps resolution demonstration



Software Checklist

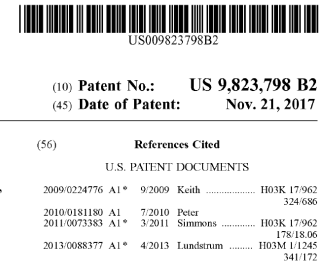
a. TS_ASM_OPTIMIZE is related to optimization level & LOW_POWER_MODE is related to low power in ts_cfg.h.
b. Configure REFERENCE_DESIGN_BOARD in ts_cfg_general.h in accord with demo choose.
c. TS_RAW_DATA_CALCULATION is defined as over-sampling is for sensitivity promotion
d. Wakeup electrode is also proximity electrode.
e. In XX_hw.h to define the number of electrode and attribution of each electrode ,wakeup & slider electrode usage
f. If the modify the sense periods (30ms is in demo) pls notice whether redesign the filter.
g. Proximity detection algorithm is feed by Raw data because of sensitivity & power consumption. Whether feed it by filtered data based on actual project
h. Decimation filter and hoppy frequency will affect the DC tracker factor.
i. How to Set the threshold delta based on filtered data in FreeMASTER. The 21 is default it is related to sensitivity.



Conclusion

Conclusion

- Keypad or HOD?
- How many electrodes?
- CAN or LIN based?
- S32K or S12ZVL?
- Select device using selector guide



US009823798B2

(12) **United States Patent**
Cholasta

(10) **Patent No.: US 9,823,798 B2**
(45) **Date of Patent: Nov. 21, 2017**

(54) **CAPACITIVE SENSOR DEVICE AND METHOD OF OPERATION**

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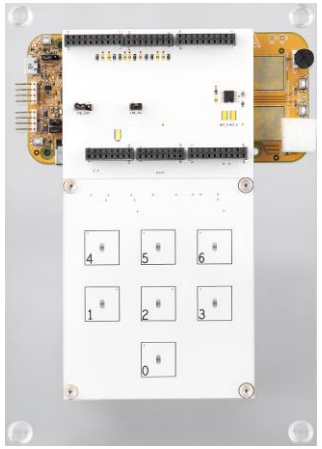
(72) Inventor: **Petr Cholasta**, Hutisko-Solanec (CZ)

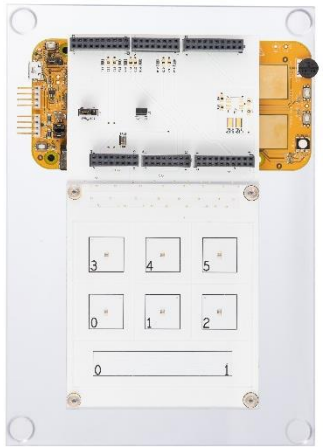
(73) Assignee: **NXP USA, Inc.**, Austin, TX (US)

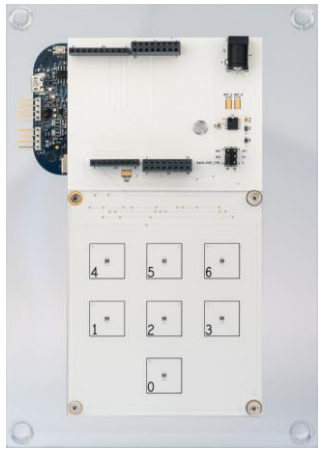
(56) **References Cited**

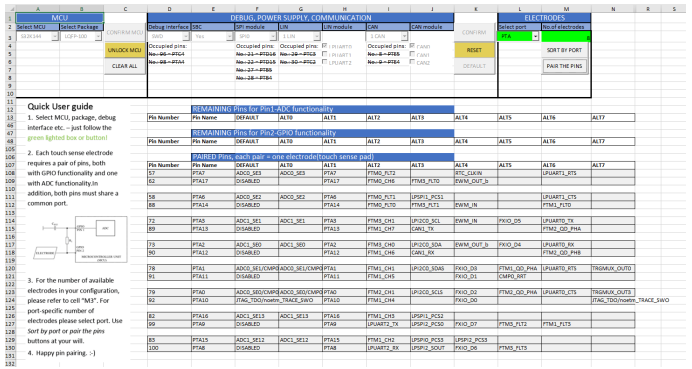
U.S. PATENT DOCUMENTS

2009/0224776	A1*	9/2009	Keith	H03K 17/962 324/686
2010/0181180	A1	7/2010	Peter	
2011/0073383	A1*	3/2011	Simmons	H03K 17/962 178/18.06
2013/0088377	A1*	4/2013	Lundstrum	H03M 1/1245 341/172



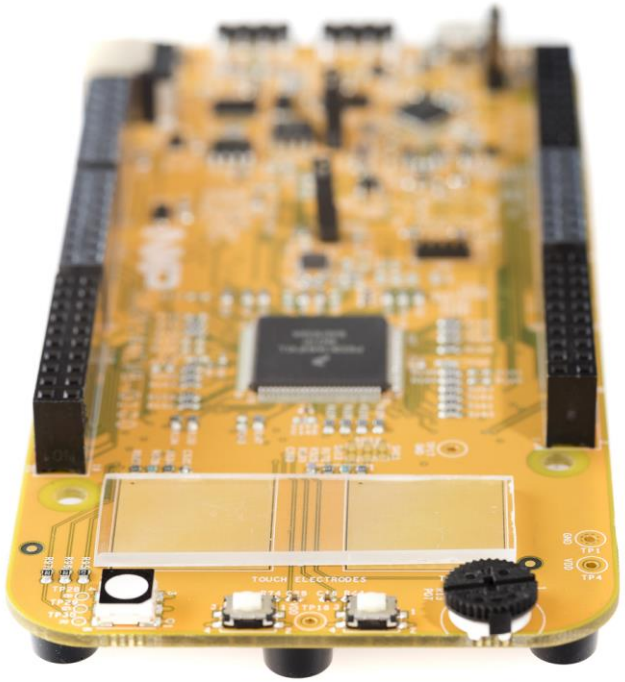






Conclusion

- Proprietary TS method
- Adjustable setting voltage by C_{EXT} value
- GP MCU Scalable family
- ASILB
- CAN FD
- Low power enabled
- Configurability (software solution)



GPIS Touch Sense Reference Design Overview

Reference Design Name		S12ZVL 7pad keyboard	S32K144 2pad keyboard	S32K144 6pad and slider	S32K144 7pad keyboard	S32K144 STW HOD
Recommended Devices		S12ZVL	S32K1xx			S32K1xx
HW Demo		○On demand	●S32K144EVB-Q100	○On demand	○On demand	○On demand
Schematic & Design & Manufacturing files		●	●	●	●	●
SW (exe file)		●TS_20_S12ZVL128_KEYBOARD_SOLUTION	●S32K144_TS_50_COMMON_TOUCH_SENSE_SOFTWARE_SOLUTION_2PAD	●S32K144_TS_50_COMMON_TOUCH_SENSE_SOFTWARE_SOLUTION_6PAD	●S32K144_TS_50_COMMON_TOUCH_SENSE_SOFTWARE_SOLUTION_7PAD	●HOD_40_S32K144_STW_HOD_SOLUTION
User Guide		●	●	●	●	●
HW design guide		●	●	●	●	●
SW design guide		●	●	●	●	●
MCU pin configuration Tool (xls) + Tutorial video		●	●	●	●	●
Test Report	EMC, EMI, ESD Test	○	○	○	○	○
	Water Test	○	○	○	○	
	Glove Test	○	○	○	○	
	Temperature Test			○		

● Public information
○ NDA required

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