

Table of Contents

1	Introduction.....	2
2	DPA Commands.....	2
2.1	Read Sensors.....	2
2.2	Read Sensors with Types.....	3
2.3	Enumerate Sensors.....	3
3	FRC Commands.....	3
3.1	2-bits sensor value - 0x10.....	4
3.2	1-byte sensor value - 0x90.....	4
3.3	2-byte sensor value - 0xE0.....	4
3.4	4-byte sensor value - 0xF9.....	4
3.5	Predefined FRC values.....	4
4	Sensor Types.....	4
4.1	[0x01] Temperature.....	4
4.1.1	WrittenData.....	5
4.2	[0x02] CO ₂ (carbon dioxide).....	5
4.3	[0x03] VOC (volatile organic compounds).....	5
4.4	[0x04] Extra-low Voltage.....	5
4.4.1	Oxidation-Reduction Potential (ORP).....	5
4.5	[0x05] Earth's Magnetic Field.....	6
4.6	[0x06] Low Voltage.....	6
4.7	[0x07] Current.....	6
4.8	[0x08] Power.....	6
4.9	[0x09] Mains Frequency.....	6
4.10	[0x0A] TimeSpan.....	7
4.11	[0x0B] Illuminance.....	7
4.12	[0x0C] NO ₂ (nitrogen dioxide).....	7
4.13	[0x0D] SO ₂ (sulfur dioxide).....	7
4.14	[0x0E] CO (carbon monoxide).....	7
4.15	[0x0F] O ₃ (ozone).....	7
4.16	[0x10] Atmospheric Pressure.....	8
4.17	[0x11] Color Temperature.....	8
4.18	[0x12] Particulates PM _{2.5}	8
4.19	[0x13] Sound Pressure Level.....	8
4.20	[0x14] Altitude.....	8
4.21	[0x15] Acceleration.....	8
4.22	[0x16] NH ₃ (ammonia in the air).....	9
4.23	[0x17] Methane.....	9
4.24	[0x18] Short Length.....	9
4.25	[0x19] Particulates PM ₁	9
4.26	[0x1A] Particulates PM ₄	9
4.27	[0x1B] Particulates PM ₁₀	9
4.28	[0x1C] TVOC (total volatile organic compound).....	9
4.29	[0x1D] NOX (nitrogen oxides).....	9
4.30	[0x1E] Activity concentration.....	10
4.31	[0x1F] Binary input.....	10
4.32	[0x20] Particulates PM ₄₀	10
4.33	[0x80] Relative Humidity.....	10
4.33.1	WrittenData.....	10
4.34	[0x81] Binary Data7.....	11
4.35	[0x82] Power Factor.....	11
4.36	[0x83] UV Index.....	11
4.37	[0x84] pH.....	11
4.38	[0x85] RSSI.....	12
4.39	[0x86] Action.....	12
4.40	[0xA0] Binary Data30.....	12
4.41	[0xA1] Consumption.....	12
4.42	[0xA2] Datetime.....	12
4.43	[0xA3] TimeSpanLong.....	13
4.44	[0xA4] Latitude.....	13
4.45	[0xA5] Longitude.....	13
4.46	[0xA6] Temperature (float).....	14

4.47	[0xA7] Length.....	14
4.48	[0xC0] Data Block.....	14
5	Examples.....	14
6	Beaming	15
7	Aggregating Repeater	15

1 Introduction

This document specifies standard IQRF sensor device [DPA commands](#) and [FRC commands](#).

The ID of this standard is 0x5E.

The standard is implemented using one DPA peripheral and three DPA commands. It is intended for various sensor combinations; regardless it is a device containing:

- only one sensor (mono-sensor),
- more sensors of the same type (poly-sensor) and/or a combination of
- more sensors of different types (multi-sensor).

The device supporting this standard can contain up to 32 sensors of any of the [predefined types](#) (quantities). Each sensor type defines a quantity, a unit, and a resolution when returning sensor data at DPA response caused by DPA request or returned by FRC. The sensors implemented by the device are addressed (indexed) consecutively using the index starting from index 0 up to 31. No index “gaps” are allowed.

An [example](#) of the device implementing 4 sensors:

- The 1st sensor at index 0: [temperature](#) sensor,
- The 2nd sensor at index 1: [temperature](#) sensor,
- The 3rd sensor at index 2: [CO₂](#) sensor and
- The 4th sensor at index 3: [humidity](#) sensor.

The following chapters describe the standard in more detail. Also, see provided Custom DPA Handler source code examples for the best practice implementation details.

All values wider than byte are encoded using little-endian style unless otherwise specified.

2 DPA Commands

The standard uses peripheral PNUM = 0x5E (stands for **SE**nsor).

When the peripheral is [enumerated](#) the Par1 equals version of this standard (currently 15).

2.1 Read Sensors

PCMD = 0x00

Reads data from the selected sensor(s). Optionally a proprietary data can be written to the sensor(s) too. Up to 32 sensors are supported.

Request

NADR	PNUM	PCMD	HWPID	0 ... 3	4 ... 3 + n * 5
NADR	0x5E	0x00	0XXXXX or 0xFFFF	Bitmap	WrittenData

Bitmap

A 32-bit bitmap (4 bytes) specifying sensors to read data from.

There are 3 options for how the Bitmap is used. Corresponding details and expected response to the request are discussed later in the Response section.

- Read 1st sensor: the bitmap is not provided at all (i.e. the Request actually contains no data). In this case, the WrittenData field cannot be present.
- Read sensor(s): other bitmap values. If an unimplemented sensor is selected in the bitmap, there is, of course, no return value and also no error is reported. Thus the full bitmap 0xFF.FF.FF.FF indexing all theoretical 32 sensors will cause reading all actually implemented sensors without previous knowledge of their real count.

WrittenData Optional data to write to the sensors. The WrittenData data block consists of a list of a group of 5 bytes for one sensor. The 1st byte of the group is the sensor index; the next 4 bytes are the actual data to write to the sensor. The meaning of the written data is either standardized (see chapter [Sensor Types](#)) or proprietary. If the length of WrittenData is not a multiple of 5 or any of the specified sensors does not implement writing data then ERROR_DATA_LEN is returned. If the content of the written data is not valid ERROR_DATA is returned.

Response

NADR	PNUM	PCMD	HWPID	ErrN	DpaValue	0 ... n
NADR	0x5E	0x80	0xFFFF	0	?	Data

Data The content depends on the request Bitmap format:

1. *Read 1st sensor:*

Same as option No 2 with Bitmap=0x00.00.00.01 (bitmap bytes 0x01, 0x00, 0x00, 0x00), i.e. 1st sensor (index 0) is selected. See below.

2. *Read sensor(s):*

Data contains a list of sensor values for all selected sensors:

Data = [1st selected sensor value], [2nd selected sensor value], ..., [last selected sensor value].

The length and format of each sensor value depend on the actual sensor type. See examples. If data from all selected sensors do not fit into the reserved Data array (56 bytes at DPA 3.00) then the response is ERROR_FAIL.

2.2 Read Sensors with Types

PCMD = 0x01

This command reads not only the sensor values but also sensor types. The command is actually the same as previously described Read Sensors command except that in the case when sensor values are returned at the response the values are always prefixed by 1 byte containing the sensor type. See examples.

2.3 Enumerate Sensors

PCMD = 0x3E

This command enumerates all implemented sensors.

Request

NADR	PNUM	PCMD	HWPID
NADR	0x5E	0x3E	0xFFFF or 0xFFFF

Response

NADR	PNUM	PCMD	HWPID	ErrN	DpaValue	0 ... n
NADR	0x5E	0xBE	0xFFFF	0	?	Sensors

Sensors n equals the number of implemented sensors. Each returned byte specifies the type (quantity) of each sensor, starting from index 0 to the last sensor. Standard sensor types are described in the dedicated chapters.

3 FRC Commands

Implemented four FRC commands return 2-bits, 1-byte, 2-byte, or 4-byte sensor values respectively depending on the sensor type. Also, the optional “sleep after FRC” feature for the low-power (battery operated) devices is implemented.

FRC user-data has the same format for all implemented FRC commands:

UserData[0] 0x5E (equals to the PNUM).

UserData[1]	Sensor type. 0x00 means any sensor type.
UserData[2]	Sensor index [eeee.iiii]
bit:0...4	Sensor index (from 0 to 31) of the specified type or any type (see UserData[1]).
bit:5...7	Extended data used by some sensor types.
UserData[3]	Options [xxxx.xxxx]
bit:0	When this bit is set then optional sleep parameters at UserData[4..6] are present. See below.
bit:1...7	Reserved.
UserData[4...6]	Optional "sleep after FRC" parameters of the same format as <u>CMD_OS_SLEEP</u> , i.e. [4...5]=Time, [6]=Control

3.1 2-bits sensor value - 0x10

Returns 2-bits sensor data of the supporting sensor types.

3.2 1-byte sensor value - 0x90

Returns 1-byte wide sensor data of the supporting sensor types.

3.3 2-byte sensor value - 0xE0

Returns 2-byte wide sensor data of the supporting sensor types.

3.4 4-byte sensor value - 0xF9

Returns 4-byte wide sensor data of the supporting sensor types.

3.5 Predefined FRC values

FRC type			Meaning
2-bits	1-byte	2-byte or 4-byte	
0b00	0x00	0x0000	No FRC response (device is not responding)
0b01	0x01	0x0001	FRC not implemented
	0x02	0x0002	Sensor error or Out of FRC range
	0x03	0x0003	Reserved

4 Sensor Types

Sensor type is a one-byte value that specifies the type (quantity) of the sensor as well as the size of the sensor data in case of Read Sensors command and FRC. The sensor type (byte) uses the following format to encode data width and actual sensor type (bits x):

[0000.0000] *undefined*

[0xxx.xxxx] => 2 bytes of data (127 options)

[100x.xxxx] => 1 byte of data (32 options)

[101x.xxxx] => 4 bytes of data (32 options)

[11xx.xxxx] => variable number of bytes (64 options), the 1st data byte specifies number of remaining data bytes (e.g. 5, 0xAA, 0xBB, 0xCC, 0xDD, 0xEE)

4.1 [0x01] Temperature

- **The return value** is 2 bytes wide signed (two's complement) temperature value, the unit is 1 °C, the resolution is 1/16 °C = 0.0625 °C, and the theoretical range is ±2,047.9375 °C. Value 0x8000 (i.e. -2,048.0000 °C) specifies a sensor error.
- **FRC 1-byte:** uses ½ °C resolution. FRC return value $F = (t + 22) * 2$ so $t = F / 2 - 22$ (i.e. 4 is -20.0 °C, 44 is 0.0 °C, 255 is 105.5 °C). Range is from -20.0 °C to 105.5 °C. When the value is out of this range, FRC error value is returned.
- **FRC 2-byte:** FRC value is 2-byte return value +0x8000 that actually causes inverting of the most significant sign bit (i.e. 0x8000 is 0.0000 °C, 0x8640 is 100.0000 °C, 0x79C0 is -100.0000 °C).

4.1.1 WrittenData

The following definitions of the data optionally written to the temperature sensor are not mandatory unless the features they support are not implemented by the temperature sensor.

4.1.1.1 Get One Point Calibration

When the following data is written to the temperature sensor, the very next read temperature value (in the same [Read Sensors \[Types\]](#) command) is not the measured temperature but the calibration offset (temperature) value that is normally added to the actual measured temperature thus calibrating the temperature sensor at one point.

0	1	2	3	4
sensor index	0x01	n/a	n/a	n/a

4.1.1.2 Set One Point Calibration

The following data is used to set the calibration offset value.

0	1	2	3	4
sensor index	0x02	LSB	MSB	0

LSB Least significant byte of the 2-byte offset (temperature) value used to calibrate the temperature. The value has the same coding as the standard temperature value. E.g. value 0xFFFF represents $-1/16\text{ }^{\circ}\text{C} = -0.0625\text{ }^{\circ}\text{C}$ one point calibration offset.

MSB Same as above, but the most significant byte.

4.2 [0x02] CO₂ (carbon dioxide)

- **The return value** is 2 bytes wide unsigned CO₂ concentration value, the unit is 1 ppm, the resolution is 1 ppm, and the theoretical range is from 0 ppm to 32,767 ppm. Value 0x8000 (i.e. 32,768 ppm) specifies a sensor error. Greater values are not used.
- **FRC 1-byte:** FRC return value uses 16 ppm resolution. Return value $F = (\text{CO}_2 / 16) + 4$ so $\text{CO}_2 = (F - 4) * 16$ (i.e. 4 is 0 ppm, 255 is 4,016 ppm). Range is from 0 ppm to 4,016 ppm. When the value is above this range, FRC error value is returned.
- **FRC 2-byte:** FRC return value is CO₂ value +4 (i.e. 0x03EC=1,004 is 1,000 ppm).

4.3 [0x03] VOC (volatile organic compounds)

- **The return value** is 2 bytes wide unsigned VOC concentration value, the unit is 1 ppm, the resolution is 1 ppm, and the theoretical range is from 0 to 32,767 ppm. Value 0x8000 (i.e. 32,768 ppm) specifies a sensor error. Greater values are not used.
- **FRC 1-byte:** FRC return value uses 16 ppm resolution. Return value $F = (\text{VOC} / 16) + 4$ so $\text{VOC} = (F - 4) * 16$ (i.e. 4 is 0 ppm, 255 is 4,016 ppm). Range is from 0 ppm to 4,016 ppm. When the value is above this range, FRC error value is returned.
- **FRC 2-byte:** FRC return value is VOC value +4 (i.e. 0x1160=4,448 is 4,444 ppm).

4.4 [0x04] Extra-low Voltage

- **The return value** is 2 bytes wide signed (two's complement) value, the unit is 1 V, the resolution is 1 mV, the range is $\pm 32.767\text{ V}$. Value 0x8000 (i.e. -32.768 V) specifies a sensor error.
- **FRC 2-byte:** FRC return value is voltage value +0x8000 that actually causes inverting of the most significant sign bit (i.e. 0xB039=45,113 is 12.345 V). Because of FRC predefined values the raw values from 0x8000 to 0x8003 (i.e. -32.767 V to -32.755 V) cannot be passed.

4.4.1 Oxidation-Reduction Potential (ORP)

Extra-low Voltage is suitable for the measurement of ORP.

4.5 [0x05] Earth's Magnetic Field

- **The return value** is 2 bytes wide signed (two's complement) value, the unit is 1 T (Tesla), the resolution is 0.1 μ T, the range is ± 3.2767 mT. Value 0x8000 (i.e. -3.2768 mT) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the magnetic field value +0x8000 that actually causes inverting of the most significant sign bit (i.e. 0xB039=45,113 is 1.2345 mT). Because of FRC predefined values the raw values from 0x8000 to 0x8003 (i.e. -3.2767 mT to -3.2755 mT) cannot be passed.

4.6 [0x06] Low Voltage

- **The return value** is 2 bytes wide signed (two's complement) value, the unit is 1 V, the resolution is $1/16$ V = 0.0625 V, and the range is $\pm 2,047.9375$ V. Value 0x8000 (i.e. -2,048 V) specifies a sensor error.

[siii.iiii.iiii.ffff]

bit: 0...3 Fractional part (unit 1/16 V).

bit: 4...14 Integer part (unit 1 V).

bit: 15 Sign.

- **FRC 2-byte:** FRC value is 2-byte return value +0x8000 that actually causes inverting of the most significant sign bit (i.e. 0x8000 is 0.0 V, 0x8E60 is 230.0 V, 0x7F40 is -12.0 V). Because of FRC predefined values the raw values from 0x8000 to 0x8003 (i.e. -2,047.8125 V to -2,047.9375 V) cannot be passed.

4.7 [0x07] Current

- **The return value** is 2 bytes wide signed (two's complement) value, the unit is 1 A, the resolution is 1 mA, the range is ± 32.767 A. Value 0x8000 (i.e. -32.768 A) specifies a sensor error.
- **FRC 2-byte:** FRC return value is 2-byte return value +0x8000 that actually causes inverting of the most significant sign bit (i.e. 0x84D2=34,002 is 1.234 A). Because of FRC predefined values the raw values from 0x8000 to 0x8003 (i.e. -32.767 A to -32.765 A) cannot be passed.

4.8 [0x08] Power

- **The return value** is unsigned 2 bytes wide value, the unit is 1 W, the resolution is $\frac{1}{4}$ W = 0.25 W, and the range is from 0.00 W to 16,383.50 W. Value 0xFFFF (i.e. 16,383.75 W) specifies a sensor error.

[iiii.iiii.iiii.iiff]

bit: 0...1 Fractional part (unit $\frac{1}{4}$ W).

bit: 2...15 Integer part (unit 1 W).

- **FRC 2-byte:** FRC return value is power value +4 (i.e. 0x0FA4=4,004 is 1,000.00 W). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 16,383.00 W to 16,383.50 W) cannot be passed.

4.9 [0x09] Mains Frequency

- **The return value** is unsigned 2 bytes wide value, the unit is 1 Hz, the resolution is 1 mHz, and the range is from 0.000 Hz to 65.534 Hz. Value 0xFFFF (i.e. 65.535 Hz) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the mains frequency value +4 (i.e. 0xC354=50,004 is 50.000 Hz). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65.532 Hz to 65.535 Hz) cannot be passed.

4.10[0x0A] TimeSpan

- **The return value** is unsigned 2 bytes wide value, the unit is 1 s, the resolution is 1 s, and the range is from 0 s to 65,534 s (18 hours 12 minutes 14 seconds). Value 0xFFFF (i.e. 65,535 s) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the timespan value +4 (i.e. 0x0E14=3,604 is 1 hour). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65,532 s to 65,535 s) cannot be passed.
- see also [\[0xA3\] TimeSpanLong](#)

4.11[0x0B] Illuminance

- **The return value** is an unsigned 2 bytes wide value, the unit is 1 lx (lux), the resolution is 1 lx, and the range is from 0 lx to 65,534 lx. Value 0xFFFF (i.e. 65,535 lx) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the illuminance value +4 (i.e. 0x07D4 =2,004 is 2,000 lx). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65,532 lx to 65,535 lx) cannot be passed.

4.12[0x0C] NO₂ (nitrogen dioxide)

- **The return value** is 2 bytes wide unsigned NO₂ concentration value, the unit is 1 ppm, the resolution is 0.001 ppm (1 ppb), and the range from 0.000 ppm to 65.534 ppm. Value 0xFFFF (i.e. 65.535 ppm) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the NO₂ concentration value +4 (i.e. 0x0036 = 54 is 0.050 ppm). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65.532 ppm to 65.535 ppm) cannot be passed.

4.13[0x0D] SO₂ (sulfur dioxide)

- **The return value** is 2 bytes wide unsigned SO₂ concentration value, the unit is 1 ppm, the resolution is 0.001 ppm (1 ppb), and the range from 0.000 ppm to 65.534 ppm. Value 0xFFFF (i.e. 65.535 ppm) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the SO₂ concentration value +4 (i.e. 0x0036 = 54 is 0.050 ppm). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65.532 ppm to 65.535 ppm) cannot be passed.

4.14[0x0E] CO (carbon monoxide)

- **The return value** is 2 bytes wide unsigned CO concentration value, the unit is 1 ppm, the resolution is 0.01 ppm (10 ppb), and the range from 0.00 ppm to 655.34 ppm. Value 0xFFFF (i.e. 655.35 ppm) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the CO concentration value +4 (i.e. 0x00A4 = 164 is 1.60 ppm). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 655.32 ppm to 655.35 ppm) cannot be passed.

4.15[0x0F] O₃ (ozone)

- **The return value** is 2 bytes wide unsigned O₃ concentration value, the unit is 1 ppm, the resolution is 0.0001 ppm (0.1 ppb), and the range from 0.0000 ppm to 6.5534 ppm. Value 0xFFFF (i.e. 6.5535 ppm) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the O₃ concentration value +4 (i.e. 0x0138 = 312 is 0.0308 ppm). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 6.5532 ppm to 6.5535 ppm) cannot be passed.

4.16[0x10] Atmospheric Pressure

- **The return value** is 2 bytes wide unsigned, the unit is 1 Pa, the resolution is 1/16 hPa = 0.0625 hPa, and the theoretical range is from 0.0000 hPa to 4,095.8750 hPa. Value 0xFFFF (i.e. 4,095.9375 hPa) specifies a sensor error.

[iiii.iiii.iiii.ffff]

bit: 0...3 Fractional part (unit 1/16 hPa).

bit: 4...15 Integer part (unit 1 hPa).

- **FRC 2-byte:** FRC return value is the atmospheric pressure value $F = (\text{Pressure} * 16) + 4$ (i.e. $0x3E84 = 16,004$ is 1,000 hPa). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 4,095.7500 hPa to 4,095.9375 hPa) cannot be passed.

4.17[0x11] Color Temperature

- **The return value** is 2 bytes wide unsigned value, the unit is 1 K (kelvin), the resolution is 1 K, and the theoretical range is from 0 to 32,767 K. Value 0x8000 (i.e. 32,768 K) specifies a sensor error. Greater values are not used.
- **FRC 2-byte:** FRC return value is color temperature value +4 (i.e. $0x138C = 5,004$ is 5,000 K).

4.18[0x12] Particulates PM_{2.5}

- **The return value** is 2 bytes wide unsigned value, the unit is 1 µg/m³, the resolution is ¼ µg/m³ and the theoretical range is from 0 to 8,191.75 µg/m³. Value 0x8000 (i.e. 8,192.00 µg/m³) specifies a sensor error. Greater values are not used.
- **FRC 2-byte:** FRC return value is particulates PM_{2.5} value +4 (i.e. $0x45 = 69$ is 16.25 µg/m³).

4.19[0x13] Sound Pressure Level

- **The return value** is 2 bytes wide unsigned value, the unit is 1 dB, the resolution is 1/16 dB and the theoretical range is from 0.0000 dB to 2047.9375 dB. Value 0x8000 (i.e. 2048 dB) specifies a sensor error. Greater values are not used.
- **FRC 2-byte:** FRC return value is the sound pressure level value +4 (i.e. $0x644 = 1604$ is 100 dB).

4.20[0x14] Altitude

- **The return value** is 2 bytes wide unsigned value, the unit is 1 m, the resolution is ¼ m, the range is from -1,024.00 m (value 0x0000) to +15,359.50 m (value 0xFFFE). Value 0xFFFF (i.e. 15,359.75 m) specifies a sensor error. Conversions are: $\text{Value} = (\text{Altitude} + 1024) * 4$; $\text{Altitude} = \text{Value} / 4 - 1024$.
- **FRC 2-byte:** FRC return value is power value +4 (i.e. $0x1004=4,100$ is 0.00 m). Because of FRC predefined values the altitude values from 0xFFFC to 0xFFFF (i.e. 15,359.00 m to 15,359.75 m) cannot be passed.

4.21[0x15] Acceleration

- **The return value** is 2 bytes wide signed (two's complement) value, the unit is 1 m/s², the resolution is 1/256 m/s² (0.00390625 m/s²), the range is ±127.99609375 m/s². Value 0x8000 (i.e. -128.00000000 m/s²) specifies a sensor error.
- **FRC 2-byte:** FRC return value is 2-byte return value +0x8000 that actually causes inverting of the most significant sign bit (i.e. $0x89CF=35,279$ is standard gravity 9.8085937 m/s²). Because of FRC predefined values the acceleration values from 0x8000 to 0x8003 (i.e. -128.00000000 m/s² to -127.98828125 m/s²) cannot be passed.

4.22[0x16] NH_3 (ammonia in the air)

- **The return value** is 2 bytes wide unsigned NH_3 in air concentration value, the unit is 1 ppm, the resolution is 0.1 ppm (100 ppb), and the range from 0.0 ppm to 6,553.4 ppm. Value 0xFFFF (i.e. 6,553.5 ppm) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the NH_3 concentration value +4 (i.e. 0x00A4 = 164 is 16.0 ppm). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 6,553.2 ppm to 6,553.5 ppm) cannot be passed.

4.23[0x17] Methane

- **The return value** is 2 bytes wide unsigned Methane concentration value, the unit is 1 %, the resolution is 0.001 % (10 ppm), and the range from 0.000 % to 65.534 %. Value 0xFFFF (i.e. 65.535 %) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the Methane concentration value +4 (i.e. 0x303D = 12349 is 12.345 %). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65.532 % to 65.535 %) cannot be passed.

4.24[0x18] Short Length

- **The return value** is 2 bytes wide unsigned value, the unit is 1 m, the resolution is 0.001 m (1 mm), and the range from 0.000 m to 65.534 m. Value 0xFFFF (i.e. 65.535 m) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the Short length value +4 (i.e. 0xD435 = 54325 is 54.321 m). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65.532 m to 65.535 m) cannot be passed.

4.25[0x19] Particulates PM_{10}

Same as [\[0x12\] Particulates \$\text{PM}_{2.5}\$](#) .

4.26[0x1A] Particulates PM_4

Same as [\[0x12\] Particulates \$\text{PM}_{2.5}\$](#) .

4.27[0x1B] Particulates PM_{10}

Same as [\[0x12\] Particulates \$\text{PM}_{2.5}\$](#) .

4.28[0x1C] TVOC (total volatile organic compound)

- **The return value** is 2 bytes wide unsigned total volatile organic compound concentration value, the unit is $\mu\text{g}/\text{m}^3$, the resolution is 1 $\mu\text{g}/\text{m}^3$, and the range from 0 $\mu\text{g}/\text{m}^3$ to 65,534 $\mu\text{g}/\text{m}^3$. Value 0xFFFF (i.e. 65,535 $\mu\text{g}/\text{m}^3$) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the total volatile organic compound concentration value +4 (i.e. 0x01F8 = 504 is 500 $\mu\text{g}/\text{m}^3$). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65,532 $\mu\text{g}/\text{m}^3$ to 65,535 $\mu\text{g}/\text{m}^3$) cannot be passed.

4.29[0x1D] NOX (nitrogen oxides)

- **The return value** is 2 bytes wide unsigned nitrogen oxides concentration value, the unit is 1 (AQI, i.e. air quality index), the resolution is 1, and the range from 0 to 65,534, although useful range is 0-500. Value 0xFFFF (i.e. 65,535) specifies a sensor error.

- **FRC 2-byte:** FRC return value is the nitrogen oxides concentration value +4 (i.e. 0x0036 = 54 is value 50). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65,532 to 65,535) cannot be passed.

4.30 [0x1E] Activity concentration

- **The return value** is 2 bytes wide unsigned activity concentration value, the unit is Bq/m³, the resolution is 1 Bq/m³, and the range from 0 to 65,534. Value 0xFFFF (i.e. 65,535) specifies a sensor error.
- **FRC 2-byte:** FRC return value is the activity concentration value +4 (i.e. 0x0036 = 54 is value 50). Because of FRC predefined values the raw values from 0xFFFC to 0xFFFF (i.e. 65,532 to 65,535) cannot be passed.

4.31 [0x1F] Binary input

- **PROPOSAL**
- The return value is non-zero unsigned 2-byte wide containing a state, a class and a counter of the binary input. The format is the following:
 - b.0 0: binary input is inactive
 1: binary input is active
 - b.1-b.7 Counter of the input state changes. Maximum value 0x7F overflows to 0x00.
 - b.8-b.14 Class of the binary input
 - 0x00 Unused
 - 0x01-0x0F Unspecified1-Unspecified15
 - 0x10 Window open
 - 0x11 Door open
 - 0x12 Flood
 - 0x13 Presence
 - ... **ToDo**
 - ... 0x7F Reserved
 - b.15 0: value ok
 1: error

The recommended visual numeric representation is the *c.s.nnn* where *c* is class in decimal radix, *s* is a state and *nnn* is counter. Example: 16.0.123 is Closed window while the window was open/closed 123 times.

- **FRC 2-byte:** FRC return value equals unmodified return value.

4.32 [0x20] Particulates PM₄₀

Same as [\[0x12\] Particulates PM2.5](#).

4.33 [0x80] Relative Humidity

- **The return value** is unsigned 1-byte wide, the unit is 1 %, the resolution is 0.5 %, and the practical range is from 0.0 to 100.0 %. Value 0xEE (i.e. 119.0 %) specifies a sensor error. Other values are undefined.

[iiii.iiif]

bit: 0 Fractional part (unit ½ %).
bit: 1...7 Integer part.

- **FRC 1-byte:** FRC return value is the return value (with 0.5 % resolution) +4 (i.e. 4 is 0.0 %, 204 is 100.0 %).

4.33.1 WrittenData

The following definitions of the data optionally written to the humidity sensor are not mandatory unless the features they support are not implemented by the humidity sensor.

4.33.1.1 Get One Point Calibration

When the following data is written to the humidity sensor, the very next read humidity value (in the same [Read Sensors \[Types\]](#) command) is not the measured humidity but the calibration offset (humidity) value that is normally added to the actual measured temperature thus calibrating the temperature sensor at one point. See the next chapter for more information.

0	1	2	3	4
sensor index	0x01	n/a	n/a	n/a

4.33.1.2 Set One Point Calibration

The following data is used to set the calibration offset value.

0	1	2	3	4
sensor index	0x02	offset	0	0

offset Signed byte with an offset (humidity) value used to calibrate the humidity. The value has the same coding as the standard humidity value except it uses two's complement to store negative offset although humidity value cannot be negative by definition. E.g. value 0xFF represents $-1/2\% = -0.5\%$ one point calibration offset.

4.34[0x81] Binary Data7

- **The return value** is 7 bits of data of the unspecified meaning. It can be proprietary used by the sensor for returning error states, binary inputs, counters, etc.
[ebbb.bbbb]
bit: 0...6 Binary data.
bit: 7 Specifies a sensor error. If this bit set then binary data is not valid. Binary data bits 0-6 must be zeroed.

- **FRC 2-bits:** FRC return bit is a bit value of the binary data7 value at the bit position specified by the 3 extended data bits at UserData[2]. If the bit is set, then 0b11 otherwise 0b10 is returned. For instance, 0x41 returns the value of the bit #2 of the binary data7 sensor with index 1.
- **FRC 1-byte:** FRC return value is the return value +4 (i.e. 4 is 0=0x00, 131=0x83 is 127=0x7F).

4.35[0x82] Power Factor

- **The return value** is unsigned 1-byte wide, the unit is 1, the resolution is 0.005, and the practical range is from 0.000 to 1.000. Value 0xEE (i.e. 1.190) specifies a sensor error. Other values are undefined.
- **FRC 1-byte:** FRC return value is the return value (with 0.005 resolution) +4 (i.e. 4 is 0.000, 204 is 1.000).

4.36[0x83] UV Index

- **The return value** is unsigned 1-byte wide, the unit is 1, the resolution is 1/8 and the range is from 0.000 to 31.750. Value 0xFF (i.e. 31.875) specifies a sensor error.
- **FRC 1-byte:** FRC return value is the return value +4 (i.e. 0x20 is value 3.500). Range is from 0.000 to 31.375.

4.37[0x84] pH

- **The return value** is unsigned 1-byte wide, the unit is 1, the resolution is 1/16 (0.0625) and the practical range is from 0.0000 to 14.0000. Value 0xFF (i.e. 15.9375) specifies a sensor error.
- **FRC 1-byte:** FRC return value is the return value +4 (i.e. 0x74 is value 7.0000).

4.38[0x85] RSSI

- **The return value** of RSSI (received signal strength indicator) is unsigned 1-byte wide, the unit is dBm, the resolution is 1/2 dBm and the range is from -127.0 dBm to 0.0 dBm. The 1-byte value is determined by the formula $V = \text{RSSI} * 2 + 254$ (e.g. value 0x5E=94 is -80.0 dBm and -60.5 dBm is 0x85=133). Value 0xFF (i.e. out of range value +0.5 dBm) specifies a sensor error.
- **FRC 1-byte:** FRC return value is the return value +4 (i.e. 0x76=118 is -70.0 dBm). Range is from -127.0 dBm to -1.5 dBm

4.39[0x86] Action

- The return value is non-zero unsigned 1-byte wide containing the value:
 - 0x00 None
 - 0x01-0x10 Button#1...button#16 pressed briefly
 - 0x11-0x20 Button#1...button#16 pressed for a long time
 - 0x21-0x30 Button#1...button#16 pressed twice briefly
 - 0x31-0x40 Button#1...button#16 pressed briefly three times
 - 0x41...0xBF Reserved
 - 0xC0...0xFA User interval
 - 0xFB Error
 - 0xFC...0xFF Unused
- **FRC 1-byte:** FRC return value is the return value +4.

4.40[0xA0] Binary Data30

- **The return value** is 30 bits of data of the unspecified meaning. It can be proprietary used by the sensor for returning error states, binary inputs, counters, etc.
[e.x. bb.bbbb.bbbb.bbbb.bbbb.bbbb.bbbb]
- bit: 0...29 Binary data.
- bit: 30 Reserved. Must be 0.
- bit: 31 Specifies a sensor error. If this bit set then binary data is not valid. All other bits 0-30 must be zeroed.
- **FRC 2-byte:** FRC return value is one of the specified halves of the binary data30 value. If bit 5 at extended data bits at UserData[2] is 0, then bit: 0...14 plus +4 is returned. If the bit is 1 then bit: 15...29 plus +4 is returned.
- **FRC 4-byte:** FRC return value is the return value +4.

4.41[0xA1] Consumption

- **The return value** is unsigned 4-byte wide value, the unit is 1 Ws, the resolution is 1 Wh, and the range is from 0 Wh to 4,294,967,294 Wh = ~4.3 GWh. Value 0xFFFFFFFF (i.e. 4,294,967,295 Wh) specifies a sensor error.
- **FRC 4-byte:** FRC return value is the return value +4.

4.42[0xA2] Datetime

- **The return value** is an unsigned 4-byte wide value, the unit is 1 s, the resolution is 1 s. The value is a widely used [Unix time](#) i.e. "number of seconds that have elapsed since 00:00:00 Coordinated Universal Time (UTC), 1 January 1970, minus the number of leap seconds that have taken place since then". The range is from 1 January 1970 to 7 February 2106 07:28:14 GMT. Value 0xFFFFFFFF (i.e. 7 February 2106 07:28:15 GMT GMT) specifies a sensor error. Please note the value is unsigned and does not cover dates before 1 January 1970.
- **FRC 4-byte:** FRC return value is the return value +4.

4.43 [0xA3] TimeSpanLong

- **The return value** is an unsigned 4-byte wide value, the unit is 1 s, the resolution is 1/16 s. The range is from 0 s to 268,435,455.9375 s (8 years 186 days 21 hours 24 minutes 15.938 seconds). Value 0xFFFFFFFF specifies a sensor error.
- **FRC 4-byte:** FRC return value is the return value +4.

4.44 [0xA4] Latitude

- **The return value** is a 4-byte wide value that stores latitude similarly to NMEA text format "ddMM.mmmm,N|S" (NMEA requires 11 bytes). WGS84 geodetic datum is expected.

[dddd . dddd . s1MM . MMMM . 00mm . mmmm . mmmm . mmmm]

bit: 0...13	Decimal fraction part of minutes.
bit: 14...15	00.
bit: 16...21	Integer part of minutes.
bit: 22	1.
bit: 23	Sign bit. 1 specifies South, 0 specifies North.
bit: 24...30	Degrees.
bit: 31	0.

Example: N 50°25.6760' = 50.427933° = NMEA "5025.6760,N" is 0x32591A68.

Value 0xFF?????? specifies a sensor error. Conversion to the decimal degrees is $d + M.m / 60$.

- **FRC 4-byte:** FRC return value equals unmodified return value.

4.45 [0xA5] Longitude

- **The return value** is a 4-byte wide value that stores longitude similarly to NMEA text format "dddMM.mmmm,E|W" (NMEA requires 12 bytes). WGS84 geodetic datum is expected.

[dddd . dddd . s1MM . MMMM . 00mm . mmmm . mmmm . mmmm]

bit: 0...13	Decimal fraction part of minutes.
bit: 14...15	00.
bit: 16...21	Integer part of minutes.
bit: 22	1.
bit: 23	Sign bit. 1 specifies West, 0 specifies East.
bit: 24...31	Degrees.

Example: E 15°22.1780' = 15.369633° = NMEA "1522.1780,E" is 0x0F5606F4.

Value 0xFF?????? specifies a sensor error. Conversion to the decimal degrees is $d + M.m / 60$.

- **FRC 4-byte:** FRC return value equals unmodified return value.

4.46[0xA6] Temperature (float)

- **The return value** is a 4-byte wide temperature value in the [IEEE754 float format \(binary32\)](#). The unit is 1 °C. NaN specifies a sensor error.
- **FRC 4-byte:** FRC value is 4-byte return value casted to 4-byte unsigned integer +4. Quantity error value NaN is coded as FRC error value 0x00000002.

4.47[0xA7] Length

- **The return value** is a 4-byte wide length value in the [IEEE754 float format \(binary32\)](#). The unit is 1 m. NaN specifies a sensor error.
- **FRC 4-byte:** FRC value is 4-byte return value casted to 4-byte unsigned integer +4. Quantity error value NaN is coded as FRC error value 0x00000002.

4.48[0xC0] Data Block

- **The return value** is multiple data bytes of the unspecified meaning. It can be proprietary used by a sensor for returning more bytes. Please [note](#) that 1st byte specifies the number of remaining data bytes.

5 Examples

Note: if not specified then PNUM=0x5E and always the same device.

Enumerate sensor types:

- Request

PCMD=0x3E Enumerate sensors

- Response

PCMD=0xBE, PData=[0x01 Temperature, 0x01 Temperature, 0x02 CO₂, 0x80 Humidity] => 1st and 2nd sensors are temperature sensors, 3rd is CO₂ and 4th is humidity sensor.

Read values from sensors of indexes 0 and 3. Write 0x11, 0x22, 0x44, 0x55 to the 3rd sensor.

- Request

PCMD=0x00 Read sensors, PData=[0x09 1st and 4th sensor, 0x00, 0x00, 0x00][0x02 3rd sensor, 0x11, 0x22, 0x44, 0x55]

- Response

PCMD=0x80, PData=[0x40 Temperature value lower byte, 0x01 Temperature value higher byte, 0xA0 Humidity value] => 1st temperature sensor returns 20.0 °C, 4th humidity sensor returns 80.0 %.

Read values of indexes 0 and 3 from sensors including their types:

- Request

PCMD=0x01 Read sensors with types, PData=[0x09 1st and 4th sensor, 0x00, 0x00, 0x00]

- Response

PCMD=0x81, PData=[0x01 Temperature, 0x40 Temperature value lower byte, 0x01 Temperature value higher byte, 0x80 Humidity, 0xA0 Humidity value] => 1st sensor is temperature sensor and it returns 20.0 °C, 4th sensor is humidity sensor and it returns 80.0 %.

Read value and type of the 1st sensor

- Request

PCMD=0x01 Read sensors with types, PData=*none* 1st sensor only

- Response

PCMD=0x81, PData=[0x01 Temperature, 0x40 Temperature value lower byte, 0x01 Temperature value higher byte] => 1st sensor is temperature sensor and it returns 20.0 °C.

Read FRC byte temperature value from the 2nd temperature sensor from all nodes. Nodes supporting this temperature FRC then deep-sleep for 5 minutes.

- Request

PNUM=0x0D FRC peripheral, PCMD=0x00 FRC Send, PData=[0x90 1-byte FRC][0x5E, 0x01 Temperature, 0x01 2nd sensor][0x01 Sleep used][0x8F Sleep time lower byte, 0x00 Sleep time higher byte, 0x20 Sleep control byte]

- Response

PNUM=0x0D, PCMD=0x80, PData=[0x?? FRC status][0x?? unused][0x40 Node#1, 0x59 Node#2, 0xF4 Node#3, 0x00, ..., 0x00] => Nodes from addresses 1 to 3 returned temperatures 10.0 °C, 22.5 °C, 100.0 °C respectively.

6 Beaming

Battery-powered sensor devices work in such a way that they spend most of the time in a low-power (sleep) state and periodically (e.g. once per minute) they wake up, then they beam values from all sensors (in the same order as they are enumerated) and then they continue to sleep. Beaming values means that the device sends a packet with its payload filled in the same way as data received from [Read Sensors with Types](#), except the values are in FRC format. The FRC values are received by [aggregating repeaters](#) and later made available for FRC. Please see [example](#).

The packet has the following properties:

- `setRFmode(_TX_STD);`
- `NonroutedRfTxDpaPacket = TRUE;`
- `_NADR = BROADCAST_ADDRESS;`
- `_NADRhigh = 0;`
- `_PNUM = PNUM_STD_SENSORS;`
- `_PCMD = PCMD_STD_SENSORS_READ_TYPES_AND_FRC_VALUES | RESPONSE_FLAG;`
- `_HWPID = <device HWPID>;`
- `DpaApiRfTxDpaPacket(Async, 0);`

Async is typically 0. When used with a value of 1, beaming is asynchronous and when received by an aggregating coordinator, it is immediately passed to its interface. Asynchronous beaming is only used for emergency values (e.g. a flood has been detected).

7 Aggregating Repeater

The aggregating repeater (AR) receives beamings from sensor devices and makes the received sensor data available for later reading by the FRC, even though the sensor device is offline (it sleeps) and therefore cannot respond to the FRC request.

When AR receives a beaming from a node, it stores the received sensor values for that node while overwriting the previous sensor values from that node. AR may also add an [RSSI](#) value (measured when the beaming was received) to the beamed sensors data.

When an [FRC command](#) to read sensor values is received, the AR behaves as follows:

- AR analyzes sensor values received for all (or selected) nodes that are to be returned by the FRC command.
- If no beamed data was received from the node, the return value for the node is “*No FRC response*” = 0.
- If any beamed data was received from the node, but the requested sensor type is not available at the requested index, then the return value is “*FRC not implemented*” = 1.
- The same value is returned if the sensor type data is available, but the specified FRC command is not supported by the specified sensor type.
- In other cases the stored sensor value is returned and the value in the AR memory is replaced with “*No FRC response*” = 0.
- Some sensor types support FRC commands with different data widths. The original FRC value is converted to the desired FRC command width.
 - [1-byte sensor value](#) (*): [Temperature](#), [CO2 \(carbon dioxide\)](#), [VOC \(volatile organic compounds\)](#)
 - [2-bits sensor value](#) (**): [Binary Data7](#)
 - [2-byte sensor value](#) (**): [Binary Data30](#)

(*) If the value is out of the supported range, a value “*Sensor error or Out of FRC range*” = 2 is returned.

(**) The sensor value in the AR remains unchanged, so it is available again for the same FRC command without receiving beaming.