



MOLECULAR PROPERTY SPECTROMETER™ (MPS™)
REFRIGERANT GAS SENSOR
USER MANUAL

Notices

SM-UM-0004-18

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Revision History

Version	Issue Date (DD/MM/YYYY)	Change
SM-UM-0004-01	30/01/2020	Initial release
SM-UM-0004-02	19/05/2020	Added section 4.1 and included CO ₂ . Added section 5 to outline CDs and electrical pinouts
SM-UM-0004-03	11/06/2020	Updated the table in section 4 to include updated list of poisons.
SM-UM-0004-04	30/09/2020	Typographical errors corrected
SM-UM-0004-05	11/03/2021	Update dimensions of S4 package so that pin locations relative to the center of the package are shown
SM-UM-0004-06	24/03/2021	Updated voltage ranges to 3.3-5V +/- 5%
SM-UM-0004-07	27/05/2021	Added note in electromechanical integration section for termination of analog out pin.
SM-UM-0004-08	31/12/2021	Certificates of compliance removed. Table of contents updated.
SM-UM-0004-09	15/04/2022	Updated with change from A2L FW3.x.x.x to A2L FW4.1.x.x
SM-UM-0004-10	18/05/2022	Fixed typos. Updated CO ₂ cross sensitivity trigger value
SM-UM-0004-11	07/06/2022	Added information about analog out + auto start + UART
SM-UM-0004-12	13/09/2022	Updated table in section 3
SM-UM-0004-13	23/09/2022	Corrected error, table p.7. Added information about PCB design considerations
SM-UM-0004-14	18/11/2022	Updated status field table.
SM-UM-0004-15	28/03/2023	Changed title and contents to be more generic (A1 and A2L). Added information related to R-410A
SM-UM-0004-16	05/05/2023	Updated section 5
SM-UM-0004-17	02/12/2024	Added information for R1234ze and R-454A. Added information on new formulation specification switch (%LFL definition based on WCF vs nominal formulation).
SM-UM-0004-18	15/4/2024	Updated images of Mini enclosure dimensions

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1. How the MPS Refrigerant Gas Sensors Work

MPS Refrigerant Gas Sensors are smart sensors with built-in environmental compensation that detect and accurately quantify low-global-warming (LGW), flammable (A2L), and non-flammable (A1) refrigerants used in HVAC applications. They are robust, extremely poison resistant, and come factory calibrated. Sensor readings are output on a Universal Asynchronous Receiver and Transmitter (UART) digital bus or industry-standard analog output. Each type of refrigerant sensor is designed and calibrated to detect a single, specific refrigerant gas (e.g. R-32).

The MPS transducer is a micro-machined membrane with an embedded Joule heater and resistance thermometer. The MEMS transducer is mounted on a PCB and packaged inside a filtered enclosure that is permeable to ambient air. Presence of a refrigerant gas causes changes in the thermodynamic properties of the air/gas mixture; these properties are measured by the transducer and processed by patent-pending algorithms to report an accurate concentration.

2. Communicating with a MPS Refrigerant Gas Sensor

This section describes the software interface requirements for MPS Refrigerant Gas Sensors and is useful to system integrators when designing a sensor assembly into a final product.

The preferred method of communicating with the sensor is over the serial interface using the UART (Universal Asynchronous Receiver/Transmitter) protocol. Section 2.1 provides the necessary information for communicating using UART. Section 2.2 provides information for measuring sensor output via the analog voltage output pin.

2.1. Serial (UART) Communication

Communication with the system over the serial interface (UART) will allow an external user or system to execute the commands provided in the Command Table in Section 2.1.5. Users may also refer to the Command Descriptions in Section 2.1.6 for usage descriptions.

Serial connection parameters:

Parameter	Size
Baud Rate	38400
Data Size	8 bits
Parity	None
Stop Bit	1 bit

2.1.1. Data Representation

All integer values (16 bits or 32 bits) are represented in Little Endian format (LSB first). This means when an integer is transmitted on the serial interface, the least significant byte (LSB) is transmitted first, and the most significant byte (MSB) is transmitted last.

Floating point numbers are represented in IEEE 754 format.

2.1.2. Protocol Specification

Communication to and from the MPS Refrigerant Gas Sensor is made up of “packets.” The communication paradigm is that of “request” and “reply.” An external host sends a “request” packet to the sensor. The sensor returns a “reply” packet to the external host. A packet consists of a fixed size “header” and a variable length “payload.” It is possible for a packet to have no payload (length of zero) where a packet contains only a header. The “payload”, if any, typically consists of “parameters” for a request or “result” for a reply. Even when a reply does not contain any result, a reply is still sent with the header as an acknowledgement of the request.

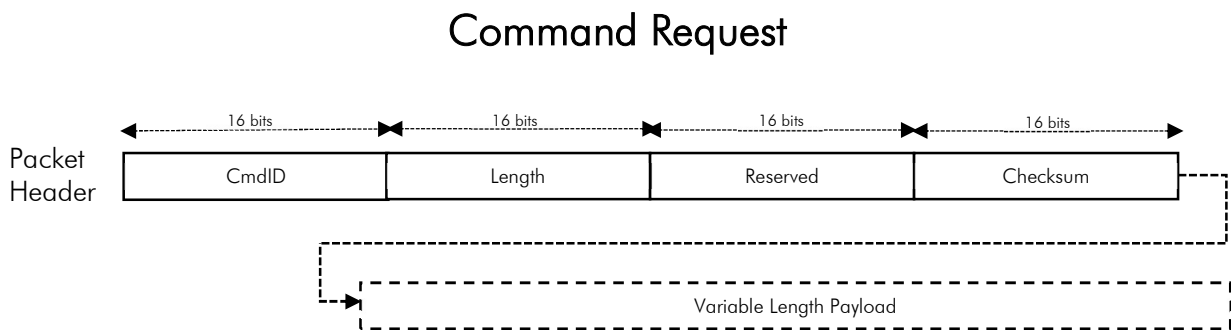


Figure 1: Request Packet Structure

The Request Packet (Figure 1) consists of the following fields:

Field	Size	Description
CmdID	2 Bytes	Command ID of this request (see Command Table in section 2.1.5). Although CmdID uses only 1 byte, it is extended to 2 bytes in the Request Header for alignment purposes.
Length	2 Bytes	Length of the Payload (0 if no payload)
Reserved	2 Bytes	Reserved for future use (zero filled)
Checksum	2 Bytes	Checksum of the entire packet
Variable Length Payload	variable	Command parameters for this request

Command Reply

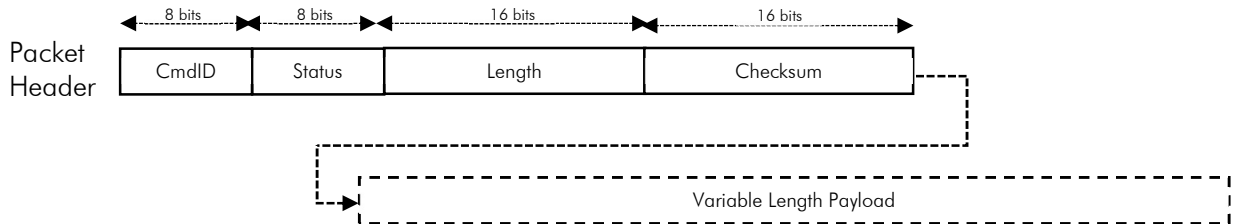


Figure 2: Reply Packet Structure

The Reply Packet (Figure 2) consists of the following fields:

Field	Size	Description
CmdID	1 Byte	Command ID (should match the original request)
Status	1 Byte	Return status of the request
Length	2 Bytes	Length of the Payload (0 if no payload)
Checksum	2 Bytes	Checksum of the entire packet
Variable Length Payload	variable	Command parameters for this request

The Status field consists of the following possible return values:

Fault	Fault Message	Explanation	Output (PPM or %LFL)	User action
0x00	OK	MPS is operating normally and has no errors	Normal	None
0x01	CRC_FAILED	Transmitted data failed checksum	N/A	Verify checksum calculation is correct. See Section 2.1.3.
0x02	BAD_PARAM	Illegal or bad parameters specified	N/A	Verify parameter given in command is correct.
0x03	EXE_FAILED	Execution of command failed	N/A	Contact support.
0x04	NO_MEM	Insufficient memory for operation	N/A	Contact support.

Fault	Fault Message	Explanation	Output (PPM or %LFL)	User action
0x05	UNKNOWN_CMD	Unknown Command ID specified	N/A	Verify Command ID is correct. See Section 2.1.5.
0x07	INCOMPLETE_COMMAND	Incomplete or truncated command	N/A	Verify entire packet header and payload (if any) is fully sent.
0x20	HW_ERR_AO	Analog out malfunction (only if AO functionality enabled)	-100	Contact support.
0x21	HW_ERR_VDD	Internal voltage regulator out of range	-100	Supply 3.3-5.0 \pm 5% VDC. If this error persists for more than 5 cycles (~ 10s), this error will latch until the sensor is power cycled and supplied correct voltage
0x22	HW_ERR_VREF	Voltage out of range	-100	Contact support.
0x23	HW_ENV_XCD_RANGE	Environmental (Temp., Press., Humid.) out of range	Normal	Return sensor to specified operating range. See Section 4.
0x24	HW_ENV_SNSR_MALFUNCTION	Environmental sensor malfunction	-100	The sensor was exposed to an extreme environmental condition that can permanently damage it, rendering it unsuitable for accurate readings. As a fail-safe, this error permanently latches the sensor and disables further operation. Sensors that have latched due to exposure to such environmental conditions will not be accepted under warranty. See Section 4 for details.
0x25	HW_ERR_MCU_FLASH	Microcontroller error	-100	Contact support.
0x26	HW_SENSOR_INITIALIZATION	Sensor in initialization mode (10 cycles)	-100	Wait 10 cycles (~20 sec) for sensor to initialize.

Fault	Fault Message	Explanation	Output (PPM or %LFL)	User action
0x31	CONDENSATION_DETECTED	Condensation condition exists at sensor (out of specification)	Normal	Raise temperature and/or lower humidity. See Section 4.
0x32	HW_SENSOR_MALFUNCTION	Gas sensing element malfunction	-100	Contact support.

2.1.3. Checksum Calculation

The algorithm for checksum calculation is that of 16-bit CRC CCITT with start byte 0xFFFF. Checksum is computed over the entire packet (header and payload). The checksum field in the header is initialized with zeros before computing checksum. If there is no payload, checksum is computed against the header only. The following sample C code can be used to calculate the checksum for a buffer of a given size:

```
#include <stdlib.h>
#include <stdint.h>

static uint16_t crc_table[256] = {
    0x0000, 0x1021, 0x2042, 0x3063, 0x4084, 0x50a5, 0x60c6, 0x70e7,
    0x8108, 0x9129, 0xa14a, 0xb16b, 0xc18c, 0xd1ad, 0xe1ce, 0xf1ef,
    0x1231, 0x0210, 0x3273, 0x2252, 0x52b5, 0x4294, 0x72f7, 0x62d6,
    0x9339, 0x8318, 0xb37b, 0xa35a, 0xd3bd, 0xc39c, 0xf3ff, 0xe3de,
    0x2462, 0x3443, 0x0420, 0x1401, 0x64e6, 0x74c7, 0x44a4, 0x5485,
    0xa56a, 0xb54b, 0x8528, 0x9509, 0xe5ee, 0xf5cf, 0xc5ac, 0xd58d,
    0x3653, 0x2672, 0x1611, 0x0630, 0x76d7, 0x66f6, 0x5695, 0x46b4,
    0xb75b, 0xa77a, 0x9719, 0x8738, 0xf7df, 0xe7fe, 0xd79d, 0xc7bc,
    0x48c4, 0x58e5, 0x6886, 0x78a7, 0x0840, 0x1861, 0x2802, 0x3823,
    0xc9cc, 0xd9ed, 0xe98e, 0xf9af, 0x8948, 0x9969, 0xa90a, 0xb92b,
    0x5af5, 0x4ad4, 0x7ab7, 0x6a96, 0x1a71, 0x0a50, 0x3a33, 0x2a12,
    0xdbfd, 0xcbdc, 0xfbbf, 0xeb9e, 0x9b79, 0x8b58, 0xbb3b, 0xab1a,
    0x6ca6, 0x7c87, 0x4ce4, 0x5cc5, 0x2c22, 0x3c03, 0x0c60, 0x1c41,
    0xedae, 0xfd8f, 0xcdec, 0xddcd, 0xad2a, 0xbd0b, 0x8d68, 0x9d49,
    0x7e97, 0x6eb6, 0x5ed5, 0x4ef4, 0x3e13, 0x2e32, 0x1e51, 0x0e70,
    0xff9f, 0xefbe, 0xdfdd, 0xcffc, 0xbf1b, 0xaf3a, 0x9f59, 0x8f78,
    0x9188, 0x81a9, 0xb1ca, 0xa1eb, 0xd10c, 0xc12d, 0xf14e, 0xe16f,
    0x1080, 0x00a1, 0x30c2, 0x20e3, 0x5004, 0x4025, 0x7046, 0x6067,
    0x83b9, 0x9398, 0xa3fb, 0xb3da, 0xc33d, 0xd31c, 0xe37f, 0xf35e,
    0x02b1, 0x1290, 0x22f3, 0x32d2, 0x4235, 0x5214, 0x6277, 0x7256,
    0xb5ea, 0xa5cb, 0x95a8, 0x8589, 0xf56e, 0xe54f, 0xd52c, 0xc50d,
    0x34e2, 0x24c3, 0x14a0, 0x0481, 0x7466, 0x6447, 0x5424, 0x4405,
    0xa7db, 0xb7fa, 0x8799, 0x97b8, 0xe75f, 0xf77e, 0xc71d, 0xd73c,
    0x26d3, 0x36f2, 0x0691, 0x16b0, 0x6657, 0x7676, 0x4615, 0x5634,
    0xd94c, 0xc96d, 0xf90e, 0xe92f, 0x99c8, 0x89e9, 0xb98a, 0xa9ab,
```

```

0x5844, 0x4865, 0x7806, 0x6827, 0x18c0, 0x08e1, 0x3882, 0x28a3,
0xcb7d, 0xdb5c, 0xeb3f, 0xfb1e, 0x8bf9, 0x9bd8, 0xabbb, 0xbb9a,
0x4a75, 0x5a54, 0x6a37, 0x7a16, 0x0af1, 0x1ad0, 0x2ab3, 0x3a92,
0xfd2e, 0xed0f, 0xdd6c, 0xcd4d, 0xbdaa, 0xad8b, 0x9de8, 0x8dc9,
0x7c26, 0x6c07, 0x5c64, 0x4c45, 0x3ca2, 0x2c83, 0x1ce0, 0x0cc1,
0xef1f, 0xff3e, 0xcf5d, 0xdf7c, 0xaf9b, 0xbfba, 0x8fd9, 0x9ff8,
0x6e17, 0x7e36, 0x4e55, 0x5e74, 0x2e93, 0x3eb2, 0x0ed1, 0x1ef0,
};

uint16_t crc_generate(uint8_t *buffer, size_t length, uint16_t startValue)
{
    uint16_t crc;
    uint8_t *p;
    int ii;

    crc = startValue;

    for(p = buffer, ii = 0; ii < length; ii++) {
        crc = (crc << 8) ^ crc_table[(crc >> 8) ^ *p];
        p++;
    }

    return crc;
}

```

For more information on how to use the above function, please look at the sample test program “Sample Code” located here: <https://nevadanano.com/downloads>

2.1.4. Startup and Measurement Sequence

Figure 3 describes the recommended steps after powering on the sensor plus the measurement sequence for getting answer data. The major steps consist of the following:

- After powering on the sensor, wait for the sensor to boot up completely (~3 seconds).
- Verify communication channel by asking the sensor for version information.
 - Protocol version can be used to determine available commands, answers, or new data.
- Start measurement in “continuous” mode.
- Wait 2 seconds for the first measurement to complete.
- Get Answer.
- Repeat process to get answer at desired frequency.

The sensor initializes for the first 10 cycles after powering up. During this period, the sensor output is set to “-100 ppm” for A1 gases, or “-100 %LFL” for A2L gases, the sensor status is set to

HW_SENSOR_INITIALIZATION (0x26), and the sensor is not capable of reporting gas concentrations. Once initialization is complete, the sensor is ready to report gas concentrations, and the status is set to 0x00.

Note: It takes approximately 2 seconds to calculate and complete a measurement. If multiple requests to read the Answer register (0x01) were made within a two-second window, one might get the same answer. This depends on whether a new measurement is calculated between multiple Answer requests. The MPS Cycle Count ("COUNT") in the Answer Response is incremented after each measurement is calculated. Therefore, when processing an "answer," one should compare the COUNT value in the answer against the COUNT value from the previous answer. If the COUNT value did not increment, this is a repeated answer. If the COUNT value incremented, this is a new answer from the latest measurement cycle. When continuous measurement is stopped and restarted, the COUNT value resets to 1 with the first measurement.

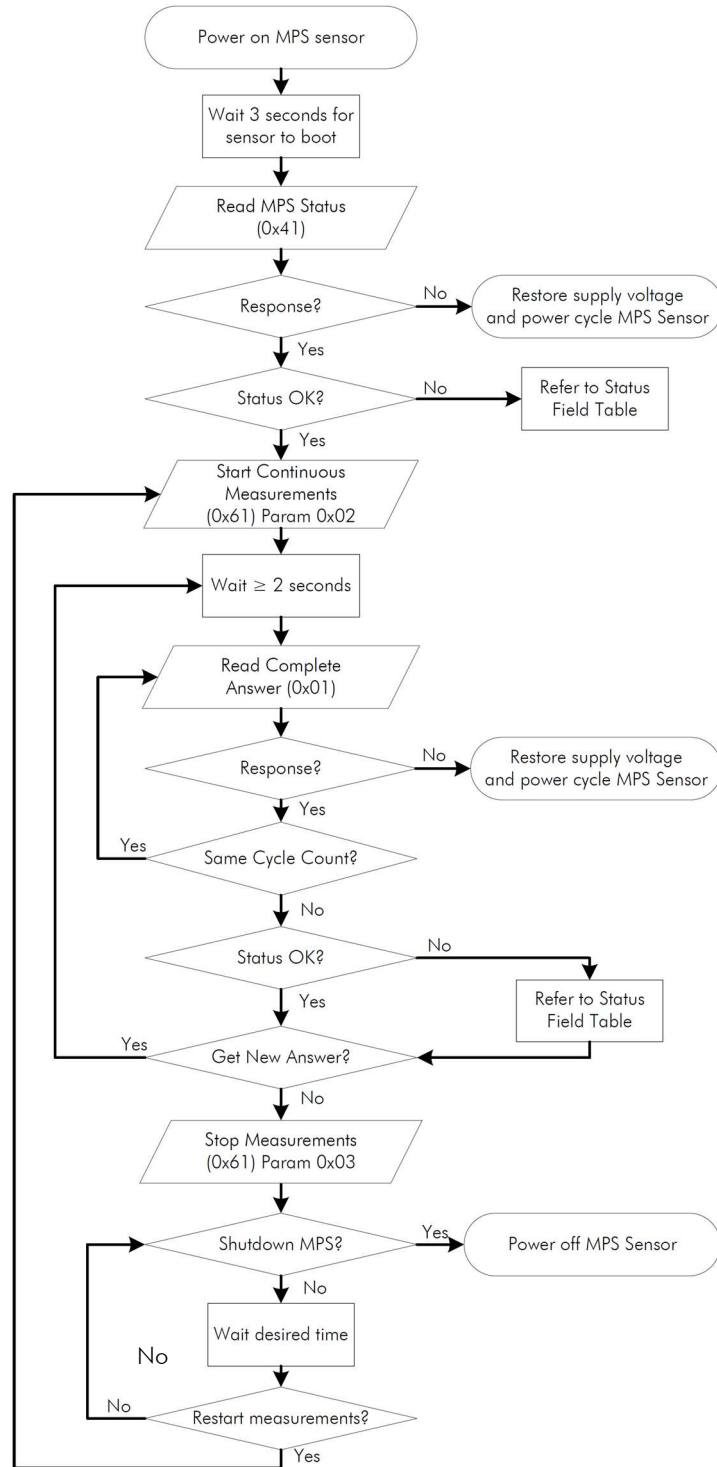
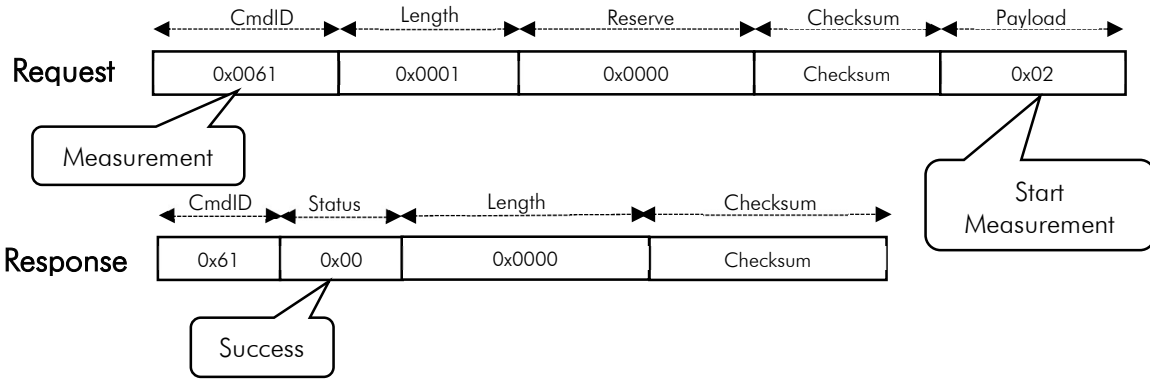


Figure 3: Startup and Measurement Sequence

Figure 4 describes sample Request and Response packets for the Perform Measurement and Get Answer Vector sequences.

Perform



Get Answer

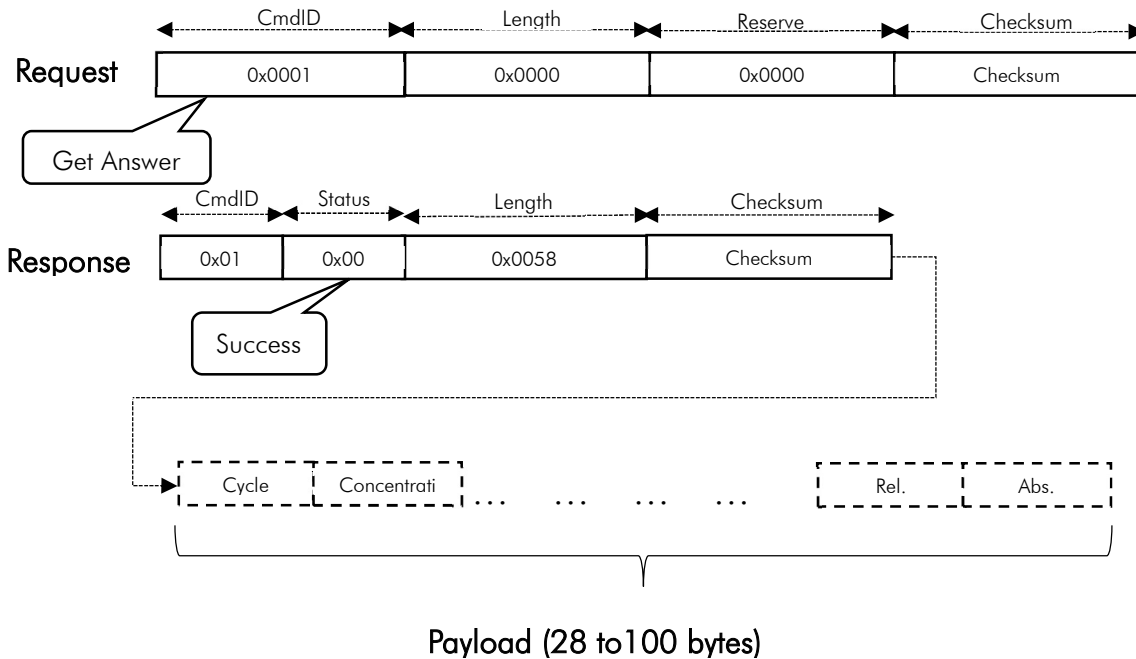


Figure 4: Sample Request and Response Packets for Performing Measurement and Get Answer Vector

2.1.5. Command Table

UART commands with calculated checksum

Hex Code	Command ID	Payload Length [bytes]		Request Packet (Little-Endian Format)				
		Request	Response	CmdID	Length	Reserved	Calculated Checksum*	Payload
0x01	ANSWER	0	28	0x01 0x00	0x00 0x00	0x00 0x00	0xed 0x76	null
0x03	CONC	0	4	0x03 0x00	0x00 0x00	0x00 0x00	0x4b 0xf9	null
0x04	ID	0	4	0x04 0x00	0x00 0x00	0x00 0x00	0x53 0x3e	null
0x21	TEMP	0	4	0x21 0x00	0x00 0x00	0x00 0x00	0x85 0x0d	null
0x22	PRES	0	4	0x22 0x00	0x00 0x00	0x00 0x00	0xf0 0xc5	null
0x23	REL_HUM	0	4	0x23 0x00	0x00 0x00	0x00 0x00	0x23 0x82	null
0x24	ABS_HUM	0	4	0x24 0x00	0x00 0x00	0x00 0x00	0x3b 0x45	null
0x41	STATUS	0	1	0x41 0x00	0x00 0x00	0x00 0x00	0x3d 0x80	null
0x42	VERSION	0	8	0x42 0x00	0x00 0x00	0x00 0x00	0x48 0x48	null
0x43	SENSOR_INFO	0	100	0x43 0x00	0x00 0x00	0x00 0x00	0x9b 0x0f	null
0x61	MEAS	1	0	0x61 0x00	0x01 0x00	0x00 0x00	0x57 0x93	0x02
0x61	MEAS	1	0	0x61 0x00	0x01 0x00	0x00 0x00	0x35 0xb7	0x22
0x61	MEAS	1	0	0x61 0x00	0x01 0x00	0x00 0x00	0x76 0x83	0x03
0x62	RESET	0	0	0x62 0x00	0x00 0x00	0x00 0x00	0x20 0x33	null

2.1.6. Command Descriptions

1. Command 0x01 – ANSWER – Read Complete Answer

Description: Returns a complete answer in one read operation.

Parameters: N/A

Response: **CYCLE_COUNT** 32-bit unsigned value. Cycle Number of this measurement (incremented after each measurement)

CONC 32-bit floating point value. Refrigerant gas concentration [ppm or %LEL]

ID 32-bit unsigned value. Refrigerant gas type ID.

	See “Command 0x04 – ID” for descriptions of gas ID values.
TEMP	32-bit floating point value. Ambient temperature [°C]
PRESSURE	32-bit floating point value. Ambient pressure [kPa]
REL_HUM	32-bit floating point value. Ambient relative humidity [%RH]
ABS_HUM	32-bit floating point value. Ambient absolute humidity [$\frac{g}{m^3}$]

2. Command 0x03 – CONC – Read Refrigerant Gas Concentration

Description: Returns refrigerant gas concentration (ppm or %LFL) as measured by the MPS.

Parameters: N/A

Response: CONC 32-bit floating point value. Refrigerant gas concentration (ppm or %LFL)

3. Command 0x04 – ID – Read Refrigerant Gas ID

Description: Returns refrigerant gas ID as determined by the MPS.

Parameters: N/A

Response: ID 32-bit unsigned value. Refrigerant gas ID.

ID	Description
0	No Gas
7	A2L Refrigerant Gas
8	A1 Refrigerant Gas
253	Unknown Gas
254	Under Range – Concentration less than 0 ppm or 0 %LFL
255	Over Range – Concentration greater than 130,000 ppm or 110 %LFL

4. Command 0x21 – TEMP – Read Temperature

Description: Returns the ambient temperature (°C) as reported by the integrated environmental sensor.

Parameters: N/A

Response: TEMP; 32-bit floating point value. Ambient temperature (°C).

5. Command 0x22 – PRES – Read Pressure

Description: Returns the ambient pressure (kPa) as reported by the integrated environmental sensor.

Parameters: N/A

Response: PRESSURE; 32-bit floating point value. Ambient pressure (kPa).

6. Command 0x23 – REL_HUM – Read Relative Humidity

Description: Returns the ambient relative humidity (%RH) as reported by the integrated environmental sensor.

Parameters: N/A

Response: REL_HUM 32-bit floating point value. Ambient relative humidity (%RH).

7. Command 0x24 – ABS_HUM – Read Absolute Humidity

Description: Returns the ambient absolute humidity ($\frac{g}{m^3}$) as calculated by the MPS.

Parameters: N/A

Response: ABS_HUM 32-bit floating point value. Ambient absolute humidity ($\frac{g}{m^3}$).

8. Command 0x41 – STATUS – Read MPS Status

Description: Returns the status of the MPS; refer to Sec. 2.1.2 for status descriptions.

Parameters: N/A

Response: STATUS 8-bit unsigned value. Status of MPS

9. Command 0x42 – VERSION – Read MPS Version Info

Description: Returns the software, hardware, and protocol versions of the MPS.

Parameters: N/A

Response: SW_VERSION	8-bit unsigned values. Version is W.X.Y.Z
HW_VERSION	8-bit unsigned values. Version is W.X

PROTOCOL_VERSION 8-bit unsigned values. Version is W.X

MPS Version Info																															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
SW Version W [7:0]								SW Version X [7:0]								SW Version Y [7:0]								SW Version Z [7:0]							

33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
HW Version W [7:0]								HW Version X [7:0]								Protocol Version W [7:0]								Protocol Version X [7:0]							

10. Command 0x43 – SENSOR_INFO – Read MPS Sensor Info

Description: Returns information about the sensor.

Parameters: N/A

Response:

SERIAL_NUM	Sensor serial number. 32 bytes, zero-padded ASCII string.
SENSOR_TYPE	Sensor type. 32-bit unsigned integer.
SENSOR_SKU	SKU assigned to the sensor. 32 bytes, zero-padded ASCII string.
CAL_DATE	Date of last calibration. 16 bytes, zero-padded ASCII string. Format is MM/DD/YYYY.
MFG_DATE	Date of manufacture. 16 bytes, zero-padded ASCII string. Format is MM/DD/YYYY.

11. Command 0x61 – MEAS – Perform Measurement

Description: Sets the sensing mode (idle, single, or continuous) and concentration mode in the measurement.

Parameters: The parameter to the Measurement command is 1 byte in length but consists of two, 4-bit values: Concentration Formulation (bits 7:4) and Mode (bits 3:0).

Measurement Value (Byte)	
Conc. Mode [7:4]	Mode [3:0]

The concentration mode (bits 7:4 of the measurement byte) bits are used for refrigerant blend sensors (e.g., R-454A, R-454B, R-454C, etc.). They set the reported concentration based on either worst-case formulation- (WCF) or nominal formulation-based definitions of %LFL. Most standards (for example, UL 60335-2-40:22) have moved to WCF-based formulations.

Conc. Mode	Name	Description
0x0	WCF_LFL	WCF-based definition of %LFL. Default value for all refrigerant sensor types.
0x2	NOM_LFL	Nominal-based definition of %LFL.

The measurement mode (bits 3:0 of the measurement byte) consists of the following possible values:

MODE	Name	Description
0x2	MPS_CONT	MPS operates in an autonomous, continuous mode
0x3	MPS_STOP	Stop measurement – no measurements are being taken

Response: N/A

12. Command 0x62 – RESET– Reset MPS

Description: Perform a soft reset of the MPS, clearing all data and states.

Parameters: N/A

Response: N/A

2.2. Sensor Analog Output Mode

The MPS Refrigerant Gas Sensor is factory-configurable to report gas concentrations via an analog signal that mimics the output of conventional catalytic bead Refrigerant Gas Sensors. By default, this feature is disabled. The analog output signal from the MPS Refrigerant Gas Sensor is generated with a digital-to-analog converter. The standard analog output range, shown in Fig. 5, is 0.4 V to 2.0 V linearly increasing with gas concentration with a resolution of ~ 1.6 mV. Upon startup, the analog output pin may report between 0.75-1.75 V momentarily (< 100 ms) during initialization.

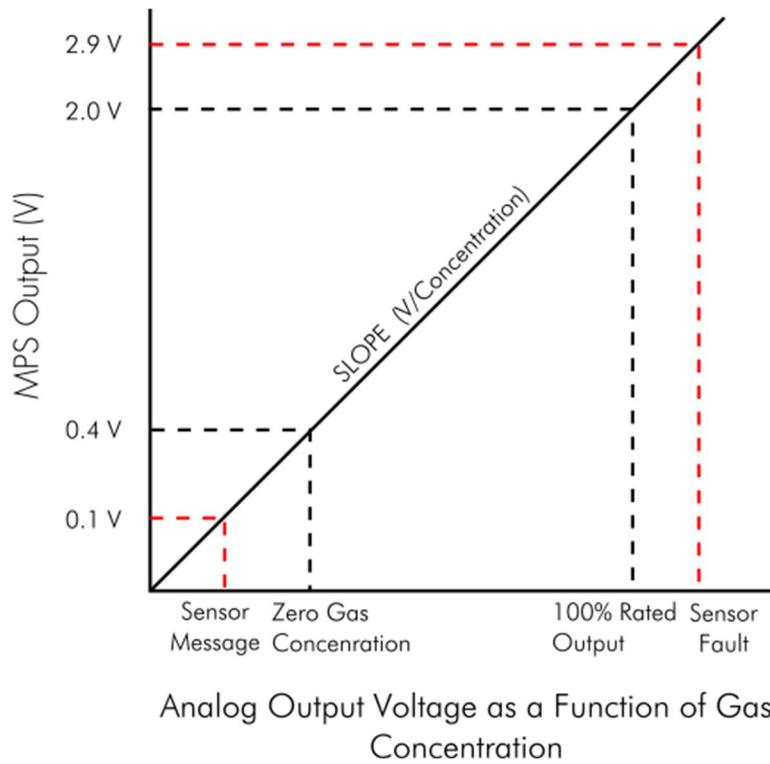


Figure 5: MPS Refrigerant Gas Sensor output when configured in analog output mode.

The following table lists the analog output voltage slopes as a function of gas concentration.

Gas Type	Analog Out Voltage Slope [V/%LFL] or [V/ppm]	Max Reported Concentration Voltage [V]	Concentration at Max Voltage
R-32, R-454A, R-454B, R-454C, R-1234ze (A2L)	1.600×10^{-2}	2.16	110 %LFL
R-404, R-407 (A1)	3.520×10^{-4}	2.16	5,000 ppm
R-410A (A1)	1.266×10^{-5}	2.04	130,000 ppm

When there is an error condition or special status, as reported by the sensor status field (outlined in Section 2.1.2.), the voltage level does not indicate gas concentration. Instead, the voltage is set to report an error or special status (see table below). Only critical statuses and messages that indicate the sensor's initialization sequence are conveyed to the user. The following table indicates the output voltage corresponding to each sensor message and critical status.

Status	Voltage [V]
HW_ERR_AO	2.9
HW_ERR_VREF	2.9
HW_ENV_SNSR_MALFUNCTION	2.9
HW_ERR_MCU_FLASH	2.9
HW_SENSOR_INITIALIZATION	0.1
HW_SENSOR_MALFUNCTION	2.9

Non-critical status messages (e.g.: [0x23] HW_ENV_XCD_RANGE, [0x31] CONDENSATION_DETECTED) are not reported via the analog output. Alternate analog output configurations are available with outputs between 0.04V and 2.4V and a configurable sensitivity slope, including rising or falling volts/ppm or volts/%LFL. Contact NevadaNano for details.

2.2.1. Analog Out Electrical Integration

Figure 6 describes a simple schematic of the analog output stage of the sensor connected to an external system to measure the analog out voltage.

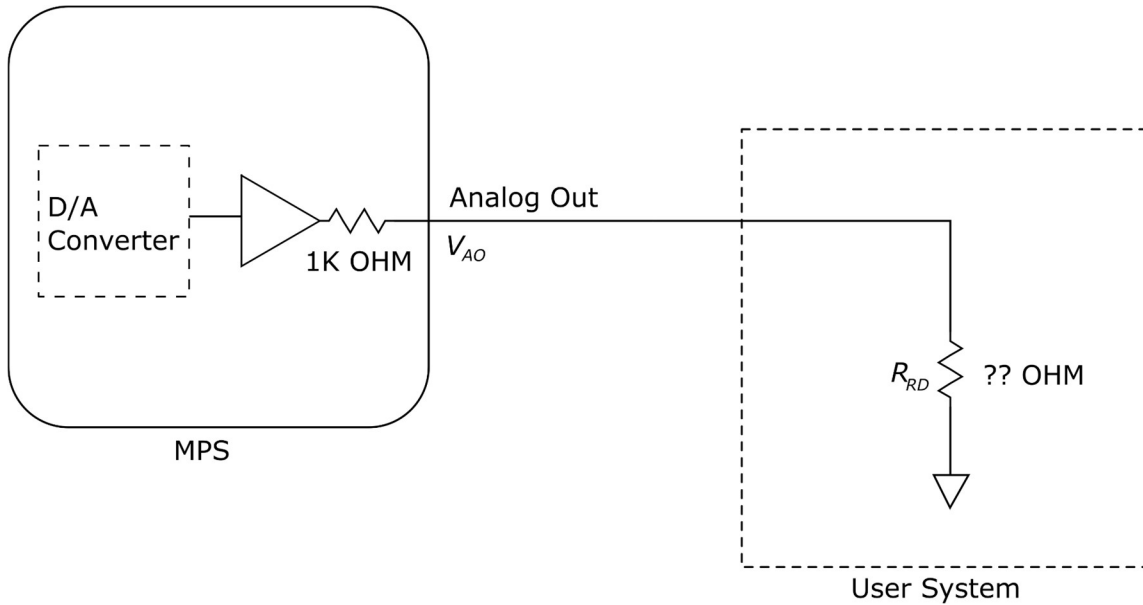


Figure 6. Analog output stage of the MPS coupled to a user system

The internal, 1-kOhm resistor within the sensor, in series with the load resistance of the user's voltage reading equipment (VRE), creates an attenuator. This attenuator reduces the voltage at the input of the VRE, according to the following formula:

$$V_{RD} = V_{AO} \left(\frac{R_{RD}}{R_{RD} + 1,000\Omega} \right)$$

Where:

V_{RD} = Voltage into the VRE

V_{AO} = Voltage out of the MPS analog out pin

R_{RD} = Resistance of the input of the VRE

1000 Ω = the output resistance of the MPS analog out

For example, as shown in Figure 7, a VRE internal resistance load (R_{RD}) of 50 k Ω will result in a 2% attenuation in the voltage and therefore a 2% attenuation in ppm reading. System designers should account for this when implementing systems using the analog out signal from the sensor with a low-input-resistance VRE.

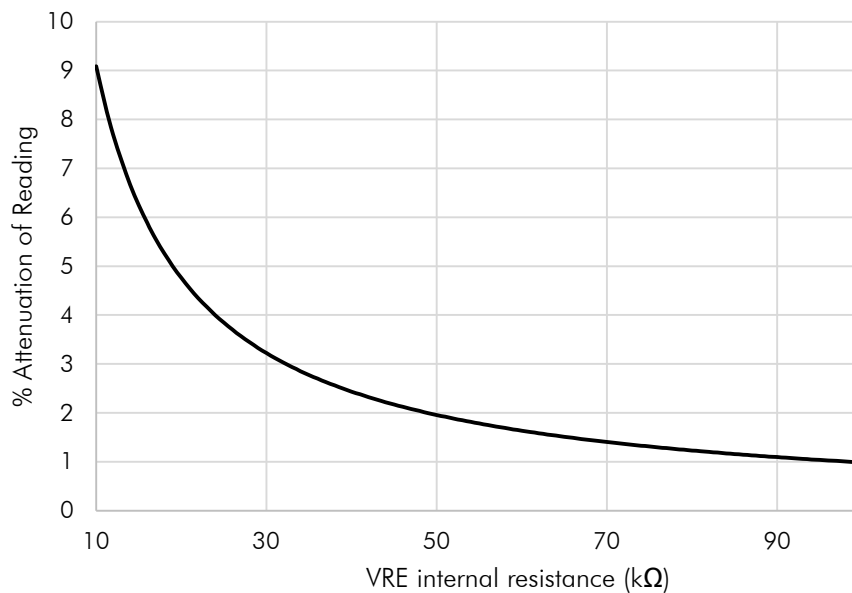


Figure 7: Voltage reading attenuation as a function of coupled system’s internal resistance

2.2.2. Using UART and Analog Output with Auto Start

There are three configurations of MPS sensor that report concentration using an analog output voltage: (1) analog output with UART; (2) analog output with auto start; and, (3) analog output with auto start and UART. An MPS sensor configured with both analog out and UART—but without auto start—is started manually using either a start command sent over the UART API or the MPS Gas Sensor Interface software. A sensor configured with auto start will begin its startup sequence as soon as power is applied to the sensor. This includes the situation where power is momentarily interrupted.

When configured with both auto start and UART, the sensor will respond to API commands sent over UART as soon as power is applied. Viewing auto started sensor output using the MPS Gas Sensor Interface software will always require restarting the sensor; the “start” button that initiates the display of sensor information in the Interface Software is hardwired to send a restart command to the sensor.

2.3. Testing MPS Refrigerant Gas Sensors

The MPS detects refrigerant gas presence and amount by comparing the molecular properties of the analyte gas with the ambient gas that was present just prior to the analyte gas exposure. The MPS was designed to work in real-world conditions where the background atmosphere has a consistent composition. To replicate real-world sensor performance during laboratory testing, it is crucial to

maintain consistent background gas composition. Otherwise, an artificial condition may arise, leading to inaccurate results.

A common testing mistake is starting the MPS in atmospheric air, then exposing it to a refrigerant test gas diluted with a synthetic, dry, nitrogen and oxygen mixture called "zero air". In such cases, the sudden subtraction of atmospheric trace gases in the test gas mixture will adversely affect the reported concentration of the analyte gas.

Figure 8 below depicts both correct and incorrect testing scenarios involving the use of zero air.

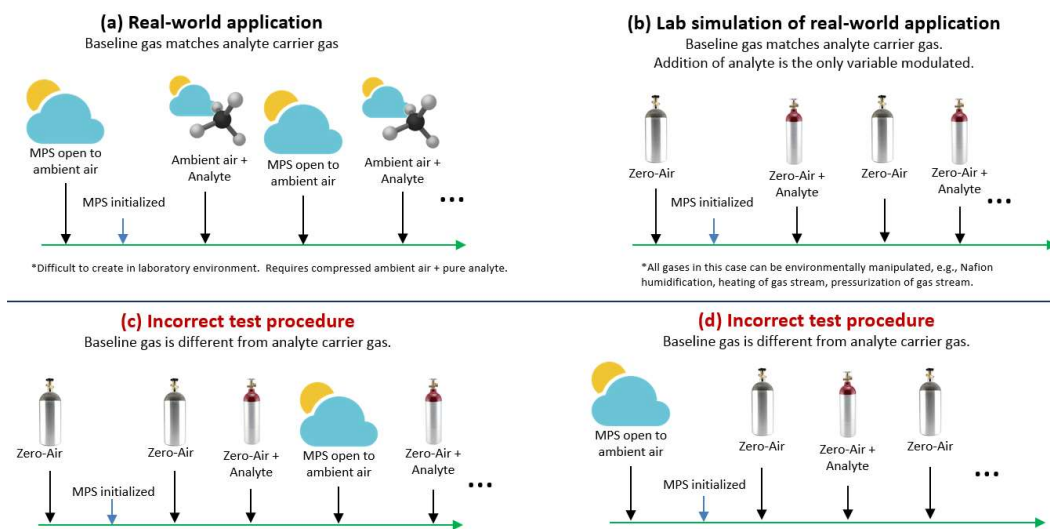


Figure 8: (a) The real-world refrigerant gas leak scenario. (b) The method for simulating the real-world scenario in a laboratory. Incorrect test procedures are shown in (c) and (d); in these cases, the carrier-only condition does not use the same "air" as the carrier + refrigerant gas condition, causing inaccurate results.

A "best practice" for performance testing of the MPS in a laboratory is as follows. First, initialize the sensor in humidified, zero air. Then, switch to a stream of humidified analyte that has been balanced with the same initial composition of zero air. Finally, switch back to humidified zero air to clear the test chamber. This process mimics the real-world conditions that an MPS Refrigerant Gas Sensor would experience when exposed to a refrigerant gas leak.

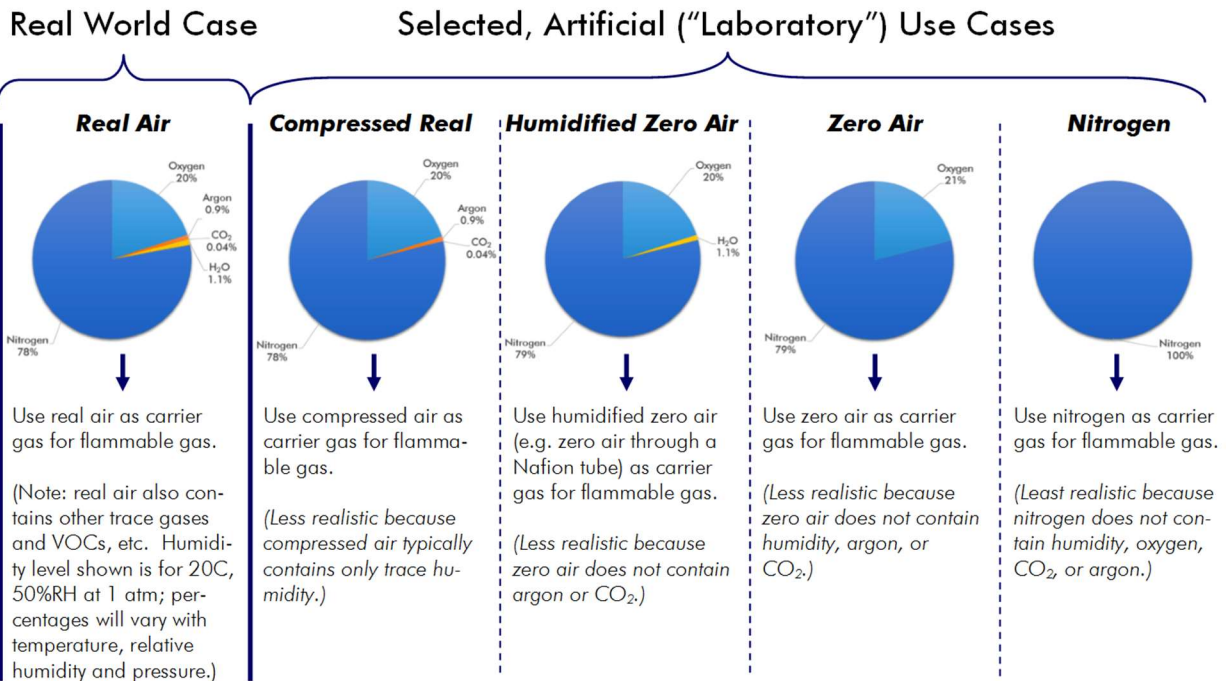


Figure 9: Various "air" options for use as the carrier, or background, gas during refrigerant gas testing. The best practice is to use one of the options toward the left side of the figure. In addition, do not switch between two different types of "air" during an experiment, as this can produce unwanted (and unrealistic) testing artifacts.

2.3.1. Setup #1: Testing in a Tank

The test setup shown in Figure 10 requires minimal equipment. A single gas cylinder of refrigerant gas is plumbed through a regulator, then a rotameter with a hand-turn valve (or an automated mass flow controller) for modulating flow rate. Humidity-permeable tubing (e.g. Nafion™ TT-110¹) can be used in-line to humidify the gas stream to the ambient humidity level. The gas is then plumbed into an enclosed volume such as a glass or plastic tank (or the plenum of an HVAC system) containing the sensors. A small fan can be included inside the tank to ensure rapid mixing. A typical test entails operating the sensors in the ambient air inside the control volume, then routing refrigerant gas into the test volume just like a refrigerant gas leak.

¹ <https://www.permapure.com/products/nafion-tubing/nafion-dryer-performance-and-selectivity/>

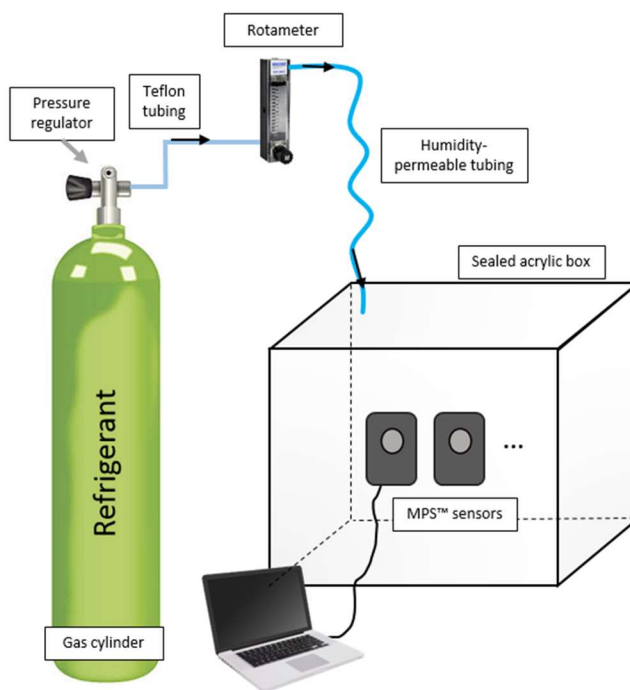


Figure 10: Setup #1--Testing in a Tank

2.3.2. Setup #2: Testing in Various Environmental Conditions

A test of sensor response in various environmental conditions can be conducted using the setup shown in Figure 11. Two regulated gas cylinders are used: one containing refrigerant, and the other containing compressed air.

Regulated gas cylinders are connected to a gas mixing system (e.g. Environics 4040) to control gas flow rates and concentrations. The gas travels through a heat exchanger and humidity-permeable tubing (e.g. Nafion™ TT-110), allowing the gas to reach the chamber temperature and relative humidity. Gas then flows serially through each of the MPS sensors and out a vent exhaust-tube. The environmental chamber is programmed with the required temperature/humidity profiles for each test. Gas profiles are created in the gas mixing system software to deliver the analyte at the correct time. Flow rate is constant at 300 mL/min for both analyte and air throughout the tests.

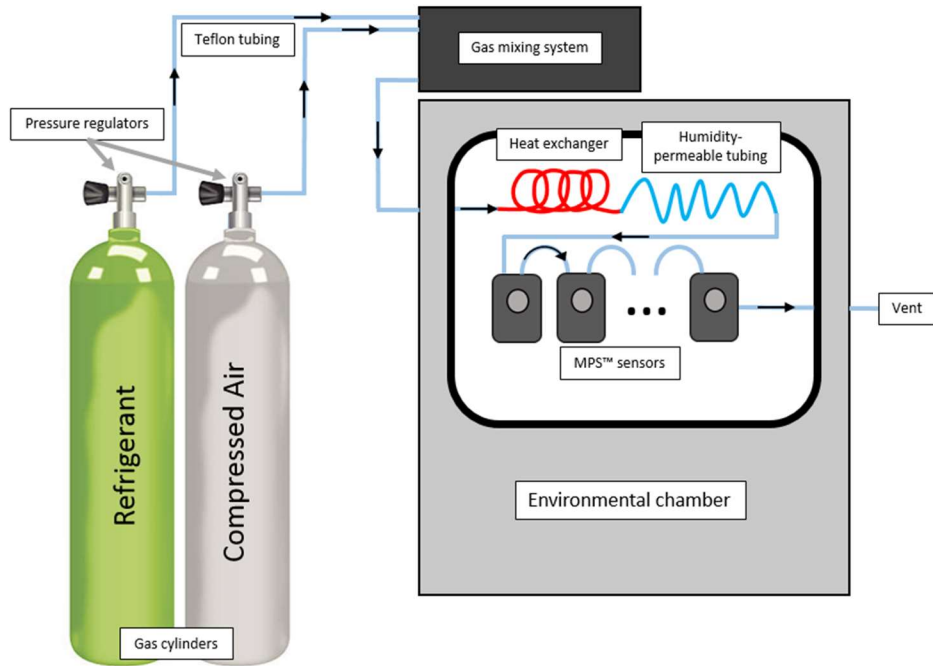


Figure 11: Setup #2: Testing in Various Environmental Conditions

3. Operating Conditions for the MPS Refrigerant Gas Sensor

There are currently two form factors of MPS Refrigerant Gas Sensor: the Intrinsically Safe (IS) Industrial form factor and the “mini” form factor. The table below provides a summary of standardized tests and test conditions to which the MPS Refrigerant IS Industrial form factor Refrigerant Gas Sensor has been subjected; similar performance can be expected for the Mini Standard form factor. The IS sensor has passed all these tests by demonstrating normal refrigerant gas detection performance both before and after each test.

Test	Specification	Summary of Test Conditions
Low Temperature Operating	IEC 60068-2-1	500 Hours @ -50°C
High Temperature Operating	IEC 60068-2-2	1000 Hours @ 85°C
Vibration	IEC 60068-2-6	31Hz – 150 Hz (2G acceleration), 1 hour per axis, 3 axes
Shock	IEC 60068-2-27	50G peak/11ms half sine pulse, 3 axes (positive and negative pulses)
Drop	IEC 60068-2-31	1-meter drop onto concrete
Damp heat - steady state	IEC 60068-2-78	500 hours @ 40°C/93% RH
Temperature cycling	JESD22-A104E	From -40°C to 85°C for 200 cycles
Sand/Dust	MIL-STD-810G Method 510.5	Sand: 150-850 μm SiO ₂ particle size, 23 m/s nom. velocity, 1.5 hrs @ 70°C per axis, 3 axes Dust: Red China Clay, 1.5 m/s nom. velocity, 6 hrs @ 20°C and 6 hrs @ 70°C
Poisoning	NevadaNano	1,200 ppm-hours H ₂ S (50 ppm for 24 hours) 10,400 ppm-hours siloxanes (Decamethylcyclopentasiloxane) (100 ppm for 4 hours, then 1,000 ppm for 10 hours) 0.25 ppm-hours NO ₂ (3 ppm for 5 minutes) 0.83 ppm-hours HCN (10 ppm for 5 minutes) 0.75 ppm-hours SO ₂ (9 ppm for 5 minutes) 0.17 ppm-hours Cl ₂ (2 ppm for 5 minutes) 4.17 ppm-hours NH ₃ (50 ppm for 5 minutes)
Electrostatic Discharge	JEDEC JS001-2017	Human Body Model, passed at 2 kV
EMC: Radiated Emissions	EN 55011	30 MHz to 1 GHz
EMC: RF Electromagnetic Field Immunity	IEC/EN 61000-4-3	80 MHz to 6 GHz at 10 V/m
EMC: Magnetic Immunity	IEC/EN 61000-4-8	30 A/m, 3 axes, 50 Hz and 60 Hz

3.1. Response to Other Gases

3.1.1. Carbon Dioxide (CO₂)

Carbon dioxide is a component of normal air at concentrations near 400 ppm. This ambient amount of CO₂ is already considered by sensor calibrations. The table below lists the levels of CO₂ above ambient concentrations that can result in false positives. The sensor is immune to poisoning by CO₂.

MPS Refrigerant Gas Sensor Type	Maximum CO ₂ Concentration Above Ambient Before False Positive
R-32, R-454B, R-454C	6,500 ppm
R-454A	8,700 ppm
R-1234ze	13,700 ppm
R-410A	2,400 ppm

Note: Exhaled human breath contains CO₂ at concentrations of approximately 40,000 ppm. During respiration, the CO₂ replaces oxygen, reducing its concentration from 20.95% by volume in normal air to 13.6-16% in exhaled air. **As such, breathing directly onto the sensor can cause it to falsely report refrigerant gas for a brief period.**

3.2. Hazardous Locations and System Integration

Integrating the MPS into intrinsically safe systems requires additional design consideration. Refer to the MPS Hazardous Locations User Guide (<https://nevadanano.com/downloads>) for information regarding certifications, protection concepts, entity parameters, etc. Note: The MPS Refrigerant Gas Sensor is only hazloc certified in the IS form factor. As such, the Mini form factor is not intended for applications requiring intrinsic safety.

4. Environmental Faults and Conditions Affecting Accuracy

The MPS Refrigerant Gas Sensor is specified to operate in the following conditions: -40 to 75 °C, 0 to 100 %RH; and 80 to 120 kPa. The MPS will fail safe and permanently latch to a non-functional state if exposed to extreme excursions (e.g., liquid water inside sensor, or temperatures > 85 °C for more than 10 seconds) outside of the MPS sensor's specified environmental limitations. The sensor has built-in self-test capabilities to detect and report excursions outside of these regimes:

- Fault 0x23, HW_ENV_XCD_RANGE, environmental (temperature, pressure and/or humidity) conditions are out of range.
- Status 0x24, HW_ENV_SNSR_MALFUNCTION, environmental (temperature, pressure and/or humidity) conditions are out of range to such an extent that the environmental sensor may no longer function properly. The sensor permanently latches.
- Fault 0x31, CONDENSE_COND, a condensation condition exists at the sensor.

The sensor is capable of operating outside of these regimes, as well as during abnormally rapid environmental fluctuations. The impact on sensor performance and output in these conditions is summarized in the following table:

Condition	Fault reported	Impact on sensor performance and output
Sensor environment out of range	0x23 - HW_ENV_XCD_RANGE	The sensor will still detect and report refrigerant gas, though output accuracy can be diminished while the condition persists.
Condensation condition at sensor	0x31 - CONDENSE_COND	The sensor will still detect and report refrigerant gas, though output accuracy can be diminished while the condition persists and for one minute afterward.
Rapid humidity changes	None	If the sensor is already reporting refrigerant gas, no adjustments are made to sensor output. If gas is not being detected, the sensor may enhance its drift compensation during periods of rapid humidity change (> 0.5 %RH/sec). The sensor will still detect and report refrigerant gas during these periods; however, accuracy may be slightly degraded.
Rapid temperature change	None	None

Sensor accuracy can also be diminished in certain cases of very slow gas accumulation (examples of “very slow” include: leak rate < 0.15 %LFL/min for R-32; leak rate < 320 ppm per minute for R410A).

5. Electromechanical Integration

The MPS A2L Refrigerant Gas Sensors are available in two form factors: the “Mini” form factor, and the certified “intrinsically safe” (IS) S4 form factor. The MPS Mini family of gas sensors is designed to be permanently mounted to a printed circuit board. In addition to the electrical interconnects, the Mini package has two features that can engage with two, unplated 1.10 mm to 1.50 mm dia. holes on the PCB for more precise and secure position of the sensor relative to the PCB.

The MPS A2L Refrigerant Gas Sensor in IS form factor is a standard “4 series” size. The sensor interface pins are compatible with industry standard receptacles or socket assemblies.

5.1. General Guidelines

The MPS Mini family of gas sensors is designed to be permanently mounted to a printed circuit board. The male header is Samtec P/N: TLW-105-06-G-S and the female connector is Samtec P/N: SLW-105-01-G-S. Both interconnects are readily available in distribution.

In addition to the electrical interconnects, the Mini package has two plastic locating features. These locating features can engage with a through-hole on the PCB for more precise and secure locating of the sensor relative to the PCB.

The IS pinout is indicated in Figure 15. The mating receptacles are available in distribution and can be found using Mill-Max P/N: 0384-0-67-80-23-27-10-0. Do not solder to the S4 pins. This will void the warranty.

Note: The Analog Out pin, if unused, must be left unterminated as an "open" or "no-connect" in the system integrator's PCB design.

The sensor housings of both the IS and Mini form factors are not sufficiently smooth at a microscopic level to expect gaskets to form a perfectly gas- or liquid-tight seal.

In powering the MPS sensor, the following criteria need to be met:

- Voltage range must be $3.3\text{-}5.0\text{ V} \pm 5\%$
- Ripple and noise should not exceed 50 mV
- The supply should be capable of providing up to 35 mA without appreciable voltage drop
 - Note: a typical sensor draws a peak current of 21 mA in all conditions, but worst-case analysis of electronic component tolerances allows for the statistically improbable possibility of current consumption up to 35 mA. System designers should therefore use 35 mA as a maximum possible current draw, while using an average current of 8.9 mA and peak current of 21 mA for calculation of typical performance, e.g. battery life. The current draw is non-monotonic and will vary based on the internal activity cycle of the sensor.
- The voltage rise rate at power up should be greater than $250\ \mu\text{s}$ per volt from a cold start (that is, when powering up a sensor that has been off for more than 5 seconds)

Achieving the proper voltage rise rate can be accomplished using voltage regulators with "soft-start" capability, though added capacitance (less preferred), or by placing a series resistor between the voltage source and the MPS power pin.

If the voltage rise rate condition above is not met when powering up a sensor that has been off for more than 5 seconds, a small percentage of sensors may power up into a state in which they do not respond to commands or do not generate the proper analog output. If this occurs, shutting power off to the sensor for between 0.5 to 2 seconds and then immediately powering the sensor back on will cause the sensor to recover and power up normally, *even if the voltage rise rate condition above is not met.*

5.2. Mini Form Factor Critical Dimensions and Pinout

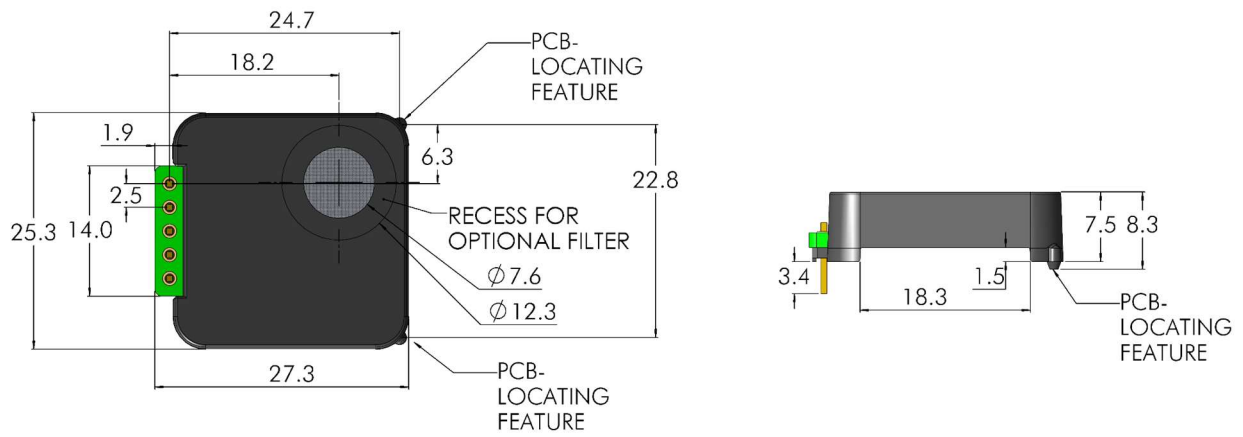


Figure 12: Mini critical dimensions (mm)

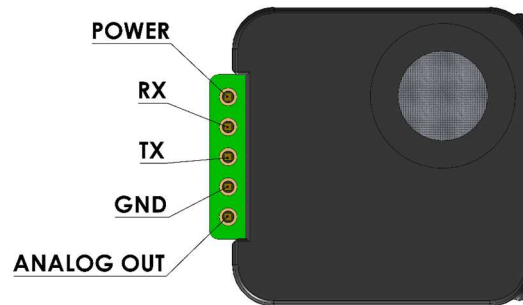


Figure 13: Mini electrical pinout configuration

5.3. A2L IS Form Factor Critical Dimensions and Pinout

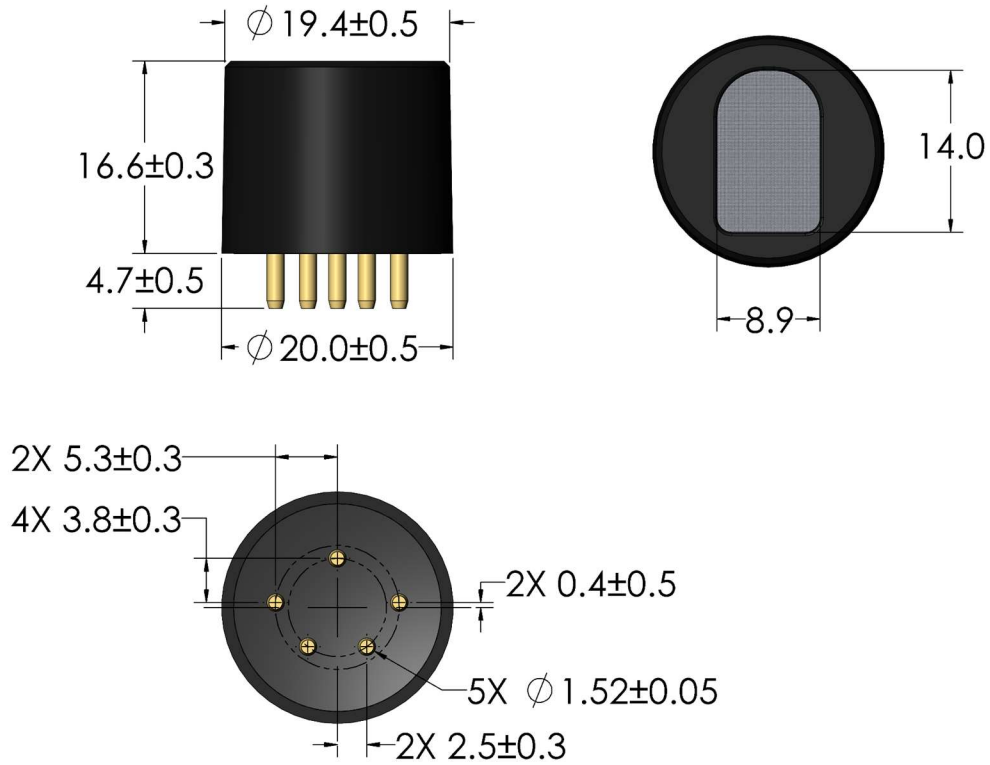


Figure 14: A2L IS critical dimensions (mm)

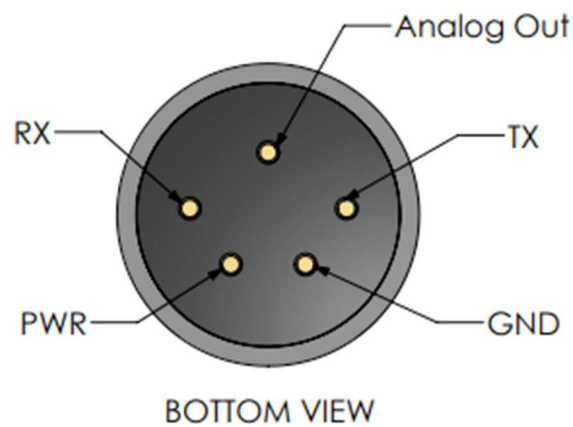


Figure 15: A2L IS electrical pin configuration

5.4. MPS Mini PCB Mounting Guidelines

5.4.1. Clearances from Heat-Generating Components

When designing the PCB layout to integrate the MPS Mini, consideration should be given to the location of any significant heat-generating components either adjacent to or under the sensor. All MPS sensor designs utilize an environmental monitoring system internal to the sensor to make accurate measurements of temperature, pressure, and humidity, and to compensate for these environmental effects. Components that raise the ambient temperature in the vicinity of the MPS—especially locally, where one portion of the Mini is heated more than other portions—could lead to inaccurate gas reporting. Careful consideration should be given to avoid raising the ambient temperature in the vicinity of the MPS more than about 3°C.

5.4.2. Enclosure Opening to Sense the Presence of Gas

The goal when designing the opening in the application enclosure should be to allow the MPS Mini clear, unobstructed access to the external environment to be sensed and to not allow the buildup of “stale” air or gases of interest in the application enclosure. Doing so could adversely affect the response of the MPS Mini sensor. The opening in the application enclosure to allow the MPS Mini sensor to detect gases should consider the following criteria:

- The opening in the application enclosure through which gases flow to the Mini should be no smaller than the opening in the top of the MPS Mini sensor.
- The MPS Mini sensor should be located as close to the external opening of the application enclosure as possible.
- The space between the MPS Mini sensor and the inner surface of the application enclosure should include a gasket sealing the area surrounding the opening in the MPS Mini sensor to prevent the buildup of “stale” air in the enclosure which could affect the response of the sensor.
- For specific integration design questions pertaining to adequate flow of gas to the Mini, contact NevadaNano for guidance.

5.4.3. Soldering the MPS Mini Sensor to a PCB

The following guidelines should be followed when soldering the MPS Mini sensor:

1. The plastic enclosure of the MPS Mini *CANNOT* withstand the heat developed in SMT reflow or wave solder operations. In addition, internal components of the sensor can be

compromised during the extreme heat of these operations. NevadaNano will not warrant sensors that have been exposed to these processes.

2. The recommended attachment method is manual solder, either by hand soldering or robotic soldering. Use a no-clean flux type wire solder, such as Kester 268 series flux core wire solder (EX: 96-7069-9515) or equivalent.
3. Using the above referenced solder will require a soldering device temperature of between 371-400 °C (700-750 °F). The soldering operation should take no more than 10 seconds per pin.
4. Do not expose the PCB assembly to cleaning operations, using either water or chemical solvents after the MPS sensor has been attached. High-pressure spray from these operations can cause ingress into the MPS sensor opening and damage the sensor.

5.4.4. Non-Plated Through-Hole Sizing for MPS Mini

There are two protuberances on the MPS Mini package that are meant to engage non-plated through-holes on the PCB, as shown in Figure 16. If the diameter of the holes is within certain values, the protrusions will engage the holes with an interference fit. This enables the sensor to be more precisely and securely located relative to the PCB. Otherwise, the holes can be sized for a clearance fit.

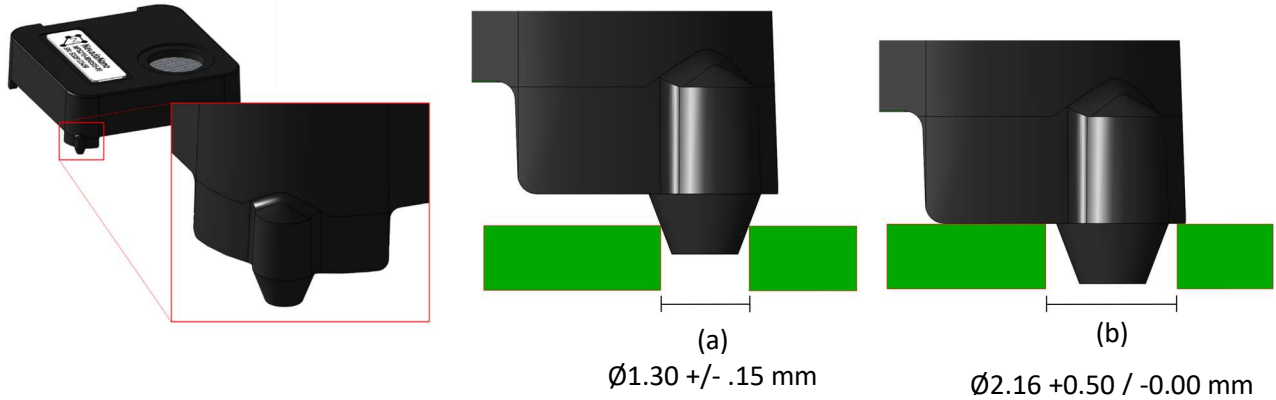


Figure 16: Locating Features. (a) Interference Fit vs (b) Clearance Fit.

Note that when an interference-fit approach is used, the package will not sit perfectly parallel to the plane of the PCB, as shown in Figure 17.

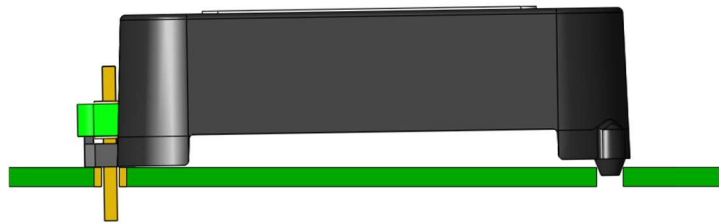


Figure 17: Mini Package with interference-fit of PCB-locating features

Figure 18 depicts the geometry and tolerance of the conical features.

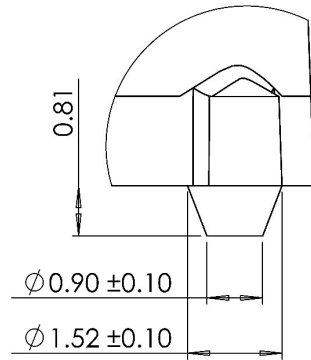


Figure 18: MPS Mini package pin dimensions, in mm.

Hole sizing for an interference fit should be calculated based on the size and location tolerance of the through-holes on the PCB. Nominal hole sizing for an interference fit should be $\phi 1.30$ mm.

If it is more desirable for the sensor to sit flat on the PCB, through-holes should be sized to at least $\phi 2.16$ mm to ensure a clearance fit. Figure 19 depicts the dimensions and tolerances for the locating-feature through-holes for both interference and clearance fits.

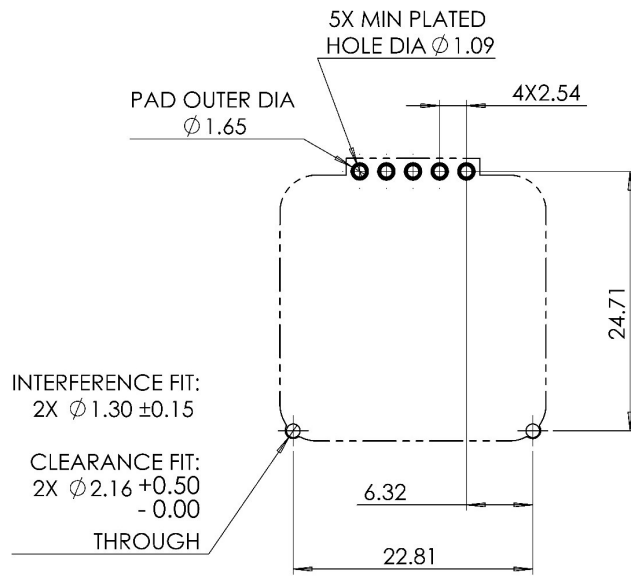


Figure 19: Recommended PCB Layout. Dimensions in mm.

6. Warranty information

MPS Refrigerant Gas Sensors carry a 2-year warranty against defects in materials and workmanship, as specified in the Standard Limited Warranty in Section 6.1. The warranty is voided if the sensors are used under conditions other than those specified in the sensor datasheet or this user manual. Please pay particular attention to these things:

Do not use or otherwise expose the sensor to the following environmental conditions:

- Temperatures above 90°C or less than -60°C
- Ambient pressures above 130 kPa or less than 30 kPa
- Do not allow water or other liquids to accumulate inside the sensor
- Do not solder to the S4 pins
- Observe the correct supply polarity and voltage ranges

6.1. MPS Refrigerant Gas Sensor Standard Limited Warranty

Nevada Nanotech Systems, Inc. warrants its MPS Refrigerant Gas Sensor, (referred to hereafter as the Product) manufactured and sold by Nevada Nanotech Systems, Inc. to be free from defects in materials and workmanship for a period of two years from the date of original purchase. This warranty is expressly limited to the original owner who purchases the equipment directly from Nevada Nanotech Systems, Inc. or from an authorized Nevada Nanotech Systems Distributor and is non-transferrable.

To maintain this limited warranty, the product must be operated, used, and maintained in accordance with the conditions specified in the MPS™ Refrigerant Gas Sensor Datasheet, and the MPS™ Refrigerant Gas User Manual. Abuse, mechanical damage, alterations, or other operations not done in accordance with these documents voids the Nevada Nanotech Systems Standard Limited Warranty.

With respect to firmware, the obligation of Nevada Nanotech Systems under this limited warranty is limited to a firmware upgrade, performed by Nevada Nanotech Systems, when such upgrade is deemed necessary, solely by Nevada Nanotech Systems, to address a critical safety or functional issue. This warranty is limited to the above and expressly excludes firmware upgrades that include enhanced or modified functionality of features.

Nevada Nanotech Systems does not warrant that the electronic or software operation of the Product will be uninterrupted or error-free, or that all such errors may be corrected. In addition to all other limitations, this limited warranty is limited by and does not apply to the following: (1) products or parts that have been altered or modified (e.g., to alter functionality or capability) by anyone other than Nevada Nanotech Systems; (2) damage caused by use with another product; (3) damage caused by accident, abuse, misuse, liquid contact, fire, or other external cause; (4) damage caused by operating the Product outside Nevada Nanotech System product guidelines; (5) Products whose electronic

module housings have been opened or otherwise tampered with; and (6) defects caused by normal wear and tear or otherwise due to the normal aging of the Product, unless damage has occurred due to a defect in materials or workmanship.

This limited warranty is expressly in lieu of any and all representations, express or implied, including but not limited to the warranty of fitness for a particular purpose. Nevada Nanotech Systems will not be liable for loss or damage of any kind connected to the use of its products or failure of its products to function or operate properly.

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The foregoing limitations will apply even if any warranty or remedy provided under this Agreement fails of its essential purpose. Some jurisdictions do not allow exclusion or limitation of incidental or consequential damages or how long an implied warranty lasts, so the above limitations may not apply to you. This limited warranty gives the Purchaser specific legal rights, and the Purchaser may also have other additional rights, which vary from State to State or by countries.

In the event of any dispute regarding the Product, prior to bringing any civil suit, the Purchaser and Nevada Nanotech Systems agree to resolve any Claims by ARBITRATION that must be brought through a mutually acceptable arbitrator in Reno, Nevada. Such arbitration will be conducted under the Commercial Arbitration Rules (Amended and Effective October 1, 2013) of the American Arbitration Association (available at <http://www.adr.org/commercial>). For the purposes of this section, references to "Purchaser" include the original OEM manufacturer, its officers, directors, employees, customers, beneficiaries, and assigns, and references to "Claim" shall include any dispute, claim or controversy arising from or relating to: (1) the Product, whether based in contract; tort; fraud; misrepresentation; state or federal statute, regulation, ordinance; or any other legal or equitable theory, and (2) this limited warranty. There shall be no right or authority for any Claims to be

arbitrated on a class action basis. This Dispute Resolution agreement is part of a transaction involving interstate commerce and is governed by the Federal Arbitration Act, which governs its enforcement and interpretation.

No other person or company is authorized to change this limited warranty, and the Purchasers are solely responsible for any other additional warranties regarding any other products that the Products are incorporated into.

To obtain warranty service for the Product, the Purchaser must contact Nevada Nanotech Systems by calling +1 775 972 8943 or emailing returns@nevadanano.com. Nevada Nanotech Systems will provide a Return Material Authorization (RMA) form for the Purchaser to complete. The Purchaser is responsible for any necessary shipping charges for returned or replaced products and all returns must be clearly marked with the RMA number issued. Nevada Nanotech Systems will decide, at its discretion, to repair or replace any of its Products found to be defective. Any replacement under this limited warranty will only be made with the same or similar product of the same or similar value and will not include cash, credits, or other types of products. All repaired or replacement products will be covered for two years from the date of the original purchase. If Nevada Nanotech Systems determines that the problem with the Product is not covered under this limited warranty, Nevada Nanotech Systems will notify the Purchaser and inform the Purchaser of service or replacement alternatives that are available on a fee basis.

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