ELECTRIC VEHICLE LI-ION BATTERY PRESSURE MEASUREMENT

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PL Pressure Sensors

MAY 2022

SECURE CONNECTIONS FOR A SMARTER WORLD

PUBLIC

AGENDA

- Pressure Sensors in Battery Applications
- NBP8/NBP9 Battery Pressure Monitor Sensors
- NBP8/NPB9 Functionality & Implementation
- NBP8/NPB9 Deliverables & Ecosystem

Pressure Sensors in Battery Applications

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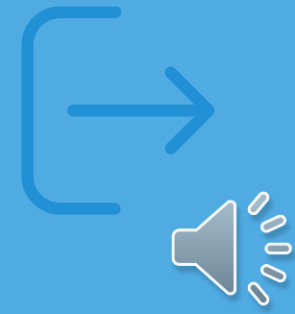
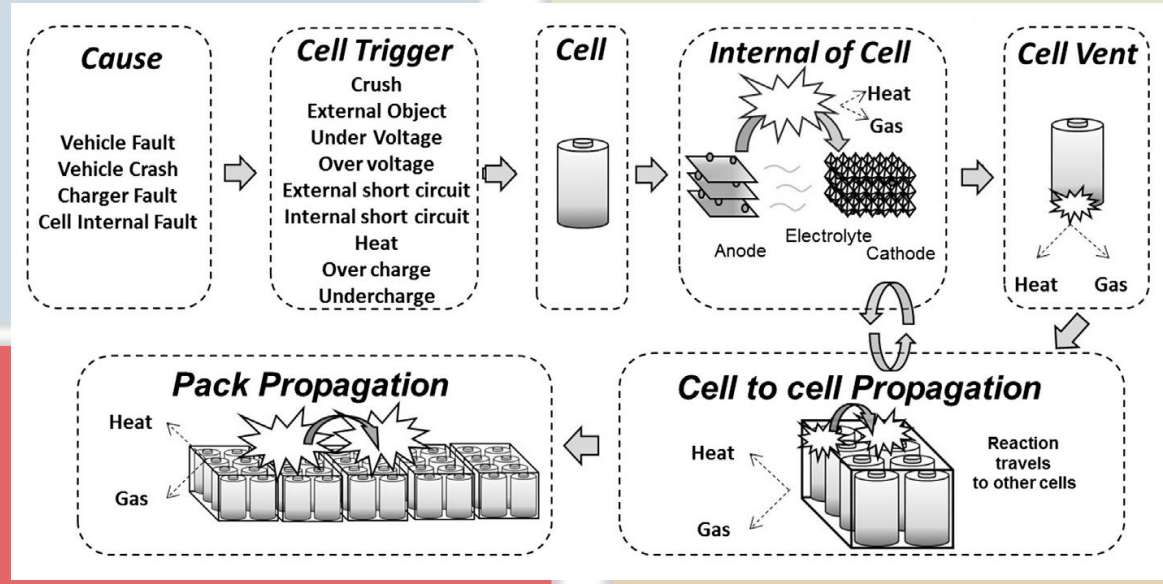


Thermal runaway propagation

Thermal runaway caused by:

Thermal runaway of a single cell usually decays after 20s ~ 60s.



Chemical reactions cause a build up of internal pressure, result in rupture of the encapsulation

Battery housing damaged

The propagation process can speed up and the housing may lose integrity in several minutes.

Adding more heat and producing additional venting gas

Adjacent cells go into thermal runaway due to thermal coupling between cells.

Absolute pressure sensors for thermal runaway detection

Detecting the pressure change within a sealed battery pack to provide early warning of thermal runaway.

- ✓ Signal clarity, short spike
- ✓ Fast detection speed, one of the fastest signals
- ✓ Easy to implement, does not depend on its position

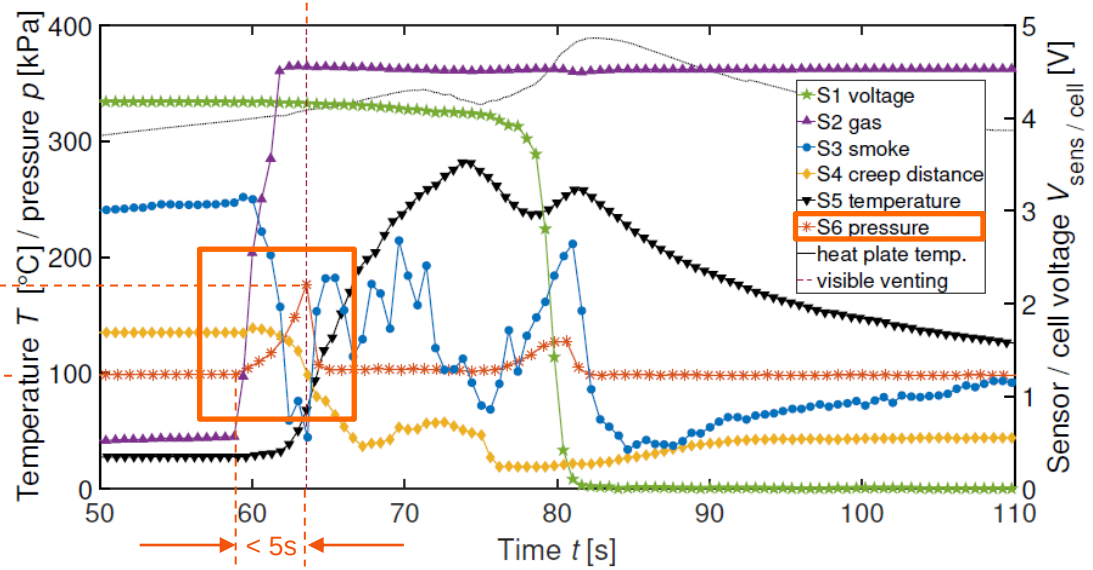
Experiment:

The venting is visible outside of the housing with the opening of the vent , the pressure drops instantly.

30 to 70 kPa

The explosion-proof valve opens the vent at a preset gauge pressure.

~ 101 kPa
Atmospheric pressure at mean sea level



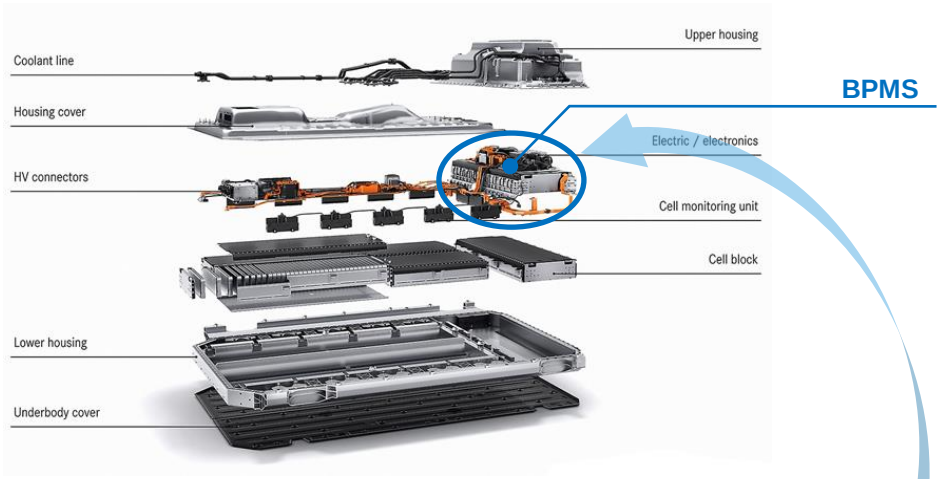
A short spike in pressure

Sources: *"Fast Thermal Runaway Detection for Lithium-Ion Cells in Large Scale Traction Batteries"*

PRESSURE SENSORS IN BATTERY APPLICATIONS
TRACTION BATTERY APPLICATION

BPMS used in lithium-ion traction battery to detect the thermal runaway of single cells.

- Located inside battery pack
- Monitors:
  - set pressure threshold
  - increase over a threshold
  - rate-of-change (ΔP/Δt)
- Sends alert to host MCU

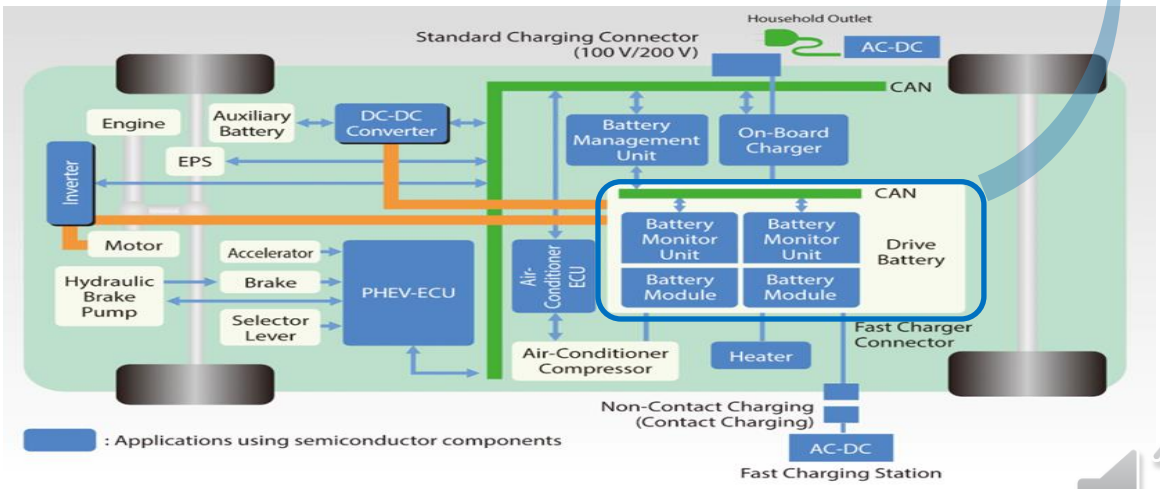


Typical application requirements

- Pressure range: 40 kPa to 250 kPa
- Operating temperature range: -40 °C to +125 °C
- Supply voltage: 3.3 to 5V
- Lower power @ parking vs. running mode
- Wakeup on pressure change
- Interface: PWM, SPI, I2C, analog

Recommended part numbers

- *NBP8FD4T1 (SPI), NBP9FD4T1 (PWM+SPI)*
- *FXPS7250D4T1(I²C/SPI), FXPS7250A4T1 (Analog)*



PRESSURE SENSORS IN BATTERY APPLICATIONS
ENERGY STORAGE SYSTEM APPLICATION

BPMS used in large battery Energy Storage System (ESS) to monitor the pressure inside packs as an earlier indicator of thermal runaway.

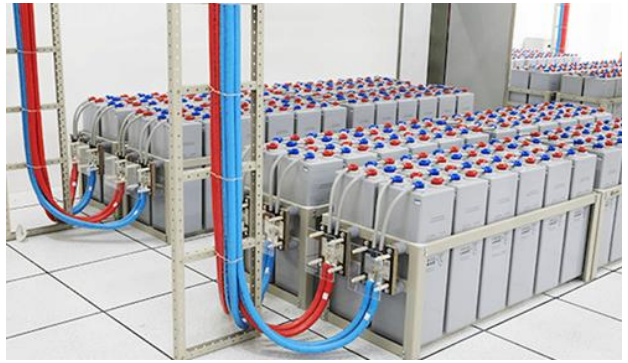
- System located inside battery pack
- Monitors:
  - Fixed pressure threshold detection
  - Relative pressure threshold detection
  - Rate-of-change pressure threshold detection
- Sends alert to host MCU typically using wireless technology

Typical Application Requirements

- Pressure range: 40 kPa to 250 kPa
- Operating temperature range: -40 °C to +125 °C
- Supply voltage: 3.3 to 5V
- Interface: PWM, SPI, I2C, analog
- Media compatibility

Recommended Part Numbers

- *NBP8FD4T1 (SPI), NBP9FD4T1 (PWM+SPI)*
- *FXPS7250D4T1(I^2C/SPI), FXPS7250A4T1 (Analog)*



Inside view of large containers
Each battery pack contains a BPMS sensor

Large containers
holding several hundred battery packs

Sources for graphics:

- *agcs.allianz.com*
- *energystorageforum.com*

PRESSURE SENSORS IN BATTERY APPLICATIONS
FXPS7 SERIES ABSOLUTE PRESSURE SENSORS

*Standard Device, no low power/stop mode, **need Host MCU** to read out pressure data and run external algorithm.*

Features:

- Absolute pressure range options:
  60 kPa ~ 165 kPa / 20 kPa ~ 250 kPa
- Operating temperature range:
  -40 °C ~ +130 °C
- Accuracy options at from 0 to 85 °C:
  ±2.3 kPa / ±2 %FSS
- Supply voltage:
  3.10 V ~ 5.25 V
- Power consumption:
  8 mA max
- 800 Hz or 1000 Hz low-pass filter for absolute pressure
- Interface options: analog, SPI, I2C
- Internal self test for transducer & signal chain
- Qualified in compliance with AEC-Q100

4 mm x 4 mm x 1.98 mm
QFN, 16 pins, 0.8 mm pitch

Ordering information

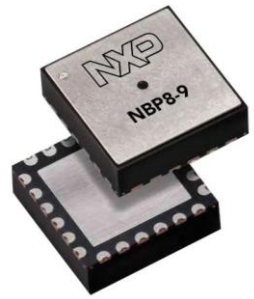
Part Number	Pressure Range	Accuracy @ from 0 to 85 °C	Interface
FXPS7165DI4TI	60 ~ 165 kPa	±2.3 kPa	I^2C
FXPS7165DS4TI	60 ~ 165 kPa	±2.3 kPa	SPI
FXPS7250DI4TI	20 ~ 250 kPa	±2.3 kPa	I^2C
FXPS7250DS4TI	20 ~ 250 kPa	±2.3 kPa	SPI
FXPS7250A4TI	20 ~ 250 kPa	±2 %FSS	Analog

PRESSURE SENSORS IN BATTERY APPLICATIONS
NBP8/NBP9 BATTERY PRESSURE MONITOR SENSORS

NBPx Battery Pressure Monitor Sensors (BPMS) ***integrate an 8-bit CPU and NXP-provided firmware*** *to create the ready-to-use pressure sensors. The BPMS is capable of* ***Sensing*** *(detecting the pressure change),* ***Thinking*** *(calculating the pressure threshold breach) and* ***Acting*** *(raising the pressure threshold breach flag to the host),* ***allows the host to remain off*** *until pressure variation is detected.*

Features:

- Absolute pressure range:
  40 kPa ~ 250 kPa
- Operating temperature range:
  -40 °C ~ +125 °C
- Accuracy at full temperature range:
  -2 kPa ~ +3 kPa
- Supply voltage:
  2.1 V ~ 3.6 V
- Ultra-low power consumption:
  70 µA @ 70 ms sample period
- Interface options: SPI, SPI+PWM
- Diagnostics on pressure transducer and internal connections
- Qualified in compliance with AEC-Q100



4 mm x 4 mm x 1.98 mm
QFN, 24 pins, 0.5 mm pitch

Ordering information

Part Number	Pressure Range	Accuracy @ from -40 to +125 °C	Interface
NBP8FD4T1	40 ~ 250 kPa	-2 ~ +3 kPa	SPI
NBP9FD4T1	40 ~ 250 kPa	-2 ~ +3 kPa	SPI+PWM

NBP8/NBP9 Battery Pressure Monitor Sensors

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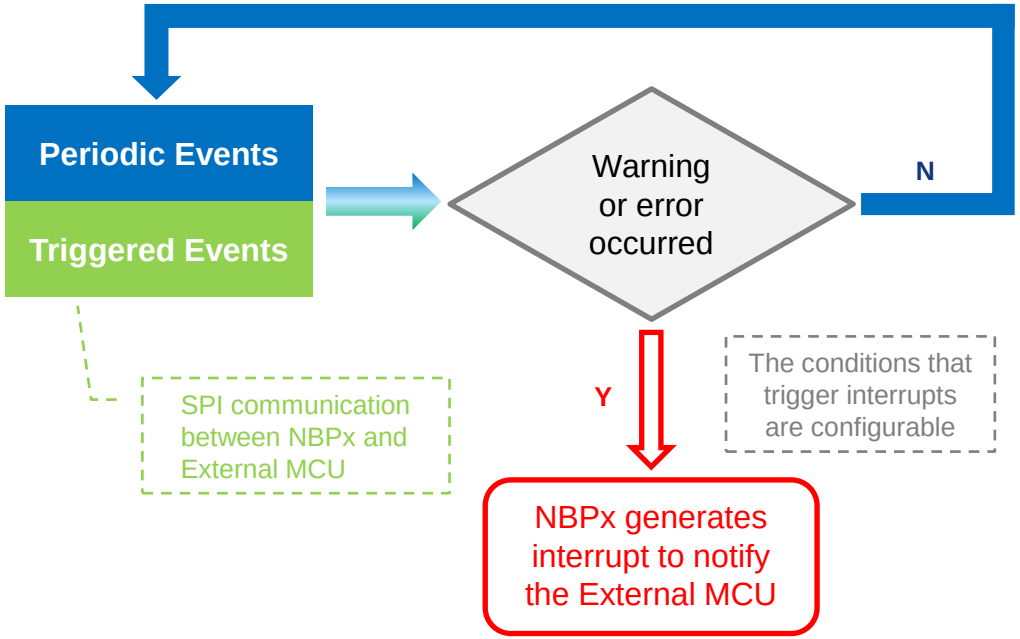
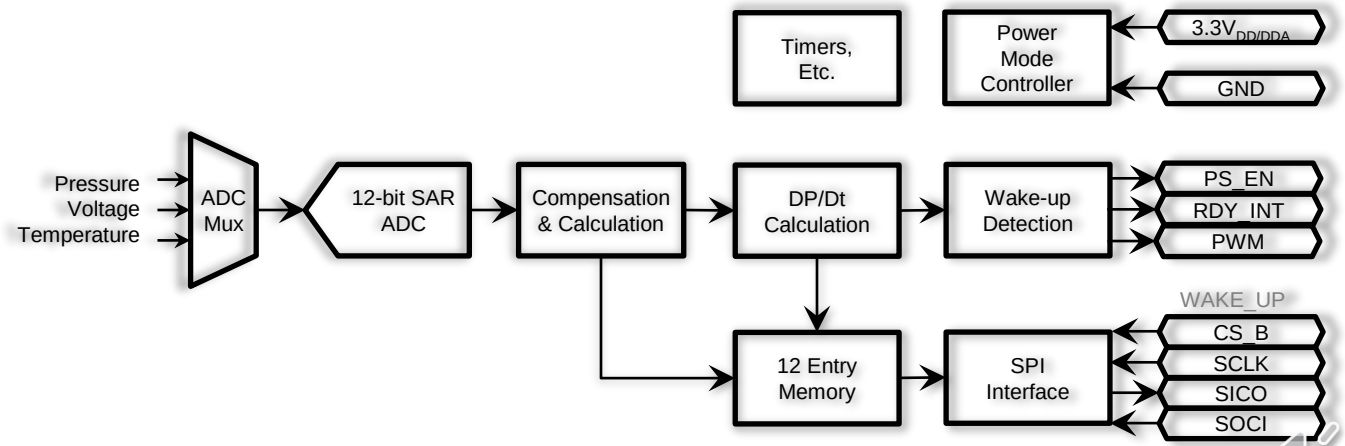
NBP8/NBP9 BATTERY PRESSURE MONITOR SENSORS ADVANTAGES AND BLOCK DIAGRAM

Advantages of NBP8/NBP9:

- User-selectable sampling interval
- Transducer measurement interfaces with low-power AFE:
  - 10-bit compensated pressure measurement
  - 8-bit compensated internal temperature measurement
  - 8-bit compensated internal voltage measurement
- 12-entry pressure FIFO



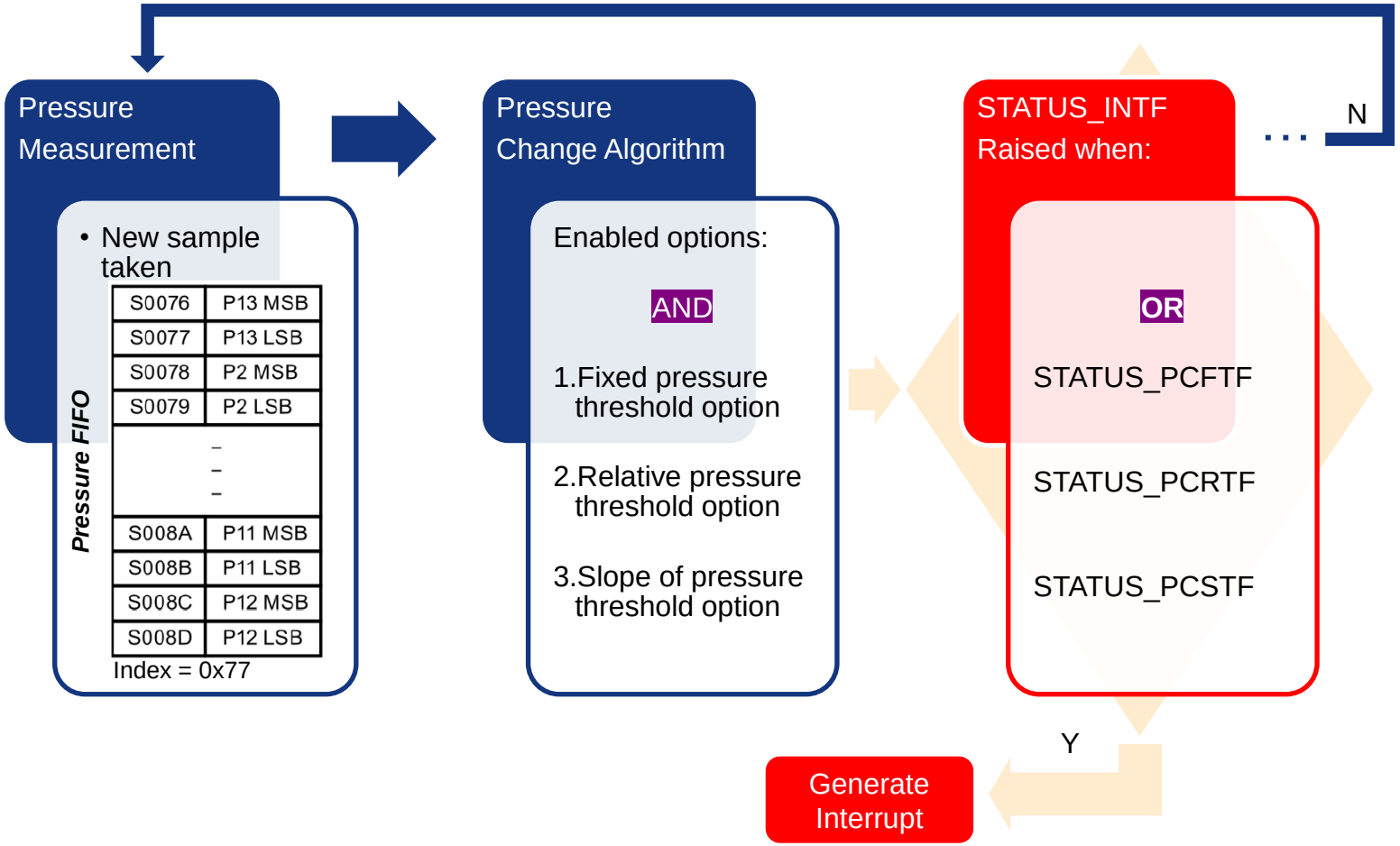
- Selectable host wake-up indications:
  - Fixed pressure threshold
  - Relative pressure threshold
  - Pressure rate of change threshold
- Client SPI to support host access to internal peripherals, registers, and memory
- PWM Output available in NBP9 for ease of integration implementation



Block diagram

Pressure Change Detection

- Three configurable options are available to monitor pressure variation and notify the external host via the INT pin when pressure change conditions have been met.



Registers:

Pressure Change Configuration: PCCFG (0x0054)
- PCCFG_STEN: Slope threshold enable
- PCCFG_RTEN: Relative threshold enable
- PCCFG_FTEN: Fixed threshold enable

Status of the latest executions: STATUS (0x0055)
- STATUS_INTF: INT pin Flag
- STATUS_PCSTF: Pressure change slope threshold Flag
- STATUS_PCRTF: Pressure change relative threshold Flag
- STATUS_PCFTF: Pressure change fixed threshold Flag

Index of the pressure FIFO: INDFIFO (0x0075)
- INDFIFO[7:0]: stores the address of the last byte written in the pressure PFIFO.

Pressure FIFO: PFIFOHx/Lx (0x0076 ~ 0x008D)
- PFIFOHx[15:8]: MSB
- PFIFOLx[7:0]: LSB
- stores the 12 latest pressure measurements

NBP8/NBP9 BATTERY PRESSURE MONITOR SENSORS DATA MEASUREMENT AND CONVERSION

Sensor Data Measurements:

- 10-bit compensated pressure measurement
  - Pressure FIFO PFIFO (0x0076 ~ 0x008D) stores the 12 latest pressure measurements
  - Index of the pressure FIFO INDFIFO (0x0075) stores the address of the last byte written in the PFIFO
  - Conversion formula: P in kPa = (0.206 kPa/LSB * PCODE) + 39.6 kPa

- 8-bit compensated internal device temperature measurement
  - Temperature measurement TCODE (0x0070) stores the most recent compensated internal device temperature measurement
  - Conversion formula: T in °C = (1 °C/LSB * TCODE) – 55 °C

- 8-bit compensated internal device voltage measurement
  - Voltage measurement VCODE (0x0071) stores the most recent compensated internal device voltage measurement
  - Conversion formula: V in Vdc = (0.01 V/LSB * VCODE) + 1.22 V

Registers:

Interrupt pulse Trigger: INTTRIG (0x0053)
- INTTRIG_ SENSERR: Sensor Error
- INTTRIG_ SENSRDY: Sensor Data Ready

Status of the latest executions: STATUS (0x0055)
- STATUS_INTF: INT pin Flag
- STATUS_SENSF: Sensor Flag

Sensor Status: SENSTATUS (0x0056)
- SENSTATUS_ADCERR: ADC Error
- SENSTATUS_LVW: Low Voltage Warning
- SENSTATUS_POVER: Pressure Overflow
- SENSTATUS_PUNDER: Pressure Underflow
- SENSTATUS_TOVER: Temperature Overflow
- SENSTATUS_TUNDER: Temperature Underflow
- SENSTATUS_VOVER: Voltage Overflow
- SENSTATUS_VUNDER: Voltage Underflow

NBP9 PWM Generation

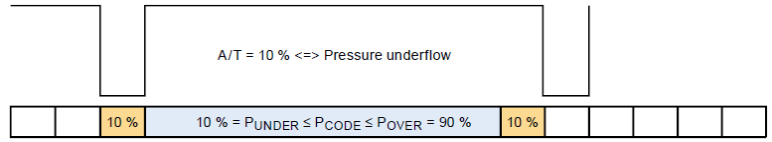
- The PWM frequency is 100 Hz.
- The PWM resolution is 8 µs typical.
- The PWM duty cycle is defined as the ratio of A/T.
- Conversion formula: PCODE in counts = A / T * 1280 -128

Registers:

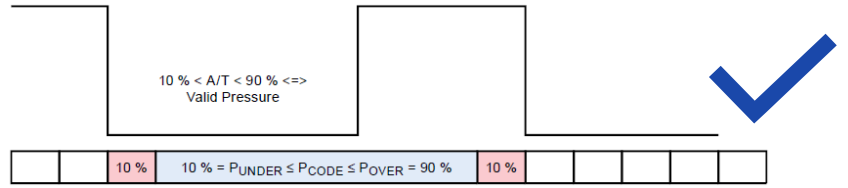
NBP9 Mode Configuration: MODECFG (0x0050)
- MODECFG_PWMPOL: selects the polarity of the PWM pin.

PWMPOL bit	Asserted	Idle
0	Logic 0	Logic 1
1	Logic 1	Logic 0

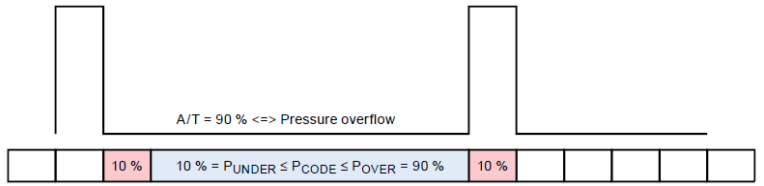
- *In normal mode, after the periodic actions with no event requiring attention occurred, the NBP9 generates a PWM signal during four periods then goes to sleep.*
- *When an event requiring attention occurs, the NBP9 continues generating the PWM signal until either the external host lowers the WAKE-UP pin or the 2048 ms timeout occurs.*



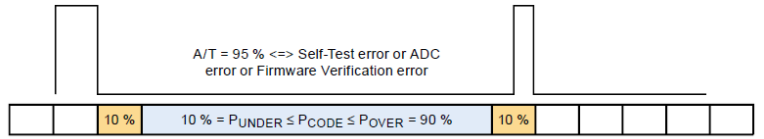
Duty Cycle = 10%: pressure underflow has occurred, $P_{CODE} = P_{UNDER}$.



10% < Duty Cycle < 90%: valid pressure value, $P_{MIN} \leq P_{CODE} \leq P_{MAX}$.



Duty Cycle = 90%: pressure overflow has occurred, $P_{CODE} = P_{OVER}$.



Duty Cycle = 95%: ADC error, self-test error or firmware verification error has occurred. Pressure value may not be valid.

NBP8/NPB9 Functionality & Implementation

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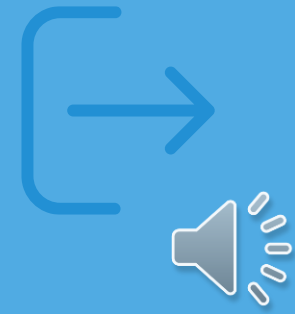
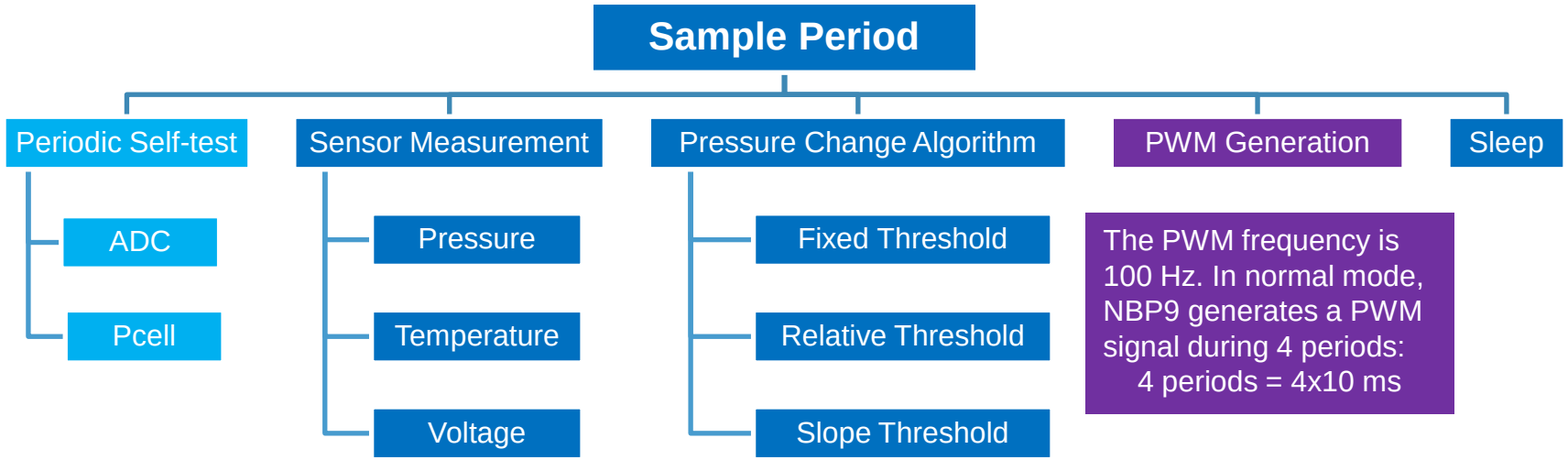


NBP8/NBP9 FUNCTIONALITY & IMPLEMENTATION
OVERVIEW OF THE EVENTS

Periodic Events



The PWM frequency is 100 Hz. In normal mode, NBP9 generates a PWM signal during 4 periods:
4 periods = 4x10 ms

Periodic events execution times

Action	Duration
ADC and Pcell self-test	3.47 ms
Sensor measurements	4.4 ms
Pressure change algorithm	100 µs
Total	8 ms

The available sampling periods are achieved by adjusting the sleep time.

Registers:

Self-Test Execution Period: STPER (0x0051)
- STPER[7:0]: configures the period at which ADC and Pcell Self-Test is performed.
- $00 disables the periodic Self-Test.
- Range of Self-Test execution period is from 1 to 255 x SAMPLING PERIOD.

Interrupt pulse Trigger: INTTRIG (0x0053)
- INTTRIG_ STERR: Self-Test Error

Status of the latest executions: STATUS (0x0055)
- STATUS_INTF: INT pin Flag
- STATUS_ PSTF: Pcell Self-Test Flag
- STATUS_ ADCSTF: ADC Self-Test Flag

Difference between NBP8 and NBP9 at Register: 0x0050

NBP8: Pressure Sampling Period

PSP[7:0]	Sample Period	Current
$00	10 ms	460 µA
$01	20 ms	241 µA
$02	40 ms	122 µA
$03	70 ms	69 µA
$04	135 ms	36 µA
$05	510 ms	10 µA
$06	1000 ms	5 µA
$07 ~ $FF	same as $06	

NBP9: Mode Configuration

MODE bit	Mode	Sample rate	Current
0	Eco	500 ms	24 µA
1	Normal	50 ms	1.8 mA

The typical sampling periods may vary due to the LFO clock tolerance.

Triggered Events

- Triggered by the appropriate command written via SPI.

Triggered Events	Triggered by	Execution times
ADC self-test	CMD_ADCST	455 µs
Pcell self-test	CMD_PST	3.32 ms
Firmware verification	CMD_FV	132 ms
Reset registers	CMD_RESET	206 µs
Clear FIFO	CMD_CLRFIFO	185 µs
Acknowledge INTF	CMD_ACKINTF	18 µs

Registers:

Interrupt pulse Trigger: INTTRIG (0x0053)
- INTTRIG_ FVERR: Firmware Verification Error
- INTTRIG_ STERR: Self-Test Error

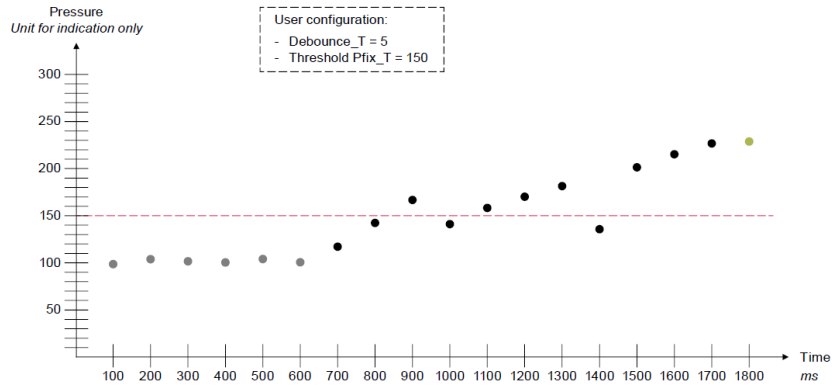
Status of the latest executions: STATUS (0x0055)
- STATUS_INTF: INT pin Flag
- STATUS_ FVF: Firmware Verification Flag
- STATUS_ PSTF: Pcell Self-Test Flag
- STATUS_ ADCSTF: ADC Self-Test Flag

Command: CMD (0x0057)
- CMD _ACKINTF: Acknowledge INT Flag
- CMD _ CLRFIFO: Clear the pressure FIFO
- CMD _ RESET: Reset all registers to reset value
- CMD _ FV: perform Firmware Integrity Verification
- CMD _ PST: perform Pcell Self-Test
- CMD _ ADCST: perform ADC Self-Test

- To be taken after completion of the SPI transfers.
- The NBPx can notify the external host by enabling pulse generation if an error is detected.

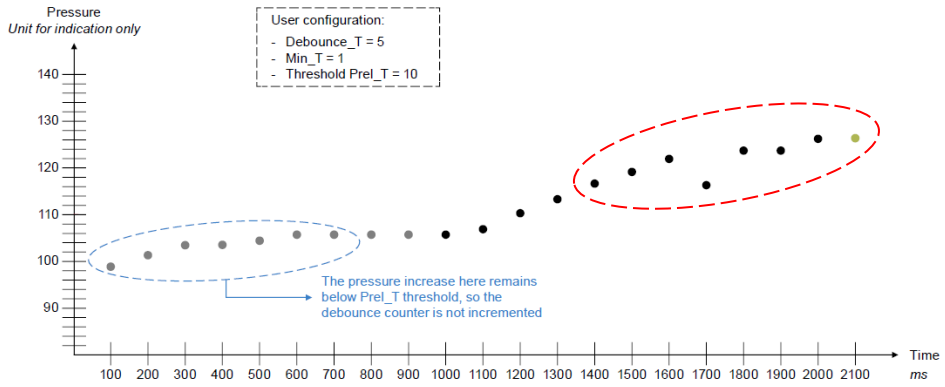
NBP8/NBP9 FUNCTIONALITY & IMPLEMENTATION
PRESSURE CHANGE DETECTION ALGORITHM

Fixed Pressure Threshold Option: P



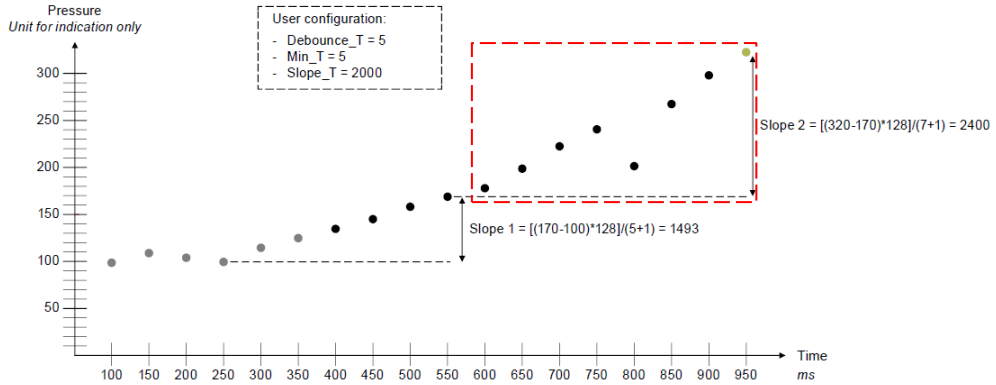
*The flag is raised when **the pressure value** exceeds the threshold.*
Pressure Change Fixed Threshold High / Low: PCFIXTH (0x0059) / PCFIXTL (0x005A)

Relative Pressure Threshold Option: ΔP



*The flag is raised when **the pressure increase** exceeds the threshold.*
Pressure Change Relative Threshold High / Low: PCRELTH (0x005C) / PCRELTL (0x005D)

Rate of Pressure Change Threshold Option: ΔP/Δt



$$PCSLOPET = \frac{Slope/Sensitivity \times 128}{1000/Sampling\_Period}$$

Where:
- Slope = ΔP/Δt in kPa/s, user inputs
- Sensitivity = 0.2 kPa/LSB
- 128 is a multiplication coefficient, to scale the slope
- Sampling_Period in ms

*The flag is raised when **the slope of pressure** exceeds the threshold.*
Pressure Change Slope Threshold High / Low: PCSLOPETH (0x005E) / PCSLOPETL (0x005F)

Registers:

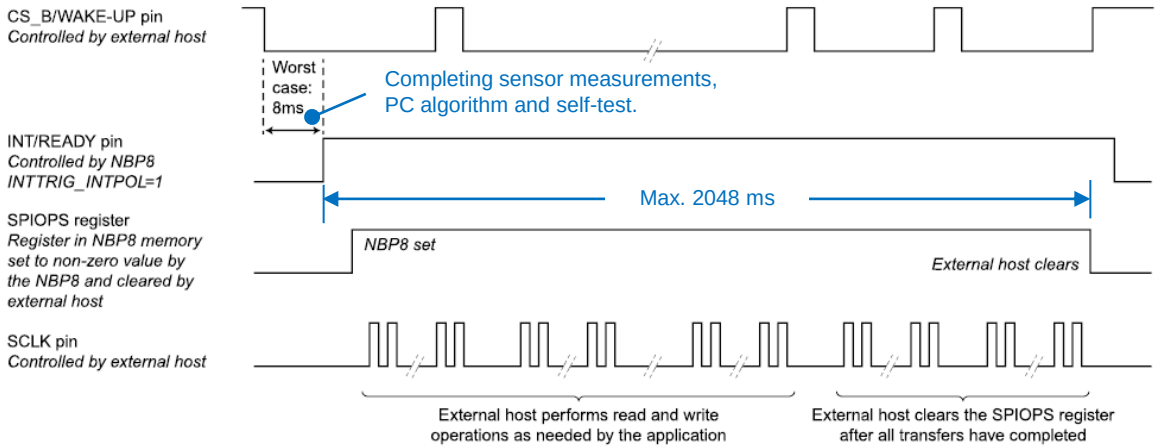
Pressure Change Debounce Threshold: PCDEBT (0x0058)
- PCDEBT[7:0]: the debounce value that a pressure change condition has been met.

Pressure Change Minimum Threshold: PCMINT (0x005B)
- PCMINT[7:0]: the minimum increase pressure in counts.

NBP8/NBP9 FUNCTIONALITY & IMPLEMENTATION
COMMUNICATION BETWEEN THE SENSOR AND HOST

Host pins
Sensor pins
Registers

*SPI transfer **requested by the external host** via the WAKE-UP pin, while the NBPx is in the sleep state.*



1. Host disables the interrupt on the INT/READY pin.
2. Host configures the CS_B/WAKE-UP pin as GPIO output low to trigger an interrupt on NBPx side.
3. NBPx wakes up immediately, enables SPI and raises the INT/READY pin when the sensor is ready for the transfers.
4. NBPx writes in the SPIOPS register to halt itself.
5. Host polls the INT/READY pin to start the SPI transfers:
   ① Host configures the CS_B/WAKE-UP pin for SPI.
   ② Must perform a first dummy transfer to clear the clock fault error.
   ③ Completed all transfers, host clears the SPIOPS register.
6. NBPx resumes operation and drives the INT/READY pin to inactive state before disabling SPI block.
7. Host enable the interrupt on the INT/READY pin again.

Registers:

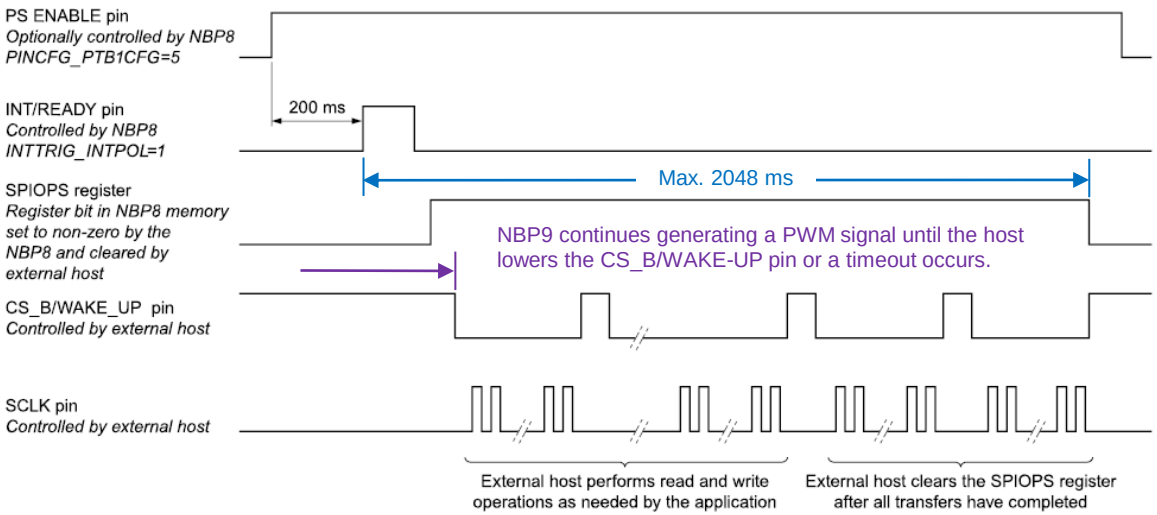
SPI Operations: SPIOPS (0x0038)
- SPIOPS[2]: Core read/write accesses on hold.

Interrupt pulse Trigger: INTTRIG (0x0053)
- INTTRIG_INTPOL: Selects the polarity of the INT/READY pin
- INTTRIG_INTDUR: Selects the duration of the pulse

NBP8/NBP9 FUNCTIONALITY & IMPLEMENTATION
COMMUNICATION BETWEEN THE SENSOR AND HOST

Host pins
Sensor pins
Registers

*SPI transfer **requested by the NBPx**, when an event requiring attention occurred.*



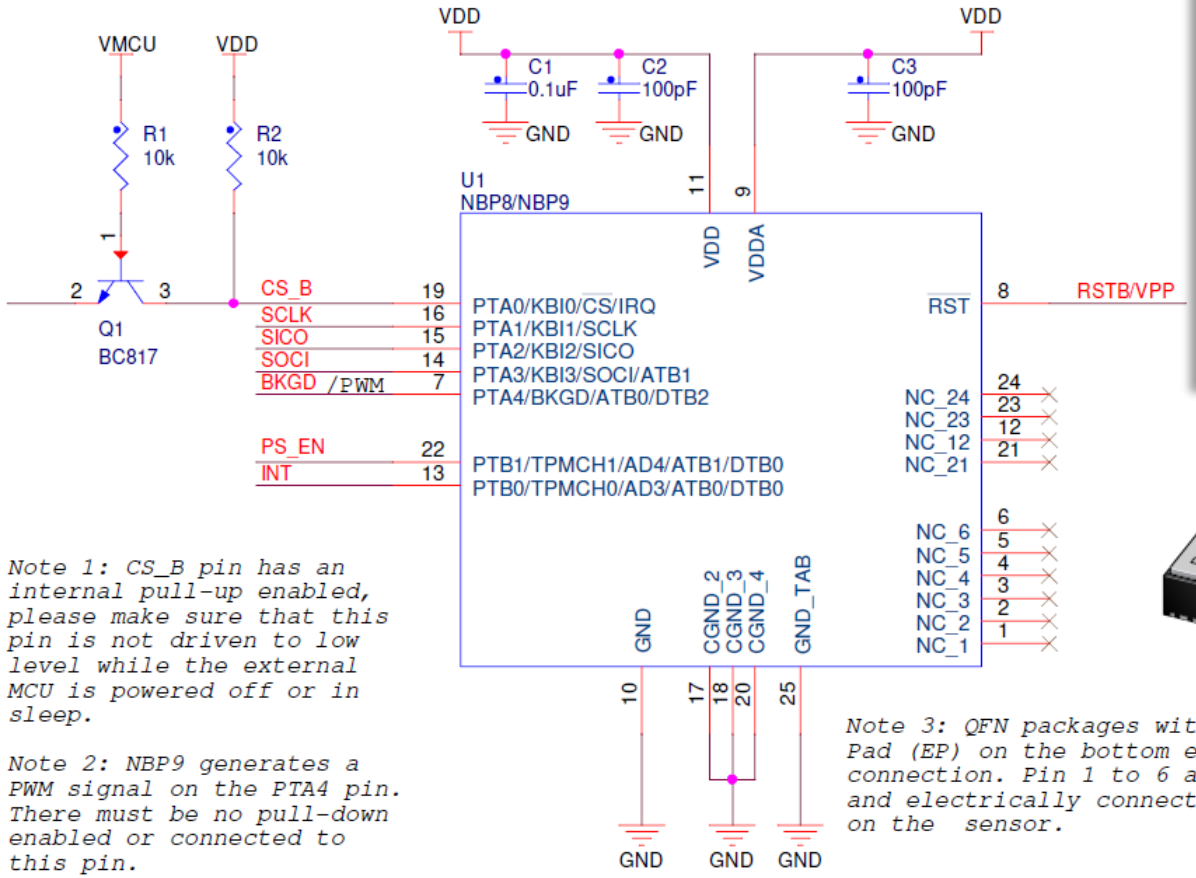
1. NBPx enables SPI， asserts the PS ENABLE pin to notify host, wait 200 ms.
2. NBPx generates a pulse on the INT/READY pin.
3. NBPx writes in the SPIOPS register to halt itself.
4. Host polls the INT/READY pin to start the SPI transfers after the pulse ended:
   ① No dummy transfer is needed since no SPI error is expected.
   ② Host acknowledges the INTF flag by writing CMD_ACKINTF bit.
   ③ Completed all transfers, host clears the SPIOPS register
5. NBPx resumes operation and clears the CMD_ACKINTF bit

Registers:

PIN Configuration: PINCFG (0x0052)
- PINCFG[2:0]: configures the PTB1 pin function as described below

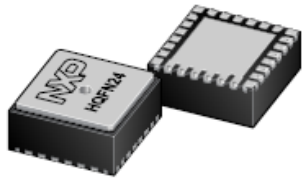
0x00 ~ 0x03	Disable
0x04	Enable, 1 is idle / 0 is asserted
0x05	Enable, 0 is idle / 1 is asserted
0x06 ~ 0x07	Disable

Schematic Design Reference

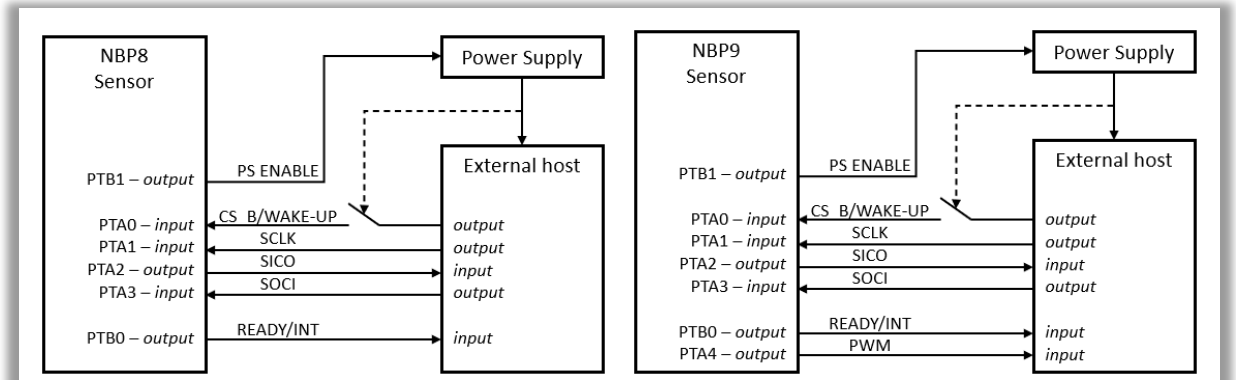


Note 1: CS_B pin has an internal pull-up enabled, please make sure that this pin is not driven to low level while the external MCU is powered off or in sleep.

Note 2: NBP9 generates a PWM signal on the PTA4 pin. There must be no pull-down enabled or connected to this pin.

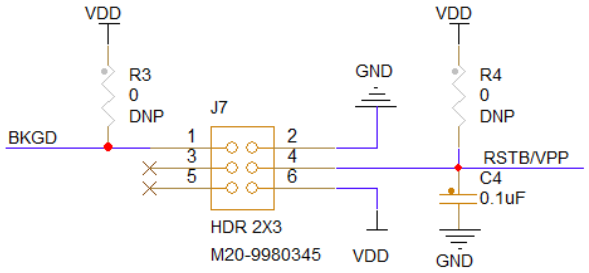


Note 3: QFN packages with an Exposed Pad (EP) on the bottom enables ground connection. Pin 1 to 6 are mechanically and electrically connected to the EP on the sensor.



Connections between the NBPx and external host

Note: All pins except CS_B are in high impedance state when the NBPx is in sleep, so the NBPx is not driving them while in sleep.



P&E BDM Multilink

Note 4: the BKGD pin and the RSTB/VPP pin have internal pull-up devices and can be connected to VDD in the application. Both pins shall be connected to VDD through a resistor (51k or greater) for in-circuit BDM. RSTB/VPP pin will only be used by customers who intend to reprogram the NBP.

NBP8/NPB9 Deliverables & Ecosystem

SECURE CONNECTIONS
FOR A SMARTER WORLD

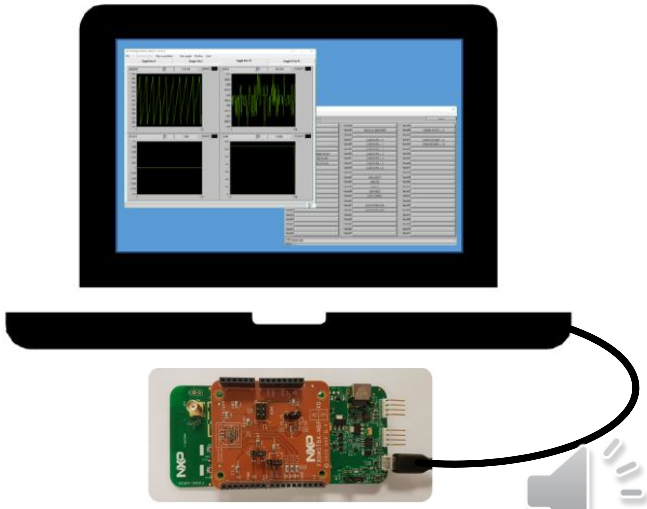
NBP8/NPB9 DELIVERABLES & ECOSYSTEM
BPMS COLLATERAL AND DOCUMENTATIONS

Product Website: *NBPx Fully Integrated Battery Pressure Monitor Sensor*

- **Documentation**
  - Datasheet:
    - *NBP8 – Battery pressure monitor sensor data sheet*
    - *NBP9 – Battery pressure monitor sensor data sheet*
  - Application Note: *AN1902 – Assembly guidelines for QFN and SON packages*

- **Development tools**
  - Freedom shield evaluation board: *FRDMSTBANBP8XD*
  - Freedom development board:
    - *FRDM-KW36*
    - *FRDM-KE15Z*
  - Application software:
    - *Application Software for the External MCU connected to the NBP8*
    - *Application Software for the External MCU connected to the NBP9*
  - NXP software development environment: *MCUXpresso IDE*
  - Download GUI: *NXP Sensor GUI*

- **Training**
  - Brainshark: *BPMS Product Training*



NBP8/NPB9 DELIVERABLES & ECOSYSTEM
BPMS FREEDOM EVALUATION AND DEMO KIT

FRDMSTBANBP8XD $52.00

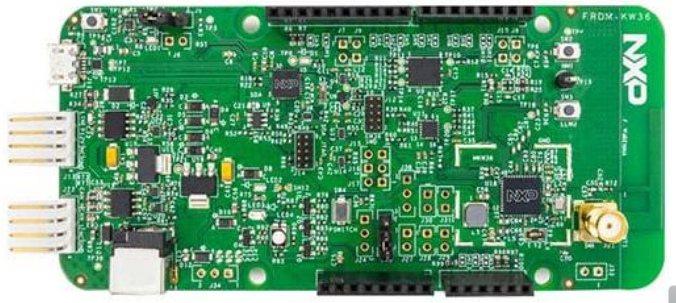
The FRDMSTBANBP8XD evaluation board incorporates a NBP8FD4T1 battery pressure monitor sensor that offers an intuitive way for pressure sensor evaluation.

FRDM-KE15Z $50.00

The FRDM-KE15Z Freedom Board is compatible with DC 5V and 3.3V power supply and features a KE15Z, a device boasting up to 256KB Flash and 32KB SRAM and numerous analog and digital peripherals. The onboard interfaces include an RGB LED, a 6-axis digital sensor, a 3-axis digital angular rate gyroscope, an ambient temperature sensor, and two capacitive touch pads.

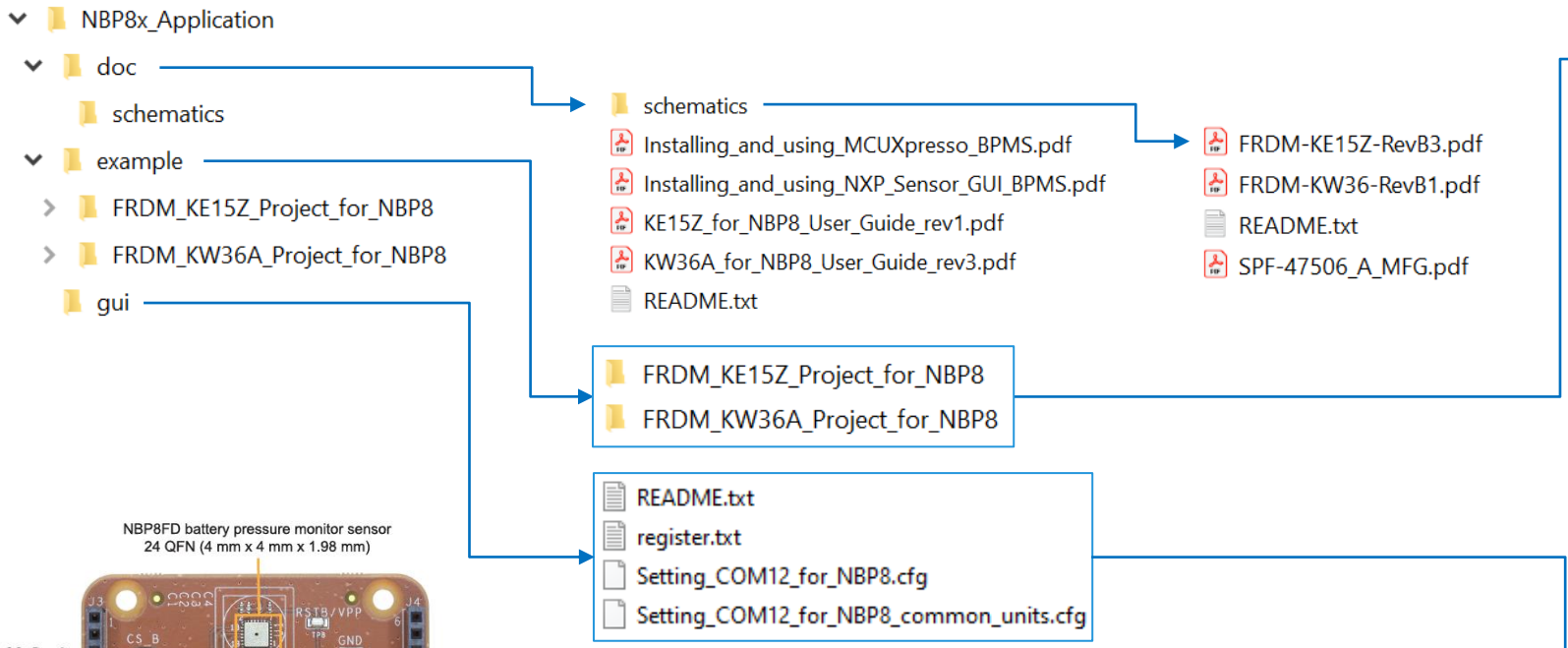
FRDM-KW36 $75.00

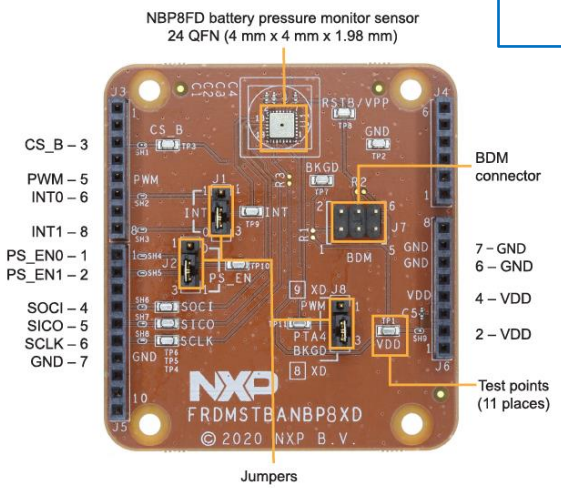
The FRDM-KW36 is a development kit enabled by the Kinetis® W KW36/35/34 (KW36) family built on Arm® Cortex®-M0+ processor with integrated 2.4 GHz transceiver supporting Bluetooth® Low Energy (BLE) v5 and Generic FSK. The KW36 integrate CAN/CAN-FD and LIN connectivity.



NBP8/NPB9 DELIVERABLES & ECOSYSTEM
BPMS APPLICATION SOFTWARE

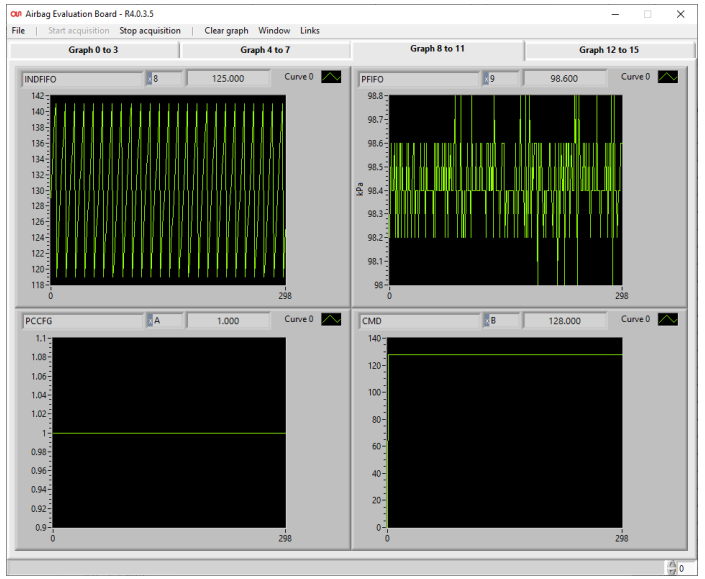
Application Software





- The FRDMSTBANBP8XD shield board comes with standard Arduino headers and can be paired and connected with NXP Freedom MCU boards for user evaluations and software development.
- For quick evaluation and prototyping, NXP provides a demo project targeted to the FRDM-KW36 / FRDM-KE15Z boards and hardware design files that help reduce the time to market.

MCUXpresso IDE



NXP Sensor GUI

TECHNOLOGY SHOWROOM

JOURNEYS BY DESIRED ENGAGEMENT

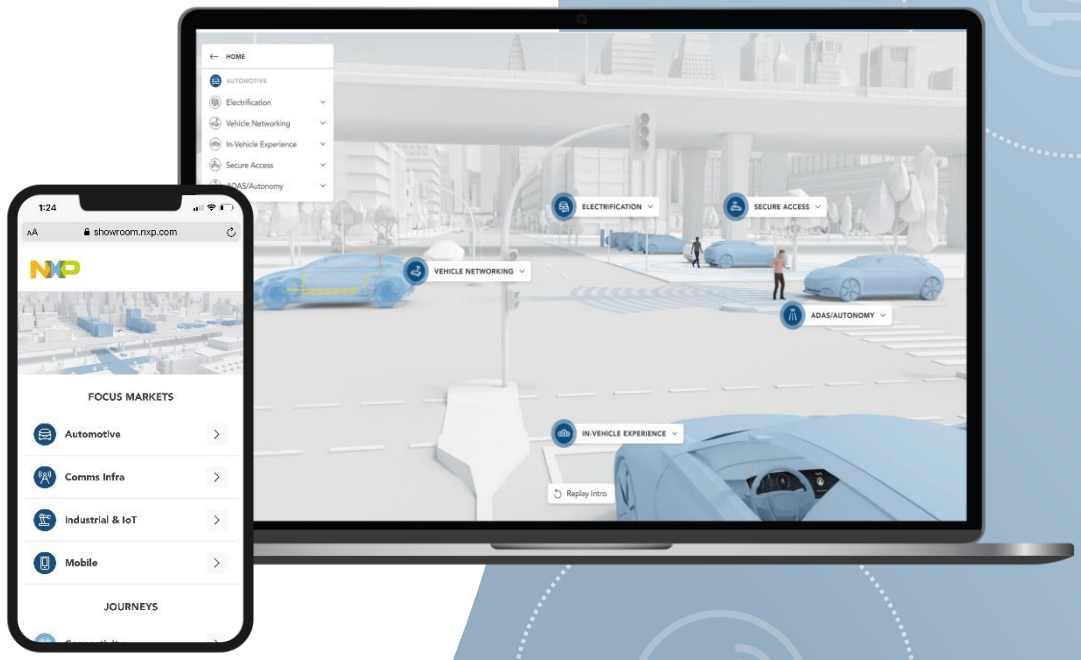
Self-guided tour
Live-streaming at set times
Guided tours

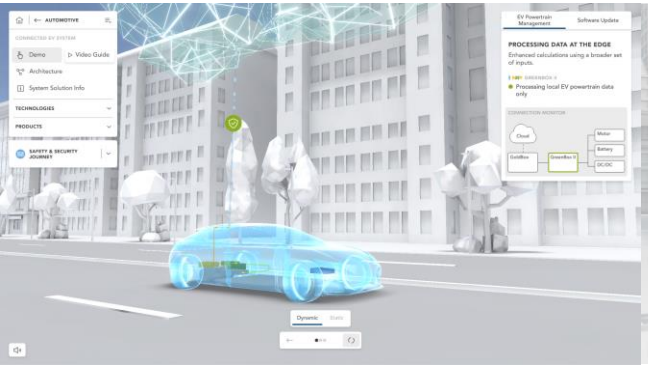
60+ VIRTUAL DEMOS

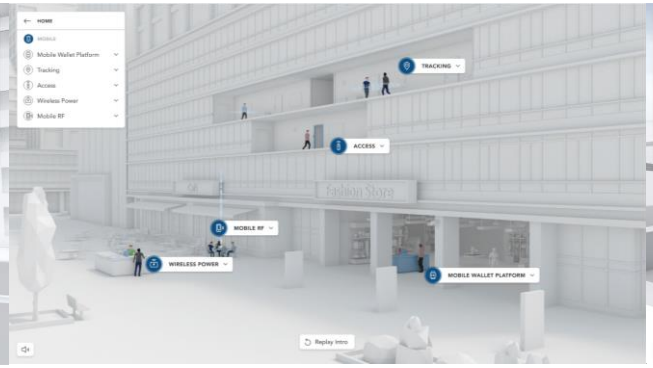
Focus on system solutions
Set up along NXP verticals

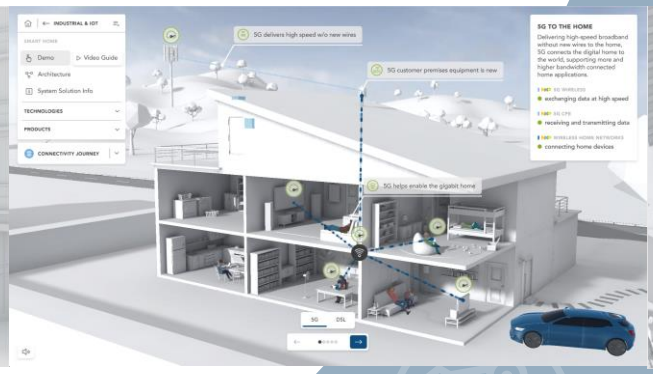
JOURNEYS BY DESIRED FOCUS

Low Power Innovations
Advanced Analog
Connectivity
Edge & AI/ML
Safety & Security









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Q&A

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