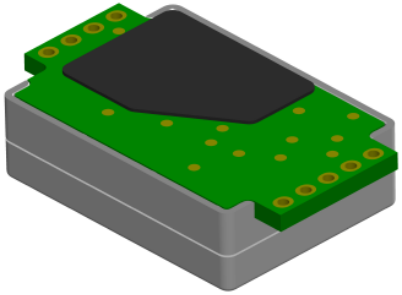
SenseAir®
Sensors for Life

LP8 CO_2 engine for battery-powered applications

User's Guide
Rev 1.13

SenseAir®
Sensors for Life

Standard Specifications



Charge per measurement:

Total	3.6 mC
IR source (lamp)	2.4 mC
Electronics	1.2 mC

Achieving RMS noise in CO2 measurements:

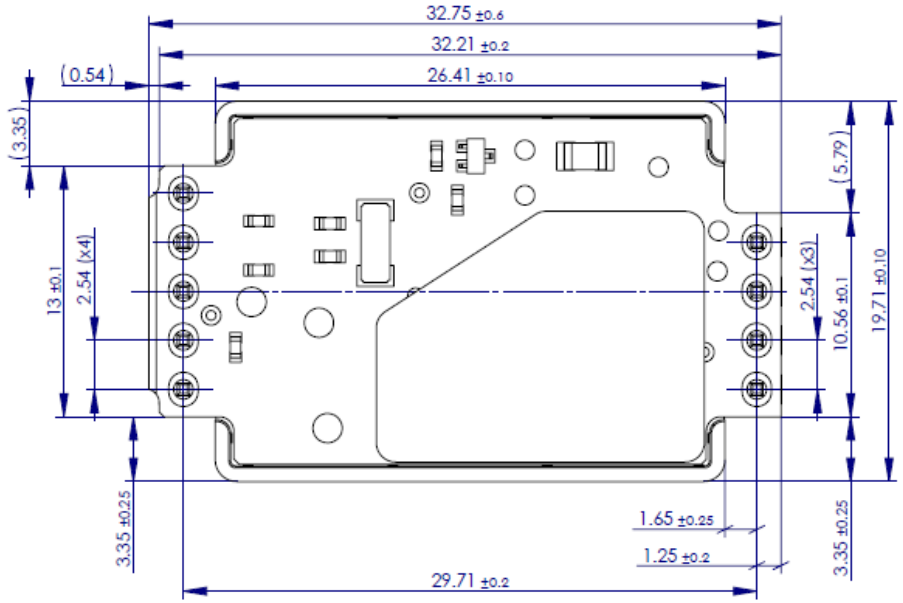
@400ppm	14 ppm
@1000ppm	25 ppm

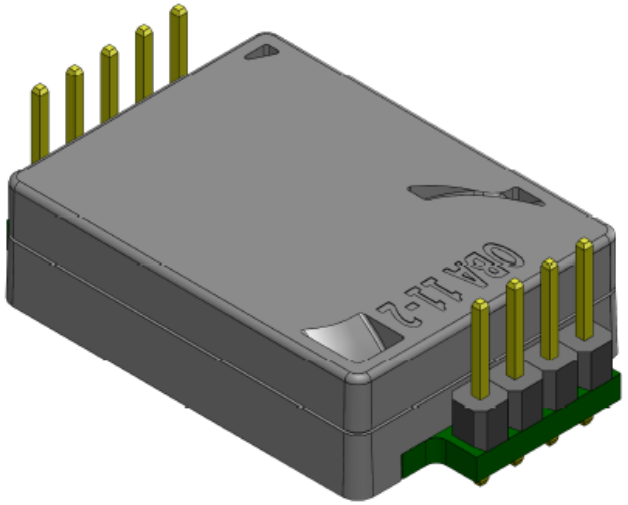
STANDARD SPECIFICATIONS

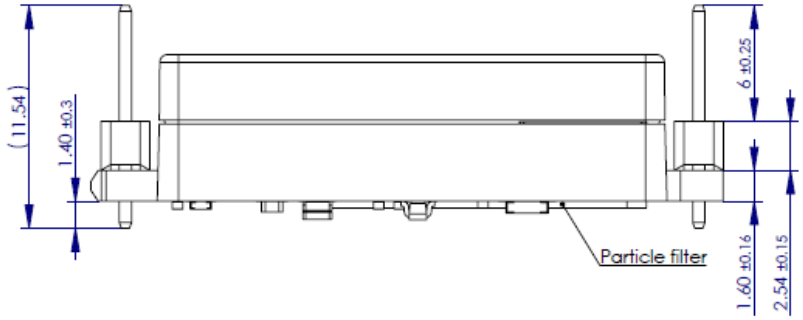
Measured gas	Carbon dioxide (CO_2)
Operating principle	Non-dispersive infrared (NDIR)
Measurement range	0 - 10000ppm
Accuracy CO_2	±50ppm ±3% of reading [1,4]
RMS noise CO_2	**14 ppm @ 400 ppm** **25 ppm @ 1000 ppm**
Accuracy Temperature	±0.7°C
Power supply	**2.9 – 5.5V**
Peak current	140 mA max. (125 mA typ. @ 25°C)
Shutdown current	1 µA [2,3]
Charge per measurement	**3.6 mC**
Energy per measurement	11.9 mJ @ 3.3V
Average current having	
16 s meas. period	225 µA [2,3]
60 s meas. period	61 µA [2,3]
120 s meas. period	31 µA [2,3]
Measurement period	≥16 s
Dimensions	**8 mm x 33mm x 20mm**
Life expectancy	>15 years
Operation range	0 - 50°C, 0 - 95% RH (non-condensing)
Communication	UART (host-slave protocol)

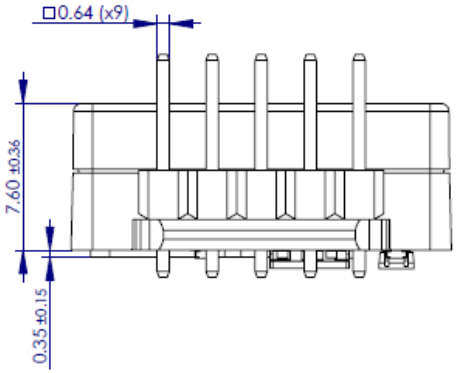
Note 1: 10 – 40°C, 20 – 60 % RH, after at least three 8 days periods, each followed by ABC command set in the Calculation Control byte
Note 2: Resistor network for measuring VCAP voltage adds 14 µA @5.5V
Note 3: External super-capacitor leakage is not considered
Note 4: Spec is ref. to uncertainty of calibration gas mixtures ±1%

Dimensions

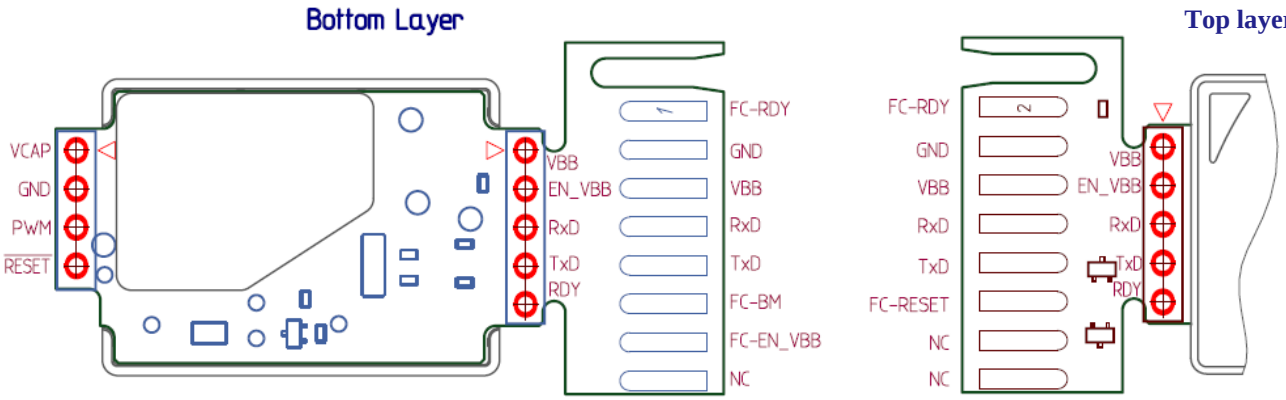

32.75 ±0.6
32.21 ±0.2
26.41 ±0.10
(0.54)
(3.35)
(5.79)
13 ±0.1
2.54 (x4)
2.54 (x3)
10.56 ±0.1
19.71 ±0.10
3.35 ±0.25
1.65 ±0.25
1.25 ±0.2
3.35 ±0.25
29.71 ±0.2




(11.54)
1.40 ±0.3
6 ±0.25
Particle filter
1.60 ±0.16
2.54 ±0.15


□0.64 (x9)
7.60 ±0.36
0.35 ±0.15

Pins description



Note: *VCAP and EN_VBB are connected to VBB at Factory Connector (if sensor is supplied with Factor Connector).*

Pin #	Name	Type	Maximum voltage, V	Description
JP1 (4-pin header)				
1	VCAP	Power	6.5	Lamp driver supply voltage. Sensor monitors this voltage using a 400k resistor network connected to the MCU ADC.
2	GND	Power	-	Ground
3	PWM	Output	3.6	I/O pin. Reserved for PWM functionality in other models.
4	RESET#	Input	2.5	Reset. Contains a pull-up, has to be driven by an open collector. Shall be left floating in LP8 because sensor is powered-up every measurement cycle – brownout MCU reset works.
JP2 (5-pin header)				
1	VBB	Power	5.5	Supply voltage of the MCU voltage regulator.
2	EN_VBB	Input	VBB	Enable pin of the voltage regulator. When in the logic low state VBB draws maximum 2µA of current.
3	RxD	Input	3.6	UART receive of sensor MCU
4	TxD	Output	3.6	UART transmit of sensor MCU
5	RDY	Output	3.6	Signal is used to synchronize sensor with a host system.

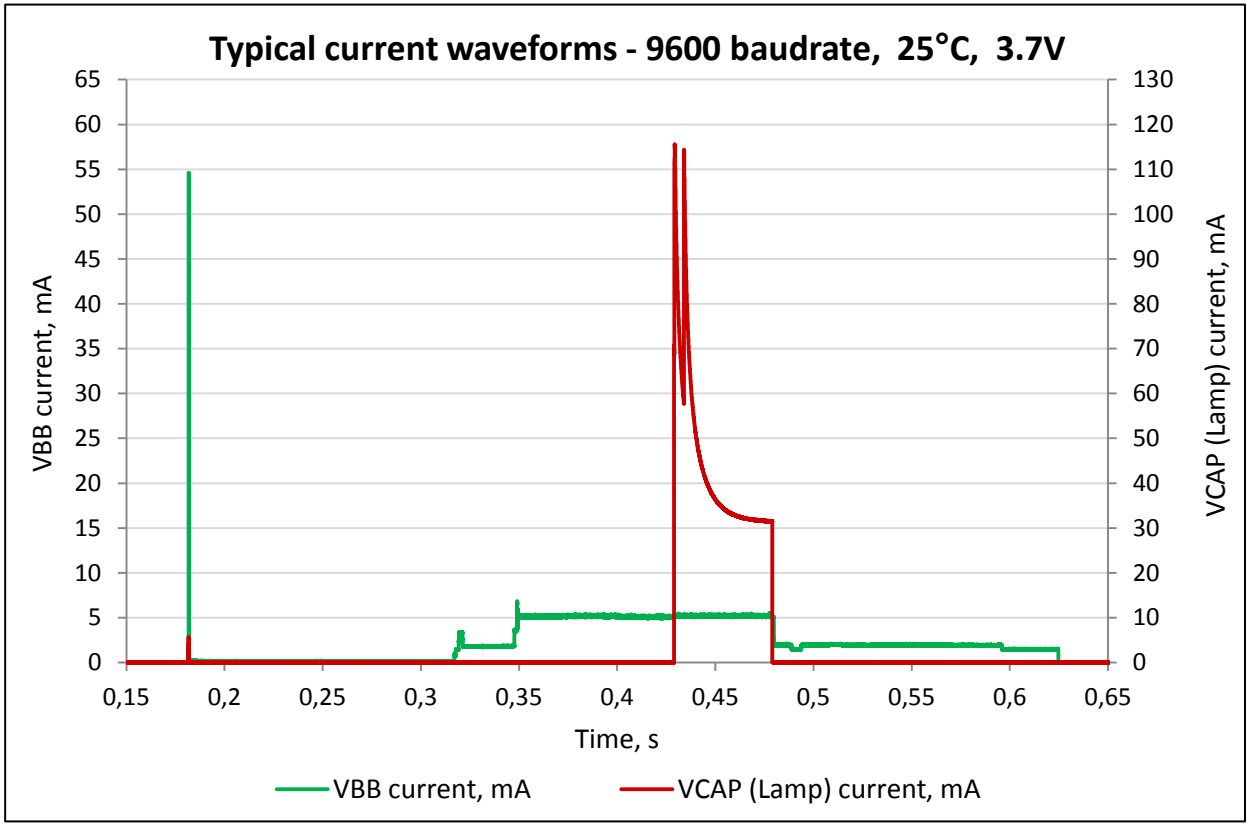
Electrical specifications

Parameter	Min	Typ	Max	Unit	Test conditions
Power supply voltage:					
VBB (sensor electronics)	2.9		5.5	V	
VCAP (lamp)	2.9		6.5	V	
Peak current					VBB = VCAP = 2.9 - 5.5V
VBB (sensor electronics) [1]		5.4	6	mA	T_{amb} = 0 - 50°C
VCAP (lamp) [2]		119	129	mA	T_{amb} = 25 °C
VCAP (lamp) [2]			134	mA	T_{amb} = 0°C (peak current decreases with increasing temperature)
Total (VBB + VCAP) [1,2]		125	140	mA	T_{amb} = 0 - 50°C
Shutdown current					
VBB (sensor electronics) [3]		1	2	µA	T_{amb} = 25°C
VCAP (lamp) with 400kΩ resistor network		14	15	µA	T_{amb} = 25°C, VCAP = 5.5V
VCAP (lamp) w/o voltage monitoring		0.1	0.2	µA	T_{amb} = 25°C, VCAP = 5.5V
Charge per measurement cycle					T_{amb} = 0 - 50°C, VBB = VCAP = 2.9 - 5.5V
VBB (sensor electronics)		1.1	1.2	mC	9600 baudrate
		1.0	1.1	mC	19200 baudrate
VCAP (lamp)		2.2	2.4	mC	

[1] Charging of 20 µF decoupling capacitance is not considered
[2] Charging of 220 nF decoupling capacitance is not considered
[3] Without pull-down resistor 100k on VBB_EN (mounted on request)

Typical current profile

Typical communication cycle with LP8 sensor requires less than 450 ms using 9600 UART communication baudrate.
If inrush current required for charging decoupling capacitors is excluded then typical values of peak current are:
VBB (electronics) – 5.4 mA; VCAP (lamp) – 119 mA; total – 125 mA.

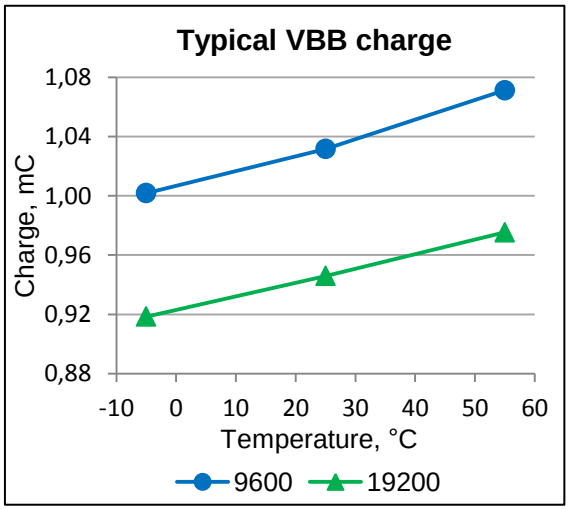


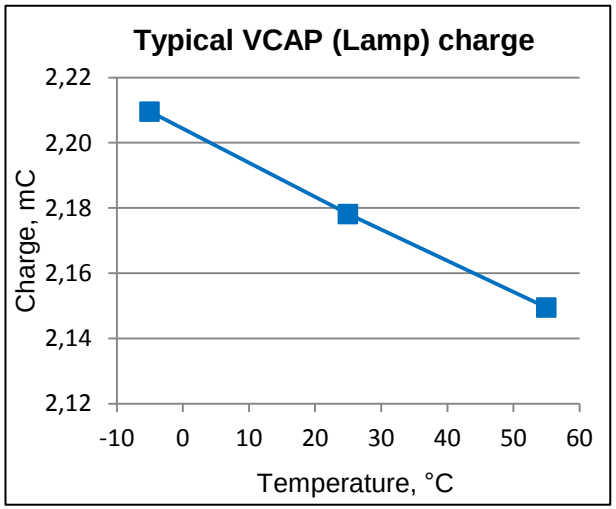
Measured charge
for the waveforms

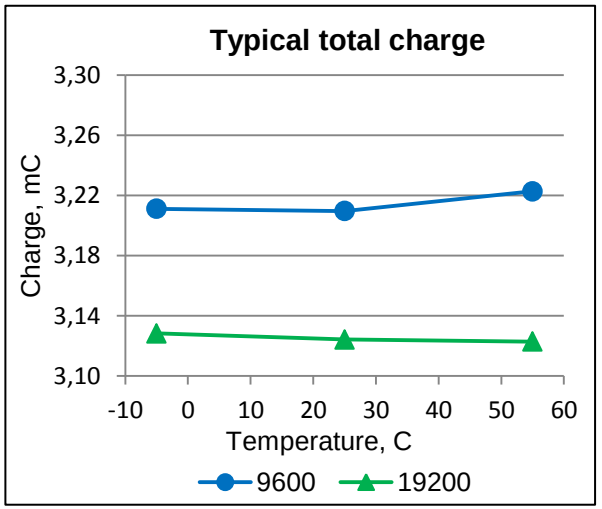
Power pin	Charge, mC
VBB (Electronics)	1,03
VCAP (IR source)	2,19
Total	3,23

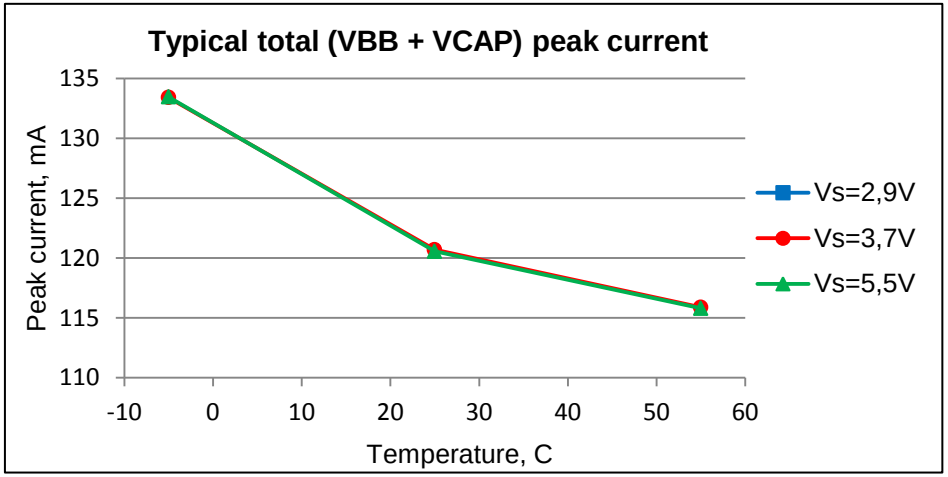
Typical consumption

The parameters below are tested in the whole supply voltage range of 2.9-5.5V. There is no significant dependence of the charge and peak current parameters on the supply voltage.

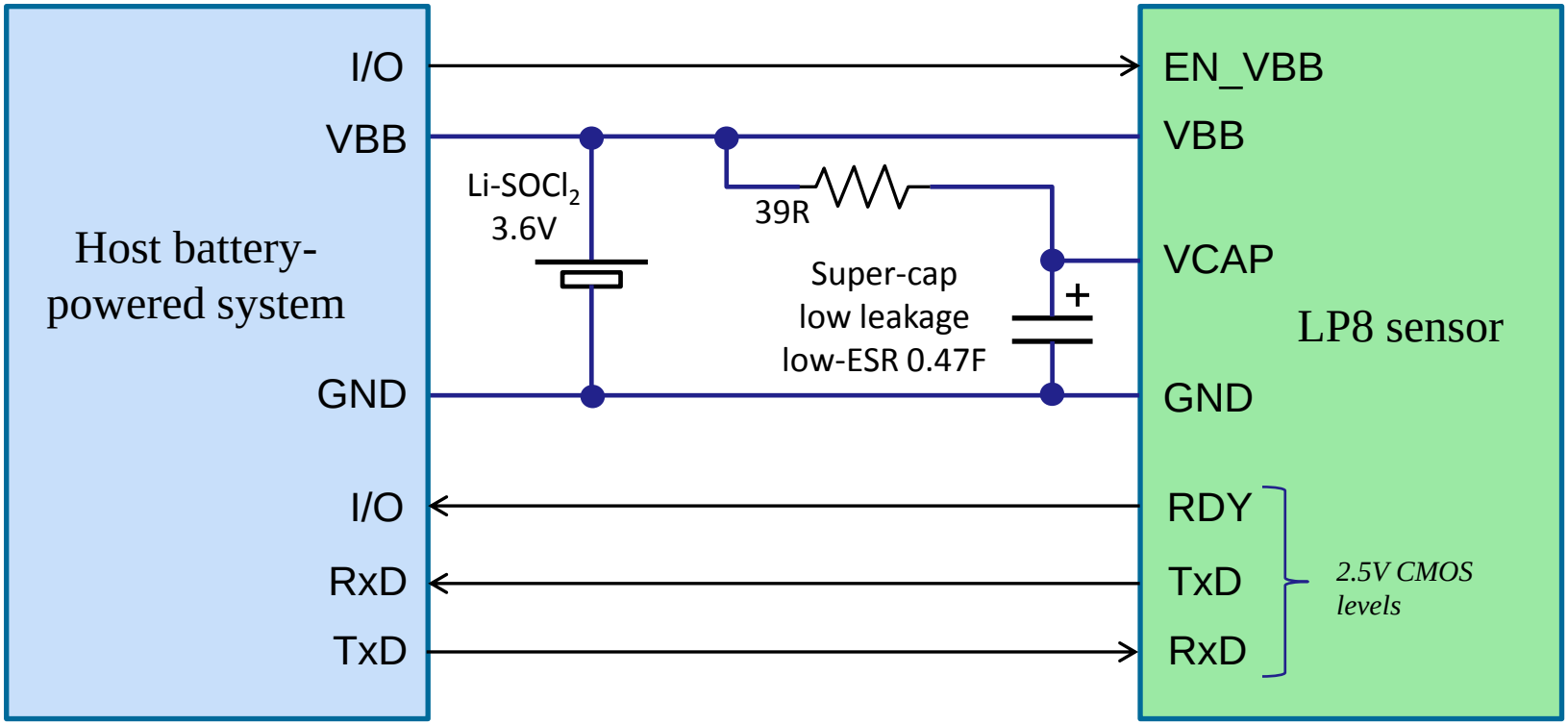








Simple host connection



- In some battery-powered systems current limiter can be simply a 5Ω resistor.
- Suggested super-cap type is Eaton Bussman PM-5R0H474-R (0.47F 5V). It is specified for 8µA leakage current @5V, 20^{0}C and 500mΩ ESR.
- Customer can use its own low-leakage switch (for example TPS22907) to switch off both VCAP and VBB between measurements. VBB can be supplied from super-cap.

Calculating average current consumption

$$I_{avg} = \frac{Q_{MCU} + Q_{lamp}}{T_{MEAS}} + I_{SHDN} + I_{C\_leak}$$

where:

I_{avg} – average current consumption
T_{MEAS} – measurement period set by customer
Q_{MCU} – MCU-part (VBB) charge per measurement
Q_{lamp} – lamp (VCAP) charge per measurement
I_{SHDN} – sum of shutdown currents of electronics and lamp driver (if customer uses its own switch the parameter is obtained from the switch specs)
I_{C_leak} – leakage current of super-capacitor

An example:

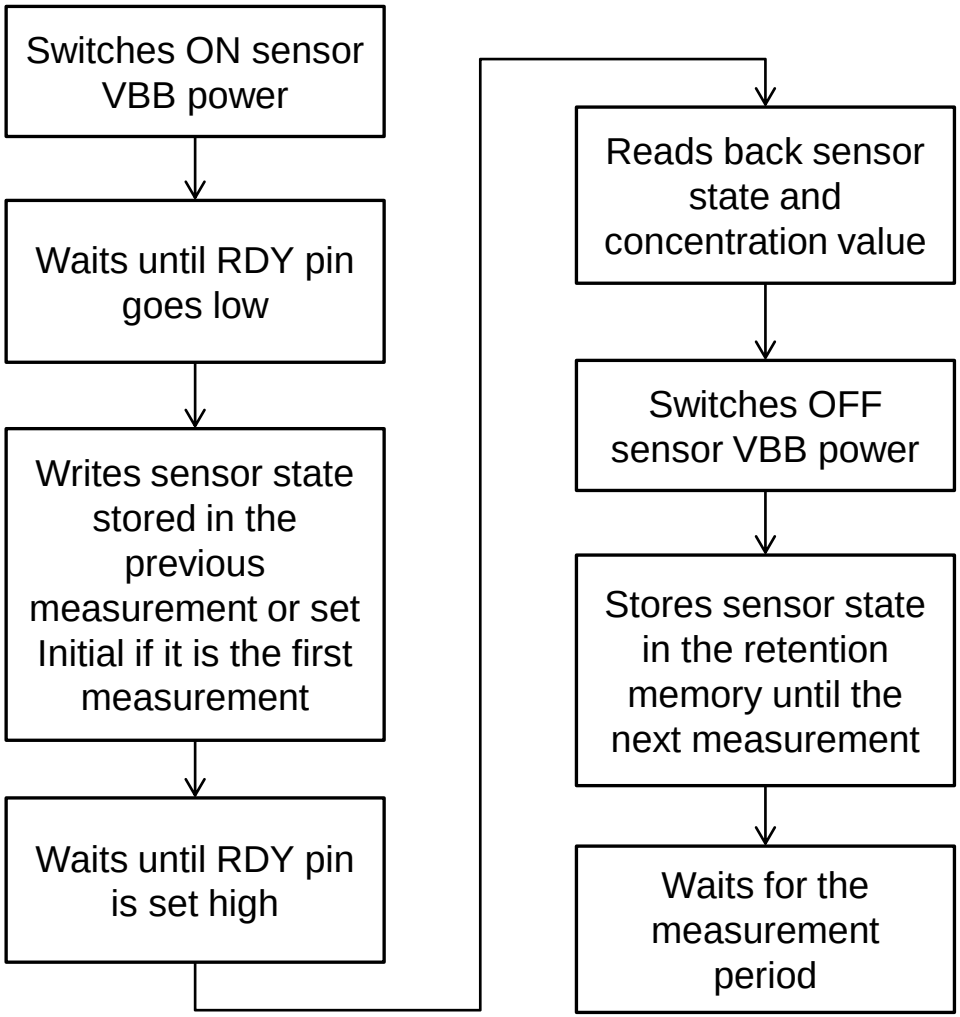
Measurement period is 30 seconds, sensor is configured with VCAP voltage monitor, super capacitor leakage current is 8 µA.

$$I_{avg} = \frac{1000\ [\mu A \cdot s] + 2200[\mu A \cdot s]}{30\ [s]} + 15\ [\mu A] + 8\ [\mu A] = 130\ [\mu A]$$

Average current consumption can be reduced by:

- Increasing measurement period.
- Using an external low-leakage switch (for example TPS22907) for both VBB and VCAP.
- Using super capacitor with lower leakage current.

Sensor control by a host MCU system



Measurement period of the sensor is determined by customer host system and may vary without degrading measurement accuracy.
Minimum allowed measurement period is 16 seconds (below 16 seconds accuracy is not guaranteed).

Low consumption hints

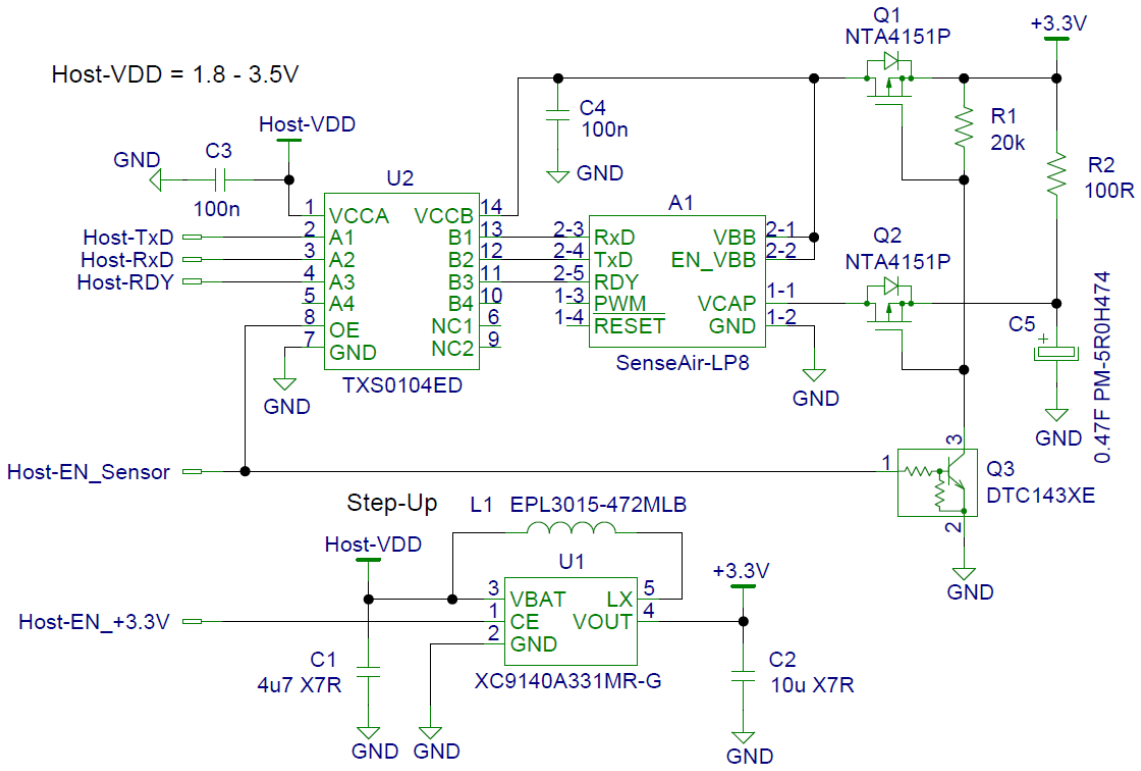
- ✓ VCAP pin has a 400kΩ resistor-divider network connected to MCU ADC used for measuring voltage supplied to the lamp driver. Monitoring that this voltage does not drop below allowed threshold during lamp pulse insures measurement accuracy of CO_2. Use a switch for VCAP voltage to eliminated excess current consumed by the network between measurements.
- ✓ A current source instead of resistor reduces time needed for charging the super-capacitor.
- ✓ Super-capacitor can be charged only for a small fraction of time prior measurement. To keep a voltage equilibrium on the super-capacitor one need to supply the same charge as consumed by single measurement, 3.6 mC. For example:

  Power supply voltage is 3.3V

  Desired voltage equilibrium on the super-capacitor is 3.1V

  Under these circumstances a 100Ω resistor will provide (3.3V-3.1V)/100Ω = 2mA current, enough to charge the capacitor during 3.6mC / 2mA = 1.8 seconds.
- ✓ Host MCU shall hold IO pins connected to TxD, RxD and RDY signals in Hi-Z or Low state when LP8 power is off. Leakage current on these pins of LP8 module in the power-off state is not specified.
- ✓ Using external switches on both VBB and VCAP with sub-microampere leakage current can help to reduce average current consumption further.

1.8 - 3.5V powered system example by BigClown Labs



4) First power-up requires long charging of the super-capacitor.

5) Further reduction of the current consumption can be achieved by introducing a low-drop current source in place of R2.

The application example is provided by BigClown Labs www.bigclown.com

Host MCU is powered from 1.8 - 3.5V supply voltage.
Measurement period is set to 30 - 60 seconds.

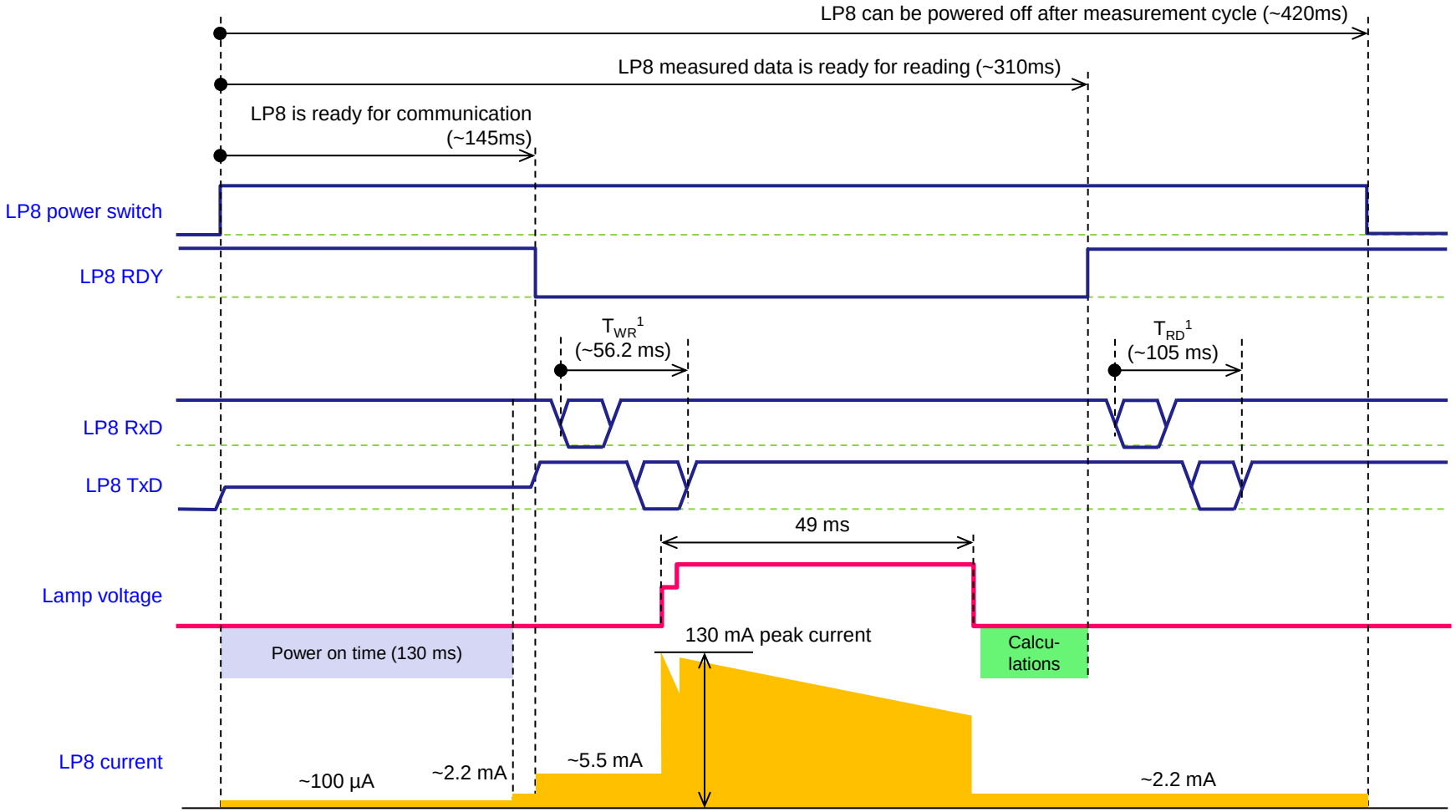
In order to achieve lowest possible average current consumption of the LP8 sensor the following circuitry and logic are employed:

1) Super-capacitor C5 is charged via R2 only for 2...5 seconds prior the sensor power up. This eliminates super-capacitor leakage current. Step-up regulator is disabled most of the time consuming only 0.1µA typical between measurements.

2) After C5 charging phase host switches on transistors Q1 and Q2. Presence of the Q2 eliminates 14µA VCAP measurement network current.

3) Sensor IO and host-MCU IO are isolated by a level-shifter with OE control pin and independent power-supply to eliminate leakage current on RxD, TxD and RDY signals during power on/off transitions and when sensor's power is off.

Time diagram



[1] typical values for 9600 baudrate

UART communication

MODBUS UART settings for SenseAir sensors:

- Device address – 0x68 or 0xFE
- Baudrate – 9600
- Parity – No
- Stop bits – 2

MODBUS ADU (Application Data Unit)			
Address field (1 byte)	Function Code	Data	CRC (Low byte first then High byte)
	MODBUS PDU		

Function Code 65 (0x41) Write to RAM MCU

Request PDU

Function code	1 byte	0x41
Starting Address Hi	1 byte	Address Hi
Starting Address Lo	1 byte	Address Lo
Number of bytes to write	1 byte	N
Data to write	N bytes	

Response PDU

Function code	1 byte	0x41

Error Response PDU

Function code	1 byte	0xC1
Error code	1 byte	Error code

Function Code 68 (0x44) Read from RAM MCU

Request PDU

Function code	1 byte	0x44
Starting Address Hi	1 byte	Address Hi
Starting Address Lo	1 byte	Address Lo
Number of bytes to read	1 byte	N

Response PDU

Function code	1 byte	0x44
Number of bytes to read	1 byte	N
Data	N bytes	

Error Response PDU

Function code	1 byte	0xC4
Error code	1 byte	Error code

Read / write sensor state and measurement result

Sensor RAM address space dedicated to the communication with host

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0x80	Calculation control	Sensor State has to be written before measurement and read back by host after measurement to be stored in the host retention memory during sleep period.														
0x90	Sensor State								Host_Pressure (S16, 0.1 hPa)		Conc (S16) *unfiltered		ConcPC (S16) *unfiltered		Space_Temp (S16, 0.01°C)	
0xA0	VCAP1 (S16, mV)		VCAP2 (S16, mV)		Error Status3	Error Status2	Error Status1	Error Status0	Conc_filtered (S16)		ConcPC_filtered (S16)		*Reserved*			

Communication sequence

Write prior measurement		
Write 26 bytes to the RAM area **0x80-0x99**		
Calculation control	Sensor State	Host_Pressure (S16, 0.1 hPa)

Read back after measurement			
Read 44 bytes from the RAM area **0x80-0xAB**			
	Sensor State		Measured Date and Error Status

SenseAir® Sensors for Life

Parameters

Parameter	Length, bytes	RAM Starting Address	Format	Units	Description
Calculation Control	1	0x80	Bit structure	N/A	Determines calculation flow in the sensor
Sensor State	23	0x81	Structure	N/A	23 bytes structure which has to be saved in the host retention memory for the next measurement.
Host_Pressure	2	0x98	S16	10 Pa (0.1 hPa)	Pressure measured by host. If pressure is not measured, then host has to write the default value of 10124 (1012.4 hPa) which assumes no pressure correction applied.
Conc	2	0x9A	S16	ppm	Non pressure-corrected unfiltered concentration value
ConcPC	2	0x9C	S16	ppm	Pressure-corrected unfiltered concentration value
Conc_filtered	2	0xA8	S16	ppm	Non pressure-corrected filtered concentration value
ConcPC_filtered	2	0xAA	S16	ppm	Pressure-corrected filtered concentration value
Space_Temp	2	0x9E	S16	0.01 °C	Temperature measured by sensor NTC
VCAP1	2	0xA0	U16	mV	VCAP voltage measured by sensor prior lamp pulse
VCAP2	2	0xA2	U16	mV	VCAP voltage measured by sensor at the end of lamp pulse
Error Status	4	0xA4	Bit Structure	N/A	Error bit structure

S16 – signed integer 16 bits
U16 – unsigned integer 16 bits

Calculation Control byte

0x10	- Initial measurement (filters reset, ABC sample reset and other initial actions)
0x20	- Sequential measurement
0x40	- Zero calibration using unfiltered data
0x41	- Zero calibration using filtered data
0x42	- Zero calibration using unfiltered data, reset filters
0x43	- Zero calibration using filtered data, reset filters
0x50	- Background calibration using unfiltered data
0x51	- Background calibration using filtered data
0x52	- Background calibration using unfiltered data, reset filters
0x53	- Background calibration using filtered data, reset filters
0x70	- ABC (based on filtered data)
0x72	- ABC (based on filtered data) + reset filters

A host system counts ABC period itself (suggested period is 8 days) and has to write ABC command to the “Calculation Control byte” when ABC period expires.

Sensor recalibration

The LP8 sensor works as a slave and totally rely on host actions applied through the “Calculation Control” byte. The differences between three types of calibration used in LP8 are:

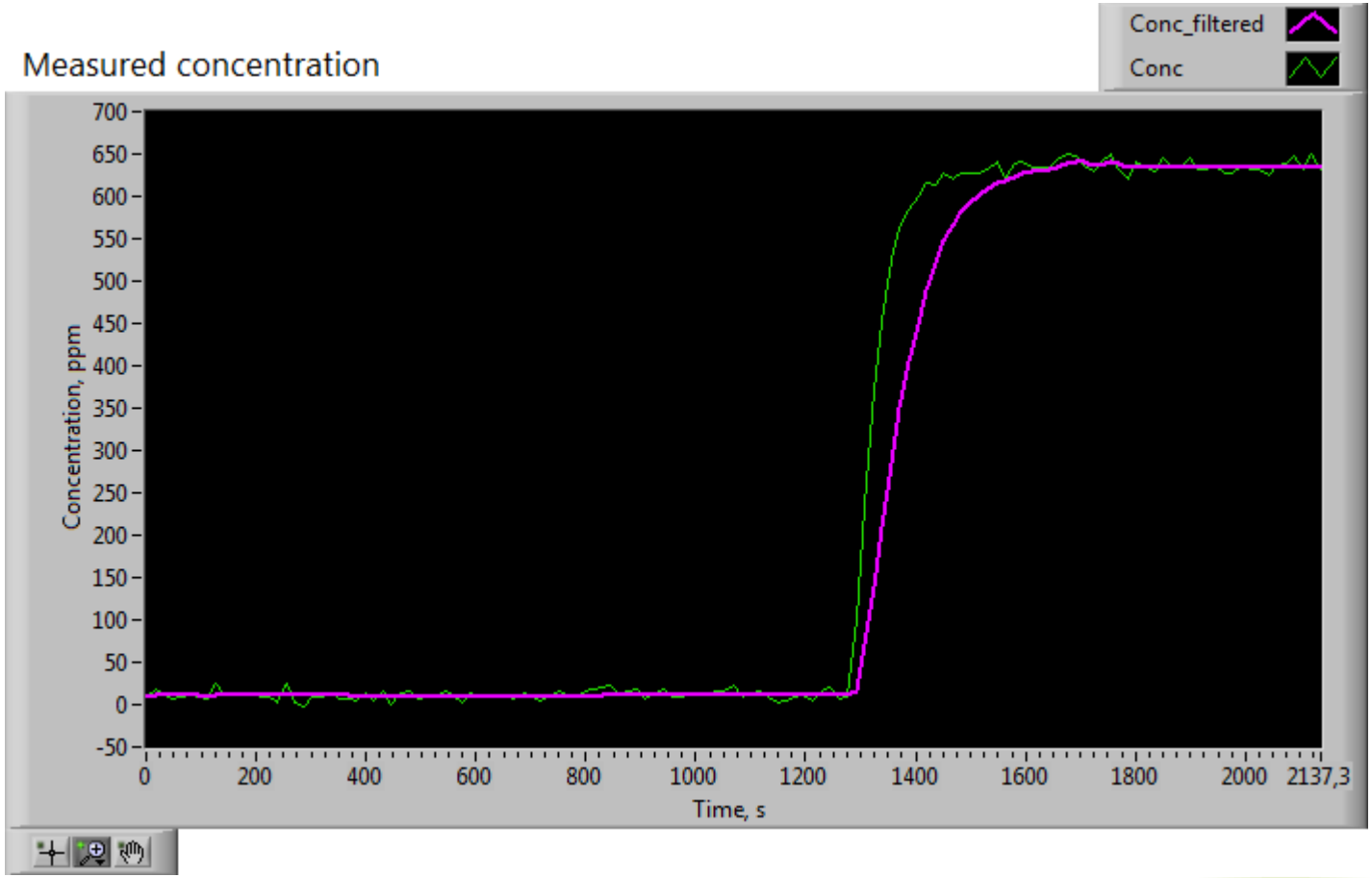
1) ABC (**A**utomatic **B**aseline **C**orrection) – sensor uses for recalibration the lowest concentration value treated as 400 ppm (together with remembered accompanying parameters) found during the period from the last “Initial state” / “ABC” / “Background / Zero calibration” commands written into the “Calculation Control” byte.
2) Background calibration (fresh air is treated as 400 ppm)
    a) Using unfiltered channel – sensor considers current unfiltered measurement values to provide recalibration
    b) Using filtered channel – sensor consider filtered values to provide recalibration (sensor has to be exposed for fresh air >40 blinks)
3) Zero calibration
    a) Using unfiltered channel – sensor considers current unfiltered measurement values to provide recalibration
    b) Using filtered channel – sensor consider filtered values to provide recalibration (sensor has to be exposed for zero gas >40 blinks)

Sensor response

Concentration in a plastic bag with LP8 sensor is changed from 0 ppm (Nitrogen) to 650 ppm.

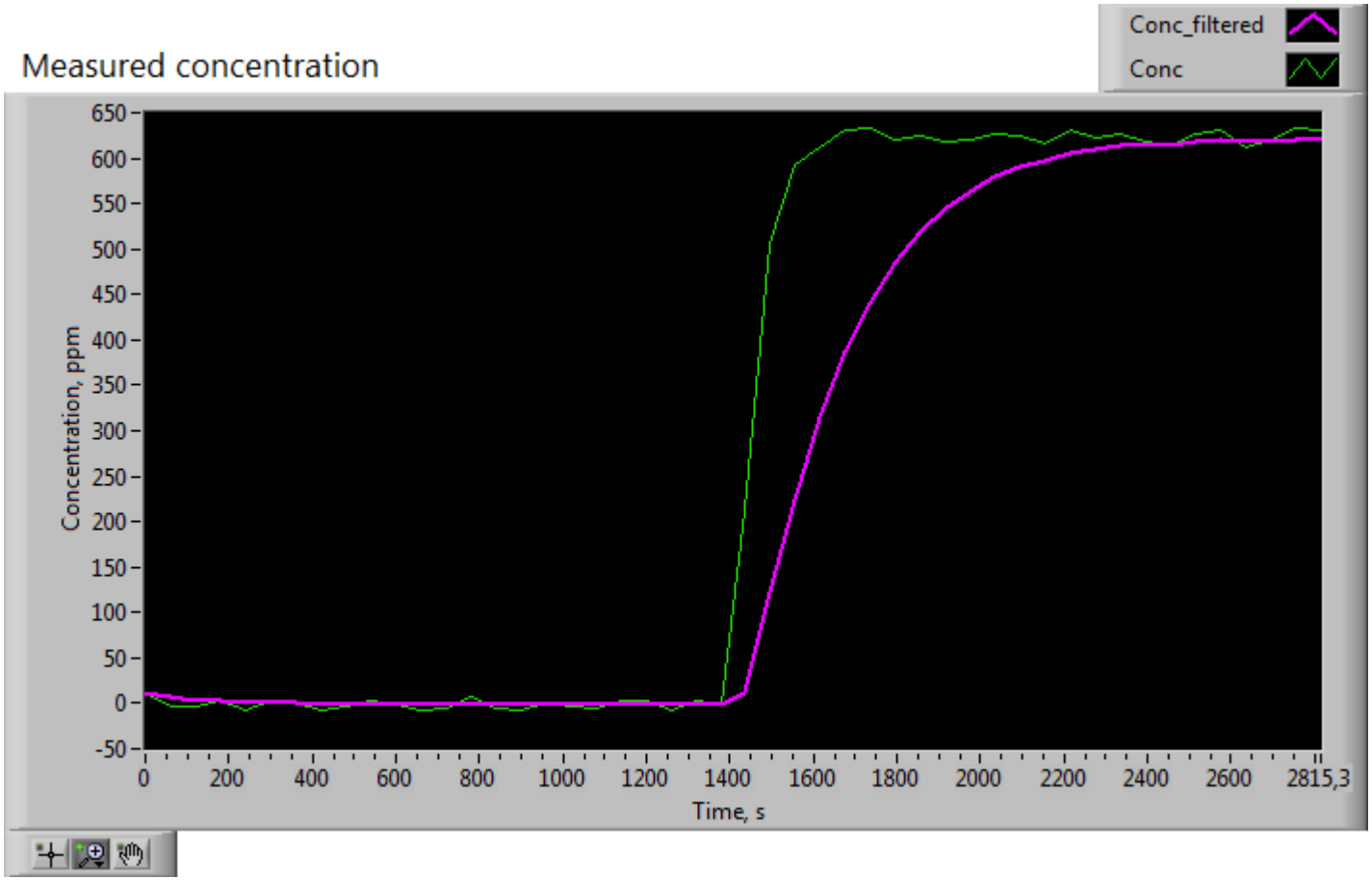
* gas flow rate is ~1.5L/min, the plastic bag volume is ~1L, so the concentration changing rate is limited by this factors as well.

Measurement period is set to 16 seconds. Filtered signal settles to 95% in 7 minutes.
Settling time of the unfiltered signal is 4 minutes.



Sensor response

Measurement period is set to 60 seconds (1 minute).
Filtered signal settles to 95% in 16 minutes.
Settling time of the unfiltered signal is approximately 5 minutes.



Error Handling

ErrorStatus structure

	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
ErrorStatus0	WarmUp	Memory	OutOfRange	SelfDiag	Calibration	AlgError	*Reserved*	FatalError
ErrorStatus1	Parameters override bits				*Reserved*	ADC Error	VCAP2 low	VCAP1 low
ErrorStatus2	*Reserved*				Unfiltered concentration channel OOR bits			
ErrorStatus3	*Reserved*				Filtered concentration channel OOR bits			

Error Handling

ErrorStatus0 byte description

Bit	Bit Name	Error Description	Suggested Action
0	FatalError	**Fatal Error** The bit is a joint bit for different error sources when sensor can not provide correct operation, among them: • Configuration EEPROM parameters are out of range or corrupted • Virtual EEPROM memory read/write error • Error in VCAP measurements	Switch off/on sensor power and start with “Initial Measurement” in the Calculation Control byte. Contact local distributor.
2	AlgError	**Algorithm Error** Configuration EEPROM parameters are out of range or corrupted	
3	Calibration	**Calibration Calculation Error** Out of range error at Zero-/Background calibration and ABC	Repeat recalibration or wait until next ABC event.
4	SelfDiag	**Self Diagnostics Error** Hardware error is detected or important EEPROM parameters are corrupted	Contact local distributor.
5	OutOfRange	**Out Of Range Error (OOR)** Indicates an error which occurs at different stages of concentration calculation algorithm. Resets automatically after source of error disappears.	Try sensor in fresh air. Perform sensor zero or background calibration. Check sensor temperature readings.
6	Memory	**Memory Error** Virtual EEPROM read/write error: page checksum error during read or write verification, FLASH operation error.	Contact local distributor.
7	WarmUp	**WarmUp bit** Bit is not set in customer mode	-

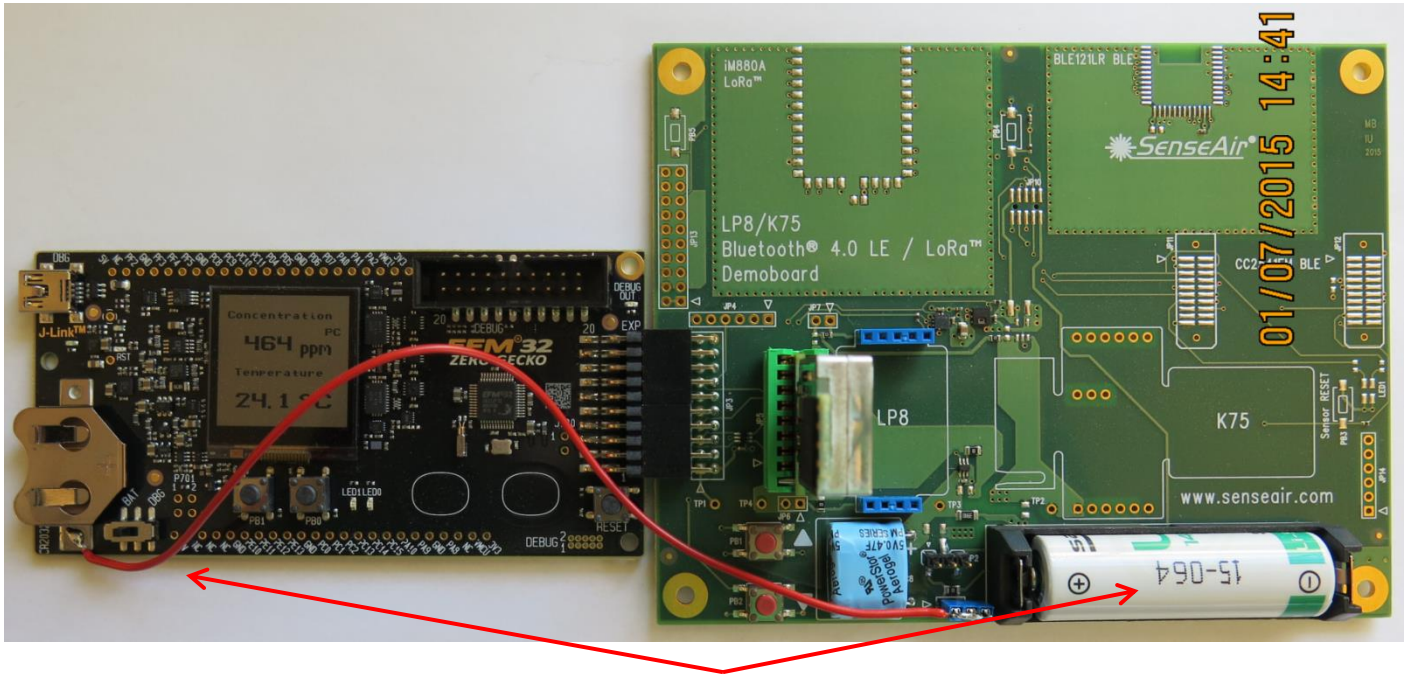
Error Handling

ErrorStatus1 byte description

Bit	Bit Name	Error Description	Suggested Action
0	VCAP1 low	**VCAP1 voltage low** Voltage measured prior lamp pulse is below preset threshold. The threshold is 2.8V±3%.	Check battery. Sensor supply voltage is below specified operational limit of 2.9V.
2	VCAP2 low	**VCAP2 voltage low** Average voltage measured at the beginning of lamp pulse (during inrush steps) is below preset threshold. The threshold is 2.7V±3%.	Equivalent series resistance of the sensor power supply source (a battery or super-capacitor) is not enough to provide low-voltage drop during 125mA lamp inrush step.
3	ADC Error	**ADC Error** MCU ADC out-of-range error has occurred.	Switch off/on sensor power and apply “initial measurement” to the Calculation Control byte. Contact local distributor.
4-7	Parameters override bits	This bits indicate which parameter is forced to a predefined value in the debug mode. Should not appear during normal operation.	-

Bits 3-0 of the **ErrorStatus2** and **ErrorStatus3** bytes decode on what algorithm stage an ”Out Of Range Error” (OOR) has occurred in unfiltered and filtered calculation channel respectively.

EFM32 Display Host Demo



Battery on the Demoboard is used to power EFM32 Starter Kit.
In turn Demoboard is supplied from the VMCU pin of the Starter Kit expansion connector.

Display part:
EFM Zero Gecko MCU starter kit with static Toshiba graphical display.
Display is updated with measurement period.

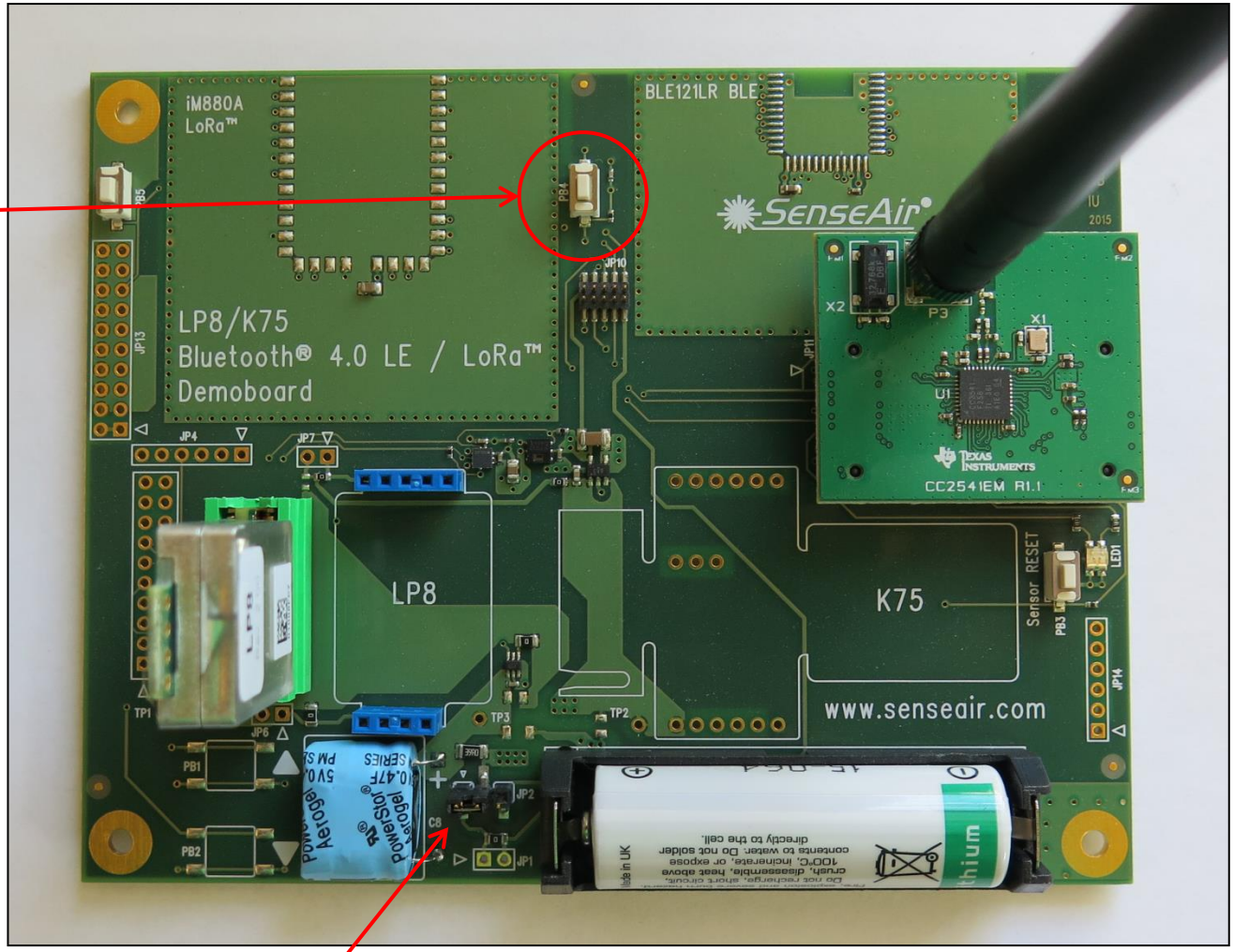
Charge per measurement:

Display Host part	2.4 mC
LP8 sensor	3.6 mC

Host firmware source code for EFM32 Starter Kit is available in the demo Dropbox folder.

BLE Host Demo

CC2541 Host reset button



jumper

Dropbox folder with software and documentation

- Electronic schematic and different BOM options of Demo-board
  …\Dropbox\Low Power Demo\LP8_K75 BLE_LoRa Demoboard\Electronic design
- CC2541EM BLE Host firmware, HEX-file
  …\Dropbox\Low Power Demo\LP8_K75 BLE_LoRa Demoboard\FW CC2541EM BLE Host\Delivery Archive\
- EFM32 Display Host firmware and source code
  …\Low Power Demo\LP8_K75 BLE_LoRa Demoboard\FW EFM32 Display Host\Delivery Archive\
- Simple LabVIEW program for current measurements
  …\Dropbox\Low Power Demo\LabVIEW\Current Monitor\
- Android demo application
  …\Dropbox\Low Power Demo\AndroidDemo\
- This file
  …\Dropbox\Low Power Demo\Documentation\

Revision History

Document Revision	Page	Changes
1.06	4	PWM pin# changed to 3, RESET# pin# changed to 4. RDY, PWM changed from I/O to Output.
	6	RxD/TxD on the host picture are swapped.
	8	«*Write sensor state stored in the previous measurement*» is changed to «*Write sensor state stored in the previous measurement or set Initial if it is the first measurement*».
	9	«*LP8 is powered*» is changed to «*LP8 can be powered off after measurement cycle*». A note 1 is added which specifies that typical timing values are taken for 9600 baudrate.
	10	The order of CRC bytes is pointed explicitly: «Low byte first, then High byte».
	12	S16 – signed integer 16 bits U16 – unsigned integer 16 bits
1.07	2	Accuracy specifications are changed to: ±50ppm ±3% of reading RMS CO2 noise specifications are changed to: 14 ppm @ 400 ppm, 25 ppm @ 1000 ppm Operation range is changed to: 0 - 50°C, 0 - 95% RH (non-condensing)
1.08	14-16	Error handling description is added to the pages 14-16
1.09	2,6, 7, 16	Peak current specifications are updated. Max. peak current is140 mA for the full voltage and temperature operating range (125 mA typical @ 25°C). Typical LP8 current profile is added. Typical consumption parameters vs. temperature and baudrate are added. Sensor recalibration concept (ABC, Zero/Background calibration) are explained on the page 16
1.10	3	Sensor dimensions are updated
1.11	5	Total peak current is added to the electrical specifications
1.12	13,14,17,18	Default pressure which gives no pressure correction (PC) = 10124 (1012,4 hPa). Filtered concentration is added to the master-slave protocol (pages 13, 14). Sensor response when gas is flashed in a plastic bag with moderate volume is shown as an example (pages 17,18)

Revision History

Document Revision	Page	Changes
1.13	2	Resistor network at VCAP pin adds current 14 µA (@5.5V).
	11,12	Low consumption hints. Application example from BigClown Labs.