Modbus on
Senseair Refrigerant Detection System

Table of contents:

Warning: The Senseair RDS products are qualified with default settings of configuration registers. If register values are changed to other values than default factory settings, ensure that changes do not invalidate device qualification.

1. Modbus protocol

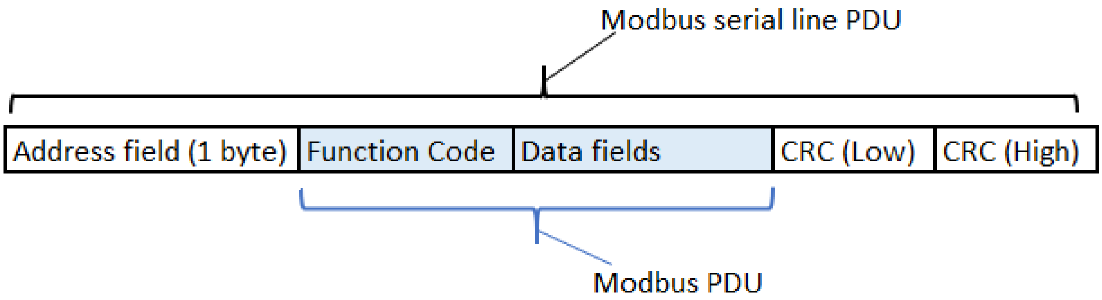
Modbus is a simple, open protocol for both PLC and sensors [1][2].

Details on Modbus can be found on the website www.modbus.org.

1.1. Serial line frame and addressing

Serial line frame

Modbus over serial line specification [2] distinguishes Modbus Protocol PDU and Modbus serial line PDU in the following way:



Addressing rules

The addressing rules are summarised in the table:

Address	Modbus over serial line V1.0	Senseair RDS
0 (0x00)	Broadcast address	Senseair RDS does not support broadcast commands
1 to 247 (0x01 to 0xF7)	Server individual address	Server individual address. Default address is 104 (0x68)
248 to 253 (0xF8 to 0xFD)	Reserved	Nothing[1)]
254 (0xFE)	Reserved	“Any sensor” [2)]
255 (0xFF)	Reserved	Nothing[1)]

Notes:

1) “Nothing” means that the sensor doesn’t recognise Modbus serial line PDUs with this address as addressed to the sensor. The sensor does not respond.

2) “Any sensor” means that any sensor with any server individual address will recognise serial line PDUs with address 254 as addressed to them. They will respond. This address is for production / test purposes only and must not be used in the installed network. This is a violation against the Modbus specification [1].

1.2. Bus timing

Parameter	Min	Typ	Max	Units
Response time-out			180	ms

“Response time-out” is defined to prevent the client (host system) from staying in “Waiting for reply” state indefinitely. Refer to page 9 of MODBUS over serial line specification [2].

For server device “Response time-out” represents maximum time allowed to take by “processing of required action”, “formatting normal reply” and “normal reply sent” alternatively by “formatting error reply” and “error reply sent”, refer to the server state diagram on page 10 of the document mentioned above.

1.3. Function code descriptions (PUBLIC)

Description of exception responses

If the PDU of the received command has wrong format:

No Response PDU, sensor doesn’t respond.

If Function Code isn’t equal to any implemented function code:

Exception Response PDU

Function code	1 byte	Function Code + 0x80
Exception code = *Illegal Function*	1 byte	0x01

If one or more of addressed Registers is not assigned (register is reserved or Quantity of registers is larger than maximum number of supported registers):

Exception Response PDU

Function code	1 byte	Function Code + 0x80
Exception code = *Illegal Data Address*	1 byte	0x02

01 (0x01) Read Coils

One bit read/write registers.

Not implemented.

02 (0x02) Read Discrete Input

One bit read only registers.

Not implemented.

03 (0x03) Read Holding Registers

16 bits read/write registers.

Refer to Modbus specification [1].

Request PDU

Function code	**1 byte**	**0x03**
Starting Address Hi	1 byte	Address Hi
Starting Address Lo	1 byte	Address Lo
Quantity of Registers Hi	1 byte	Quantity Hi
Quantity of Registers Lo	1 byte	Quantity Lo

Response PDU

Function code	**1 byte**	**0x03**
Byte Count	1 byte	2 x N*
Register Value	N* x 2 bytes	

* N = Quantity of Registers

If Address is out of range:

Exception Response PDU

Function code	**1 byte**	**0x83**
Exception code = *Illegal Data Address*	1 byte	0x02

If Quantity=0 or Quantity>Number of Registers:

Exception Response PDU

Function code	**1 byte**	**0x83**
Exception code = *Illegal Data Value*	1 byte	0x03

04 (0x04) Read Input Registers

16 bits read only registers.

Refer to Modbus specification [1].

Quantity of Registers is limited to 32.

Request PDU

Function code	**1 byte**	**0x04**
Starting Address Hi	1 byte	Address Hi
Starting Address Lo	1 byte	Address Lo
Quantity of Registers Hi	1 byte	Quantity Hi
Quantity of Registers Lo	1 byte	Quantity Lo

Response PDU

Function code	**1 byte**	**0x04**
Byte Count	1 byte	2 x N*
Register Value	N* x 2 bytes	

* N = Quantity of Registers

If Address is out of range:

Exception Response PDU

Function code	**1 byte**	**0x84**
Exception code = *Illegal Data Address*	1 byte	0x02

If Quantity=0 or Quantity>Number of registers:

Exception Response PDU

Function code	**1 byte**	**0x84**
Exception code = *Illegal Data Value*	1 byte	0x03

05 (0x05) Write Single Coil

One bit read/write register.

Not implemented.

06 (0x06) Write Single Register

16 bits read / write register.

Not implemented.

15 (0x0F) Write Multiple Coils

One bit read / write registers.

Not implemented.

16 (0x10) Write Multiple Registers

16 bits read/write register.

Refer to Modbus specification [1].

Address of Modbus Holding Registers for 1-command reading/writing is limited in range 0x0000..0x0045.

Request PDU

Function code	**1 byte**	**0x10**
Starting Address Hi	1 byte	Address Hi
Starting Address Lo	1 byte	Address Lo
Number of Register Hi	1 byte	Value Hi
Number of Register Lo	1 byte	Value Lo
The Number of Data Bytes	1 byte	2 x N*
Register Value to Write	2 x N* bytes	Value to write

* N = Quantity of Registers

Response PDU (is an echo of the Request)

Function code	**1 byte**	**0x10**
Starting Address Hi	1 byte	Address Hi
Starting Address Lo	1 byte	Address Lo
Number of Register written Hi	1 byte	Value Hi
Number of Register written Lo	1 byte	Value Lo

If Address is out of range:

Exception Response PDU

Function code	**1 byte**	**0x90**
Exception code = *Illegal Data Address*	1 byte	0x02

20 (0x14) Read File record

Not implemented.

21 (0x15) Write File record

Not implemented.

22 (0x16) Mask Write Register

16 bits read/write register.

Not implemented.

23 (0x17) Read / Write Multiple Registers

16 bits read/write register.

Not implemented.

43 / 14 (0x2B / 0x0E) Read Device Identification

Refer to Modbus specification …

The sensor only supports Read Device ID code 4, individual access.

Objects 0x00 ..0x02 (basic identification) are available (see table)

Object ID	Object Name / Description	Type	Modbus status	Category	Implementation status
0x00	Vendor Name	ASCII string*	Mandatory	Basic	Implemented
0x01	ProductCode	ASCII string*	Mandatory	Basic	Implemented
0x02	MajorMinorRevision	ASCII string*	Mandatory	Basic	Implemented
0x03	VendorUrl	ASCII string	Optional	Regular	Not Implemented
0x04	ProductName	ASCII string	Optional	Regular	Not Implemented
0x05	ModelName	ASCII string	Optional	Regular	Not Implemented
0x06	UserApplicationName	ASCII string	Optional	Regular	Not Implemented
0x07.. 0x7F	Reserved				
0x80	Memory map version	1 byte unsigned	Optional	Extended	Not Implemented
0x81	Firmware revision, consists of: Firmware type, Revision Main, Revision Sub	3 bytes unsigned	Optional	Extended	Not Implemented
0x82	Sensor serial number (sensor ID)	4 bytes unsigned	Optional	Extended	Not Implemented
0x83	Sensor type	3 bytes unsigned	Optional	Extended	Not Implemented

*The ASCII strings are different for different models. As an example:

Vendor Name = “Senseair” (length 8 bytes)

Product Code = “009-3-0007” (length 10 bytes)

MajorMinorRevision = “1.00” (length 4 bytes)

Example: Read objects of category “Basic”

Request PDU, Object ID 0x00 to 0x02

Function code	**1 byte**	**0x2B**
MEI Type	1 byte	0x0E
Read Device ID code	1 byte	0x04 (individual access only)
Object ID	1 byte	0x00..0x02

Response PDU, Object ID 0x00 to 0x02

Function code	**1 byte**	**0x2B**
MEI Type	1 byte	0x0E
Read Device ID code	1 byte	0x04, same as in request
Conformity level	1 byte	0x81, basic identification for individual or stream access
More Follows	1 byte	0x00
Next Object ID	1 byte	0x00
Number of objects	1 byte	0x01
Object ID	1 byte	0x00..0x02
Object length	1 byte	0x08 or 0x0A or 0x04 (see definition of ASCII strings)
Object value	n byte	Object Data

If wrong MEI Type:

Exception Response PDU

Function code	**1 byte**	**0xAB**
Exception code = *Illegal Function Code*	1 byte	0x01

If Object ID is not in range 0x00..0x03:

Exception Response PDU

Function code	**1 byte**	**0xAB**
Exception code = *Illegal Data Address*	1 byte	0x02

If wrong Device ID:

Exception Response PDU

Function code	**1 byte**	**0xAB**
Exception code = *Illegal Data Value*	1 byte	0x03

Note: The exception response for function code 43 is implemented according to the RFC "RFC Non extended Exception code format of 43 Encapsulated Transport.doc" which is in status "Recommended for approval" at time of writing. This is in contrast with the Modbus specification [1] where the exception responses for function code 43 also have a MEI type field.

23 (0x17) Read / Write Multiple Registers

16 bits read/write register.

Not implemented.

1.4. References

[1] MODBUS Application Protocol Specification V1.1b
[2] MODBUS over serial line specification and implementation guide V1.02

2. Modbus on Senseair RDS

2.1. Modbus settings

Senseair RDS supports baud rates up to 115200 bps. Default configuration is 9600 bps.

Other Modbus settings are as follows:

Setting	Value
Default server address	104 (0x68)
Baud rate	9600 bps
Parity	None
DataBits	8
StopBits	1

For details on how to change Modbus settings, see HR20 and HR70.

2.2. Modbus registers

The Modbus registers are mapped in memory and the mapping is interpreted by the sensor at command reception.

The register maps are summarised in Table 1 and Table 2. All registers are 16-bit words. The associated number is the Modbus register number. The register address is calculated as (register number -1). For example, the address of IR4 is 3.

2.1. Input Registers (IR)

IR#	Addr	Name	Description (read only registers)		
IR1	0x00	ErrorStatus			
			Bit	**Error description**	**Suggested action**
			0	**Fatal error** Indicates that initialisation of analog front end failed	Try to restart sensor by power on/off. Contact local distributor.
			1	**Communication error** Attempt to read or write to not exiting addresses/registers detected.	Try to restart sensor by power on/off. Check wires, connectors and communication protocol implementation. Contact local distributor.
			2	**Algorithm error** Corrupt parameters detected.	Try to restart sensor by power on/off. Contact local distributor.
			3	**Calibration error** Indicates that calibration has failed (ABC, Zero, Background or Target calibration).	Try to repeat calibration. Ensure that the environment is stable during calibration.
			4	**Self-diagnostics error** Indicates internal failure. Detailed information of the failure can be found in bit 9-10.	Try to restart sensor by power on/off. Contact local distributor.
			5	**Out of range** Indicates that the measured concentration, temperature, or set pressure are outside the sensor’s measurement range	Ensure that the environment is within the sensors operating range (see Product specification) If pressure compensation is enabled, provide valid pressure value for pressure compensation. Perform suitable gas calibration (zero, background or target calibration). Contact local distributor.
			6	**Memory error** Error during memory operations	Try to restart sensor by power on/off. Contact local distributor.

			7	**No measurement completed** Bit set at startup, cleared after first measurement	0 – First measurement cycle completed 1 – No measurement completed
			8	**Low internal regulated voltage** Flag is set if sensor's internal regulated voltage dropped below 2.8V and sensor's reset occurred. Flag shall be cleared by proper power-off/on sequence, reset command or by writing into "Clear ErrorStatus" register.	Check power supply. This means output voltage from internal regulator is too low. Could indicate internal voltage regulator malfunction or too low power supply voltage. Measurement data is not valid.
			9	**Measurement timeout** Flag is set if sensor is unable to complete the measurement in time. This flag is set in combination with the Self-diagnostic flag.	Flag is cleared after a successful measurement. If flag is set permanently, try to restart sensor by power on/off. Contact local distributor.
			10	**Abnormal signal level** Flag is set if an invalid measurement sample is detected. This flag is set in combination with the Self-diagnostic flag.	Flag is cleared after a successful measurement. If flag is set permanently, try to restart sensor by power on/off. Contact local distributor.
			11	**Heater Measurement error**	Measurement of sensor heater element temperature failed. Contact local distributor.
			12	**Heater PID config error**	Heater control incorrectly configured. Please check configuration settings.
			13	**Output config error**	Output incorrectly configured. Please check configuration settings.
			14	**Temperature out of range**	Measured temperature of heater element outside normal operation range. Please check sensor ambient temperature!
			15	**Scale factor error** Flag is set if current scaling factor defined by HR21 and HR22 registers is not correct Note: For firmware revision 1.2 and above	Flag is cleared after writing correct scaling factor value and following reset of the sensor

IR2	0x01	Reserved	
IR3	0x02	Reserved	
IR4	0x03	Measured concentration Filtered Pressure Compensated	Filtered pressure-compensated gas concentration. Signed 16 bit value. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type). IR4 is equal to IR10 if pressure compensation is disabled at HR19 (default)
IR5	0x04	Temperature	Chip temperature. Signed 16 bit value, unit °C x100. For example, register value = 2223 means 22.23°C.
IR6	0x05	Heater NTC Temperature	Heater NTC on motherboard temperature. Signed 16 bit value, unit °C x100. For example, register value = 2223 means 22.23°C.
IR7	0x06	Measurement count	Counter incremented after each measurement, range 0 – 255. Counter value can for example be used by the host system to ensure that the sensor has done a measurement since last time measured concentration was read.
IR8	0x07	Measurement cycle time	Measurement cycle time shows current time in present measurement cycle, incremented every 2 seconds. For example, IR8 = 3 means that 6 seconds has passed in current measurement cycle. The value is set to 0 when the sensor starts a new measurement. This value can be used by the host system to synchronise readings with sensor measurements.
IR9	0x08	Measured concentration Unfiltered Pressure Compensated	Unfiltered pressure-compensated gas concentration. Signed 16 bit value. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type). IR9 is equal to IR11 if pressure compensation is disabled at HR19 (default)
IR10	0x09	Measured concentration Filtered	Filtered gas concentration. Signed 16 bit value. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).
IR11	0x0A	Measured concentration Unfiltered	Unfiltered gas concentration. Signed 16 bit value. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).
IR12	0x0B	Heater PWM duty cycle counts	Heater timer duty cycle count, 0x2EE0 = 100%
IR13	0x0C	Output PWM duty cycle counts	Output PWM duty cycle count, 0x2EE0 = 100% If Output is configured to digital high/low this register will have a value of 0x2EE0 when high and 0 when low.
IR14	0x0D	Scaled measured concentration Filtered Pressure Compensated	Measured concentration (IR4) scaled by scale factor defined by HR21 and HR22 registers. Signed 16 bit value. Note: For firmware revision 1.2 and above
…		Reserved	
IR22 **IR23**	0x15... 0x16	ETC	Elapsed time counter. Unsigned 32 bit value, unit hours. ETC = IR22 * 65536 + IR23 Note: For firmware revision 1.2 and above

IR24	0x17	FW type	Firmware type. Unsigned 16 bit value.
…		Reserved	
IR29	0x1C	FW rev.	Firmware revision. Unsigned 16 bit value. (bit 15 - 8 main) & (bit 7 - 0 sub)
IR30	0x1D	Sensor Id (bit31 – bit16)	Sensor Id. Unsigned 32 bit value.
IR31	0x1E	Sensor Id (bit15 – bit0)	
IR32		Reserved	

Table 1. Input Registers (IR)

2.2. Holding Registers (HR)

<table>
<tr><th>HR#</th><th>Addr</th><th>Name</th><th>Description (read/write registers)</th></tr>
<tr><td>HR1</td><td>0x00</td><td>Calibration Status</td><td>These bits are set after successful calibrations. The bits need to be cleared/reset by host system; it is recommended to do this before trigging a calibration using the HR2 register.
<table>
<tr><th>Bit</th><th>Description</th></tr>
<tr><td>0</td><td></td></tr>
<tr><td>1</td><td></td></tr>
<tr><td>2</td><td>Factory calibration restored</td></tr>
<tr><td>3</td><td>ABC calibration</td></tr>
<tr><td>4</td><td>Target calibration</td></tr>
<tr><td>5</td><td>Background calibration</td></tr>
<tr><td>6</td><td>Zero calibration</td></tr>
<tr><td>7</td><td></td></tr>
</table></td></tr>
<tr><td>HR2</td><td>0x01</td><td>Calibration Command</td><td>Calibration is initiated by the commands in the table below.

The sensor will perform a calibration based on the first measurement immediately after the calibration command was received. After having performed the calibration, all following measurements will use the adjusted calibration parameters.

It is recommended that HR1 is cleared before initiating a calibration.
<table>
<tr><th>Command</th><th>Name and description</th></tr>
<tr><td>0x7C02</td><td>Restore factory calibration.

Restores calibration parameters to factory calibration values.</td></tr>
<tr><td>0x7C03</td><td>Forced ABC calibration.

Sensor will perform an ABC calibration after receiving this command if sensor has valid ABC data. The command can be used if one for some reason wants to do an ABC adjustment before one ABC period has passed (when a normal ABC calibration is done).

This command only works if ABC is enabled, see HR14 & HR19.</td></tr>
<tr><td>0x7C05</td><td>Target calibration.

Calibration using HR3 value as calibration target.</td></tr>
<tr><td>0x7C06</td><td>Background calibration

Calibration using ABC target as calibration target.</td></tr>
<tr><td>0x7C07</td><td>Zero calibration.

Calibration using 0 ppm gas as calibration target.</td></tr>
</table></td></tr>
<tr><td>HR3</td><td>0x02</td><td>Calibration Target</td><td>Calibration target used by target calibration (HR2 - 0x7C05 command). Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).</td></tr>
</table>

<table>
<tr><td>HR4</td><td>0x03</td><td>Measured concentration Override</td><td>Default value = 32767 (no override). If a value lower than default is written to the register, both the gas filtered and unfiltered registers will be set to this value. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).</td></tr>
<tr><td>HR5</td><td>0x04</td><td>ABC Time</td><td>Time passed since last ABC calibration in hours.</td></tr>
<tr><td>…</td><td>0x05</td><td>Reserved</td><td></td></tr>
<tr><td>HR12</td><td>0x0B</td><td>Measurement Period (EE)</td><td>Measurement period in seconds (range from 2 to 65534). Odd numbers will be rounded up to nearest even number.

A system reset is required after changing configuration. Default value is 2.</td></tr>
<tr><td>HR13</td><td>0x0C</td><td>Number of samples (EE)</td><td>Number of samples in one measurement (range from 1 to 1024). A higher number leads to a better accuracy but also a higher power consumption.

A system reset is required after changing configuration. Default is 8 samples.

One sample takes max 300ms, this means that (Number of samples * 0.3s) should be less than or equal to time between measurements.
If time for executing all samples in a measurement is longer than measurement period, sensor will execute all samples and after that start a new measurement. This means that the actual measurement period will be longer than measurement period specified in HR12.

Note: Odd numbers will be internally rounded down to nearest even number and values below 2 will be replaced with 2.</td></tr>
<tr><td>HR14</td><td>0x0D</td><td>ABC period (EE)</td><td>Period for ABC cycle in hours (range from 1 to 65534). Default is 720 hours.

ABC enabled by writing 1 to 65534 at HR14 and bit 1 = 0 at HR19.

ABC disabled by writing 0 or 65535 to HR14 or bit 1 = 1 at HR19.</td></tr>
<tr><td>HR15</td><td>0x0E</td><td>Clear ErrorStatus</td><td>Write any number to this register to clear ErrorStatus</td></tr>
<tr><td>HR16</td><td>0x0F</td><td>ABC Target (EE)</td><td>Target value for background and ABC calibrations. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).</td></tr>
<tr><td>HR17</td><td>0x10</td><td>Static IIR filter parameter

(EE)</td><td>Parameter for static IIR filter, range from 2 – 10. A higher value corresponds to harder filtration. Filter configuration is controlled by HR19</td></tr>
<tr><td>HR18</td><td>0x11</td><td>SCR</td><td>The SCR register is used to reset the sensor.

Register value = 0xFF, sensor will reset/restart itself.</td></tr>
<tr><td>HR19</td><td>0x12</td><td>Meter control (EE)</td><td>Bit field used to enable/disable sensor functions
<table>
<tr><th>Bit</th><th>Description</th></tr>
<tr><td>0</td><td>0 – Heater enabled (default)

1 - Heater disabled</td></tr>
<tr><td>1</td><td>0 - ABC enabled (default)

1 - ABC disabled</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>
<table>
<tr><td>2</td><td>0 – Static IIR filter enabled (default)
1 - Static IIR filter disabled</td></tr>
<tr><td>3</td><td>0 – Dynamic IIR filter enabled (default)
1 – Dynamic IIR filter disabled
To enable dynamic IIR filter both static IIR filter (bit2) and dynamic IIR filter (bit3) has to be enabled</td></tr>
<tr><td>4</td><td>0 – Pressure compensation enabled
1 – Pressure compensation disabled (default)</td></tr>
<tr><td>5</td><td>0 – Output pin enabled (default)
1 – Output pin disabled</td></tr>
<tr><td>6</td><td>0 – NTC measurements enabled (default)
1 - NTC measurements
If NTC measurements are disabled, the heater PID regulator will have no input to regulate and will not give any output.</td></tr>
<tr><td>7</td><td></td></tr>
</table>
EEPROM mapped register</td></tr>
<tr><td>HR20</td><td>0x13</td><td>Modbus address (EE)</td><td>Modbus address, range 1 – 247 (0x01 – 0xF7). Default value is 104 (0x68). A sensor reset is needed to activate the new address.
EEPROM mapped register</td></tr>
<tr><td>HR21</td><td>0x14</td><td>Concentration scale factor, nominator part (EE)</td><td rowspan="2">Registers HR21 and HR22 are used to scale IR4 and HR23-27.
To calculate IR14 register value:
IR14 = IR4*HR21/HR22
The HR21, HR22 registers are unsigned 16 bit.
If both registers are equal to 0xFFFF, the scaling is disabled and IR14 register value is just a copy of IR4 register.
If scaling factor is invalid, the “Scale factor error” bit will be set in “ErrorStatus” register at startup.
EEPROM mapped registers.
A sensor reset is needed to activate the new setting.
Note: For firmware revision 1.2 and above</td></tr>
<tr><td>HR22</td><td>0x15</td><td>Concentration scale factor, denominator part (EE)</td></tr>
<tr><td>HR23</td><td>0x16</td><td>Scaled Calibration Target</td><td>Calibration target used by target calibration (HR2 - 0x7C05 command).
Note: For firmware revision 1.2 and above</td></tr>
<tr><td>HR24</td><td>0x17</td><td>Scaled Measured concentration Override</td><td>Default value = 32767 (no override). If a value lower than default is written to the register, both the gas filtered and unfiltered registers will be set to this value.
Note: For firmware revision 1.2 and above</td></tr>
<tr><td>HR25</td><td>0x18</td><td>Scaled ABC Target (EE)</td><td>Target value for background and ABC calibrations.
Note: For firmware revision 1.2 and above</td></tr>
</table>

HR26	0x19	Scaled RDB (EE)	RDB (HR64) scaled by Scale Factor. High bit is not scaled. Note: For firmware revision 1.2 and above
HR27	0x1A	Scaled PRC (EE)	PRC (HR65) scaled by Scale Factor. High bit is not scaled. Note: For firmware revision 1.2 and above
HR47	0x2E	Barometric air pressure value	Barometric air pressure value. Signed 16 bit, unit 0.1 hPa. Range from 3000 – 13000 (300 – 1300 hPa). For values outside pressure range, error flag “out of range” will be set and compensation will be done with min or max pressure value.
..		Reserved	
HR50	0x31	Heater PID Setpoint temperature (EE)	Setpoint temperature for PID regulator temperature. Signed 16 bit value, unit °C x100. For example, register value = 2223 means 22.23°C. Default value is 2500.
HR51	0x32	Heater PID Output low limit (EE)	Minimum allowed output from PID regulator to heater where 12000 = 100% and 0 = 0%. Must not exceed 12000. Default value is 0.
HR52	0x33	Heater PID Output high limit (EE)	Maximum allowed output from PID regulator to heater where 12000 = 100% and 0 = 0%. Must not exceed 12000. Default value is 12000.
HR53	0x34	Heater PID kP (EE)	PID regulator proportional constant. Default value is 768.
HR54	0x35	Heater PID kP scale (EE)	PID regulator proportional constant scale. Proportional constant will be divided by this value. Default value is 128.
HR55	0x36	Heater PID kI (EE)	PID regulator integral constant. Default value is 128.
HR56	0x37	Heater PID kI scale (EE)	PID regulator integral constant scale. Integral constant will be divided by this value. Default value is 128.
HR57	0x38	Heater PID kEOP (EE)	PID regulator integral anti-windup tracking constant. Default value is 0.
HR58	0x39	Heater PID kEOP scale (EE)	PID regulator integral anti-windup tracking constant scale. Tracking anti-windup constant will be divided by this value. Default value is 0.
HR59	0x3A	Heater PID Output bias (EE)	PID regulator output bias. Default value is 0.
HR60	0x3B	Heater PID max error off (EE)	Maximum allowed error before PID regulator shuts down, if this function is enabled in PID Control Register. Signed 16 bit value, unit °C x100. For example, register value = 2223 means 22.23°C. Default value is 0.
HR61	0x3C	Heater PID Overheat warn (EE)	The SpaceTemp (IR5) temperature at which the regulator will start to decrease the output if this functionality is enabled in PID control register. Signed 16 bit value, unit °C x100. For example, register value = 2223 means 22.23°C. Default value is 5000.
HR62	0x3D	Heater PID Overheat shutdown (EE)	The SpaceTemp (IR5) temperature at which the regulator will set the output to zero if this functionality is enabled in PID Control Register.

<table>
<tr><td></td><td></td><td></td><td>Signed 16 bit value, unit °C x100. For example, register value = 2223 means 22.23°C. Default value is 8000.</td></tr>
<tr><td>HR63</td><td>0x3E</td><td>PID Control Register (EE)</td><td>These bits are used to control the PID regulator. Only one of bit 0 or 1 can be set. If neither or both bits are set, there is no integrator anti-windup.

When using clamping anti-windup, if the output is saturated the integrator will not try to increase it above or below its limits.

When using tracking anti-windup, the integrator is unwinded by using the difference between the unsaturated and the saturated output multiplied by the tracking constant. Also known as Back-calculation.

Default value is 0x11 (Clamping anti-windup and Overheat protection enabled)
<table>
<tr><th>Bit</th><th>Description</th></tr>
<tr><td>0</td><td>Integrator anti-windup clamping (default)</td></tr>
<tr><td>1</td><td>Integrator anti-windup tracking</td></tr>
<tr><td>2</td><td>Reserved</td></tr>
<tr><td>3</td><td>Reserved</td></tr>
<tr><td>4</td><td>Overheat protection enable (default)</td></tr>
<tr><td>5</td><td>Max error shutdown enable</td></tr>
<tr><td>6</td><td>Reserved</td></tr>
<tr><td>7</td><td>Force PID regulator off</td></tr>
</table></td></tr>
<tr><td>HR64</td><td>0x3F</td><td>Output RDB (EE)</td><td>Regulators dead-band. When measured concentration is below this limit there will be no output. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).

See “Understanding Output configuration” for more information.</td></tr>
<tr><td>HR65</td><td>0x40</td><td>Output PRC (EE)</td><td>Proportional regulator constant. How many units of concentration the output should increase linearly over, from the minimum to maximum output. Unit is same as sensor resolution (for example 1ppm or 10 ppm, depending on sensor type).

See “Understanding Output configuration” for more information.</td></tr>
<tr><td>HR66</td><td>0x41</td><td>Output max limit (EE)</td><td>Max value for the duty cycle, where 100% = 12000 = 0x2EE0 and 0% = 0. For example, a maximum duty cycle of 80% is 12000 * 0.8 = 9600.

See “Understanding Output configuration” for more information.</td></tr>
<tr><td>HR67</td><td>0x42</td><td>Output min limit (EE)</td><td>Min value for the duty cycle, where 100% = 12000 = 0x2EE0 and 0% = 0. For example, a minimum duty cycle of 20% is 12000 * 0.2 = 2400.

See “Understanding Output configuration” for more information.</td></tr>
<tr><td>HR68</td><td>0x43</td><td>Output offset (EE)</td><td>Offset for the output duty cycle. Max offset is 100% = 12000 = 0x2EE0.

See “Understanding Output configuration” for more information.</td></tr>
<tr><td>HR69</td><td>0x44</td><td>Output is digital (EE)</td><td>Set register to 0 to configure output as PWM.

Set register to any non-zero value to configure the output as digital on/off with hysteresis, this mode disregards MinLimit and MaxLimit.</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>See “Understanding Output configuration” for more information.</td></tr>
<tr><td>HR70</td><td>0x45</td><td>UART configuration (EE)</td><td>Bit field used to configure UART settings.
The first table shows what every bit in the field represent.

The following tables show what value to set the bits to get desired configuration
<table>
<tr><th>Bit</th><th>Description</th></tr>
<tr><td>0</td><td>Baudrate bit 0 (BB0)</td></tr>
<tr><td>1</td><td>Baudrate bit 1 (BB1)</td></tr>
<tr><td>2</td><td>Baudrate bit 2 (BB2)</td></tr>
<tr><td>3</td><td>Parity bit 0 (PB0)</td></tr>
<tr><td>4</td><td>Parity bit 1 (PB1)</td></tr>
<tr><td>5</td><td>Stopbit bit 0 (SBB0)</td></tr>
<tr><td>6</td><td>Don’t care</td></tr>
<tr><td>7</td><td>Don’t care</td></tr>
</table>
<table>
<tr><th>BB2</th><th>BB1</th><th>BB0</th><th>Baudrate</th></tr>
<tr><td>0</td><td>0</td><td>0</td><td>9600 (default)</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>19200</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>38400</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>57600</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>115200</td></tr>
</table>
<table>
<tr><th>PB1</th><th>PB0</th><th>Parity</th></tr>
<tr><td>0</td><td>0</td><td>None (default)</td></tr>
<tr><td>0</td><td>1</td><td>Odd</td></tr>
<tr><td>1</td><td>0</td><td>Even</td></tr>
</table>
<table>
<tr><th>SBB0</th><th>Stopbits</th></tr>
<tr><td>0</td><td>One (default)</td></tr>
<tr><td>1</td><td>Two</td></tr>
</table>
EEPROM mapped register</td></tr>
</table>

Table 2. Holding Registers (HR)

Registers with (EE) after their names use sensors EEPROM, this means that too frequent writes to these registers will lead to a corrupt EEPROM. Total number of EEPROM write cycles should be less than 10000.

When writing multiple (EE) registers in one sequence then this write cycle will be counted as just ONE write cycle out of the 10000 that are allowed writes to the EEPROM.

It is important to wait until a response from the sensor is received before powering down the sensor. If the sensor is powered down when EEPROM write operations are ongoing it may result in corrupt parameters.

Registers marked as “Reserved” can be read and written, however it is strongly recommended to not use these registers.

3. Understanding Output configuration

Senseair RDS has several different output possibilities and can be configured with software. The output can be either PWM or digital high/low. There are different hardware output pins where the PWM signal can be translated to a voltage or a current output. The following parameters can be configured in software:

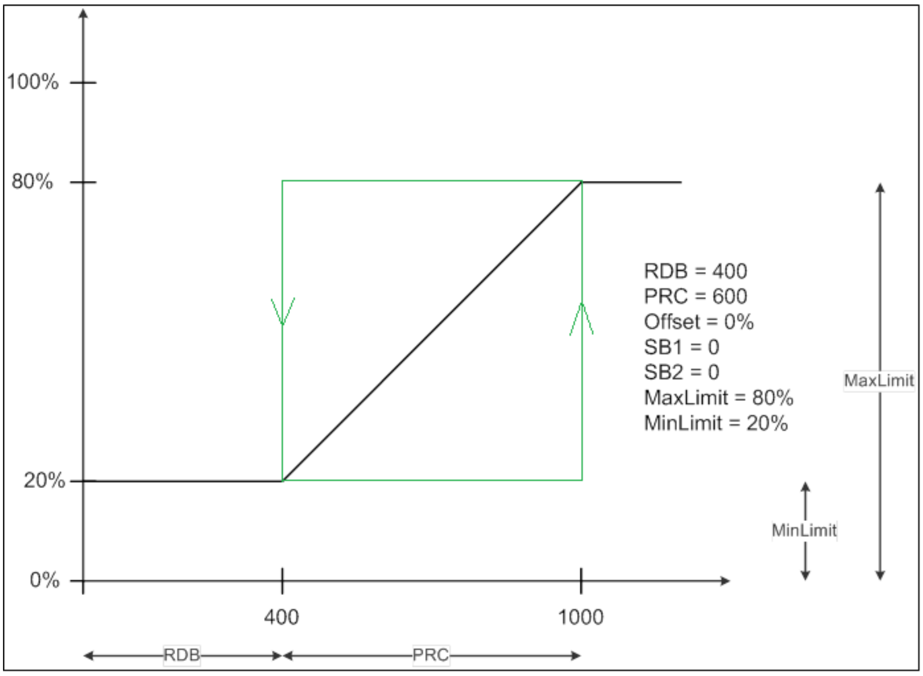
MaxLimit – Max output duty cycle (100% = 12000 = 0x2EE0)
MinLimit – Min output duty cycle (0% = 0 = 0x00)
RDB – Regulator dead band
PRC – Proportional regulator constant
SB1 – ShapeBit1, RDB high bit – mirror in y-axis
SB2 – ShapeBit2, PRC high bit – mirror in x-axis
Offset – X-axis offset (100% = 12000 = 0x2EE0)
IsDigital – PWM or digital high/low output.

In PWM mode, the duty cycle will increase from MinLimit to HighLimit linearly when the measured concentration exceeds RDB and is below RDB + PRC.

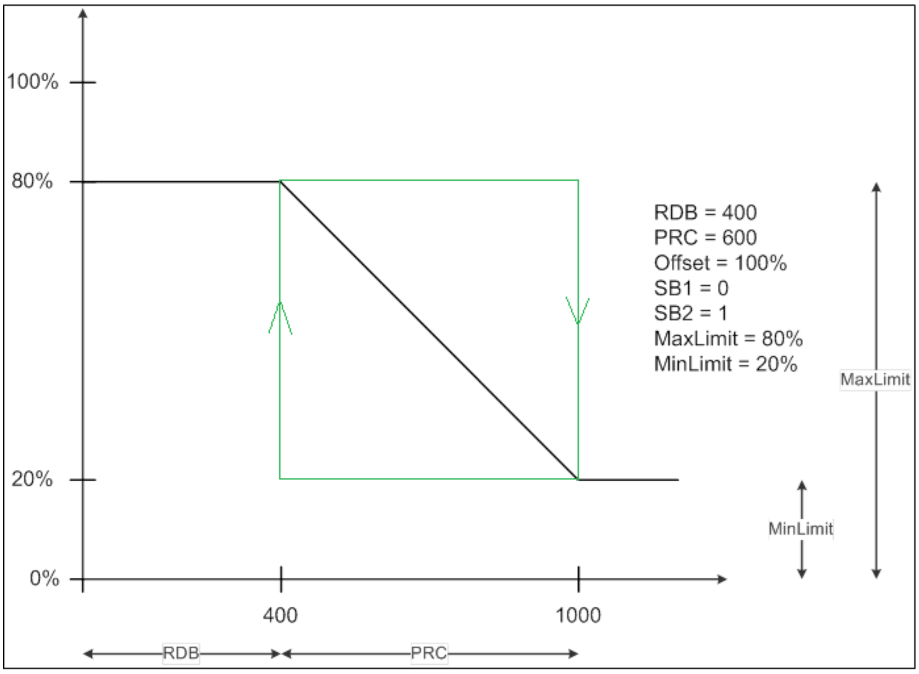
In Digital high/low mode, the output pin will go high when measured concentration is larger than RDB + PRC and return to low when measured concentration is lower than RDB. This mode disregards MinLimit and MaxLimit.

Offset and ShapeBits can be used to mirror behaviour.

Configuration examples can be seen below:
Green lines show behaviour of the digital output, black lines show PWM duty cycle output.



Example 1



Example 2

When the hardware is configured to voltage or current output, 100% duty is equivalent to 10 V or 20 mA respectively.

Warning: In case any internal error should be detected (ErrorStatus register <> 0), the outputs will be set to 0 to indicate a SYSTEM RESPONSE*.

If output configuration is modified from factory default, avoid any configuration that defines 0V / 0mA as normal state (no refrigerant leak detected) or use Modbus communication to read ErrorStatus register to ensure no internal error has occurred.

* SYSTEM RESPONSE is defined and required by IEC / UL 60335-2-40

4. Examples

4.1. Read Error Status and Measured concentration

Reading input registers IR1 to IR4: Error Status, IR2, IR3 and Measured concentration.

Note: Example is for R32 type sensor. For other types of sensors, LFL and sensor resolution can differ.

Request(hex):

$$68\ 04\ 00\ 00\ 00\ 04\ \underbrace{F8\ F0}_{\text{CRC}}$$

Response(hex):

$$68\ 04\ 08\ \underbrace{00\ 00}_{\text{Error status}}\ 00\ 00\ 00\ 00\ \underbrace{05\ 47}_{\text{Conc}}\ \underbrace{B7\ F2}_{\text{CRC}}$$

Error status = 0

Multiply gas concentration by sensor resolution = 1351 * 10 = 13510 ppm (for R32 sensor, resolution is 10ppm)

To convert from ppm to % of LFL for R32, divide by LFL (144000ppm for R32) and multiply by 100:

(13510 / 144000) * 100 = 9.38 % of LFL

this can be simplified to dividing measured concentration value by 144:

1351 / 144 = 9.38 % of LFL

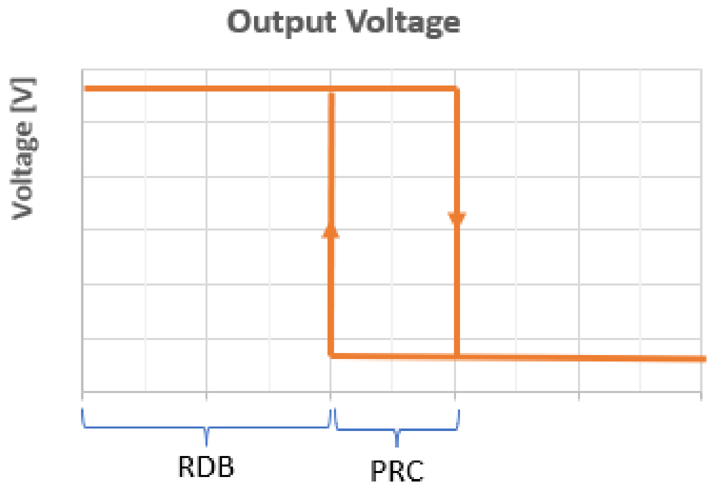
For details about CRC calculation see [1].

4.2. Output configuration

This shows an example of how to configure the output as digital high/low with hysteresis.

The output function is controlled by HR69 Output is digital, HR 64 RDB and HR65 PRC.
HR69 controls whether the pin is in PWM or Digital high/low mode.

In Digital high/low mode, the output pin will change state when measured concentration is larger than RDB + PRC and return to initial state when measured concentration is lower than RDB:



Notes:

- Output pin logic can be inverted or non-inverted. See "*Understanding Output configuration*" for more information.
- This example is for R32 sensor. For other types of sensors, modify the calculations to use the LFL of the actual gas type. Also make sure that units of RDB and PRC matches the resolution of the sensor. See additional note at end of this example!

To configure the output pin, we need to define the wished concentration threshold and the hysteresis. Let's for this example set threshold to 10% of LFL and hysteresis to 1% of LFL. This means that RDB should be set to 9% of LFL and PRC to 1% of LFL.

To convert from % of LFL to ppm, multiply by LFL (144000ppm for R32) and divide by 100:

(9 * 144000) / 100 = 12960 ppm

As the resolution of the R32 sensor is 10 ppm, we also need to divide by 10

12960 ppm / 10 = 1296

This can be simplified to multiplying wished value (in this example, 9% of LFL) by 144:

9 * 144 = 1296

First set RDB to 9% of LFL:

Calculate value to write: 9 * 144 = 1296. Converted to hexadecimal = 0510
Write 1296 to HR64:

Request:

68 10 00 3F 00 01 02 05 10 63 91

Response:

68 10 00 3F 00 01 38 FC

Then set PRC to 1% of LFL:

Calculate value to write: 1 * 144 = 144. Converted to hexadecimal = 0090
Then, we also need to mirror in X-axis, to set the output pin logic to inverted. This is done by setting the highest bit of PRC, so that PRC = 8090

Write 144 to HR65:

Request:

68 10 00 40 00 01 02 80 90 0B 6E

Response:

68 10 00 40 00 01 09 24

Set output pin configuration to digital on/off:

Write any non-zero value to HR69 (in this example, we write 1):

Request:

68 10 00 44 00 01 02 00 01 AA 86

Response:

68 10 00 44 00 01 48 E5

Additional note:

To repeat the same example for R290 sensor type, one needs to consider different LFL of R290 and resolution of sensor (1ppm for R290 type). To repeat the above example, the calculation would instead be:

To convert from % of LFL to ppm, multiply by LFL (21000ppm for R290) and divide by 100:

(9 * 21000) / 100 = 1890 ppm

This can be simplified to multiplying wished value (in this example, 9% of LFL) by 210:

9 * 210 = 1890

RDB and PRC can then be set accordingly.

4.3. Set Modbus address

Set sensors Modbus address to 10.

Request:

68 10 00 13 00 01 02 00 0A E6 A6

Response:

68 10 00 13 00 01 F9 35

Sensor starts to use new address after a sensor reset (reset command or power cycle).

4.4. Enable/Disable ABC

Enable and disable ABC by writing to HR14 and HR19.

Enable ABC:

1. Clear bit1 in HR19

   Start by reading HR19.

   Request(hex):

   68 03 00 12 00 01 2D 36

   Response(hex):

   68 03 02 00 F2 65 C8

   Clear bit1 in register and write back

   HR19 = HR19 & 0xFFFD = 0x00F2 & 0xFFFD = 0x00F0

   Write back new HR19 value.

   Request(hex):

   68 10 00 12 00 01 02 00 F0 67 34

   Response(hex):

   68 10 00 12 00 01 A8 F5

2. Read HR14 and verify that it is desired ABC period.

   Request(hex):

   68 03 00 0D 00 01 1C F0

   Response(hex):

   68 03 02 00 B4 E4 3A

3. If HR14 (ABC period) is not the desired period, write desired ABC period to HR14. In this example ABC period is set to 200 hours.

   Request(hex):

   68 10 00 0D 00 01 02 00 C8 64 89

   Response(hex):

   68 10 00 0D 00 01 99 33

Disable ABC:

1. Set bit1 in HR19

   Start by reading HR19.
   Request(hex):
   68 03 00 12 00 01 2D 36

   Response(hex):
   68 03 02 00 F0 E4 09

   Set bit1 in register and write back.
   HR19 = HR19 | 0x0002 = 0x00F0 | 0x0002 = 0x00F2

   Write back new HR19 value.
   Request(hex):
   68 10 00 12 00 01 02 00 F2 E6 F5

   Response(hex):
   68 10 00 12 00 01 A8 F5

A possible alternative is to set HR14 to zero.

4.5. Enable/Disable dynamic IIR filter

Enable and disable dynamic IIR filtration by writing to HR19.

Enable dynamic IIR filter.

Start by reading HR19.

Request(hex):

68 03 00 12 00 01 2D 36

Response(hex):

68 03 02 00 FF A4 0D

Clear bit2 and bit3 in register and write back

HR19 = HR19 & 0xFFF3 = 0x00FF & 0xFFF3 = 0x00F3

Write back new HR19 value.

Request(hex):

68 10 00 12 00 01 02 00 F3 27 35

Response(hex):

68 10 00 12 00 01 A8 F5

Disable static and dynamic IIR filter.

Start by reading HR19.

Request(hex):

68 03 00 12 00 01 2D 36

Response(hex):

68 03 02 00 F3 A4 08

Set bit 2 and bit 3 in HR19 and write back.

HR19 = HR19 | 0x000C = 0x00F3 | 0x000C = 0x00FF

Write back new HR19 value.

Request(hex):

68 10 00 12 00 01 02 00 FF 27 30

Response(hex):

68 10 00 12 00 01 A8 F5

4.6. Zero Calibration

Trig a zero-point calibration and read calibration status after calibration.

Write zero calibration command (0x7C07) to HR2

Request:

68 10 00 01 00 01 02 7C 07 04 D1

Response:

68 10 00 01 00 01 59 30

Read calibration status from HR1

Request:

68 03 00 00 00 01 8D 33

Response:

68 03 02 00 40 E5 95

HR1 = 0x40 = Zero calibration succeeded

To achieve best possible result from calibration it is important that the sensor is in a stable environment.

4.7. Pressure compensation

Enable and disable pressure compensation by writing to HR19. When pressure compensation is enabled, sensor will use value is HR47 to pressure compensate gas. If no value has been written to HR47 no pressure compensation will be done.

Enable pressure compensation.

Start by reading HR19.

Request(hex):

68 03 00 12 00 01 2D 36

Response(hex):

68 03 02 00 FF A4 0D

Clear bit4 in register and write back

HR19 = HR19 & 0xFFEF = 0x00FF & 0xFFEF = 0x00EF

Write back new HR19 value.

Request(hex):

68 10 00 12 00 01 02 00 EF 26 FC

Response(hex):

68 10 00 12 00 01 A8 F5

Disable pressure compensation.

Start by reading HR19.

Request(hex):

68 03 00 12 00 01 2D 36

Response(hex):

68 03 02 00 EF A5 C1

Set bit 4 in register and write back.

HR19 = HR19 | 0x0010 = 0x00EF | 0x0010 = 0x00FF

Write back new HR19 value.

Request(hex):

68 10 00 12 00 01 02 00 FF 27 30

Response(hex):

68 10 00 12 00 01 A8 F5

4.8. Write pressure to sensor

Write pressure 997 hPa to sensor HR47. Sensor works with unit 0.1 hPa so value to write to the sensor has to be calculated.

Value to write = 997 * 10 = 9970.

Request:

68 10 00 2E 00 01 02 26 F2 F9 A9

Response:

68 10 00 2E 00 01 68 F9

If pressure compensation is enabled, and a value has been written to HR47, the sensor will pressure compensate gas. If the value written to sensor is not in the range 3000 – 13000, the sensor will use 3000 or 13000 for the pressure compensation.

Pressure value written to the sensor will be used in the next gas calculation. This means that it can take up to one measurement period before pressure compensated measured concentration is based on the new pressure value.

4.1. Write scaling factor

Note: Only applicable for firmware revision 1.2 and above

To change scaling factor, one shall write new scaling pair of values into HR21/HR22 registers. For example, if one wants to change representation of value in IR14 for Senseair RDS R32 to %LFL for R454A gas (see Scaling factors from ppm to %LFL for common gases):

Values to write:

HR21 = 8943 (0x22EF)

HR22 = 4096 (0x1000)

Request:

68 10 00 14 00 02 04 22 EF 10 00 15 80

Response:

68 10 00 14 00 02 08 F5

Validate the writing after sensor reset (or by software command or by hardware reset):

Request:

68 03 00 14 00 02 8D 36

Response:

68 03 04 22 EF 10 00 35 78

5. Scaling factors from ppm to %LFL for common gases

The Senseair RDS has multiple variants of the articles for different gases and ranges.

To calculate the %LFL or ppm from the sensor reading one can use following formulas:

ppm:

$$ppm = Sensor_{reading} * K_{ppm}$$

%LFL:

$$\%LFL = Sensor_{reading} / K_{\%LFL} * 100\%$$

The sensor resolution in ppm ($Kppm$) and LFL scaling factor ($K\%LFL$) are product dependent values, please consult product specification for exact values - the table below shows these values for most common sensors.

Note! The table below shows theoretically calculated values. To ensure correct operation, user must verify settings and sensor readings in real-world application.

Gas	Kppm, sensor resolution in ppm	K%LFL	Recommended concentration scale factor, nominator part (register HR21)	Recommended concentration scale factor, denominator part (register HR22)	%LFL LSB in IR14
For RDS R32:					
R32	10	144.4	22756	32768	0.01%
R454A	18.47	45.8	8943	4096	0.01%
R454B	12.06	98.2	4171	4096	0.01%
R454C	26.65	29.6	6919	2048	0.01%
R455A	27.67	43.6	18789	32768	0.01%
For RDS R290:					
R290	1	210	100	210	0.01%

6. Revision history

Date	Revision	Page (s)	Description
2022-10-18	1	All	New document (preliminary version)
2023-01-24	2	16 20-25 32	Corrected default ABC period to 720 hours Modified description of HR69 and output settings. Added example how to configure digital output.
2023-03-03	3		Changed description of Output and PID HRs. Added HR70 and a chapter to understand output configuration.
2023-07-25	4	20, 27 various	Removed default values of HR64 - 69. Updated output configuration example 3.4 Added notes about LFL and sensor resolution being different for different sensor types
2023-09-05	5		Moved section “Understanding Output configuration” to before examples, and rearranged examples. Expanded example to cover R290 sensor type. Minor typos corrected throughout document. Added warning note on first page.
2023-11-02	6	All	Changed logo
2023-11-02	7	All	Added Rev link
2023-11-06	8	All	Changed to ©2023 Senseair AB.
2024-06-26	9	16 23 All 14,18 14 13 27 35-36	Corrected Unit of HR16 Added warning note about internal error will set outputs to 0 Changed to ©2024 Senseair AB. Add registers for scaled concentration and calibration targets Add register for Elapsed Time Counter New error “Scale factor error” flag Corrected example 4.2 with setting of shape bit Added example of scaling factors

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