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Fiber Based Methane Leak Detection

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Abstract

Fiber-based Methane Leak Detection System

The current focus in the post-Macondo era is the need to make the offshore work environment safe. The use of a fiber-based backbone to perform a number of functions in an installation with the potential of an explosive atmosphere has significant potential. Currently the novel fiber backbone has the capability to provide three basic functions: area and equipment lighting, distributed remote temperature sensing, and distributed remote methane sensing. The application of fiber optics for lighting and distributed sensing is a mature concept. It is the use of fiber optics for methane detection that is novel.

Methane sensing utilizing discrete passive sensors connected to a central sensing unit with fiber optic cable. The system utilizes a low power (10mW) diode laser in conjunction with a distributed fiber network and a series of ruggedized sensor modules. It is largely unaffected by common environmental conditions which can cause erroneous readings with many other sensor types including high humidity, anaerobic conditions, and the presence of other non-target gases. The system is tolerant of dust contamination, and fully functioning at signal losses of up to 90%. It can be configured as a distributed network with hundreds of sensing points at distances of up to 20 km from a central control unit. Methane levels from 0.5 to 100% can be accurately measured. Standard communication grade fiber cable is utilized. Unlike conventional methane detection systems currently employed, this system does not require calibration at the remote sensor. Various alarm schemes can be configured to look for rising methane levels, over-limit conditions, as well as breaks in the sensing fiber.

This paper describes the concepts and provides examples of real-world implementations of how this technology can provide for safe offshore working conditions.

Manuscript

Overview

The proposed system will utilize a facility wide fiber optic backbone to monitor the conditions within the installation, specifically methane levels and temperature. This paper will focus on the methane sensing aspects of the system. In the event of an excursion from normal operating conditions, a series of progressive alarm signals will be generated. These signals will be communicated to existing supervisory control systems. In addition, the proposed system will include a series of fiber based visual annunciators placed at appropriate locations within the facility. The annunciators will be able to communicate current conditions via varying color and light patterns.

The technologies utilized are all relatively mature technologies, with significant field-testing completed in severe environments. The three major components of the system (methane detection, distributed temperature sensing, and overall control and alarm annunciation) will each have its own dedicated fiber network within the backbone. The three networks will be bundled together and routed through the installation in common wireways.

The fiber backbone utilizes commercially available data communication cables jacketed and cabled appropriately for the installation. The methane detection system is further described below:

The fiber optic-based distributed methane detection system is based on a product offering developed at OptoSci Ltd., a spin-off company from the University of Strathclyde in Glasgow, Scotland focused on the development of innovative photonics technologies eminating from internal and academic research. The system is currently in use in landfills and tunnels to monitor methane and natural gas. The system utilizes a low power (10mW) diode laser in conjunction with a distributed fiber network and a series of ruggedized sensor modules. It is largely unaffected by common environmental conditions which can cause erroneous readings with many other sensor types including high humidity, anaerobic conditions, and the presence of other non-target gases. The system is tolerant of dust contamination, and fully functioning at signal losses of up to 90%. It can be configured as a distributed network with hundreds of sensing points at distances of up to 20 km from a central control unit. Methane levels from 0.5 to 100% can be accurately measured. Standard communication grade fiber cable is utilized. Unlike conventional methane detection systems currently employed, the system described does not require calibration at the remote sensor. Various alarm schemes can be configured to look for rising methane levels, over-limit conditions, as well as breaks in the sensing fiber. Key attributes of the system include:

- Real-time methane gas monitoring is enabled at hundreds of points over long distance (up to 20km) fiber optic networks
- System is totally electrically passive outside the central controller, which will be housed in an appropriate enclosure, or in a central control room outside the hazardous gas zone, offering complete intrinsic safety and compatibility with all current safety standards
- Rugged sensor modules, as shown in Fig. 1, consist of a perforated stainless steel sensor tube, junction box, and drip shield. They have rapid response and are unaffected by anaerobic conditions, catalytic poisoning, other non-target gases, water sprays and excessive humidity

- Gas sensing technique is self-referencing, which provides inherent calibration stability and ensures that the full system only requires a single, one-off calibration at the central controller
- Automatic system self-checking function at central controller gives advance warning of any potential controller, network or sensor problems facilitating a predictive maintenance protocol
- The system offers high gas sensitivity, wide measurement range (0.05% to 100% CH_4), exceptional gas selectivity and no gas cross-sensitivity
- Plug-in modular format offers flexibility, easing component replacement and system expansion
- Sensors have many years of proven, continuous, stable operation in hostile environments, require no scheduled maintenance and allow constant condition monitoring at the central controller
- Sensors (see Fig. 1) can tolerate up to 90% signal loss, providing good immunity to high dust conditions.

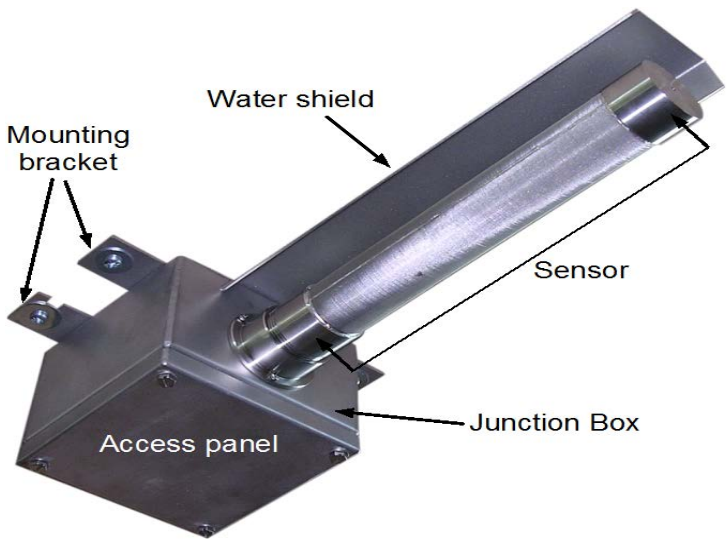

Fig. 1a – Remote Optical Methane Detector

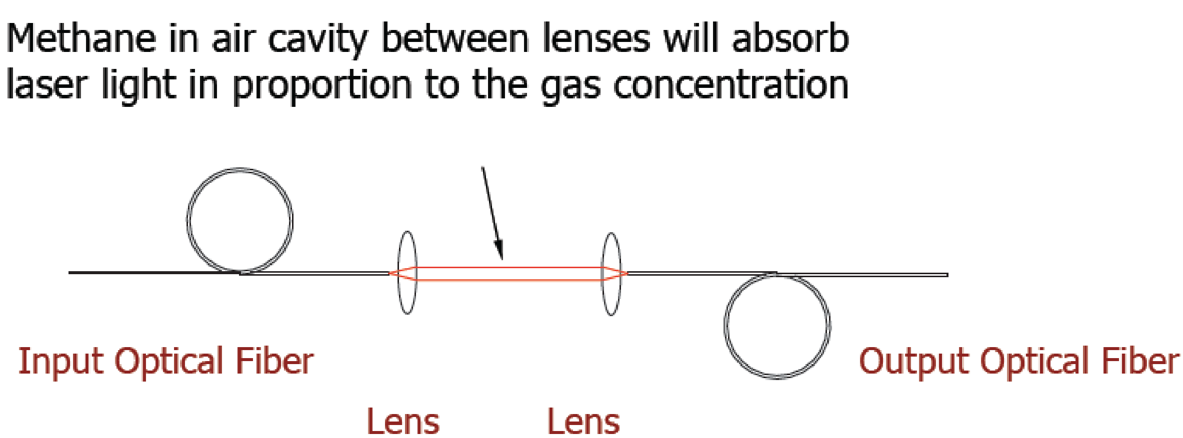

Fig. 1b – Remote Optical Methane Detector

Comparison to competitive sensor technologies

Pellistor Sensors (common current sensor type)

- Dust can block the sinter stopping sensor operation, reducing response time or affecting the accuracy of the reading.
- Water sprays have a similar effect to dust.
- Calibration interval is usually required at 3 months minimum.
- Pellistors are only accurate up to the LEL (5% CH_4Vol) concentration. Higher than this and the readings are not reliable. Spontaneous large releases of gas would saturate the sensor and give no indication of failure.
- Cannot operate in atmosphere with less than 10% oxygen. This can be problematic in areas where these conditions are likely (e.g. methane layers close to ceiling).
- Safety concerns – Although the systems are certified safe for hazardous environments, the presence of electrical power at the active sensor is a concern for operators.

Mid IR Sensors

- Mist / water vapour can generate false readings or prevent the sensor from detecting gas at all.
- Dust deposits on the window / mirror causes sensor failure
- This system uses a power supply at each sensor head (usually for heating the optics to minimise condensation) and although products are rated intrinsically safe, this is still a concern for operators who would prefer a passive system.
- Experience shows that low concentrations (<2% LEL) return noisy signals, therefore this type of sensor is of limited use for low gas concentrations.
- Although 12 monthly calibration is the stated interval, experience shows that this is required more regularly (offshore, calibration is required approximately at 6 monthly intervals).

Benefits of Remote Fiber based sensing

- Application is perfect for a large multipoint optical sensor network and cost benefits would be gained using this type of system
- One off calibration at the central control unit would decrease cost of ownership as no regular calibration would be required
- Does not require oxygen in atmosphere to detect target gas
- Sensing cells are passive with no electrical power supply ensuring safety and immunity to EMI
- The ability to measure up to 100% CH_4 Volume and the accuracy at low concentrations is a considerable advantage over alternative solutions and would help to detect even small gas releases.
- Central control unit (CCU) with all sensor data is located remote from the active sensing area.
- No false readings due to dust & water vapor

– Dust: Sensor design has been configured to have to reduce the possibility of dust coating the optics. However, any maintenance schedule required can be extended because each sensor can tolerate up to 90% signal loss and the system will automatically highlight any need for sensor maintenance or cleaning at the CCU.

Sensing Technology

Tuneable Diode Laser Spectroscopy (TDLS)

– Tune narrow linewidth laser through the target gas absorption line with reference and signal readings taken on each scan. As laser is tuned through the gas absorption line the light is absorbed in proportion to the gas concentration. Particular advantages of TDLS are:
  - Self-referencing, eliminating zero point drift and need for re-calibration
  - Not affected by input optical power variations
  - Exhibits no cross-sensitivity to other gases

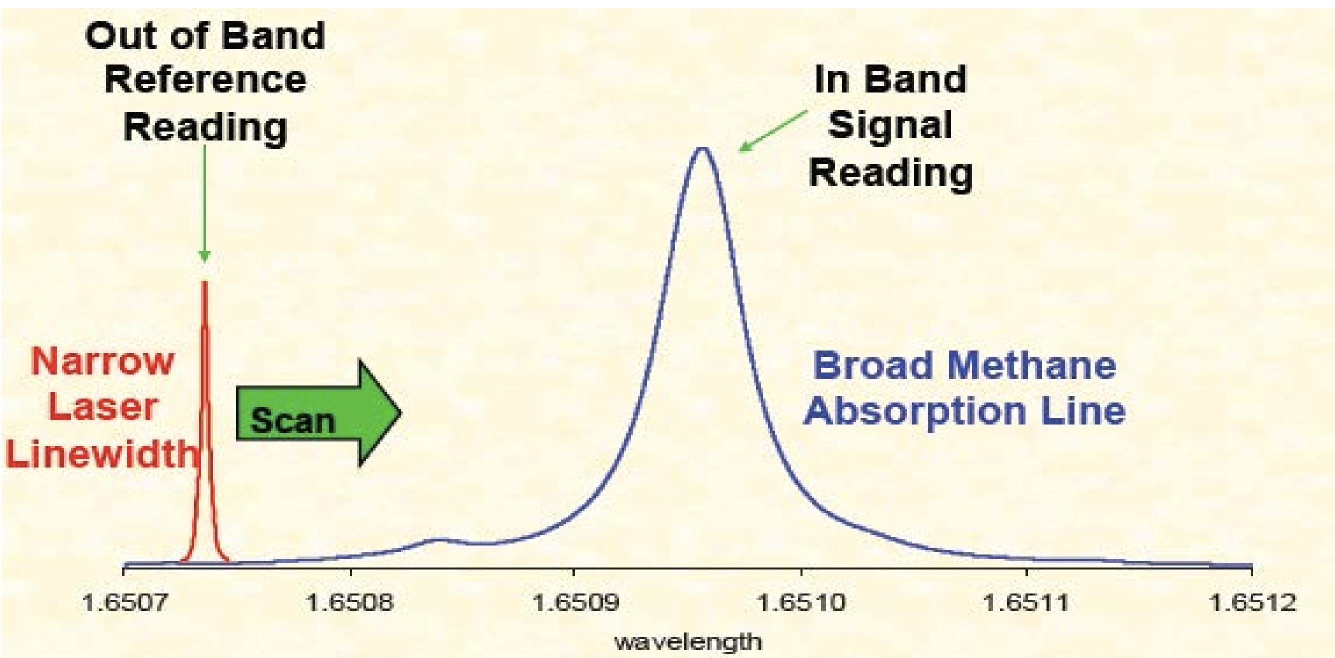

Fig. 2 – Scan Protocol

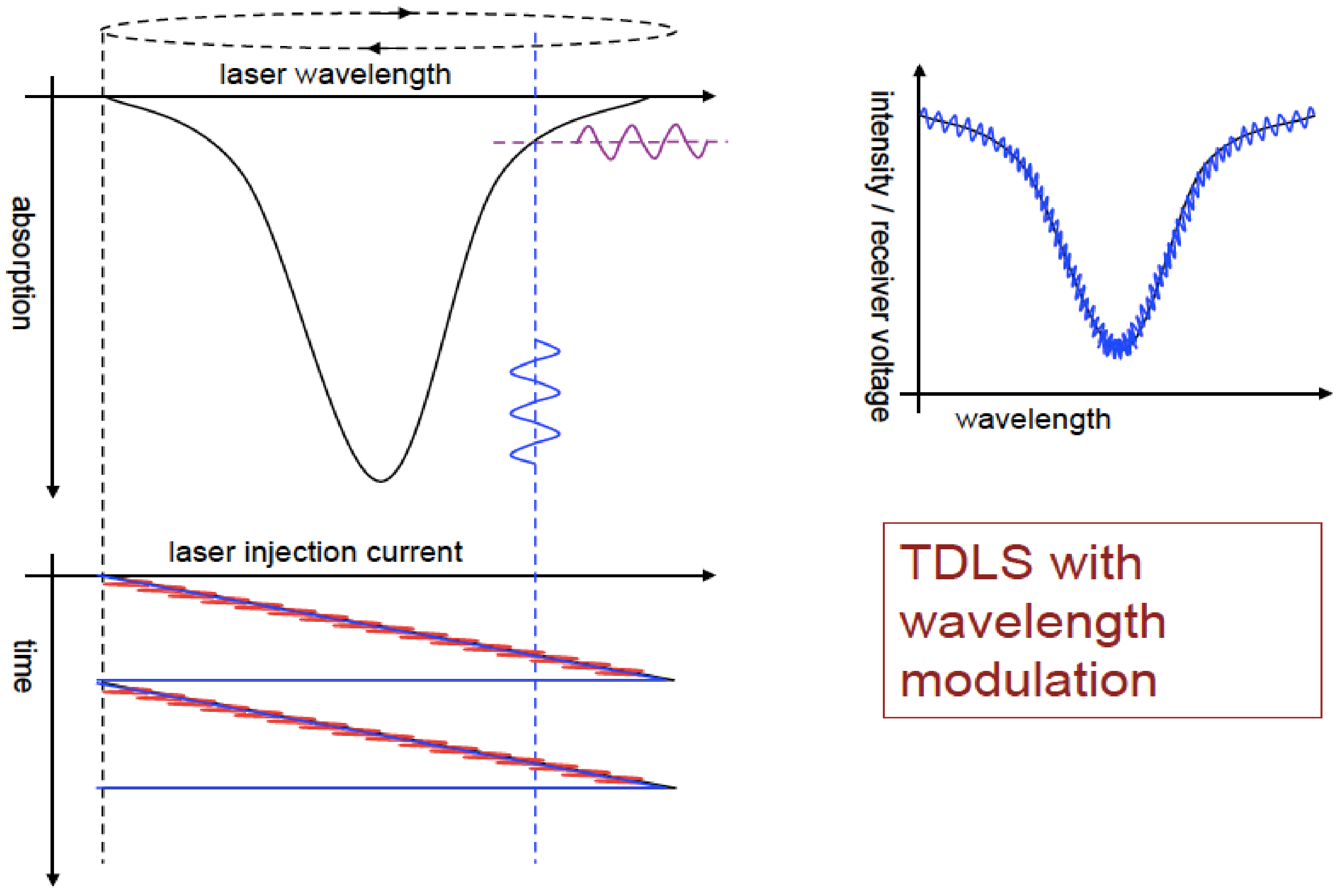

Fig. 3 – Principle of operations

Two methods of TDLS are used dependant on the relative concentration of methane present. For concentrations of > 1% a direct detection method is used. With concentrations less than 1 % a wavelength modulation technique is used. The two methods are described below.

With TDLS and direct detection a gas absorption line somewhere in the near-IR. e.g. a methane absorption line at 1651nm. We begin by tuning the DFB laser to the proximity of the line using a combination of temperature and fine current control. We then apply a time-varying ramp signal (anywhere between 2 and 20Hz usually) to the laser's injection current to repeatedly sweep the laser's center frequency across the absorption feature. As we sweep through the line the transmission signal at the receiver is recorded. The signal is normalized to any power fluctuations and referenced to a point in the scan that is non-absorbing (a technique known as zero-point referencing) to produce the *absorption line transmission function*. The amplitude of this signal is then directly proportional to the gas concentration. By repeatedly sweeping the entire absorption feature and taking a zero-point reference the system is inherently self-calibrating.

In instances of weak absorption. e.g. methane concentrations <1% the directly recovered signals lack the necessary sensitivity due to offset errors and system noise. To overcome this we employ TDLS with wavelength modulation…

In addition to the ramp sweep on the laser's injection current, we employ a relatively high frequency (10 to 100kHz) sine wave simultaneously. Interaction of this sine wave with the gas absorption line results in an amplitude modulation signal at the same frequency. If resolution and sensitivity were no limit we would see the absorption line transmission signal, as with direct detection, with a residual amplitude modulation signal (brought about by the modulation of the injection current introducing a sinusoidal intensity modulation at the same frequency). Lock in detection at the receiver then recovers the first and second harmonics of the desired wavelength modulation induced amplitude modulation signal. These first and second harmonic signals are then proportional to the absorption line transmission function and it is therefore possible, through careful signal processing, to extract the gas concentration.

The CCU is capable of switching automatically between both TDLS measurement systems when required and performs individual measurements for each receiver signal to provide accurate concentration measurements across the range at each individual sensor location.

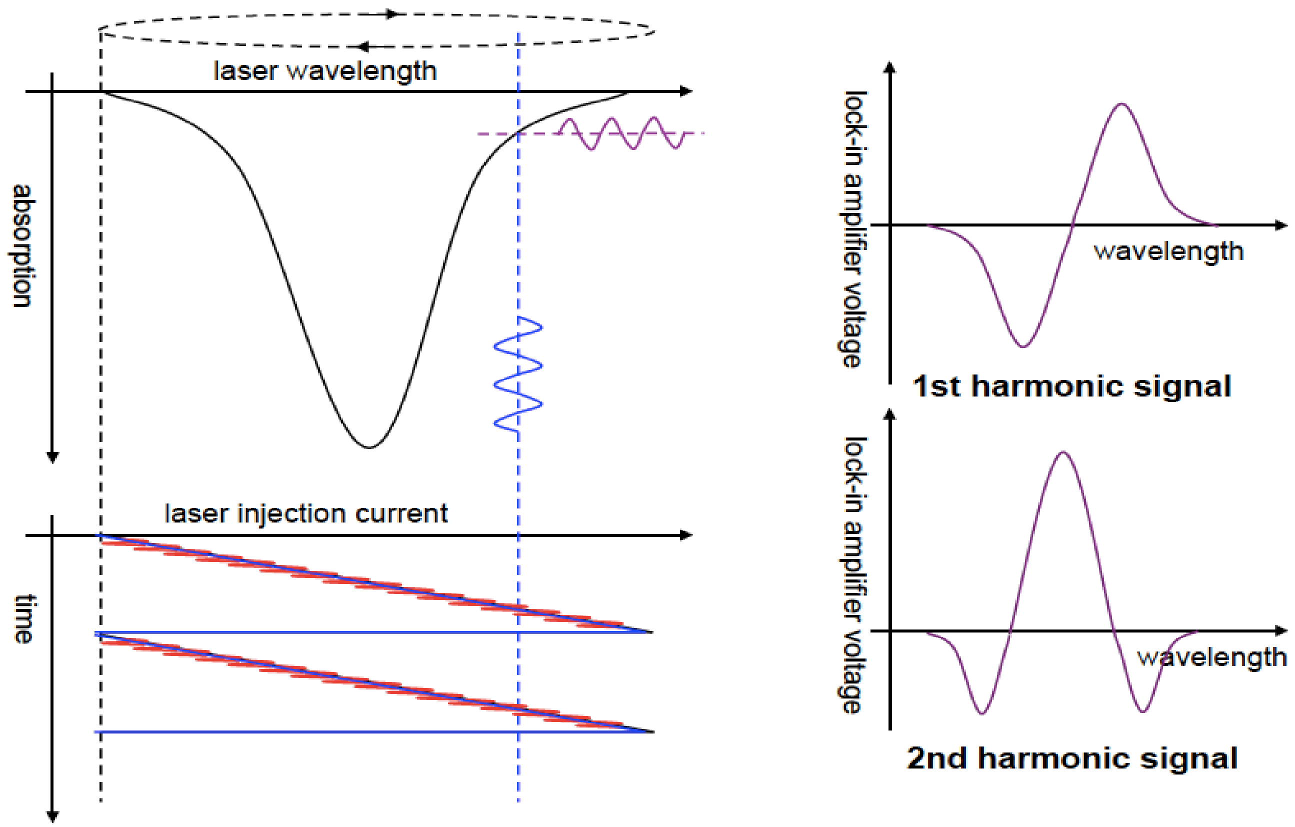

Fig. 4 – Principle of operations – wavelength modulation

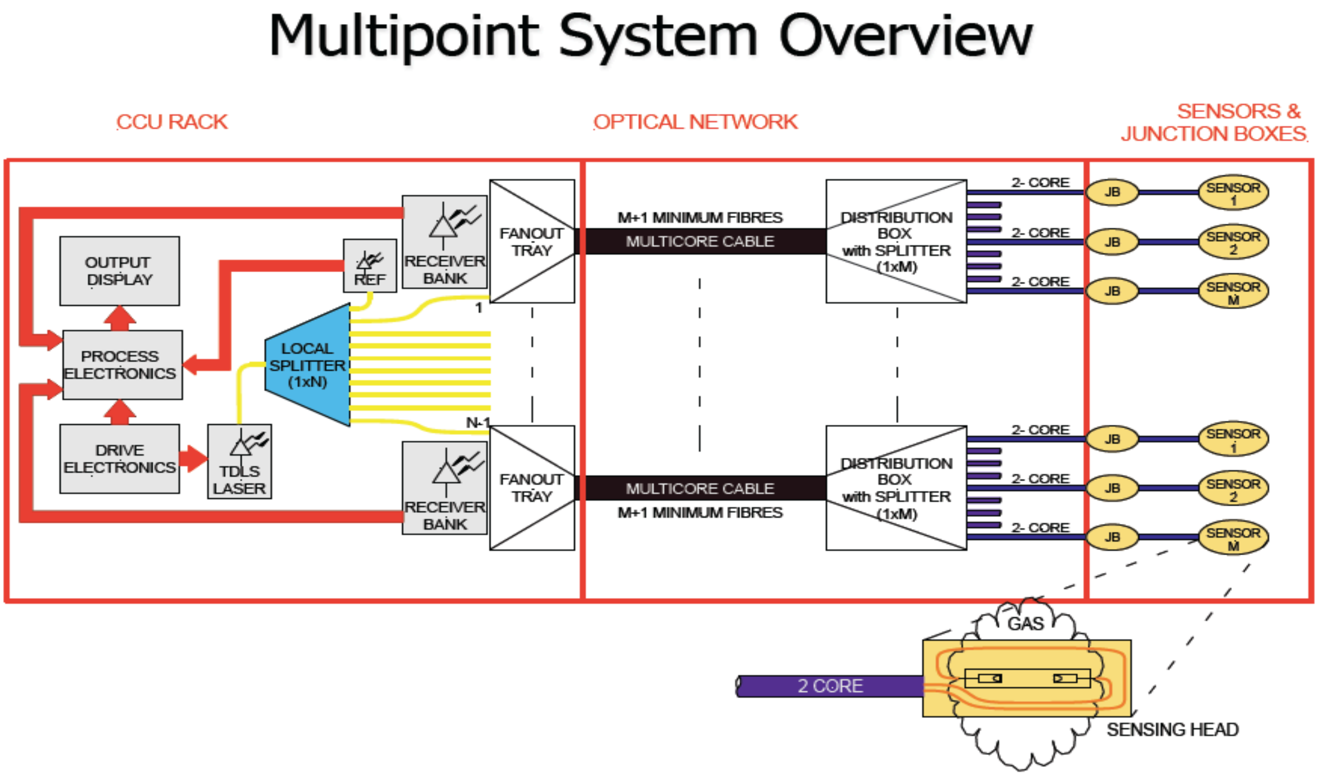

Fig. 5 – Overall system overview

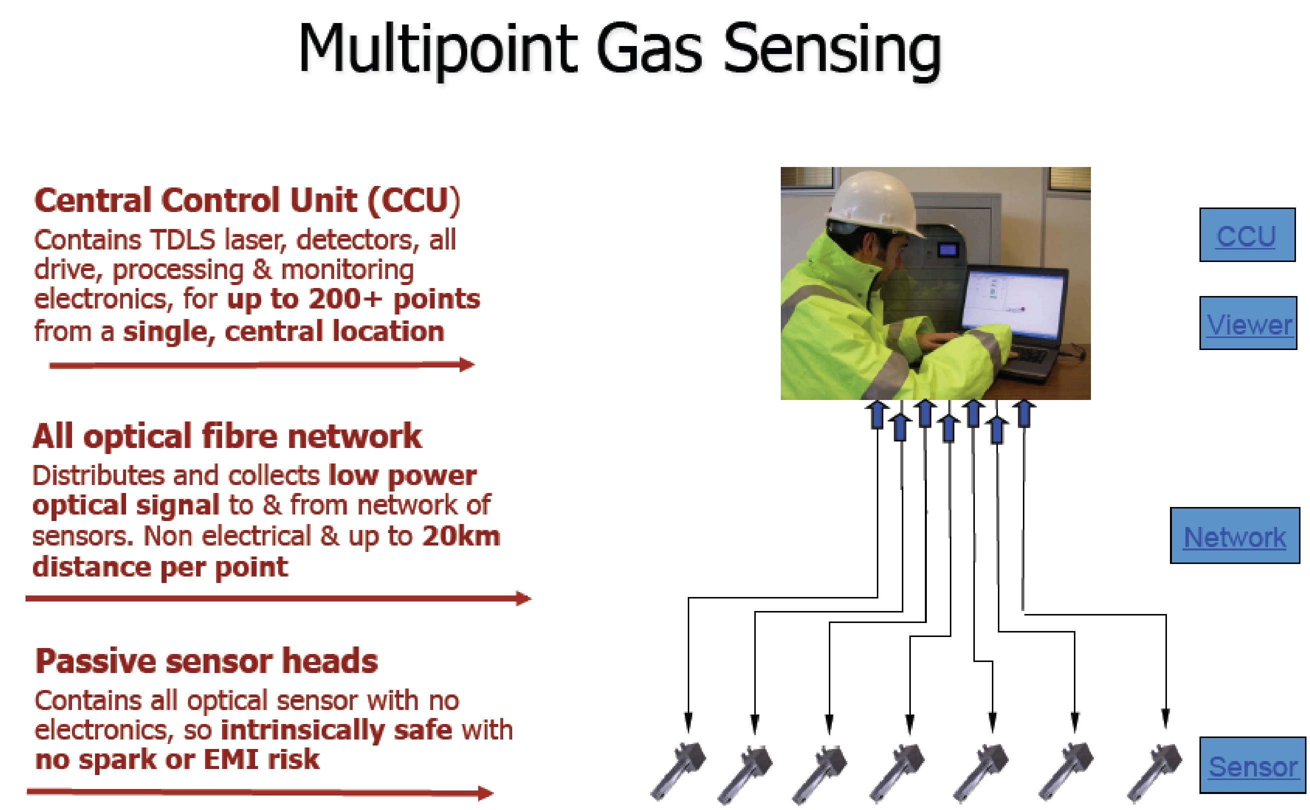

Fig. 6 – Overall system description

System Field Trials

2000 – 2003 Patersons Landfill Site, Glasgow, Scotland

- Designed, developed and installed 46 point laser & fibre optic sequential methane monitoring system on working landfill site (in-waste & perimeter wells) - World first
- Proved system's continuous multipoint CH4 monitoring capability and several on-site gas events identified
- Found sensor failures after 6 months of full time operation in hostile landfill gas environment - metal corrosion on sensor components by acidic solutions - new material design proposed.

2003 – 2005 WRG Brogborough Landfill Site, Milton Keynes, England

- 54 point seq. methane monitoring system installed for landfill field trial (in-waste & perimeter wells)
- New sensor design (non-metallic sensor element components) provided long-term, reliable operation in corrosive landfill gas environment
- >2 years continuous sensor operation and >1 million sensor hours accumulated in hostile field conditions
- Produced an extensive CH4 gas dataset which could be utilised to assist the overall management of the gas field.

2006 – 2008 Patersons Landfill Site, Glasgow, Scotland

- Developed & installed 11 point switched CH4 & CO2 seq. perimeter monitoring system
- Proved that the system could reliably and continuously detect both CH4 & CO2 on the same fibre optic sensing network CH4 (range: 0.05 to 100% v/v), CO2 (range: 5 to 100% v/v).

2009 – 2011 Tokyo Gas, Japan

- New methane system designed & developed to simultaneously update all sensors and make system suitable for gas safety monitoring applications
- Successfully trialled & tested 3-point fast update (FU) demo system at Tokyo Gas test facilities to Japanese Industrial Standards over 6 month period in 2010
- Reached advanced negotiations for installation of 200+ point system in service tunnels (all utilities & natural gas) running under a university campus
- Unfortunately, 2011 Japanese tsunami disaster & internal changes at Tokyo Gas put further progress on hold to date.

April – Aug. 2011: Mine in Jiangsu Province, China

- Three stainless steel gas sensors installed 5km down a working mine in China for 4 months
- One sensor connected to 3-point demo system (in surface room) via a 10km fibre link & installed at entrance to furthest gas extraction duct. Constant methane readings (5000ppm) recorded & measurements compared regularly against traditional portable sensor
- Sensors continued to accurately read methane levels and suffered minimal contamination and no loss of performance in underground mine environment.

Oct. 2011 – Oct. 2012: Hong Kong & China Gas Company, Hong Kong

- 3-point methane FU demo system installed, tested and operated successfully over a year in one of three main HKCGC gas distribution tunnels under Hong Kong (1km to 2.6km length)
- System monitoring for potential methane leaks from Towngas (synthetic gas, 30% CH_4, 20% CO_2) and natural gas (~90% CH_4) pipelines

Nov. 2011 – Date: Hainan Minsheng Gas Corporation, China

- 19" rack based multipoint (50+) fast update system designed & developed.
- First installation of multipoint rack system under contract at Xiuying Gas Plant, Hainan Island, China
- 11-point methane detection system operating successfully since November 2011 and continuously monitoring for LNG leaks in various site control rooms and gas unloading stations.

October 2012 – Date: Chengdu Gas Company, China

- 30-point 19" rack based fast update system installed under contract in Chengdu city, China during Oct 2012
- As Chengdu is an area of potential seismic activity, system will continuously monitor for natural gas pipeline leaks in subterranean service ducts under the city streets.

Projected Feb 2013: Mine Trials in West Virginia, USA

- 10-point, 19" rack based fast update system to be installed, trialled & tested in a mine environment in West Virginia, USA (US Federal Government contract)

References:

1 H.O. Edwards, J.P. Dakin, *Gas Sensors using correlation spectroscopy compatible with fiber optic operation*, Sensors and Actuators B, 11 (1993)
2 F.N. Kissel, *Handbook for Methane Control in Mining,* NIOSH Information Circular 9486, June 2006
3 C.D. Taylor, J.E. Chilton, A.L. Martikainen, *Use of Infared Sensors for Monitoring of Methaen in Underground Mines,* NIOSH 2004
4 B. Culshaw, *Fiber Optics in Sensing and Measurement,* IEEE Journal of Selected Topics in Quantum Electronics, Vol. 6 No. 6 November/December 2000
5 B. Culshaw,(2005) *Fiber-Optic Sensors: Applications and Advances*. Optics and Photonics News,16 (11). pp. 24-29. ISSN 1047-6938
6 T.H. Dubaniewicz, Jr. K.L. Cashdollar, W.D. Monaghan, *Laser Ignition of Flammable Gas,* NIOSH, Pittsburgh Research Laboratory 1998
7 T.H. Dubaniewicz, Jr, J.E. Chilton*, Remote Fiber Optic Methane Monitor,* United States Department of the Interior, Bureau of Mines, Report of Investigations RI 9407 1992
8 T.H. Dubaniewicz, Jr, J.E. Chilton*, Optically Powered Remote Gas Sensor,* United States Department of the Interior, Bureau of Mines, Report of Investigations RI 9558 1995
9 T.H. Dubaniewicz, Jr*, Treshold Powers and delays for igniting propane and butane-air mixtures by cw laser-heated particles* NIOSH May 2006