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Precis of Evaluation International report E 1966 X 15 "GasSecure GS01 Wireless Gas Detector"

1 Introduction

This memo provides a precis of Evaluation International (EI) report E 1966 X 15 [1]. The EI report details tests carried out to evaluate the performance of the GasSecure GS01 Wireless Gas Detector. The instrument is a battery-powered detector that monitors the free-space concentration of hydrocarbon gases, alerting operators to the presence of flammable gases and warning them of the risk of explosion. More information about the GS01 gas detector can be found in [2] and [3].

The evaluation programme was devised by the National Physical Laboratory (NPL) UK, in response to a test requirement list supplied by the end user BP and had two focus areas:

a) Aspects of the wireless functionality of the detector were tested in the presence of deliberate radio interference, in a fully anechoic room (FAR). See Section 2 below for details.
b) The sensitivity of the detector to low concentrations of hydrocarbon gases in air was tested using the NPL multi-gas, multi-pressure humidity facility. See Section 3 below for details.

To enable the testing of the GasSecure GS01, supporting instrumentation was supplied by Yokogawa (manufacturer) and BP (sponsor of project).
The test program was carried out in the period August through October 2015.

2 Wireless stability, coexistence and interoperability tests

GS01 detectors communicate using the ISA100.11a protocol (hereafter referred to as ISA100 Wireless), according to the IEEE 802.15.4 standard, with a 2 MHz channel bandwidth.
The task was to test that a GasSecure ISA100 Wireless network can coexist with other WiFi based devices and networks, operating in the same 2.4 GHz ISM (industrial scientific medical) band. Such devices or network should not cause significant increase in signal latency in the wireless gas detection network. This task was split into 4 tests.

The key parameter for these tests is the Packet Error Rate (PER, see definition in Appendix) in the ISA100 Wireless communication, which was evaluated as a function of the interference applied.

2.1 Coexistence of network with coincident WiFi interference

The goal for this test was to understand the physical separation required between an IEEE802.11 based Wi-Fi transmitter and the ISA100 Wireless node (in our setup the wireless access point WAP) to minimise the risk of jamming and the 'side lobe' interference from the Wi-Fi transmitter operating adjacent to ISM channel of the GasSecure wireless network.

To this end, the GasSecure and Wi-Fi network were set to transmit on the same ISM channel and on neighbouring ISM channels while Wi-Fi transmitter power was varied to simulate distance changes. In other words, larger power relates to a WiFi node at closer separation. Figure 1 illustrates how each WiFi (IEEE 802.11g) band compares with the 2 MHz ISA100 (IEEE 802.15.4) channels.
The WiFi power was determined as the maximum allowed Equivalent Isotropic Radiated Power (EIRP, see definition in Appendix) within each channel. In Europe this is set as +20 dBm, however in other regions this may be significantly higher.

PER was monitored in order to identify the distance at which the Wi-Fi transmitter starts to jam the WAP. The test results presented here correspond to a GS01 detector placed 50 m from the Yokogawa WAP.

Table 1 shows the PER for the case where the GS01 is on a fixed channel (17 to 20) with clear channel assessment (CCA, see definition and note in Appendix) switched off, and the WiFi is transmitting at 20 dBm EIRP on its channel 6. Note that the full report [1] also features results for EIRP of 10 and 36 dBm.

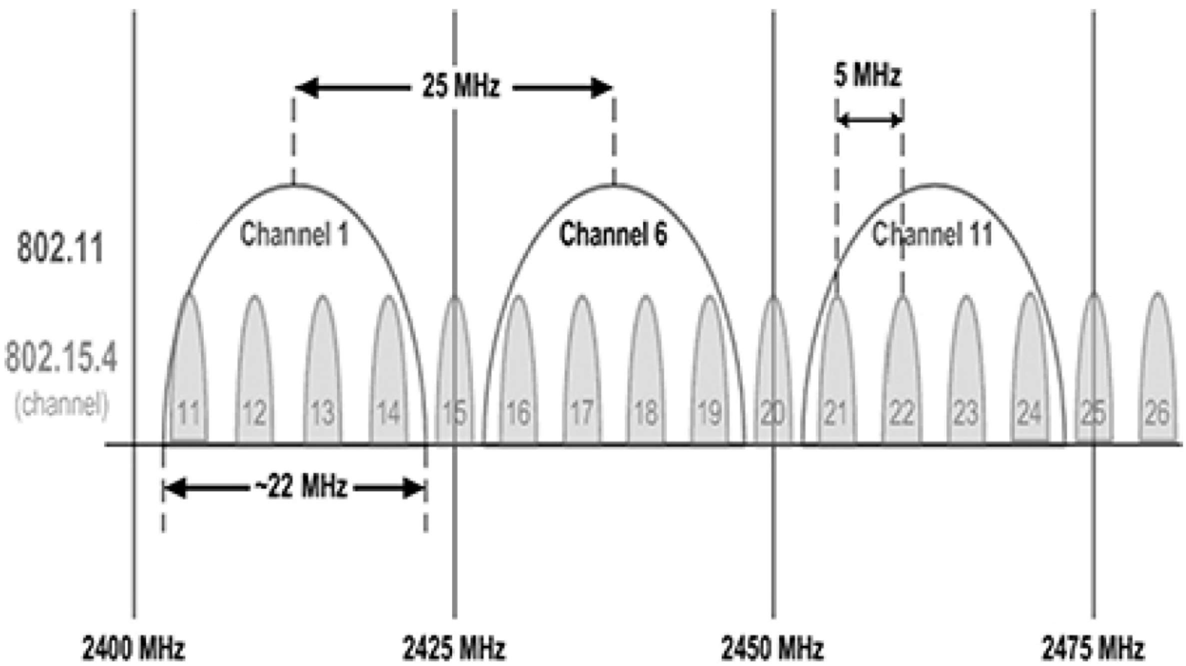

Figure 1: Illustration of the spectrum covered by WiFi channels and ISA100 channels.

Table 1 shows that ISA100 channel 20 is unaffected from WiFi interference down to the minimum tested separation of 67 m. As a rule of thumb PER should not be higher than approximately 15 to 20 %. Keeping this in mind and using ISA100 channel 19 as example this channel should only be used for separations of at least 106 m.

Table 1: PER (%) for WiFi node transmitting 20 dBm EIRP (E-field co-polar with WAP antenna), using IEEE 802.11g Channel 6. The GS01 is forced to operate in the ISA100 channels listed in each column.

Separation (m)	Ch17	Ch18	Ch19	Ch20
67.4	100	100	100	0
75.6	100	100	100	0
84.8	100	100	96	0
95.2	94	100	52	0
106.8	63	80	19	0
119.8	21	36	2	0
134.4	0	10	1	0
150.8	0	1	0	0
169.2	0	0	0	0
189.9	0	0	0	0

2.2 Coexistence of network with 4 simultaneous WiFi channels

The goal for this test was to investigate the effect of deliberate interference from fully occupied WiFi channels (IEEE 802.11g) on ISA100 Wireless communication PER. The test results may be used to determine a policy for channel blacklisting, i.e. blacklisting of heavily used channels with the aim of increasing the probability for successful transmission.

The PER was recorded as 4 channels of WiFi interference were turned on in sequence (1, 11, 6, then 14; see Figure 1). The GS01 was enabled to channel hop across the ISA100 bands; using all channels except 14, 16, 19, and 22, which were reserved for other network functions. The GS01 used for this test had the CCA function switched on, but it was by mistake not activated (see note in Appendix). If CCA was activated due to receiving noise, the PER is expected to be zero.
Each fully occupied WiFi channel had the same power, and this is converted to an equivalent separation between the WiFi source and WAP, for a maximum EIRP of 20 dBm. See Table 2 for results. Note that the full report also shows results for a 4 dB greater WiFi interference level (corresponding to a separation of 70 m).

Table 2: PER presented as 4 simultaneous channels are turned on in sequence, as per the first column.

WiFi Channel	Separation to WiFi (m)	PER (%)
1	111.1	15
11	111.1	27
6	111.1	34
14	111.1	38

2.3 Coexistence with Additive White Gaussian Noise (AWGN)

The goal of this test was to investigate the effect of deliberate interference from Additive White Gaussian Noise on the ISA100 Wireless network, again monitoring the PER. Please refer to the full report [1] for a comprehensive definition of the AWGN. The test results may be used to determine what channels users may need to blacklist based on frequency site survey results (site surveys will measure the noise floor for each channel).

PER is presented as the AWGN interference is increased, see Table 3. The first column in this table gives the power generated by the noise source used. The test was done with a GS01 that had CCA turned off (see note in Appendix). The results are presented for a distance of 50 m between WAP and GS01. As an example, the noise PFD has been converted into total noise power in a 2 MHz channel width, assuming isotropic antenna gain to determine power received at the input to the WAP antenna. AWGN noise power less than -72 dBm will cause less than 20% PER (for reliable communication PER should not be higher than approximately 15 to 20 %).

Table 3: PER presented against applied AWGN

AWGN (dBm)	Received noise power (dBm) calculated for 2MHz Channel	PER (%)
0	-74.68	0
1	-73.68	1
2	-72.68	4
3	-71.68	26
4	-70.68	66
5	-69.68	91
6	-68.68	100

2.4 Network latency and redundancy

During the following test the network was loaded with two Yokogawa wireless sensors (temperature and pressure), in addition to the GS01 detectors. This was to simulate an industrial environment.
The goal of this test was to validate the GS01 response time when exposed to flammable gas while using one and two hops to communicate back to the gateway.

Two GS01 detectors, s/n 560 (primary) and 559 (secondary), were placed in the anechoic room, see Figure 2 for illustration. The distance from both the primary and secondary GS01 to the WAP was 5 m. A Yokogawa GX20 Paperless recorder was used to display alarms and the % LEL measured by the detectors.

Methane at 45% LEL was supplied to the primary GS01 and the time taken for the paperless recorder to indicate a “high gas” alarm was recorded. Times were adjusted for the time taken for the trigger gas to flow down the pipeline to the primary GS01, which was calculated knowing the flow rate (5 litres per minute), and this value is listed as the 'delay in line' in the result tables. The uncertainty in reported trigger latency is ±1.5 seconds. For this reason, in Table 4 it was possible for the adjusted trigger time to be slightly negative.
Table 4 shows the latency for the primary GS01 communicating directly to the gateway (one hop). Table 5 shows the latency for the case where the primary GS01 is forced to use a secondary link i.e. communicate to the gateway via s/n 559 (two hops).

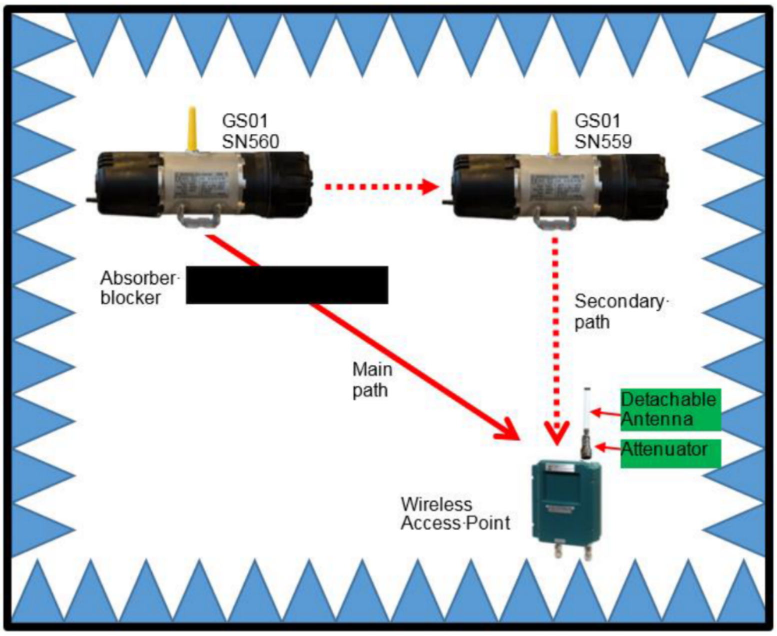

Figure 2: Schematic of layout used for latency testing

Table 4: Latency test with primary communication path (one hop).

Measurement	Time to trigger high gas alarm (s)	Delay in line (s)	Net latency (s)
1	7	5.2	1.8
2	5	5.2	-0.2
3	6	5.2	0.8
		Average	0.8

Table 5: Latency test with secondary communication path (two hops).

Measurement	Time to trigger high gas alarm (s)	Delay in line (s)	Net latency (s)
1	10	5.2	4.8
2	8	5.2	2.8
3	9	5.2	3.8
4	8	5.2	2.8
5	8	5.2	2.8
		Average	3.6

3 Ultrasonic sensor sensitivity tests

The GS01 uses a combination of two sensors to detect the presence of hydrocarbon gases:

a) An ultrasonic speed-of-sound sensor that continuously monitors changes in the ambient air density.
b) An optical (infrared) absorption sensor that is used for accurate measurements of the hydrocarbon gas concentration.

The infrared sensor uses more power than the ultrasonic and is therefore kept on stand-by if the ultrasonic sensor does not detect any changes in the air composition. As a change in air

density could be due to the presence of hydrocarbon gases, this instigates an immediate measurement by the infrared sensor.
The objective of this test was to test the minimum lower explosive limit (LEL) concentration of methane, propane and butane that will be detected by the ultrasonic sensor under different temperature and humidity conditions.

The published GS01 detector response time is 5 seconds for methane and propane concentrations above 10 % LEL and 30 % LEL, respectively [2]. To reach this short detector response time the gateway must be set up with a 2 sec sampling interval [2]. In the absence of hydrocarbon gas, the detector will not publish on all available time slots, but per default only publish on every 6th slot in order to save battery power. First in the presence of hydrocarbon gas of sufficient concentration i.e. at least 10 % LEL (referred to as internal low alarm limit), all time slots will be used.
Therefore, a 12 sec delay to the response time with gases of concentrations close to the internal low alarm limit can result due to the detector not publishing on all available communication timeslots until hydrocarbon gas of sufficient concentration is detected.

The set-up shown schematically in Figure 3 was used for these tests. The gas flowing through the measuring cell of the detector was switched from synthetic air to synthetic air mixed with a known concentration of hydrocarbon gas to test the response time of the GS01. The response time reported in this test is the difference between the time of switching gas supply and the time a “high gas” alarm (set point 7 % LEL) is triggered by a Yokogawa GX20 paperless recorder connected to the gateway via Modbus TCP.
A combination of uncertainties (pipework volume, flow rate of the test gas, the resolution of the paperless recorder timer, and timing errors in the manual valve operation) result in a response time uncertainty of approximately 3 seconds. This is the reason that negative net values of response time were sometimes measured.

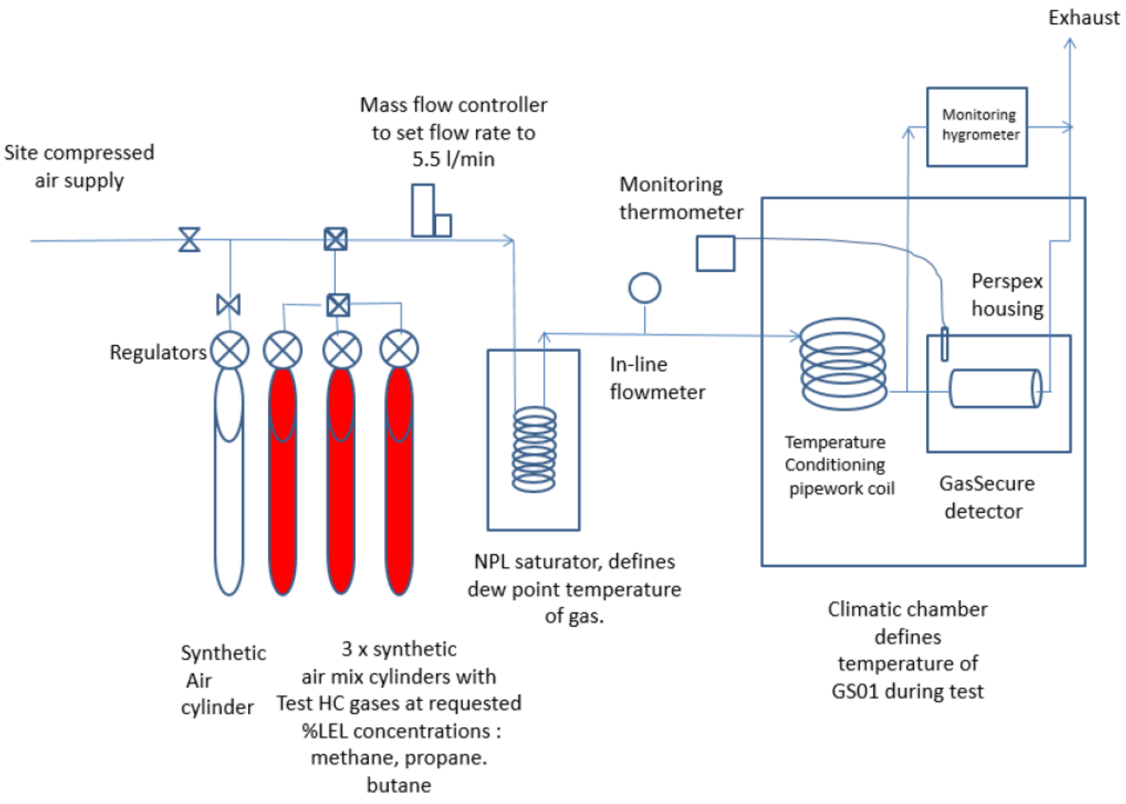

Figure 3: Schematic diagram of set-up for ultrasonic sensitivity tests

The following three gas mixtures were tested[1]:

1. Methane 10 % LEL (0.44 % vol methane, balance synthetic air)
2. Propane 30 % LEL (0.51 % vol. propane, balance synthetic air)
3. Butane 15 % LEL (0.21 % vol butane, balance synthetic air)

Tests were carried out at two different set points as per Table 6.

Table 6: Set points for ultrasonic sensor sensitivity tests

	Set point 1	Set point 2	Expanded uncertainty (k = 2)
Temperature [°C]	10	20	±0.2
Relative Humidity [%]	95	50	±1.1

Ten repeat tests switching from synthetic air to a synthetic air mixture containing hydrocarbons and back again were made for the cylinder containing methane, whereas three such tests were made for the cylinders containing propane and butane.

Tables 7 – 9 detail results with the detector at the 10 °C 95 %rh condition (set point 1) and Tables 10 – 12 detail results with the detector at the 20 °C 50 %rh condition (set point 2). Note that with reference to the full report [1] and in particular the Manufacturers Comments in Section 2.4 of [1], the tables below show the results after the firmware of the GS01 under test was updated to version 3.1.0.

Table 7: Response times for tests using synthetic air mixture with methane (nominal value 10 % LEL) at 10 °C, 95 %rh

Temperature [°C]	Relative Humidity [%]	Time taken to trigger high gas alarm [s]
10.03	94.55	5
10.03	95.07	9
10.04	93.91	6
10.04	94.50	6
10.05	95.18	8
10.05	94.66	5
10.05	95.28	3
10.06	94.82	10
10.07	95.34	6
10.08	94.83	7

[1] All LEL values in [% vol] according to IEC 60079-20

Table 8: Response times and measured value of % LEL for tests using synthetic air mixture with propane (nominal value 30 % LEL) at 10 °C, 95 %rh

Temperature [°C]	Relative Humidity [%]	Time taken to trigger high gas alarm [s]
10.07	95.39	1
10.07	94.42	-1
10.07	94.89	0

Table 9: Response times for tests using synthetic air mixture with butane (nominal value 15 % LEL) at 10 °C, 95 %rh

Temperature [°C]	Relative Humidity [%]	Time taken to trigger high gas alarm [s]
10.09	94.46	1
10.09	93.67	0
10.08	94.65	-2

Table 10: Response times for tests using synthetic air mixture with methane (nominal value 10 % LEL) at 20 °C, 50 %rh

Temperature [°C]	Relative Humidity [%]	Time taken to trigger high gas alarm [s]
20.08	49.75	8
20.09	49.73	2
20.11	49.75	5
20.12	49.72	8
20.13	49.66	7
20.14	49.64	8
20.15	49.62	7
20.15	49.65	5
20.16	49.50	14
20.16	49.49	11

Table 11: Response times and measured value of % LEL for tests using synthetic air mixture with propane (nominal value 30 % LEL) at 20 °C, 50 %rh

Temperature [°C]	Relative Humidity [%]	Time taken to trigger high gas alarm [s]
20.18	49.48	-1
20.18	49.49	-2
20.18	49.33	-1

Table 12: Response times for tests using synthetic air mixture with butane (nominal value 15 % LEL) at 20 °C, 50 %rh

Temperature [°C]	Relative Humidity [%]	Time taken to trigger high gas alarm [s]
20.16	49.40	-2
20.16	49.40	0
20.15	49.48	-1

4 Conclusions

4.1 Wireless stability, coexistence and interoperability tests

In practical terms, what these test results mean is the following

- ISA100 Wireless channels just outside a 20 MHz wide WiFi channel are free from interference at least down to the minimum tested separation of 67 m at an EIRP of 20 dBm; cf. Table 1 (example for ISA100 Wireless channel 20 and WiFi channel 6).
- For communication on ISA100 Wireless channels inside the 20 MHz band of a WiFi channel (channels 17, 18, 19 as per Table 1) minimum distances between the WiFi source and the ISA100 node must be respected. As a rule of thumb the PER should not be higher than 15 – 20 %. Note also that the test results correspond to a constant interference EIRP of 20 dBm (fully occupied channel), which is a worst case.
- When two or more WiFi channels are heavily used simultaneously (cf. Table 2) the PER remains relatively low even with CCA not active. This is due to the guard bands between the WiFi channels (cf. Figure 1). The WiFi transmitter was not able to completely jam the ISA100 Wireless network even with four channels used at the same time.
- For a GS01 with CCA off at 50 m from the WAP, the AWGN interference power in a 2 MHz channel has been estimated assuming a net antenna gain of 0 dBi on the WAP unit (lossless, omni-directional). Under these conditions, AWGN noise power of more than -72 dBm will cause more than 20% PER and blacklisting of ISA100 channels therefore needs to be considered beyond this noise level.
- The GS01 wireless gas detector responds very quickly to hydrocarbon gas. In our experiment with exposure to 45 % LEL methane the recorded time from the occurrence of gas to the triggered alarm by the recording device was on average 0.8 sec and 3.6 sec for wireless communication with one and two hops, respectively.

4.2 Ultrasonic sensor sensitivity tests

These tests confirm that the ultrasonic sensor is sensitive to the following gas mixtures

- Methane 10 % LEL (0.44 % vol methane, balance synthetic air)
- Propane 30 % LEL (0.51 % vol. propane, balance synthetic air)
- Butane 15 % LEL (0.21 % vol butane, balance synthetic air)

and that the gas concentration is output to a recording device within the short time delays as per manufacturer specification.
Note that these tests were carried for two set points namely temperature / relative humidity of 10 °C / 95 % and 20 °C / 50 %.

5 References

[1] Evaluation Report E 1966 X15 “GasSecure GS01 Wireless gas Detector”, published by Evaluation International, Dec 2015

[2] GasSecure GS01 user manual, document ID 112464

[3] GS01 data sheet, rev 3.0, Dec 2015

6 Appendix

Packet error rate

The packet error rate (PER) is an important parameter to indicate the quality of radio communication. PER is a unit-less performance measure, which is normally expressed as a percentage. It is defined as follows:

$$PER\ [\%] = \frac{Incorrectly\ received\ data\ packets}{Total\ number\ of\ packets\ transmitted}$$

A packet is declared incorrect if at least one bit is erroneous.

Equivalent isotropic radiated power

In radio communication systems, equivalent isotropic radiated power (EIRP) is the amount of power that a theoretical isotropic antenna (which evenly distributes power in all directions) would emit to produce the peak power density observed in the direction of maximum antenna gain. EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna. The EIRP is often stated in terms of decibels over a reference power emitted by an isotropic radiator with an equivalent signal strength. The EIRP allows comparisons between different emitters regardless of type, size or form.

Clear channel assessment

Clear Channel Assessment (CCA) is mechanism for wireless co-existence defined in the IEEE 802.15.4 standard. CCA is used to determine the current state of use of a wireless medium and aids in contention avoidance. CCA is best described as a “listen before talk” algorithm.

Note on CCA on versus off

During testing, NPL decided to apply the noise source towards the WAP using a horn antenna. Since a horn antenna is directional, the GS01 saw very little noise (approximately 20 dB less than the WAP due to the horn antenna side lobes) and CCA was not activated on the GS01. Unfortunately this caused the “CCA on tests” to achieve the same results as the “CCA off tests”.