



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



NNTS Proprietary Information

SM-UM-0002-14

Notices

SM-UM-0002-14

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Version	Issue Date (DD/MM/YYYY)	Change
SM-UM-0002-01	06/09/2019	First released version
SM-UM-0002-02	13/09/2019	Corrections to status field table and 0x09 command description
SM-UM-0002-03	20/09/2019	Updated status field table (new status 0x37), updated 0x04 command output table (new IDs 253, 254)
SM-UM-0002-04	07/10/2019	Updated status field table and Section 4. Note: this version of the manual pertains to firmware versions 3.0.0.0 and forward.
SM-UM-0002-05	14/10/2019	New command to query 'sensor info' (0x43)
SM-UM-0002-06	02/12/2019	Updated status table and Section 4.1. Note: this version of the manual pertains to firmware versions 3.0.2.0 and later. Added Section 2.2, Analog output mode
SM-UM-0002-07	10/12/2019	Added Section 4.2 and Section 5
SM-UM-0002-08	03/01/2020	Added Section 6
SM-UM-0002-09	15/01/2020	Updated Sections 4.1 and 6.2
SM-UM-0002-10	31/01/2020	Minor formatting changes/fixes
SM-UM-0002-11	15/02/2020	Minor update to Section 6
SM-UM-0002-12	1/06/2020	Added Sections 1.1, 7, 8. Update to section 6
SM-UM-0002-13	17/07/2020	Sensor performance data removed. Now published on datasheet instead.
SM-UM-0002-14	17/12/2020	Updated Section 5 to reflect improvements in 3.0.5.0 firmware. Updated Section 2.2 for clarity.

1. How the MPS Flammable Gas Sensor Works

The MPS Flammable Gas Sensor is a smart sensor with built-in environmental compensation that detects and accurately quantifies over a dozen gases as well as gas mixtures. It is intrinsically safe, robust, extremely poison-resistant, and calibrated for all gases by performing only a single calibration with methane. Sensor readings are output on a standard digital bus or industry-standard analog output.

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 flammable 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 and to classify the flammable gas.

Other sensing technologies (e.g. catalytic bead, NDIR) require a “k-factor” multiplier to convert raw sensor signals to gas concentrations in %LEL. These “k-factors” are based on known relative sensitivities of these sensors to different gases. A single “k-factor”, corresponding to a particular gas, must be selected manually during system setup; if the sensor is then exposed to a gas other than the one selected, significant errors in reported concentration occur.

In contrast, the MPS Flammable Gas Sensor applies a real-time conversion factor automatically, using the latest measured thermal properties of the ambient air/gas and the environmental conditions (Figure 1). The %LEL values reported for the bulk, which may contain a mixture of gases, achieves the same high levels of accuracy achieved with single gases. Additional smart algorithms enable determination of the class of gas present, according to the categories in Figure 2.

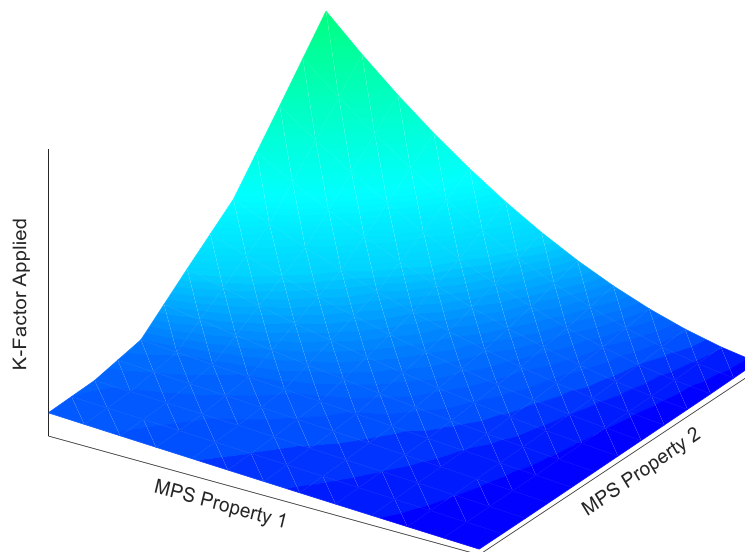


Figure 1: The MPS uses multiple measured properties of the air/gas mixture to automatically apply a real-time conversion factor—enabling high accuracy for over a dozen different gases at all times.

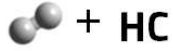
CLASS 1: Hydrogen

Molecular weight: 2.0 [g/mol]
 Density: 0.09 [kg/m³]
 # carbons: 0



CLASS 2: Hydrogen Mixture

Avg. Mol. weight: 1-14 [g/mol]
 Avg. Density: 0.1-0.6 [kg/m³]
 # carbons: varies



*This classification is unique as it guarantees the presence of hydrogen and another flammable gas

CLASS 3: Methane/Natural Gas

Avg. Mol. weight: 16 to 19 [g/mol]
 Avg. Density: 0.6-0.9 [kg/m³]
 Typical # carbons: 1-2



CLASS 4: Light Gas (or Light Gas Mixture)

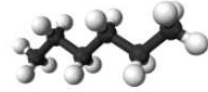
Avg. Mol. weight: 25 to 75 [g/mol]
 Avg. Density: 1.2-2.5 [kg/m³]
 Typical # carbons: 1-4



Example Gases: Ethane, Propane, Butane, Isopropanol

CLASS 5: Medium Gas (or Medium Gas Mixture)

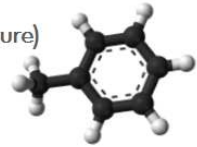
Avg. Mol. weight: 50 to 120 [g/mol]
 Avg. Density: 1.5-4.0 [kg/m³]
 Typical # carbons: 2-8



Example Gases: Pentane, Hexane

CLASS 6: Heavy Gas (or Heavy Gas Mixture)

Avg. Mol. weight: 80+ [g/mol]
 Avg. Density: 3.5+ [kg/m³]
 Typical # carbons: 6+



Example Gases: Octane, Toluene, Xylene

Figure 2: The MPS Flammable Gas Sensor outputs the class of gas present. This capability to discriminate amongst gases is what enables the sensor to provide accurate %LEL readings for over a dozen different flammable gases. The MPS is the only technology on the market with this capability.

2. Communicating with the MPS Flammable Gas Sensor

This section describes the software interface requirements for the MPS Flammable Gas Sensor and is useful to system integrators when designing the sensor assembly into a final product. The sensor communicates over the serial interface using the UART (Universal Asynchronous Receiver/Transmitter) protocol. Alternatively, the sensor can be factory-configured in analog-out mode, where the sensor outputs a voltage proportional to the gas concentration, detailed in Section 2.2.

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 Flammable 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.

Command Request

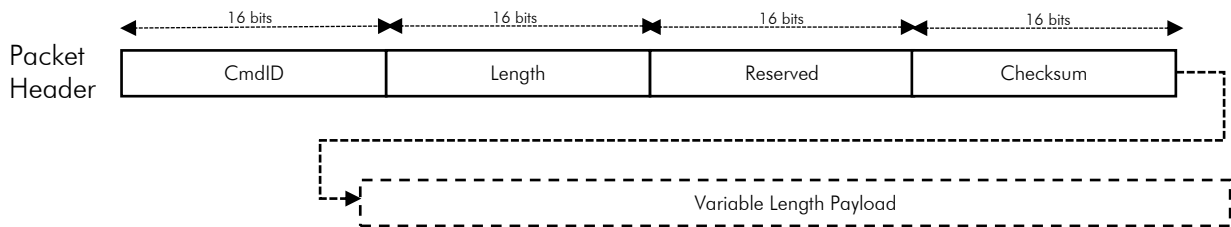


Figure 3: Request Packet Structure

The Request Packet (Figure 3) 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

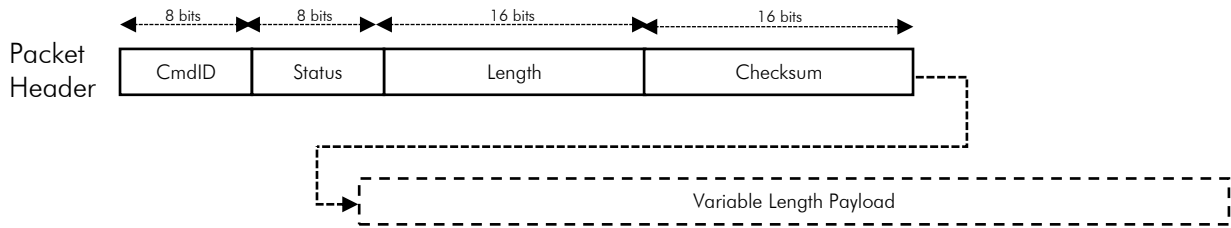


Figure 4: Reply Packet Structure

The Reply Packet (Figure 4) 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	%LEL Output	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.
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 %LEL	Contact support.
0x21	HW_ERR_VDD	Internal voltage out of range	-100 %LEL	Contact support
0x22	HW_ERR_VREF	Voltage out of range	-100 %LEL	Supply 3.3-5.0 \pm 5% VDC. If this error persists for more than 5 cycles, this error will latch until the sensor is power cycled and supplied correct voltage
0x23	HW_ENV_XCD_RANGE	Environmental (Temp., Press., Humid.) out of range	Normal	Return sensor to specified operating range. See Section 4.1.
0x24	HW_ENV_SNSR_MALFUNCTION	Environmental sensor malfunction	-100 %LEL	Occurrence of this error will latch the sensor in this condition and no longer allow normal operation. Contact support.
0x25	HW_ERR_MCU_FLASH	Microcontroller error	-100 %LEL	Contact support.
0x26	HW_SENSOR_INITIALIZATION	Sensor in initialization mode (10 cycles)	-100 %LEL	Wait 10 cycles (~20 sec) for sensor to initialize.
0x30	HW_SENSOR_NEGATIVE	Sensor output < -15%LEL; accuracy affected if flammable gas initially detected while in this condition	Normal	Wait for sensor to return to zero. If message persists >10 minutes, contact support.
0x31	HW_CONDENSE_COND	Condensation condition exists at sensor (out of specification)	Normal	Raise temperature and/or lower humidity. See Section 4.1.
0x32	HW_SENSOR_MALFUNCTION	Gas sensing element malfunction	-100 %LEL	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, 0xcdbc, 0xfbff, 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://nevedanano.com/downloads>

2.1.4. Startup and Measurement Sequence

Figure 5 describes the recommended steps after powering on the sensor, as well as 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.
 - Firmware version information can be used to determine if a new firmware version is available for upgrade.
 - 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 %LEL”, the sensor status is set to HW_SENSOR_INITIALIZATION, 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 2-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.

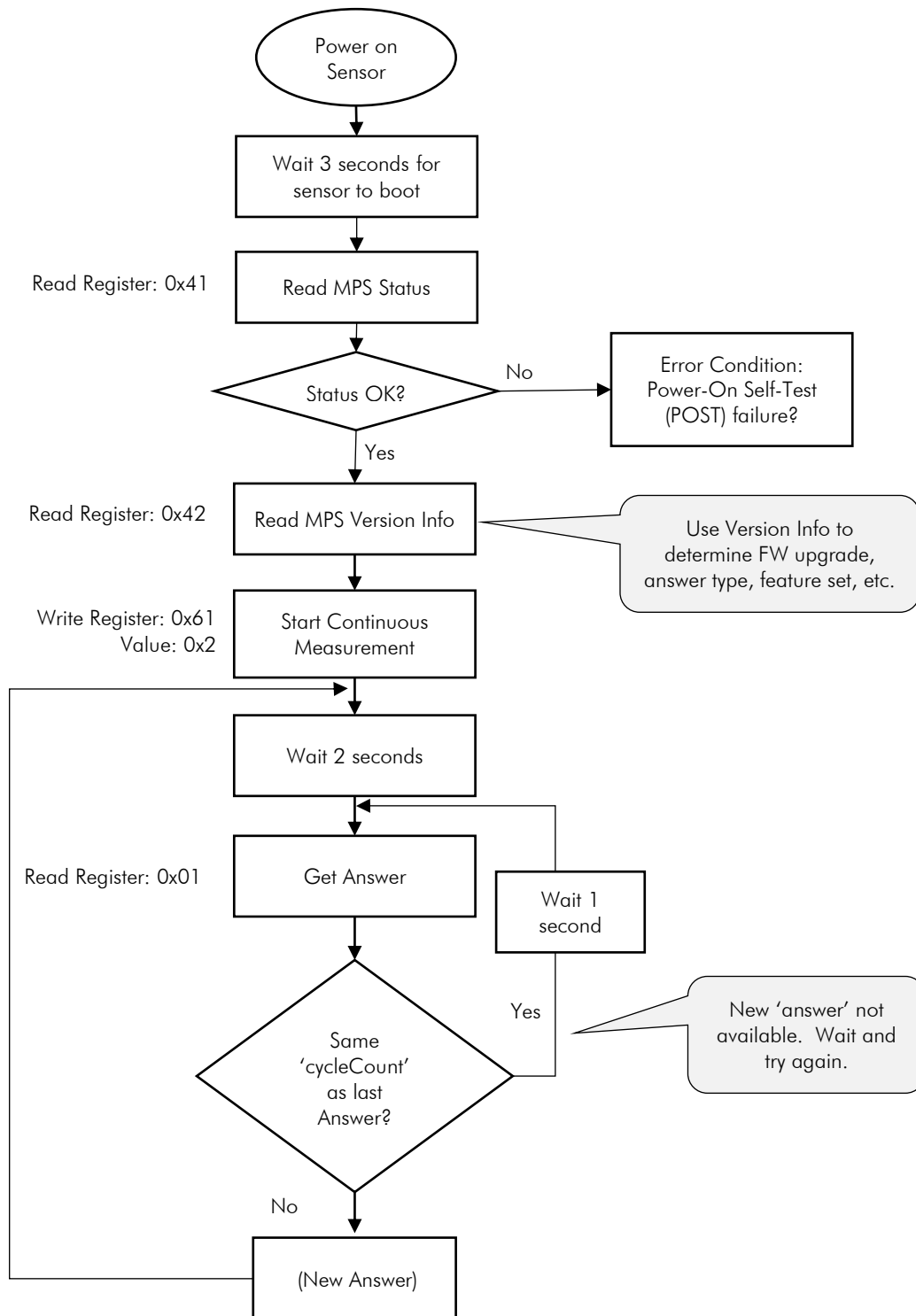


Figure 5: Startup and Measurement Sequence

2.1.5. Command Table

Hex Code	Command ID	Payload Length [bytes]	
		Request	Response
0x01	ANSWER	0	28
0x03	CONC	0	4
0x04	ID	0	4
0x21	TEMP	0	4
0x22	PRES	0	4
0x23	REL_HUM	0	4
0x24	ABS_HUM	0	4
0x41	STATUS	0	1
0x42	VERSION	0	8
0x43	SENSOR_INFO	0	68
0x61	MEAS	1	0
0x62	SHUT_DOWN	0	0

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. Flammable gas concentration [%LEL or %VOL]
ID	32-bit unsigned value. Flammable gas 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 Flammable Gas Concentration

Description: Returns flammable gas concentration (%LEL or %VOL) as measured by the MPS.

Parameters: N/A

Response: CONC 32-bit floating point value. Flammable gas concentration (%LEL or %VOL)

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

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

Parameters: N/A

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

ID	Description
0	No Gas
1	Hydrogen
2	Hydrogen Mixture
3	Methane
4	Light Gas
5	Medium Gas
6	Heavy Gas
253	Unknown Gas
254	Under Range – Concentration less than -5 %LEL
255	Over Range – Concentration greater than 100 %LEL

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

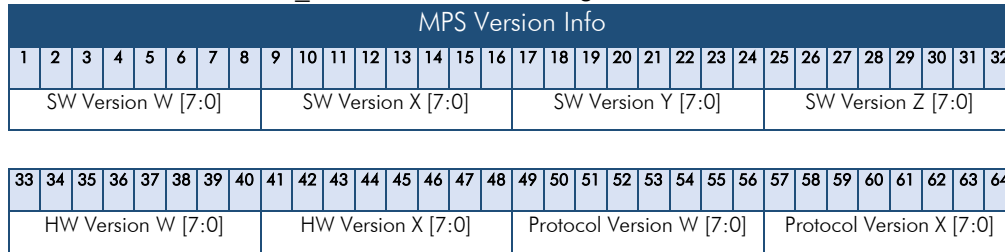
Response: STATUS 8-bit unsigned value. Status of MPS.

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



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

Description: Returns information about the sensor.

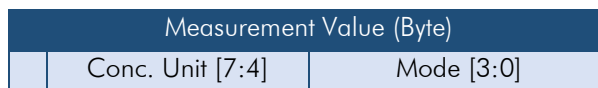
Parameters: N/A

Response: SERIAL_NUM Sensor serial number. 32 bytes, zero-padded ASCII string.
 SENSOR_TYPE Sensor type. 32-bit unsigned integer. (Note: “MPS Flammable Gas Sensor” sensor type = 0x03)
 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 unit” in the measurement.

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



The “concentration unit” (bits 7:4 of the measurement byte) can be either %LEL or %VOL. By specifying the desired unit, the response for commands 0x0 and 0x03 will be either %LEL or %VOL.

Unit	Name	Description
0x0	PERCENT_LEL	Concentration reported as %LEL.
0x1	PERCENT_VOL	Concentration reported as %VOL.

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 – SHUT_DOWN – Shut down MPS

Description: Prepares the MPS for a shutdown by saving necessary data and states.

Parameters: N/A

Response: N/A

2.2. Sensor Analog Output Mode

The MPS Flammable Gas Sensor includes versions that are factory-configurable to report gas concentrations via an analog signal that mimics the output of conventional catalytic bead flammable gas sensors. If you are working with an MPS Flammable Gas Sensor where analog output is enabled (refer to the Part Number Ordering Guide in the datasheet), the analog output signal is generated with a digital-to-analog converter. The standard analog output range, shown in Figure 7, is 0.4 V (0 %LEL) to 2.0 V (100 %LEL), linearly increasing at 0.016 V/%LEL. The MPS Flammable Gas Sensor comes in two versions. A 5-Pin digital version with UART interface plus the analog output signal where the digital interface initializes measurements for both digital output via the Tx and Rx pins as well as measurement results on the analog output pin. The other version is a 3-Pin sensor with only Analog Output that uses “auto start” to begin reading out concentration measurements on the analog output pin. Upon power-up, the analog output pin may report between 0.75-1.75 V momentarily (<100 ms) during initialization. As with the digital communication mode, the MPS output concentration resolution is 0.1 %LEL for analog outputs.

(Note: alternate analog output configurations are available, with output voltage range and “zero” voltages configurable between 0.04 and 2.9V. The sensitivity slope can also be configurable, including rising or falling Volts per %LEL. Contact NevadaNano for details.)

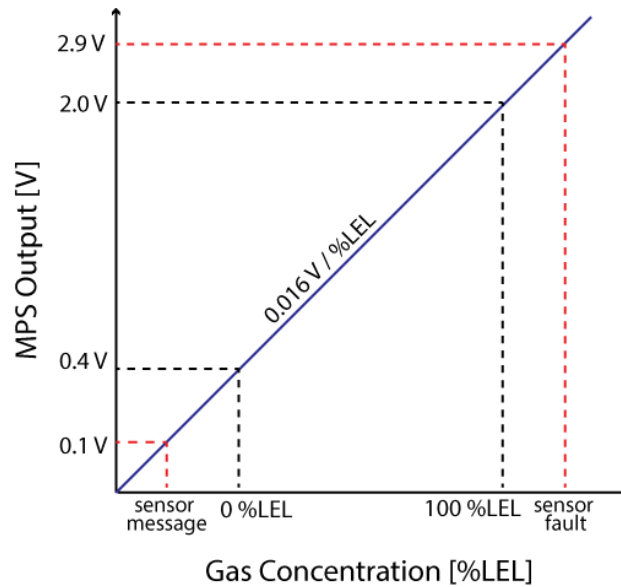


Figure 7: MPS Flammable Gas Sensor output when configured in analog mode.

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, messages that indicate the sensor’s initialization sequence, or the indication that the sensor output is negative are conveyed to the user. Non-critical status messages (e.g.: HW_ENV_XCD_RANGE, HW_CONDENSE_COND) are not reported in analog output mode. The following table indicates the output voltage corresponding to each sensor message and critical status.

Status	Voltage [V]
HW_ERR_VDD	2.9
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_NEGATIVE	0.1
HW_SENSOR_MALFUNCTION	2.9

Figure 8 shows a simple schematic of the analog output stage of the MPS sensor connected to a detector with a given detector load resistance.

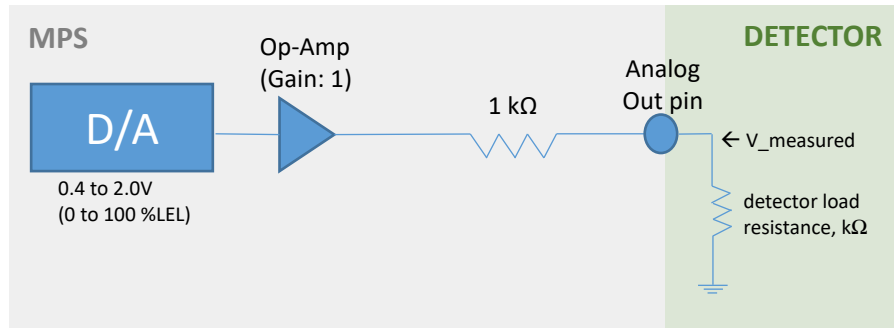


Figure 8: Analog output stage of the MPS and input stage of detector.

The 1-kΩ series resistor in the MPS limits the current that the analog output can provide in order to prevent damage to the sensor should the output be shorted. Systems using the analog output pin need to take this current drive limit into account when designing an input circuit to measure the analog voltage.

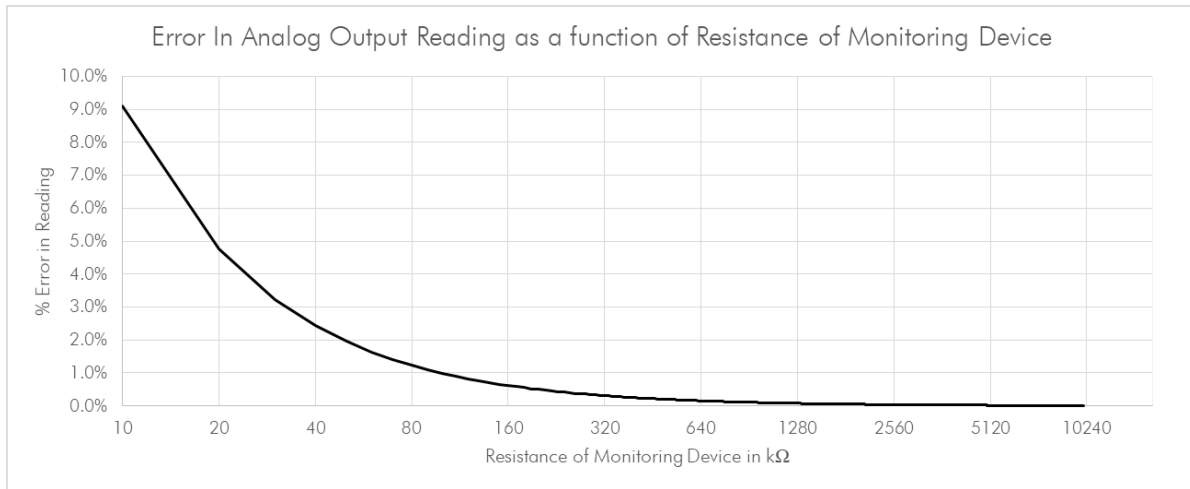


Figure 9: Percent error in voltage reading (i.e. the error in “V_{measured}” in Figure 8) versus resistance load (i.e., the “detector load resistance” shown in Figure 8).

For example, as shown in Figure 9, a load of 100 kΩ on the analog output pin will result in a 1% error in the voltage reading (and therefore a 1% error in %LEL reading). System designers should account for this when implementing systems using the analog out signal from the MPS.

3. Electromechanical Integration

The MPS Flammable Gas Sensor is designed to be compatible with many industry-standard LEL sensors or as a direct replacement for legacy catalytic-type combustible sensors. The sensor interface

pins are compatible with the following receptacles: Mill-Max 9401-0-15-15-23-27-10-0 (closed bottom) and 0384-0-67-80-23-27-10-0 (open bottom). The pinout and critical dimensions are indicated in Figure 10.

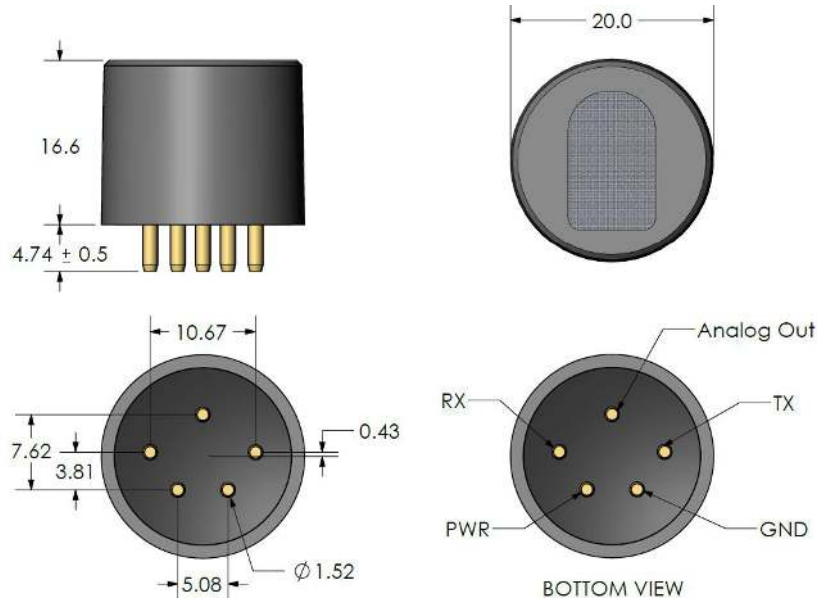


Figure 10: MPS Flammable Gas Sensor mechanical dimensions (in mm) and pinout. Note that TX and RX pins are not present in “3-pin” configurations.

The MPS Flammable Gas Sensor is a standard “4 series” size – 20 mm \varnothing , and 16.6 mm high. The sensor housing is constructed from Ultem PEI plastic. The sensor holds an ATEX-default IP2X rating, and has passed additional testing in accordance with MIL-STD-810G Method 510.5 for dust resistance. The sensor is susceptible to liquid ingress and will not function properly if water or other liquids inundate the sensor chamber. To improve water ingress protection, a user may include microporous membrane (ex: Porex PTFE PM21ML). Addition of a membrane to the sensor may slow the speed of response, dependent upon on the gas. Lighter gases (e.g., methane) are relatively unaffected, while larger-molecule gases like toluene and xylene may indicate slower response and some suppression of the reported concentration by the MPS.

4. Testing the MPS Flammable Gas Sensor

The MPS measures molecular properties to determine the quantity of flammable gas present in a sample. The system is optimized for “real-world” operation. As such, the effects of humidity, temperature and pressure are automatically compensated out. However, sudden, wholesale changes to the molecular properties of the sample (i.e. artificial changes which can only be generated in a lab test rig) can lead to inaccurate MPS outputs. This of course excludes changes due to the presence of flammable gas. An example of an inadvisable change (shown in Fig. 11c, 11d) would be alternating between ambient air (which contains argon, carbon dioxide and other trace gases) and flammable gas + synthetic “zero air” balance (which contains none of the trace constituent gases in ambient air).

To properly simulate the real-world application (Fig. 11a) in artificial laboratory testing, the same type of “air” must be used for the background and the carrier of the flammable gas for the duration of the test. An example of a proper protocol is shown in Fig. 11b. Using a variation of the “incorrect” procedure will invalidate the accuracy of MPS measurements.

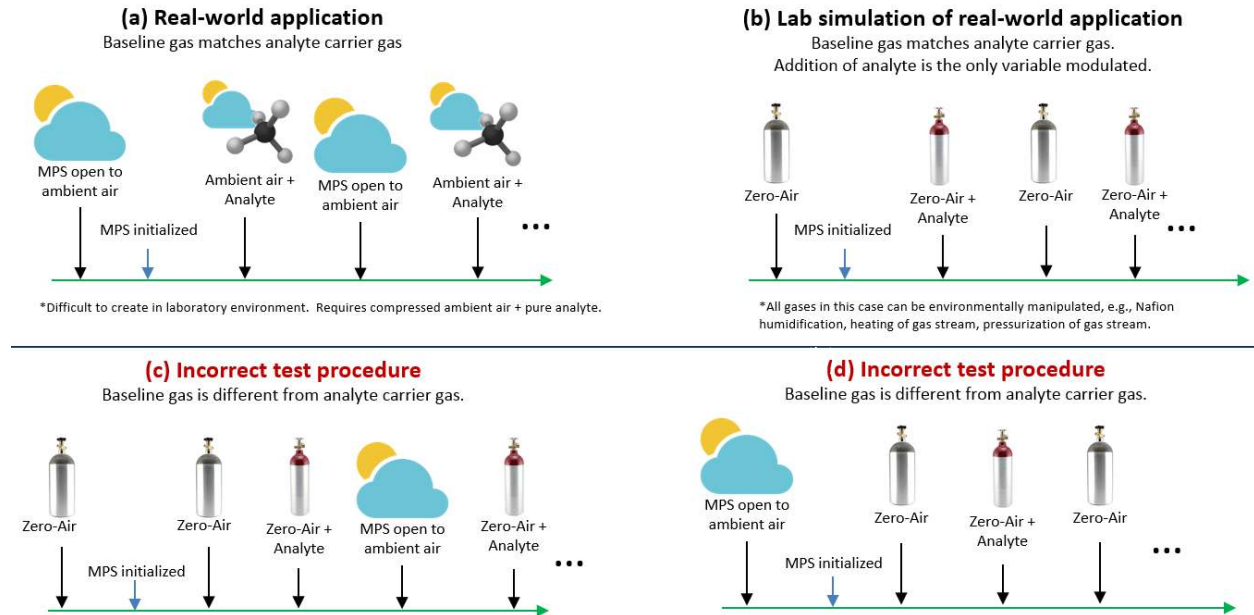


Figure 11: (a) The real-world flammable gas leak scenario. (b) The method for simulating the real-world scenario in a laboratory. Incorrect test procedures are shown in (c) and (d); in these cases, the carrier-only condition does not use the same “air” as the carrier + flammable gas condition, causing inaccurate results.

A “best practice” for performance testing in a laboratory is to use a humidified zero-air background, followed by a switch to a humidified analyte stream with the same zero-air composition as balance gas, then a switch back to humidified zero-air to clear the test chamber. This mimics real-world MPS performance, where flammable gas is introduced into relatively invariant ambient air (Fig. 11a).

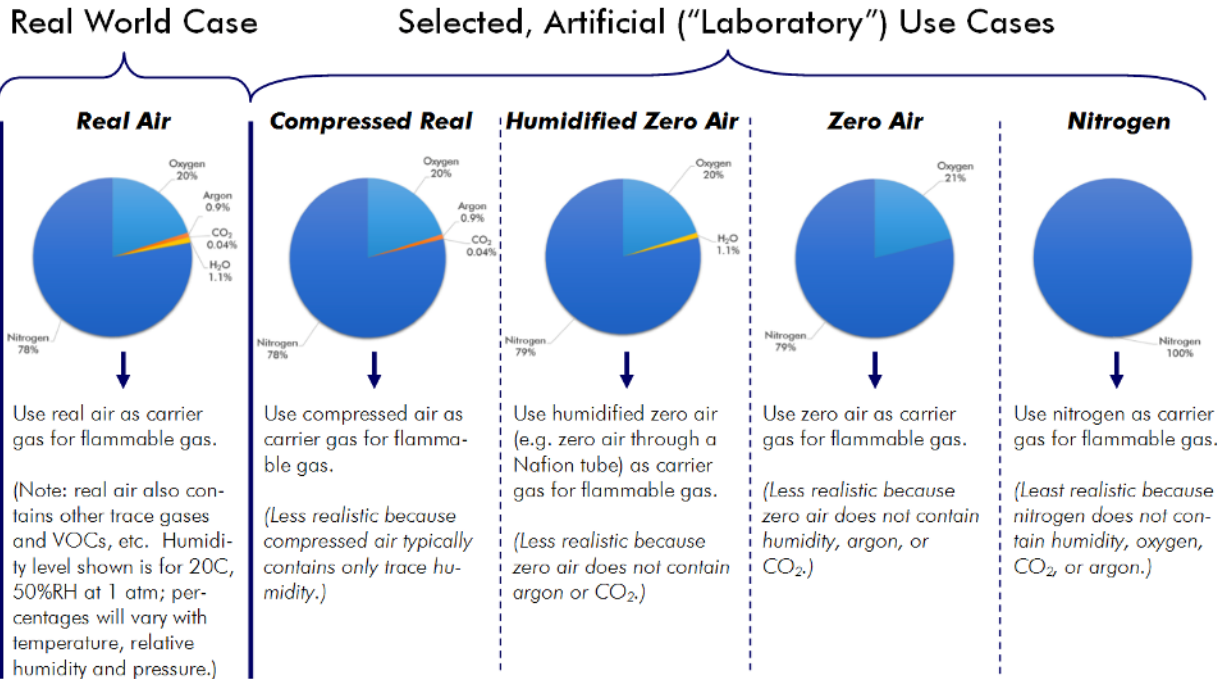


Figure 12: Various "air" options for use as the carrier, or background, gas during flammable gas testing. The best practice is to use one of the options toward the left side of the figure. In addition, do not switch between two different types of "air" during an experiment, as this can produce unwanted (and unrealistic) testing artifacts.

4.1. Typical Test Setups

Various test setups can be used to perform tests with the MPS Flammable Gas Sensor. One common test setup uses two regulated gas cylinders: zero air (20.9 %volume oxygen in nitrogen), and 50 %LEL methane in a balance of zero air.

4.1.1. Setup #1: Gas Testing in Various Environmental Conditions

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-110¹), 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 zero air throughout the tests.

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

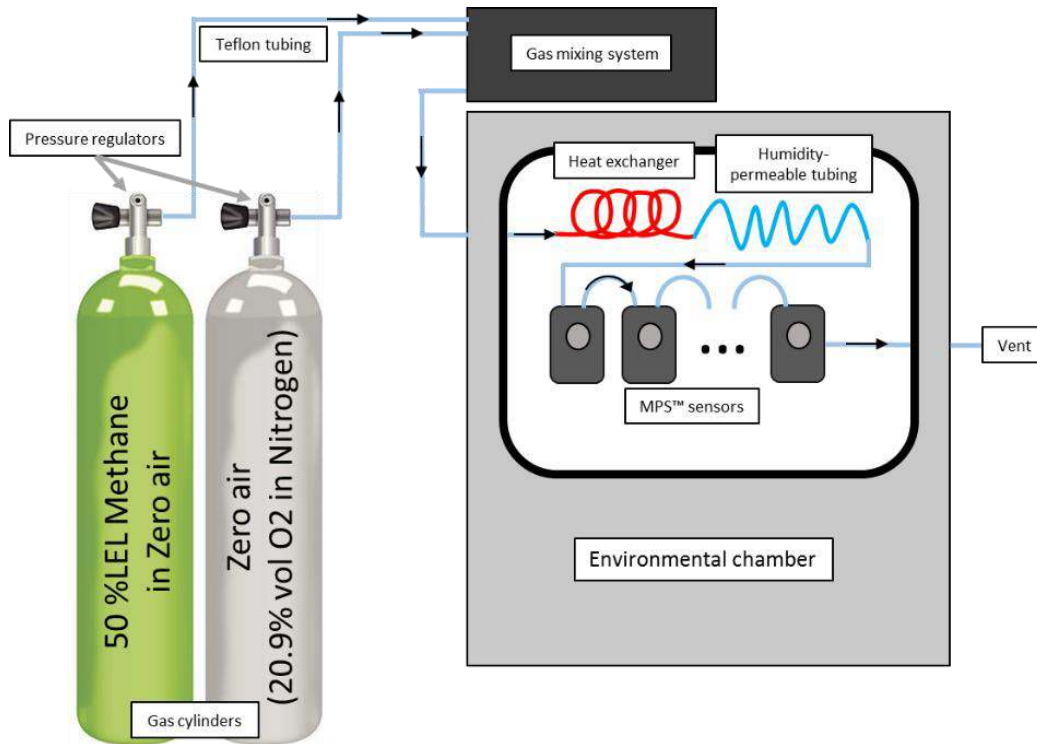


Figure 13: Setup #1: Gas Testing in Various Environmental Conditions

4.1.2. Setup #2: General Benchtop Testing

Regulated gas cylinders are connected together via a 3-way valve, a rotameter, and humidity-permeable tubing to the sensors. The sensors are encased in a plastic box with a removable lid that seals against the face of the sensor. The lid contains an inlet and an outlet that allows for multiple sensors to be connected in series. The 3-way valve allows gas switching, the rotameter enables flow control, and the Nafion™ tubing humidifies the gas stream. The flow is regulated at 300 mL/min throughout the test to maintain near-constant gas concentration throughout all sensors.

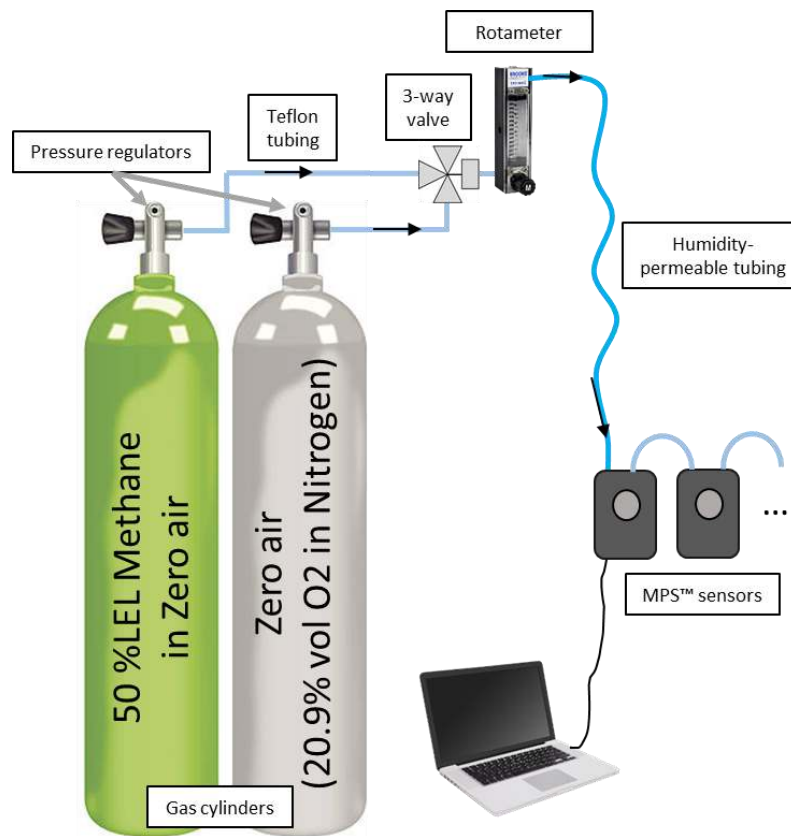


Figure 14: Setup #2: General benchtop testing.

5. Environmental Faults and Conditions Affecting Accuracy

The MPS Flammable Gas Sensor is specified to operate in the following conditions: -40 to 75 °C, 0 to 100 %RH; and 80 to 120 kPa. The sensor has built-in self-test capabilities to detect and report excursions outside these regimes:

- Fault 0x23, HW_ENV_XCD_RANGE -- Environmental (Temp., Press., Humid.) out of range
- Fault 0x31, HW_CONDENSE_COND -- Condensation condition exists at 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 such conditions is summarized in the following table:

Condition	Fault reported	Impact on sensor performance and output
Sensor environment out of range	Fault 0x23 HW_ENV_XCD_RANGE	The sensor will still detect and report flammable gas, though output accuracy can be diminished while the condition persists.
Condensation condition at sensor	Fault 0x31 HW_CONDENSE_COND	The sensor will still detect and report flammable 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 flammable gas, no adjustments are made to sensor output. If gas is not being detected, the sensor output may be automatically adjusted to 0 %LEL for a maximum of 10 cycles (20 seconds) in a row during a rapid humidity increase. This adjustment has been programmed such that the largest possible concentration change to go unreported is 15 %LEL (methane). The sensor will still detect and report flammable gas, though accuracy can be diminished for up to 80 seconds.
Rapid temperature change	None	The sensor will still detect and report flammable gas, though output accuracy can be diminished while the condition persists. For an MPS sensor exposed on all sides to ambient air, it is possible for this condition to occur when moving from conditioned, indoor air to cold or hot outdoor conditions, or vice versa. For MPS sensors integrated in portable or fixed detector units, the added thermal mass and insulation provided by the unit serves to slow the thermal transients acting on the MPS, making this condition less likely.

6. 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.

7. Sensor Data for Temperature, Humidity, and Pressure

The MPS Flammable Gas Sensor is equipped with an integrated sensor that measures temperature, humidity, and pressure. These data are available to end users (Sec. 2.1.6) and are generally representative of ambient environmental conditions; note, however, the MPS environmental sensor measures the conditions *within* the sensing chamber, which may not perfectly match ambient environmental conditions due to the slight self-heating of the sensor chamber by the MPS' internal electronics. Typically, environmental readings provided by the MPS are slightly warmer than ambient (approximately 4 °C) and have lower *relative* humidity than ambient (approximately 10-20 %RH), while the *absolute* humidity (which can be calculated, if desired, using the MPS' temperature and relative humidity outputs) tends to track well with the ambient absolute humidity. MPS environmental readings are dependent on the temperature and heating profile of the system into which the sensor is integrated and the MPS' proximity to components that generate additional heat.

8. Warranty information

MPS Flammable Gas Sensors carry a 2-year warranty against defects in materials and workmanship, as specified in the Standard Limited Warranty in Section 8.1. 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 sensor pins
- Observe the correct supply polarity and voltage ranges

8.1. MPS Flammable Gas Sensor Standard Limited Warranty

Nevada Nanotech Systems, Inc. warrants its MPS Flammable 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™ Flammable Gas Sensor Datasheet, the MPS™ Flammable Gas Sensor User Manual, and the MPS™ Hazardous Locations User Guide. 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, emailing customer-support@nevadanano.com, or requesting return at

<https://www.nevadanano.com/mps-flammable-gas-sensor-support>. Nevada Nanotech Systems Customer Service will give the warranty guidelines and issue a Return Merchandise Authorization (RMA) number that authorizes return of the material for verification of defects. 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 one year 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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