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Wireless communication in safety systems

GS01 Hydrocarbon IR Detector

ST-34-2002

Wireless communication in safety systems

Wireless sensors have been around for some time. The motivating factors for installing wireless equipment are easy to identify; simplicity of installation and flexibility in operation. Just as the benefits are easy to see, so are the potential challenges. The main challenges with safe wireless communication are to guarantee a short response time and to immediately detect loss of contact with sensors.

Wireless instruments are most often battery powered and are hence energy constrained. This limits the rate at which the instruments can report process values. For most process monitoring applications, this is not a major obstacle as the process values in question tend to change relatively slowly. However, for safety applications, the picture is somewhat different. For safety, continuous monitoring is necessary and a short latency (response time) needs to be guaranteed if a safety critical situation arises. However, the average bandwidth requirement is modest. Thus the primary difficulty in designing a wireless safety system is having a guaranteed short latency whilst not depleting the batteries. In addition, full control of all network message traffic is required, and loss of contact with a device must be identified immediately.

WIRELESS GAS DETECTION

GasSecure has developed an optical gas detector, the GS01, that operates with significantly lower power consumption than today's state of the art detector units. This allows for wireless operation with battery life up to two years. In addition the GS01 will not need recalibration and performs equally or better than state of the art detectors.

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GasSecure GS01

For safety applications, the communication with the controller needs to meet reliability requirements according to SIL2 (Safety Integrity Level) guidelines as described in IEC 61508 Ed2.0. GasSecure's SafeWireless communication system meets the rwequirements of fast response time, power efficiency and full control of network traffic. The detector itself is also developed according to IEC 61508 Ed2.0 and meets the performance requirements of IEC 60079-29-1.

WIRELESS NETWORK TOPOLOGY

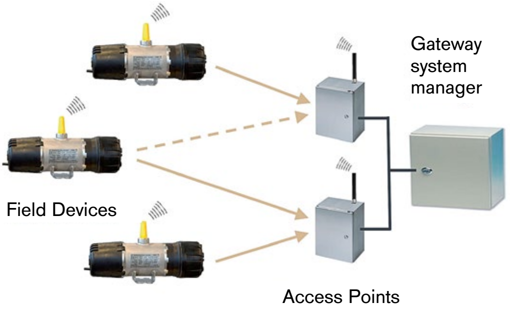

Figure 1: Example of a star topology network with paired access points. Secondary (back-up) communication links are indicated with dashed arrow.

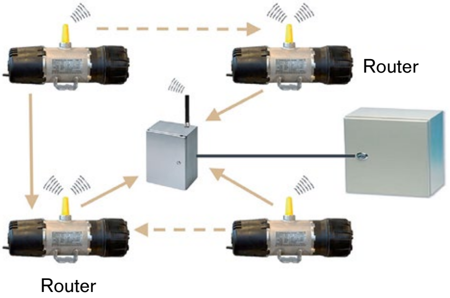

Figure 2: Example of a mesh topology network. Two field devices operate as routers. Secondary (back-up) communication links are indicated with dashed arrow.

The simplest network topology is the star. In the star topology, an access point communicates directly with each wireless field device. This topology will minimise the latency, because each device is directly linked to an access point. With multiple access points, secondary (backup) links can be established (See Figure 1 page 3).

The mesh topology (See Figure 2 page 3), in which additional wireless nodes are installed to act as relays, offers a more advanced set-up. The nodes may also have sensing capability (role A and B see above) and they may, or may not, be battery powered. Wireless mesh topology is used to extend coverage by means of intermediate links and may enhance communication reliability by providing redundant paths between devices. If the primary path of a field device is obstructed or becomes unavailable, the system manager can choose to transmit the data along the secondary path. This leads to very stable and predictable network availability.

The GS01 gas detector supports the previously mentioned topologies and it also allows for the combination of both, so that a network configuration can be designed that best satisfies the needs of the specific application. Another important parameter to consider in mesh-type networks is the number of allowed intermediate links (radio hops) from a field device to an access point. Increasing the number of hops allows networks spanning over a large geographical area. The disadvantage is increased latency of the data packets and increased processing load on the routers, which in turn will slightly raise their energy consumption. Note for the GS01, the published detector response time of 5 seconds is guaranteed for maximum two hops.

The deployment of a wireless gas detector network is simple. The gas detectors are placed in their preferred locations and powered on. Subsequently, each gas detector will communicate with the available routers and access points, obtaining an image of the network and the available communication paths and their quality. The aggregated information is stored in the system manager, which is responsible for setting up the communication relationships.

The system manager updates continuously the image of the network ensuring that the communication relationships are optimum at all times and adapted to changes in the network topology.

WIRELESS SENSOR NETWORK STANDARDS

There are several communication standards and protocols to choose from for field wireless instrumentation. For safety applications, the ISA100 Wireless™ standard is the most promising contender for the following reasons:

- Object orientation facilitates the design of user-specific applications and the integration of safety protocols.
- Contract based communication (uplink and downlink) guarantees limits for bandwidth, latency, and priority.
- Device interoperability supports the ability of devices from multiple vendors to communicate and maintain the complete wireless network.

ISA100 Wireless is a wireless networking technology standard developed by the International Society of Automation (ISA). This ISA standard is intended to provide reliable and secure wireless operation for safety, control, and monitoring applications. This standard defines the protocol suite, system management, gateway, and security specifications for low data rate wireless connectivity with fixed, portable, and moving field devices supporting very limited power consumption requirements.

The GS01 gas detector from GasSecure fully supports the ISA100 Wireless standard and is therefore very easy to deploy in an ISA100 environment with compliant gateways and other ISA100 field devices.

FULFILLING THE SIL2 REQUIREMENTS WITH SAFEWIRELESS™

GasSecure's SafeWireless communication concept is designed to combine low power operation with a short response time (latency).

In addition, this concept guarantees full control of all network traffic and immediately identifies any loss of contact with a field device.

Safe communication is based on cyclic exchange of messages i.e. all data packets need to be answered one-by one. All communication is initiated by the safety controller, which will send a data packet that must be answered by the field instrument within the so-called process safety time. For hydrocarbon gas detection, this process safety time is commonly set to 60 seconds.

Once the controller has received a response from the field device, it will immediately issue the next data packet. If the field device does not respond before the process safety time has elapsed, then this device is marked as unavailable in the control system.

SafeWireless communication also fulfils the requirements of functional safety standard IEC 61508 for safety integrity level (SIL) 2. Most important, the following four error-handling mechanisms are supported: Sequence numbering, time-out in the absence of response, device code name, and data consistency checking. The purpose of these mechanisms is to detect failures of the safety device in terms of e.g. packet loss, unacceptable network delay, bit errors, and replay attacks. Several options exist for implementing these required safety features. The approach chosen by GasSecure is to utilise a certified implementation of an open safety protocol.

GasSecure has identified PROFIsafe over PROFINET, due to the widespread use of the latter in safety and process control applications.

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SAFEWIRELESS COMMUNICATION

For wireless data transfer it is advisable to allow several attempts for transmitting a data packet within the process safety time, in order to achieve robust and reliable communication.

For the GS01, a reasonable balance between low energy consumption and robust wireless communication is to have 3 to 4 attempts within the process safety time, i.e. one downlink data transmission every 15 to 20 seconds. In safety applications, a common limit for the acceptable interval from when hydrocarbon gas enters the detector measuring cell until the data packet with the gas concentration is received by the safety controller is 7 seconds. In order to fulfil this latency requirement, there need to be defined timeslots every two seconds for uplink data packets. The GS01 gas detector will therefore, during setup, request that sufficient bandwidth be set aside for this uplink transmission rate.

In the absence of hydrocarbon gas, these frequent timeslots will however not be used and the gas detector will limit communication to once every 15 to 20 seconds, thereby minimising the average power consumption.

In the presence of hydrocarbon gas, the GS01 needs to report the detected gas concentration immediately and within the 7 second requirement. However, downlink data packets arrive only every 15 - 20 seconds and there is a one-to-one mapping between incoming packets and the device response thereto. In other words, once the detector has responded to a data packet it is unable to report gas concentration until the next data packet is received from the safety controller.

This apparent dilemma is solved in SafeWireless by holding the response to a data packet until just before the following data packet is expected. This way the “blind” time is kept to two seconds and the detector is always primed and ready to report gas immediately.

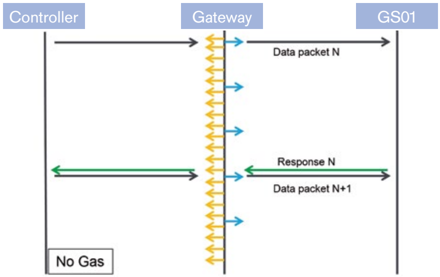

Figure 3: SafeWireless communication in the absence of hydrocarbon gas. The downlink data packets (black arrows) are typically sent 3 – 4 times per minute and answered by the GS01 (green arrows) just before the next packet will be sent from the controller. Yellow and blue arrows indicate allocated timeslots for uplink and downlink communication, respectively.

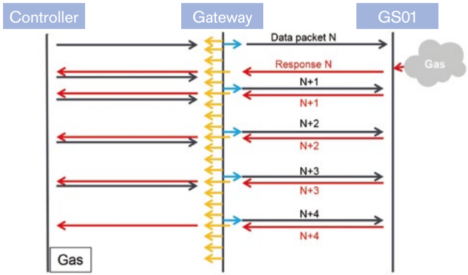

Figure 4: SafeWireless communication in the presence of hydrocarbon gas. On the occurrence of gas the instrument responds instantaneously (red arrow) using the first available timeslot (yellow arrow) for uplink communication. Communication is more frequent in the presence of gas i.e. all timeslots for downlink communication (blue arrows) are used now.

The concept with two modes of communication for “No Gas”and “Gas”, as illustrated in Figure 3 and 4 is unique to the GS01 from GasSecure.

REDUNDANCY

Safety systems are designed to avoid single points of failure. There are several ways to implement redundancy in a field wireless network. The availability of routers (wireless nodes) constitutes redundancy at the detector level, as explained in Section “Wireless Network Topology”. However, redundant operation may also be required uplink in safety applications, at the gateway and system manager, the access point, and the controller level.

For the gateway (including system manager), redundancy is typically implemented by two gateway units placed side-byside and connected with a short synchronisation cable. The primary unit is in operation mode, whereas the secondary unit is in stand-by, but at all times fully synchronised. Should the primary unit fail, then the stand-by gateway can take over operation within seconds.

Redundancy at the access point level is as per ISA100 Wireless standard referred to as Duocast. In essence, Duocast technology provides the function for a field wireless device to transmit the same data to two paired access points (See Figure 1 page 3). Thereby, the communication path is made redundant, and should the primary access point fail, then the secondary communication path is automatically available.

Finally, having two or more controllers introduces redundancy at the highest level in the control architecture. This is supported by the ISA100 Wireless standard as well.

The GS01 represents a totally new concept in hydrocarbon gas detection. Its unique low power detection principle has paved the way for wireless communication. Furthermore, the implementation of SafeWireless™ enables its use in safety critical applications.

GasSecure's patent pending wireless communication system meets the requirements of fast response time, power efficiency and full control of network traffic.

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GasSecure GS01 – Reliable infrared gas detection with no need for field calibration

Single beam triple wavelength technology – unique to the GS01 gas detector – is the key reason why GasSecure can offer lifetime calibration for their product. In other words, field calibration will never be required for this gas detector.

INTRODUCTION

The GasSecure GS01 represents a totally new concept in hydrocarbon gas detection using single-beam triplewavelength infrared (IR) technology for fast gas detection with extremely low power consumption. This paper explains the detection concept and in particular how this concept enables a lifetime calibration-free detector design.

The GS01 detector utilises IR absorption spectroscopy. This method for measuring gas concentration is based on the absorption of IR radiation at gas-specific wavelengths in a volume containing the target gas. Specific molecules will absorb light at known wavelengths, and most hydrocarbon gases, including methane and propane, absorb infrared light at approximately 3.3 microns.

The GS01 gas detector compares the amount of light at the wavelength where hydrocarbon molecules absorb light (known as the gas sample wavelength position) with the light intensity in the neighbouring areas of the electromagnetic spectrum where no such absorption occurs (known as the reference wavelength position). Thus, the GS01 calculates gas concentration from the ratio of the intensities at the gas sample wavelength and the reference wavelengths.

Note also that in neither wavelength area (gas sample and reference) will other atmospheric constituents such as water vapor, nitrogen, oxygen, or carbon dioxide absorb light.

IR absorption spectroscopy is rooted in the principles expressed in the Beer-Lambert Law:

$$T = e^{(-ANL)}$$

where T is the transmission at the specific wavelength, A the absorption coefficient of the particular gas molecule, N the gas concentration, and L the path length the beam travels in the gas volume. Measuring T and knowing A and L (note that L is fixed by design for the GS01), N can be found.

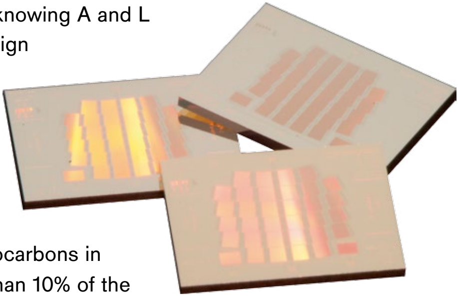

Figure 5: The MEMS chip

The measurement itself is not particularly challenging, since explosive mixtures of hydrocarbons in air typically absorb more than 10% of the incident light in the spectral band around 3.3 μm for a path length of 13 cm, as applied by the GS01.

More challenging is designing a gas detector for harsh environments with virtually no zero and no span drift in a wide operating temperature range. Such a design significantly reduces the cost of ownership, because regular field calibrations are no longer required.

TRIPLE-WAVELENGTH DETECTION

Although there are variations, the principal optical design of traditional IR point detectors comprises broadband light sources, optical filters, a beamsplitter, and solid-state photodetectors. The filters select the correct wavelengths for the gas and reference measurement from the incoming broadband light. The GasSecure approach is different by applying state-of-the-art MEMS (Micro Electro Mechanical System) technology for the optical filtering, which distinguishes the GS01 from all other commercially available IR hydrocarbon point detectors.

The filter is a patented silicon MEMS chip proprietary to GasSecure (See Figure 5 p15) that disperses, focuses, and modulates the incident light. By applying a control voltage to this chip, it is switched between the gas state and the reference state at a frequency of 1 kHz. In the gas state, a wavelength area where hydrocarbons absorb light is focused onto a single photodetector. In the reference state wavelengths, where hydrocarbons do not absorb, are focused onto the same detector. Note that the reference state is composed of two spectral areas located to the left and right of the gas state wavelength position, hence the term triple-wavelength detection.

(See Figure 6 p17) shows the respective filter function curves for both states as generated by the MEMS chip (a) in the absence of hydrocarbons and (b) in the presence of Methane. The presence of Methane molecules reduces the amount of light in the gas state, but not in the reference state.

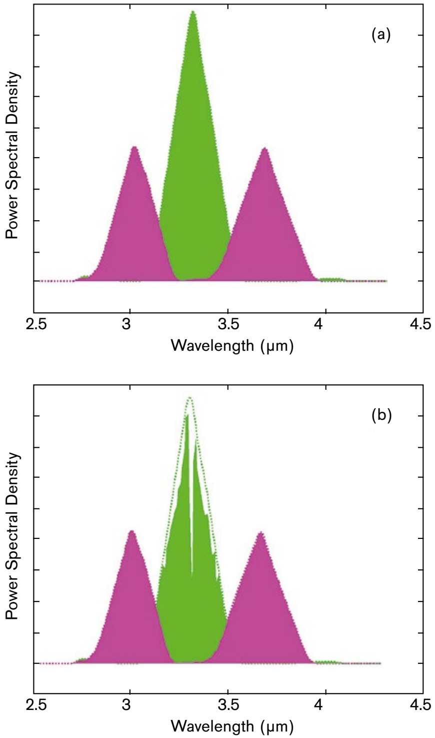

Figure 6: The filter functions used for hydrocarbon detection, corresponding to the two states of the MEMS (green = gas state and purple = reference state), (a) in the absence of hydrocarbon gas and (b) in the presence of Methane.

The gas concentration is then calculated from the ratio of the light intensities reaching the photodetector in both states. Therefore, any other influences on optical transmission such as drifting source intensity or fouling of the windows are effectively eliminated, because these influences will equally affect the gas and reference state light intensity and cancel in the ratio of both.

This is illustrated schematically (See Figure 7 p19). Moreover, working with two reference wavelengths situated on both sides of the hydrocarbon absorption wavelength, will correct for first order wavelength-dependent error sources, primarily a changing emission spectrum of the infrared source.

These linear changes of the emission spectrum will increase the light intensity in one sideband, but simultaneously reduce intensity in the opposite sideband. The sum of both i.e. the strength of the reference signal remains unchanged. Hence, the gas concentration can be measured more reliably.

This triple-wavelength detection principle is unique to the GS01 from GasSecure.

GasSecure GS01

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SINGLE-BEAM DESIGN

As already stated, the MEMS chip serves a number of purposes namely dispersing and focusing light and switching between two optical states. By applying a control voltage to the chip, the diffracted light is spatially redistributed between the diffraction orders. In the gas state, light with wavelengths where hydrocarbons absorb is focused onto the detector, whereas light with wavelengths where hydrocarbons do not absorb is focused onto the same detector in the reference state.

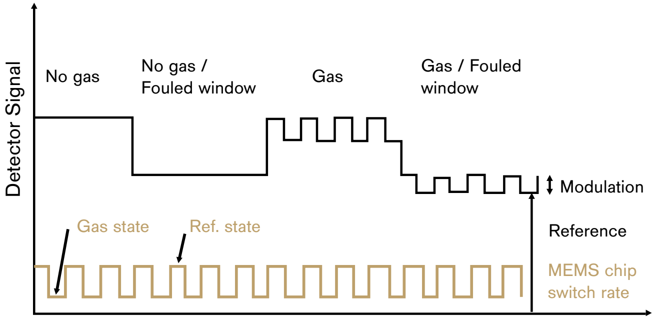

Figure 7: Detector signal in the event of No gas / Gas and Fouled window (the latter representing “other influences” on transmission). Note the ratio used for calculating the gas concentration (Modulation / Reference intensity) remains unchanged.

This in turn enables a very simple optical design with a minimum number of components: One IR source, mirror and window, MEMS chip, and one photodetector (See Figure 8 below). Note that the diagram shows the instrument in the gas state, because light filtered for the gas state (green line) is focused onto the detector. Upon switching the MEMS chip light filtered for the reference state (purple line) will be focused

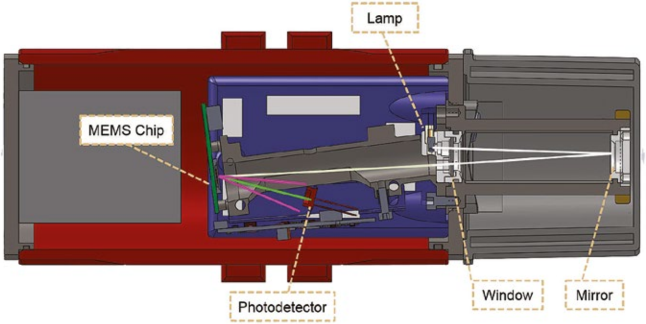

Figure 8: Cross sectional view of the GS01 gas detector showing the main optical components and the light path. The white line represents the incident broadband light from the lamp, whereas the filtered light for gas and reference measurement is represented as green and purple line, respectively.

onto the same detector. The light path and the optical components (lamp, photodetector, MEMS chip, mirror and window) are all the same for the gas and the reference measurement. As the switching between the states is extremely fast (1 kHz), also the environmental conditions (temperature, humidity, pressure) are the same for both states. This design is referred to as single-beam detection, and combined with triple-wavelengths is a unique feature for GasSecure's GS01 gas detector.

Ageing of IR light sources or solid-state photodetectors will not affect the GS01 gas concentration calculation, simply because the same components are used for the gas and the reference measurement. Aging effects will affect all optical components equally and therefore cancel in the ratio of both measurements.

Moreover, the MEMS chip is a reliable and long-time stable electronic component without conventional moving parts. The crystalline silicon is perfectly elastic, and the forces of gravity, vibration, or acceleration have no influence on the repeatable micrometer-scale movement. The filter functions for gas and reference state (See Figure 6 p17) are defined by etching patterns in the silicon chip. These patterns are physical surface reliefs with no ageing effects.

Triple-wavelength detection and single-beam design – both unique to the GS01 gas detector – are the key reasons why GasSecure can offer lifetime calibration for their product. In other words, field calibration by the user will never be required for this gas detector.

FIELD TEST DATA

The Norwegian oil company Statoil was one of the first to deploy the GS01 gas detector from GasSecure on an oil and gas production platform offshore, namely Gullfaks C. The wireless gas detectors were manufactured and factory calibrated in November 2012 and commissioned on the platform in January 2013. In October 2013, GasSecure staff returned to the platform for detector validation.

Table 1 below shows the zero point for 10 detectors, all located in one fire area, when exposed to dry nitrogen from a gas cylinder. All detectors are well within the stated specification of +/- 3 %LEL, confirming a stable zero point one year after factory calibration and without any need for re-calibration in the field.

DEVICE TAG	ZERO POINT [%LEL]
DG-M24T-69	0
DG-M24T-70	0.6
DG-M24T-71	0.4
DG-M24T-72	-1
DG-M24T-73	0.7
DG-M24T-74	-0.4
DG-M24T-75	0.1
DG-M24T-76	1.7
DG-M24T-77	0
DG-M24T-78	-0.1

Table 1: Zero point measurement on GS01 detectors installed on Gullfaks C platform one year after factory calibration.

A major oil & gas company in Malaysia selected the GS01 gas detector for a refinery application. The detectors were manufactured and calibrated in March 2013 and commissioning for this project finally took place in April 2014. As part of the preceding acceptance test all detectors were validated in March 2014 with 2.5 %vol. methane (in synthetic air) providing a nominal reading of 57 %LEL. Table 2 shows the recorded readings, which are all within GasSecure's specification of +/- 5 %LEL for concentrations greater than 50 %LEL, notably one year after factory calibration and without any re-calibration in the field.

DEVICE TAG	READING WITH TEST GAS 2.5 %VOL CH4 [%LEL]
292GDA007	55.8
283GDA002	54.6
283GDA003	53.2
293GDA001	58.2
292GDA008	57.9
291GDA011	57.1
291GDA012	61.8
294DGA011	61.2
294DGA012	52.6
294GDA012	53.6
225GDA021	53.9
225GDA022	55.9

Table 2: Validation of GS01 detectors as part of a customer acceptance test, one year after the initial factory calibration.

SUMMARY

The GasSecure GS01 gas detector is taking infrared (IR) absorption spectroscopy to the next level using patented MEMS (Micro Electro Mechanical System) optical filters. With this technology, GasSecure has designed a gas detector for harsh environments with no zero and no span drift in a wide operating temperature range.

Three wavelengths are utilised for the gas and reference measurement and this triple-wavelength detection provides a more reliable quantification of the gas concentration.

The MEMS filter also enables a true single-beam design i.e. the light path and all optical components are the same for the gas and the reference measurement. With this design any long-term aging effects, primarily source intensity and detector sensitivity changes, are effectively eliminated.

In conclusion, the GS01 creates value for the customer with reliable infrared operation and a calibration-free design that eliminates the costs associated with field calibration.

NOTES

CORPORATE HEADQUARTERS
Drägerwerk AG & Co. KGaA
Moislinger Allee 53–55
23558 Lübeck, Germany

www.draeger.com

MANUFACTURER
GasSecure
Hoffsveien 70 C
0377 Oslo, Norway
post@gassecure.com
www.gassecure.com

REGION DACH
Dräger Safety AG & Co. KGaA
Revalstraße 1
23560 Lübeck, Germany
Tel +49 451 882 0
Fax +49 451 882 2080
info@draeger.com

REGION EUROPE
Dräger Safety AG & Co. KGaA
Revalstraße 1
23560 Lübeck, Germany
Tel +49 451 882 0
Fax +49 451 882 2080
info@draeger.com

REGION MIDDLE EAST, AFRICA
Dräger Safety AG & Co. KGaA
Branch Office
P.O. Box 505108
Dubai, United Arab Emirates
Tel +971 4 4294 600
Fax +971 4 4294 699
contactuae@draeger.com

REGION ASIA PACIFIC
Draeger Safety Asia Pte Ltd
25 International Business Park
#04-20/21 German Centre
Singapore 609916
Tel +65 6308 9400
Fax +65 6308 9401
asia.pacific@draeger.com

REGION CENTRAL AND SOUTH AMERICA
Dräger Panama S. de R.L.
Complejo Business Park,
V tower, 10th floor
Panama City
Tel +507 377-9100
Fax +507 377-9130
contactcsa@draeger.com

Locate your Regional Sales Representative at:
www.draeger.com/contact

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