From: Giovanni Tomasi <gptomasi@rslfibersystems.com>
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Subject: RIN 1219-AB85
Attachments: RIN 1219-AB85_MSHA 2014-0029_B-AMS_NewTech_Remote_RSL_Final.pdf

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Attached please find RSL Fiber Systems' response to RIN 1219-AB 85, MSHA-2014-0029, Section B, Atmospheric Monitoring Systems and New Technology for Remote Monitoring Systems

The PDF document contains:

1. Cover letter
2. RESPONSE TO RIN 1219-AB85 / MSHA-2014-0029 - Section B
3. Appendix A: Fiber Optic Methane Sensing System
4. Appendix B: Fiber Optic Distributed Temperature Sensing System

Regards,

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AB85-COMM-15

Giovanni P. Tomasi
CEO / Chief Technology Officer

June 25, 2015

MSHA, Office of Standards, Regulations, and Variances
1100 Wilson Boulevard, Room 2350
Arlington, Virginia 22209-3939

SUBJECT: Response to RIN 1219-AB85 / MSHA-2014-0029

B. Atmospheric Monitoring Systems and New Technology for Remote Monitoring Systems

Dear Sir/Madam;

RSL Fiber Systems (RSL) submits these comments in response to MSHA Docket Number MSHA-2014-0029, section B. Atmospheric Monitoring Systems and New Technology for Remote Monitoring Systems. RSL is a development and implementation company applying fiber optic based technologies and systems to the mining industry.

Two baseline technologies are described in this response:

1. Remote, self referencing fiber optic methane detection system based on Tunable Diode Laser Spectroscopy (TDLS);
2. Distributed Temperature Sensing (DTS) based on Raman Optical Frequency Domain Reflectometry (OFDR).

Both technologies have been in use for over ten years for a variety of sensing and monitoring applications in landfills and subway tunnels (methane detection), and in highway tunnels, pipelines, electrical cables, LNG operations, and any other application where temperature changes indicate the presence of fire, of a malfunction, or a leak (DTS). RSL has been adapting and further developing these safety systems for use in coal mines to improve the safety and the working conditions of miners.

The mining profession produces over 1/3 of America's energy, is critical to our Country's industrial strength and military power, but is extremely dangerous and lately has suffered due to the regulatory burden. Between 1976 and 2010 methane gas has been responsible for many explosions in coal mines killing 186 miners, including the explosion at Upper Big Branch in 2010 where 29 miners lost their lives. The extensive research work performed by Dr. Jurgen Brune and Dr. Karl Zipf confirm that explosive concentrations of methane and air will form in longwall gobs. This research also identifies the locations where remote methane detectors need to be installed, including in areas inaccessible by personnel, to greatly improve safety and prevent deadly accidents from reoccurring.

A commercially available remote fiber optic methane detection system from OptoSci Ltd., a spin-off company from the University of Strathclyde in Glasgow, Scotland, in use in landfills and tunnels to monitor methane and natural gas was adapted to use in coal mines under NIOSH Research Opportunity Number: 2012-N-14257. The project was very successful with the remote fiber optic based methane sensing system performing flawlessly in the lab and during the In-Mine tests. Despite long-term exposure to a very demanding environment, there was no system degradation or failure. Along with the methane sensing system, RSL evaluated the use of fiber optic Distributed Temperature Sensing to detect the health of mining equipment and the presence of fire in mine tunnels.

In order to facilitate the seamless implementation of these safety systems into coal mines, RSL is collaborating with Pillar Innovations in Morgantown, WV. Pillar is a leading provider of communication systems, controls, fire suppression systems, fiber optic networks, and installation services to the mining industry, designing and integrating mine wide Atmospheric Monitoring Systems (AMS) and control systems. In these systems, CO sensors are used to detect the presence of fire and, by detecting the CO levels at different sensors along an entry, the movement of a smoke cloud can be detected. These mine wide monitoring and control systems are designed as "master" systems where other systems can be integrated and displayed on the same Human Machine Interface (HMI).

The remote fiber optic methane sensing system and the DTS, integrated into an AMS will provide the mine operators with real time information on the formation, presence, and movement of methane through the mine and of the formation of potential conditions leading to a fire.

These two critical technologies, methane sensing and DTS, can be combined with existing air velocity and direction monitors for a full mine-wide gas, airflow, and fire detection system.

RSL Fiber Systems, OptoSci Ltd, and Pillar Innovations are looking forward to the opportunity of applying the technologies and products described in the following sections to improve the safety of coal miners.

Best Regards,

Giovanni Tomasi

Attached:

1. RESPONSE TO RIN 1219-AB85 / MSHA-2014-0029 - Section B
2. Appendix A: Fiber Optic Methane Sensing System
3. Appendix B: Fiber Optic Distributed Temperature Sensing System

RESPONSE TO RIN 1219-AB85 / MSHA-2014-0029 - Section B

The following includes the *Questions in Italic* for reference.

Some of the information provided is repeated in the answers to different questions for the convenience of the reader.

> *6. Continuous remote monitoring systems, such as AMS and tube bundle systems, can be used to detect unexpected ventilation system changes or methane inundations. Please comment, including rationale, on whether and under what circumstances MSHA should require the use of a continuous remote monitoring system. Please include impact on miner health and safety, impact on mining method, and any other related impact. What would be the costs to add monitoring systems or to extend existing systems in mines?*

B. 6. (a) Methane gas is generated during the mining process and, as studies performed by Dr. Jurgen Brune confirm, explosive concentrations of methane and air will form in longwall gobs. Methane must be controlled to levels below 2% for worker safety. This methane emitted from various sources can populate active or remote areas, build to dangerous levels, and then migrate with air movement undetectable to mine operations. Sensing systems used today can provide point data for methane levels via handheld gas detectors and remote point sensors but all these methane detection systems require electrical power at the sensing unit and periodic calibration, making them impractical for use in the remote and closed areas of the mine. Additionally, these methane sensors are not networked to provide data on methane movement and relay the information to the mine control room, displaying the information on a Human Machine Interface (HMI).

Accurately and continuously detecting the presence of methane in different areas of a mine including in the closed off areas and the gob will allow the mine operators to adjust the mine ventilation accordingly to prevent methane from reaching dangerous levels in the working areas and reaching explosive concentrations throughout the mine.

The multipoint fiber optic methane sensing system described in more detail in the response to Question14 provides an inherently safe, all optical method of remote, real-time monitoring of methane evolution in both closed and working areas of a coal mine.

B.6. (b) Carbon Monoxide detectors are used to detect the presence of fires and the movement of the smoke as it travels through the mine. Fires can be caused by equipment malfunctions such as bearings overheating due to wear or cables' insulation overheating and burning due to damaged conductors. A Distributed Temperature Sensing (DTS) system consisting of a fiber optic cable acting as a linear heat detection sensor that can detect localized temperature changes in specific areas of the mine before the malfunction results in damaged equipment and a fire. DTS systems are mandated in Europe in automotive and underground metro tunnels over 4 km in length to detect the conditions that may lead to a fire. Similar DTS based systems can be adapted for use in coal mines.

B.6. (c) The cost benefits of remote monitoring systems include the elimination of the need for periodic calibration, reduction or elimination of down time due to the formation and movement of methane in the work areas, reduced costs in equipment repair and maintenance due to health monitoring for predictive equipment maintenance, reduced costs associated with gas and fire related accidents, and reduced energy costs due to the optimized use of the mine ventilation system. A cost discussion and comparison to traditional systems is provided in response to Question 14. As noted in the response to Question 10, the output of the fiber optic methane sensing system and the DTS system can be directly integrated and displayed on current Human Machine Interface (HMI) systems used in coal mines, thereby extending the real-time monitoring capability of existing HMI systems.

> *7. Where should continuous remote monitoring systems be installed in underground coal mines? Please be specific as to locations and provide rationale, including the impact on miner health and safety.*

B.7. Continuous remote methane monitoring systems should be installed in the active and remote areas of the mine to detect the formation, presence, and movement of methane. The fact that the all-optical methane sensors do not require periodic maintenance, including cleaning and calibration, allows them to be installed in all areas, even those that will become inaccessible like the longwall gob. The research by Dr. Karl Zipf and Dr. Brune detail the locations where methane sensors should be installed.

Distributed Temperature Sensing (DTS) systems should be installed in the active areas of the mine and in any area where equipment is present to detect localized temperature changes indicating equipment malfunctions before they become catastrophic and detect the presence of fire before it spreads through the mine. The DTS system sensing unit is a fiber optic cable that can be easily installed along equipment and in cable trays to detect temperature changes along its length with accuracy of 0.5°C (1°F) every 0.5 meters (1.5 ft) for lengths above 4 km.

Miners' health and safety will be safeguarded by preventing dangerous situations like fires and methane accumulations from occurring.

> *8. Under what conditions should additional gas monitoring sensors and sensors that measure air velocity and direction be used to monitor the longwall face and its tailgate corner to minimize accumulations of methane, other gases, and dust? Where should these sensors be located?*

B.8. Methane gas can form in the active areas and in the remote areas, including in the gob behind the longwall. It is advantageous to monitor methane in the area being mined, at the tailgate corner, and in the gob. Methane sensors can be placed behind the longwall in the gob, at the tailgate, and at the active area, suspended and secured to the underside of the chocks. An air velocity detector can be used at the tailgate corner to monitor the velocity of the airflow exiting the longwall active area.

Extensive research has been performed in the areas of methane formation, movement and the need for detection in coal mines by Dr. Brune, Dr. Zipf, and others. The resulting recommendations for the location of remote methane sensors can be implemented with the remote fiber optic methane sensing system described in the response to Question 14.

> *9. What are the advantages, disadvantages, and costs of continuously monitoring the underground coal mine environment for accumulations of gases, air velocity, and airflow direction?*

B. 9. The advantages of a continuous methane, air velocity, airflow direction, and fire detection system are improved safety for mine personnel, early detection of dangerous mine conditions, preventative maintenance on equipment (via the DTS system) before catastrophic failure occurs, and improved productivity due to the ability to monitor and control the formation of methane.

Typically up to 1/3 of a mine's entire electrical power costs are due to running the ventilation systems[1]. 24/7 mine wide gas monitoring via the fiber optic methane sensing system gives the mine operator the potential to control ventilation fans based on local gas levels to conserve energy and costs as even small improvements can lead to savings of $M's[2].

> *10. How could continuous remote monitoring technology be linked to communication and tracking technology to form an integrated monitoring system? Please explain.*

B. 10. Mine-wide monitoring and control systems provide near real time data on multiple aspects of the mine operations including equipment status, carbon monoxide (CO) sensing, and other functions in the mine control room and at other remote locations. Alarms can be programmed if certain conditions occur, prompting the mine operator to take the required actions. The mine wide system integrates multiple controls and data signals into one single system and display, with the ability to obtain more detailed information on any function being monitored and for specific areas of the mine. These mine wide monitoring and control systems are designed as "master" systems where other control systems can be integrated and displayed on the same Human Machine Interface (HMI). The remote fiber optic methane monitoring system and Distributed Temperature Sensing (DTS) system are designed with the ability to be either the "master" controller, allowing for additional systems to be displayed on the HMI, or "slave" controllers, where the output can be displayed on an existing HMI. RSL Fiber Systems in collaboration with Pillar Innovations in Morgantown, WV a leading provider of communication systems, controls, fire suppression systems, fiber optic networks, and installation services to the mining industry, is integrating the fiber optic methane sensing system and the DTS into the Pillar mine wide monitoring and control system.

> *11. How can integrated monitoring systems be linked to machine-mounted monitors? What are the advantages, disadvantages, impact on miner health and safety, and costs of integrated monitoring systems?*

B.11. A remote methane sensor can be installed on a machine such as a continuous miner and connected to the same Central Control Unit (located in the control room) described in response to question 14. Two (2) fibers in one of the termination racks (shown in Figure 2) closest to the active area can be dedicated to the machine mounted sensor and connected to the sensor via a duplex fiber optic cable of a construction similar to tactical cables used for communications in field deployed military systems. Since each methane sensor is individually addressable, the operator in the control room can identify the

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[1] Underground Mine Ventilation http://en.wikipedia.org/wiki/Underground_mine_ventilation

[2] Anglo American mining company saved $105M in 2014 through 5% energy efficiency improvements http://www.edie.net/news/6/Anglo-American-CSR-report--Collaboration-drives-success/

specific machine-mounted methane sensing units. These sensors will measure the methane concentration levels at the machine every one (1) second. If the fiber optic cable is cut, an alarm will be displayed on the HMI in the control room, allowing the control room operator to notify the machine operator of the need to replace the cable.

A cost discussion is provided in response to Question 14.

> *12. What types of continuous remote monitoring systems can continue to safely operate and function after an explosion, fire, or any other mine accident? How long can such systems operate after an explosion or fire, since power is likely to be deenergized due to the emergency? What can be done to improve the survivability and reliability of continuous remote monitoring systems after an explosion or fire?*

B.12. (a) With the fiber optic methane sensing system described in the response to Question 14 only low power optical signals are transmitted through the fiber cables and sensors in the mine. Electrical power is only required at the Central Control Unit which is located outside the mine in the control room. Hence the fiber optic methane sensing system will continue to safely operate and function after an explosion, fire, or other accident as long as the fiber optic cables connecting the sensors are operational and the sensors were not damaged by the fire or explosion.

B.12. (b) These fiber addressed sensors will continue to operate indefinitely when electrical power is cut to the underground mine areas, since no electricity is required at the sensing units.

B.12. (c) Reliability can be improved by utilizing rugged fiber optic cables, MIL type connectors, and designing the sensing unit housing to withstand high stresses.

RSL Fiber Systems is evaluating cables from multiple manufacturers to verify compatibility with the methane monitoring system in areas of optical losses, stability through a wide temperature range, and mechanical resistance. A list of "methane sensing approved" cables will be provided to installers and end users.

Another approach to improve the system survivability is to implement adequate system redundancy by utilizing a dual path for the fiber optic cables connecting the sensors, alternating the sensors from each path. If a fire or explosion destroys the cables in one of the paths leading to the sensors, half of the sensors will continue to function since they utilize cables from the alternate path. Figure 1 illustrates a possible configuration where sensors are used in the gob behind the longwall utilizing the dual path approach for the cables.

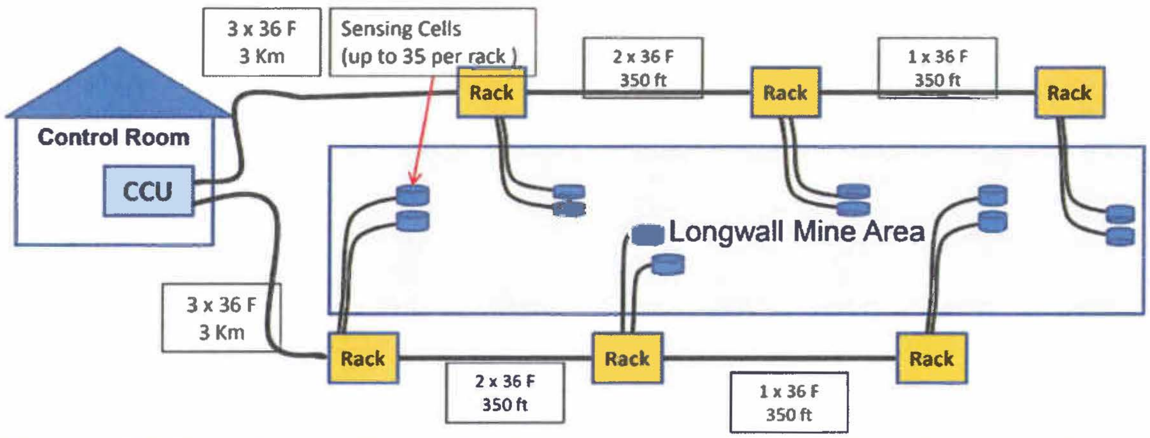

Figure 1: Methane Sensing System Implementation in a Longwall Application with cable and sensing redundancy by installing Dual Fiber Optic cable Path

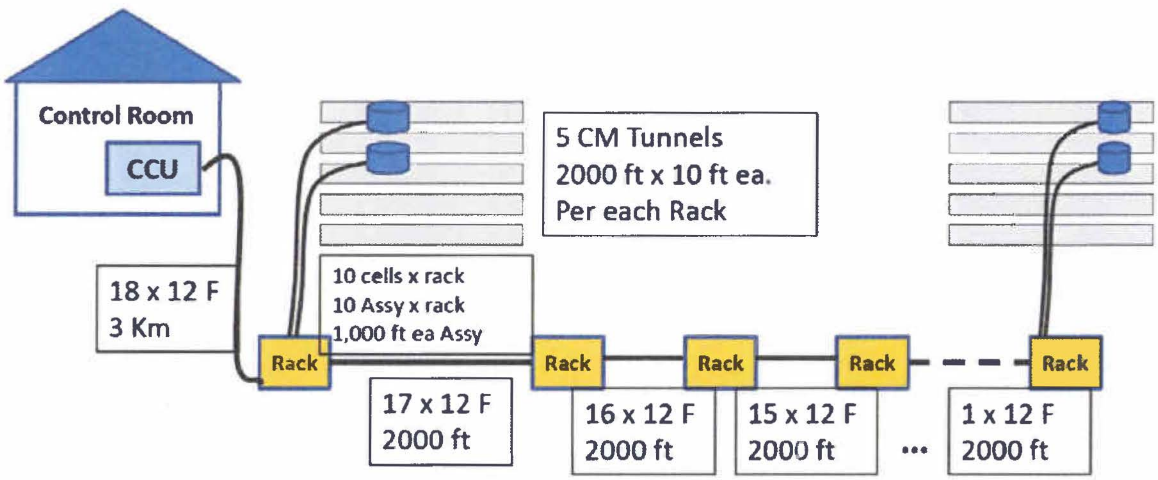

Figure 2: Methane Sensing System Implementation in a Continuous Mining Application

B.12. (d) The fiber optic Distributed Temperature Sensing system will continue to safely operate after an explosion, fire, or other mine accident as long as the fiber optic cables are not damaged by such event. Since no electricity is needed at the sensing points, the DTS will continue to operate indefinitely. A dual path approach similar to what is described for the methane sensors can be taken for the DTS to insure redundancy.

> *13. What types of technologies exist to remotely determine methane-air mixtures and other gas, dust, and fume levels in bleeders and bleederless ventilation systems, other than traditional AMS and tube-bundle systems? Please be specific and note if this technology is practical and feasible.*

B.13. The remote, intrinsically safe fiber optic methane detection system described in response to Question 14 is currently available and can detect the presence of methane in bleeders and bleederless ventilation systems. A network of optical sensors sharing the same Central Control Unit can be used to detect methane throughout the mine including: in the operational sections, within mined out / sealed areas, in the ventilation systems, etc. Each sensor is individually addressable, allowing the operators to identify the specific location of the particular sensor and the level of methane detected.

14. MSHA is aware that fiber optic systems are being developed that would transmit data to a central location on the surface of the mine. Please provide system capabilities, specifications, and cost information on these systems, as well as any other relevant technologies. Show citation box.

B.14. (a) REMOTE METHANE DETECTION

<u>System Capabilities</u>

An all-optical, fiber optic based methane detection system can be suitable for use throughout coal mines to remotely detect, monitor, and track the movement of methane in the mine. In addition, the ability to continuously monitor methane levels in the mined-out and sealed areas of the mine can generate data on methane emissions and provide important guidance on the ventilation demands of the mine.

A remote fiber optic methane detection system from OptoSci Ltd., Glasgow, Scotland combines laser based gas spectroscopy with fiber optic technology to allow inherently safe, real-time methane detection from hundreds of points over 20 km distances (more detailed system information is included in Appendix A). The system has been used in landfills and utility tunnels to monitor methane and natural gas and was adapted by RSL for use in coal mines under a National Institute of Occupational Safety and Health (NIOSH) research project (NIOSH Research Opportunity No: 2012-N-14257). The system performed flawlessly in the lab and during the in-mine trials. Despite long-term exposure to a very demanding environment, there was no system degradation or failure. The field trials verified that the system was not adversely affected by common mine conditions including high humidity, anaerobic conditions, vibration, dust, and the presence of other non-target gases which can cause erroneous readings with many other sensor types.

<u>System Specifications</u>

- <u>Intrinsically Safe</u>: Only low power (10's of microwatt) optical signals are transmitted through the optical fibers and sensors in the underground mine areas and is backed up by the sensor's full ATEX and IECEx explosive atmosphere system certification.
- <u>Critical Incident Operation</u>: Mine wide methane level data still available even if electrical power is cut to the underground mine since the only electrically powered components are contained in the Central Control Unit (CCU) which is located outside the mine in the control room.
- <u>Flexible</u>: One CCU can simultaneously update gas readings every 2 seconds from up to 240 sensing points spread over 20 km underground distances. Plug-in modules also allow straightforward system expansion.

- Precise and Reliable: Measures methane from 0.05% to 100% volume with no saturation or hysteresis, instantly responds to any methane present in a sensor, and system retains full functionality and accuracy even with sensor signal optical losses of up to 90%.
- Maintenance Free Mine Wide Monitoring: Self-referencing Tunable Diode Laser Spectroscopy (TDLS) detection technique combined with factory calibrated laser and an array of identical sensors in ruggedized housings with no parts that wear out, ensures there is no requirement for sensor re-calibration. This calibration stability combined with automatic system self-checking data at the CCU for each sensor minimizes any ongoing maintenance requirements and makes the sensors ideal for 24/7 mine wide methane monitoring and in particular for mined-out, sealed or difficult to access areas of a mine.

RSL Fiber Systems is evaluating cables from multiple manufacturers to verify compatibility with the methane monitoring system in areas of optical losses, stability through a wide temperature range, and mechanical resistance. A list of "methane sensing approved" cables will be provided to installers and end users.

The fiber optic remote methane sensing system can be combined with a mine wide Atmospheric Monitoring System (AMS) to detect the formation, movement, and concentration of methane clouds, and provide a display on the Human Machine Interface (HMI). This will alert the mine operators to the presence of methane and allow the operators to monitor the methane levels and the gas cloud movement as it is being ventilated from the mine.

System Cost

The fiber optic methane sensing system cost per sensor decreases as more sensors are connected to a single CCU. Up to 240 individual sensors can be operated from one CCU, with each sensor located up to 20 km from the CCU. The cost per sensor is based on the related hardware including amount of cable required from the CCU to the sensor, receiver modules, fanout trays, distribution boxes, and sensor housing construction. Cost estimates based on large scale implementation bring the hardware cost of the remote fiber optic methane sensing system to a level comparable to legacy sensors when 50 to 60 sensors are used with each CCU. The distance from the CCU to the sensor naturally affects the cost as it determines the length of fiber optic cables required.

Other cost related factors of the fiber optic methane sensing system to consider when comparing the cost to the legacy methane sensors include:

1. The fiber optic methane sensors do not require periodic cleaning or calibration as the legacy sensors do, reducing or eliminating the maintenance costs.
2. The fiber optic methane sensors do not require electrical cables connected to the sensor to provide power as some legacy sensors do, removing any additional potential spark risk underground.
3. Safe 24/7 remote monitoring of methane throughout the mine using the fiber optic methane sensing system will also save the Mine Operator the annual cost and time of daily and weekly manual recording of spot gas readings in critical accessible areas of the mine, as well as now allowing continuous monitoring in closed and sealed off mine sections too.

4. The all optical fiber optic methane sensors will continue to detect operate even when electrical power is cut to the underground mine areas since they do not require any electrical power, battery replacement, or a wireless communication network as the remote legacy sensors do. This can have significant safety and emergency benefits after an event, as well as potentially reducing downtime in mine areas which are unaffected.

B.14. (b) DISTRIBUTED TEMPERATURE SENSING

Distributed Temperature Sensing (DTS) systems are optoelectronic devices that measure temperatures by means of optical fibers functioning as linear sensors. Temperatures are recorded along the optical cable as a continuous profile. Temperature can be determined with great accuracy over distances exceeding 40 km.

Temperature variations of as little as 0.5°C can be detected along the fiber optic cables with a spatial resolution of less than 0.5 meters, based on the DTS equipment and the system configuration. DTS systems can monitor the temperature in tunnels, in coal mines, along pipelines, in electrical cables, in gas sample line tubing assemblies, along conveyors, at bearings and motors, in Liquefied Natural Gas (LNG) operations, and in any application where variations in temperature indicate a change in the surrounding environment, leakage of gases or fluids, or degradation in equipment performance. DTS is used for fire detection, heat detection, leakage detection, monitoring the current flowing through electrical cables, machinery health monitoring, and other situations where continuous temperature sensing is required over a distance or at multiple points using the same sensing device.

Up to sixteen (16) channels can be monitored from one (1) DTS controller with up to one thousand (1,000) sensing zones per channel. Each channel can consist of 40 km of cable.

A more detailed DTS system description is provided in Appendix B: Fiber Optic Distributed Temperature Sensing System.

<u>System Cost</u>

The DTS system cost per sensing point decreases as the number of points increase, since the fiber optic cables act as linear sensors. The DTS hardware can reach the break-even point with discrete remote temperature sensors at 30 to 40 sensing points when factors including the system required to power and network the discrete sensors is taken into considerations. Other factors favoring the DTS system include the ability to function when the mine power is shut off and the ability to monitor temperature along the entire length of the cable, conveyor belt, or cable tray, not just at discrete points.

15. If fiber optic technology is capable of operation when electrical power is deenergized underground, how long can such systems remain operable after power is deenergized? What is the maximum distance such technology is capable of transmitting data to the mine surface?

B. 15 (a) The fiber optic based remote sensing methane monitoring system will operate indefinitely when the electrical power is de-energized underground since the only system component requiring electrical power is the Central Control Unit (CCU) which is located outside the mine in the control room. Hence mine-wide methane concentration levels and methane movement will continue to be monitored and displayed on the HMI even without electrical power in the mine.

B. 15. (b) The Distributed Temperature Sensing system will operate indefinitely when the electrical power is de-energized since the only system component requiring power is the controller located in the mine control room. Temperature data including the presence of localized heat areas and fire will continue to be provided and displayed on the HMI.

B.15. (c) The maximum return fiber link distance between the methane sensing system CCU and each sensor is 20 km based on a system with 240 sensors connected to one (1) CCU. Longer distances can be achieved when using a lower number of sensors.

B.15. (d) The maximum distance between the DTS controller and farthest sensing point is 40 km, with up to 1,000 sensing points per channel.

16. Please describe how fiber optic technology can be used in areas of the mine that require the use of permissible or intrinsically safe equipment.

B.16. (a) The fiber optic based remote methane detection system uses a low power (10mW) diode laser in the CCU which is located in the mine control room. This laser output optical signal is divided in the CCU and distributed to the various underground sensors via a single mode optical fiber cable network. Hence only optical signals are transmitted between the CCU and the sensors throughout the mine. The sensors are intrinsically safe within the mine environment as each fiber channel carries only 10's of microwatts of optical power to each sensing cell for the methane measurements. This has been shown in previous NIOSH studies[3] to be over 10,000 times lower than the optical power levels required to heat and cause ignition of explosive level methane/air mixtures in a coal dust filled environment.

The fiber optic gas sensor technology has also received full Explosive Atmosphere (ATEX - Baseefa14ATEX0128 and IECEx - IECEx BAS14.0069) certification, approving it for continuous use within the underground mining and other industrial environments where potentially explosive gases may be continuously present.

B.16. (b) The fiber optic DTS uses a low power (10mW) diode laser in the Controller with multimode fiber cables. It is intrinsically safe within the mine environment. The advantage of the proposed Optical Frequency Domain Reflectometry (OFDR) DTS is the fact that the lasers operate in continuous wave mode, hence, the system does not need high power pulsed lasers.

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[3] Dubaniewicz Jr., T.H., 2006 "Methane-air mixtures ignited by CW laser-heated targets on optical fiber tips: Comparison of targets, optical fibers, and ignition delays" National Institute for Occupational Safety and Health Study, Journal of Loss Prevention in the Process Industries 19 (2006) 425-432.

APPENDIX A – Fiber Optic Methane Sensing System

A.1 Fiber Optic Methane Sensing System Overview

The multipoint fiber optic gas sensing system (see Figure A.1) is principally composed of three sections:

- The Central Control Unit or "CCU" is basically the brains of the system and contains the laser, detection, processing and all of the electrically powered system elements.
- The Optical Fiber Cable Network then splits and transmits the laser signal from the CCU over long distances to an array of
- Optical Gas Sensors, with the sensor data returned back, via the optical network, for analysis and processing at the CCU.

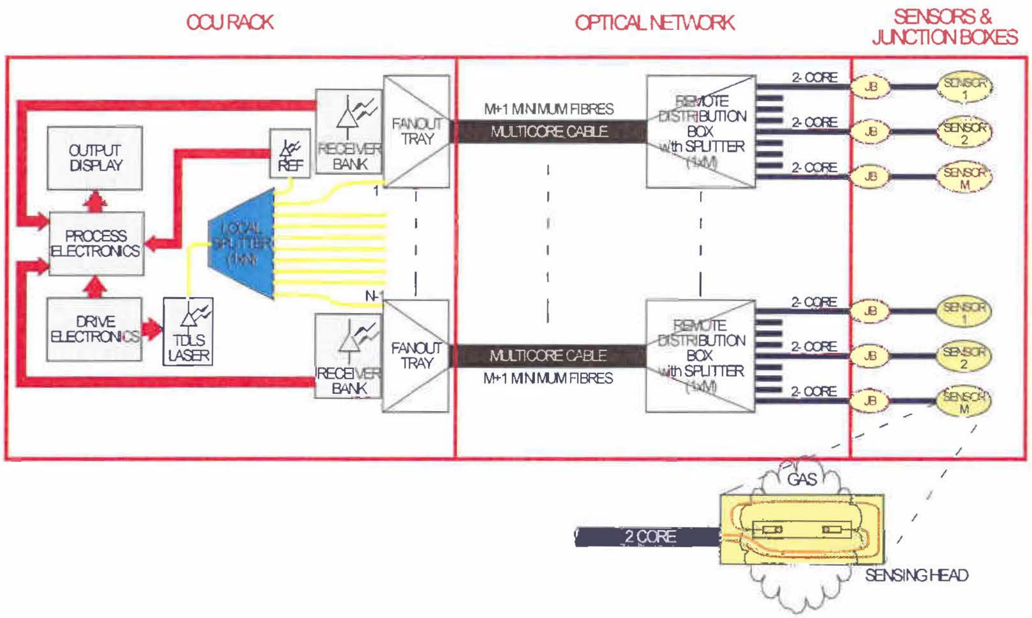

Figure A.1: Remote Fiber Optic Methane Sensing System (© OptoSci Ltd.)

The data from the CCU can then be displayed locally or integrated and displayed on another proprietary Human Machine Interface (HMI).

A.2 Tunable Diode Laser Spectroscopy (TDLS)

The basic gas detection technique used in the fiber optic remote sensing system is tunable diode laser spectroscopy or TDLS.

- A narrow linewidth laser is tuned through the target gas (methane) absorption line with reference and signal readings taken on each scan.
- As the laser is tuned through the gas line, the light is absorbed in direct proportion to the methane concentration present.

- Various laser modulation and advanced detection and signal processing techniques are then used to further increase the gas detection sensitivity and range and convert each return signal into a methane concentration.

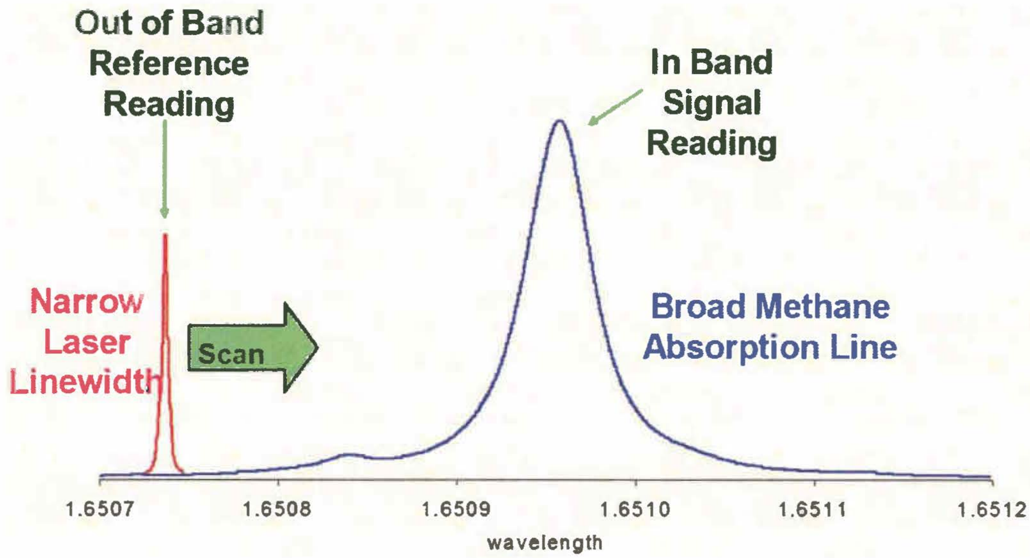

Figure A.2: Basic Tunable Diode Laser Spectroscopy (TDLS)

A.3 System Features & Benefits

The novel combination of TDLS gas detection and fiber optic technology provides the fiber optic sensing system with numerous unique and useful characteristics:

- The multipoint fiber optic system design allows hundreds of sensors to be simultaneously interrogated over large (>20 km) operating distances from a single central instrument location. This makes the system ideal for continuous multipoint gas monitoring in large underground mines.
- The TDLS detection technique is self-referencing which eliminates zero point or calibration drift. A factory calibrated laser signal distributed to an array of identical optical sensors with no parts that wear out in normal operation, ensures ongoing calibration stability. This also removes any future requirement to re-calibrate individual sensors in the field.
- All information is transmitted optically throughout the fiber network and sensors, so no electrical signals are present and hence there is no spark risk in areas exposed to potentially explosive gases. The optical power levels in the sensors are four orders of magnitude lower than the permissible limits for interrogating potentially explosive gas mixtures. Consequently the sensors and network installed in the gas detection environment are intrinsically safe and flash zone compatible. The system is also fully ATEX & IECEx certified for use in coal mines and other potentially explosive gas filled environments.

- As the optical signal from the laser and each sensor is continuously monitored at the CCU it provides an automatic self-checking function and an early warning of any potential system, network or sensor problems. The detection system also incorporates automatic gain control, which allows over 90% (10dB) additional loss of optical signal without any degradation of gas detection performance.
- The sensor components have been selected for stability in harsh environments and have accumulated over a million sensor hours of continuous operation in challenging environments. The system also passed all relevant tests for gas detection, humidity, dust and vibration as embodied in the MSHA performance requirements of Code of Federal Regulation (CFR) Title30 for Part-27 (methane monitoring system) and Part-22 (portable methane detectors).
- The linewidth of the system laser is over 100 times narrower than a typical gas absorption line at atmospheric pressure. Hence, selection of the laser wavelength allows the system to be precisely targeted to a specific gas of interest ensuring that there is no cross-sensitivity with other gases.

A.4 Electrical sensors vs. fiber optic methane detection for multipoint mine wide gas monitoring

The key problem with electrical sensors for fixed gas monitoring in mines is the fact that they need a local power source and hence always have a potential spark risk, so can't be installed and left in areas where methane may be present. The sensor heads must also to be regularly recalibrated and parts need replaced so they are not suited for installation in sealed and hard to access areas of a mine. In addition, electrical transmission of data is limited to ~1 km before electrically powered repeaters and amplifiers are required. The fiber optic methane detection system uses intrinsically safe optical sensing with no spark or ignition risk and can record gas levels 24/7 from hundreds of sensors over 20 km distances. As the sensors are completely passive they require no replacement parts. They are also calibration stable and exhibit excellent long term operation making the system ideal for mine wide methane monitoring.

Table A.1 compares the remote fiber optic methane detection system with other technologies used to detect methane in coal mines.

Table A.1: Sensing Technologies Comparison

Characteristic	Remote FO Sensors	Catalytic (Pellistor)	Mid – IR Gas Analyser	Electro-Chemical
Calibration Free Sensor	Yes	No	No	No
Self Referencing at Each Measurement	Yes	No	No	No
Passive (no electricity) at sensing point	Yes	No	No	No
Requires periodic maintenance at sensing point	No	Yes	Yes	Yes
Multipoint Capability [1]	240+	Limited	Limited	Limited

Characteristic	Remote FO Sensors	Catalytic (Pellistor)	Mid – IR Gas Analyser	Electro-Chemical
Measurement Range [2]	0.05% - 100% Vol.	50 ppm - LEL (5% Vol.)	0.1% - 100% Vol.	0.1% - 100% Vol.
Operates when Mine Power is Shut Off	Yes	No	No	No
Long Distance Sensing	≥ 20km	No	No	No
Intrinsic Safety & EM Immunity	Yes	No	No	No
Oxygen required in gas sample?	No	Yes	No	No
Interference from Other Gases [3]	No	Yes	Yes	Yes
Fast Response & Recovery Time	Yes	No	Yes	No
Non-Contact Measurement	Yes	No	Yes	No

[1] Multipoint options are available for Pellistor, Mid-IR, and Electro-Chemical although generally linking a small number of points. Electrically powered sensor system operation does not naturally lend itself to multipoint applications due to electrical power supply requirements at each sensor head and associated costs.

[2] Claims of 0% Volume in Mid-IR manufacturer datasheets but use in the field indicates that below 0.1% methane volume (2% LEL), noise on the signal makes readings unreliable.

[3] Gases close to absorption line affect reading of Mid-IR detectors.

APPENDIX B: Fiber Optic Distributed Temperature Sensing System

B.1 Distributed Temperature Sensing System Overview

Distributed Temperature Sensing (DTS) systems are optoelectronic devices that measure temperatures by means of optical fibers functioning as linear sensors. Temperatures are recorded along the optical cable as a continuous profile. Temperature can be determined with great accuracy over distances exceeding 40 km.

Temperature variations of as little as 0.5°C can be detected along the fiber optic cables with a spatial resolution of less than 0.5 meters, based on the DTS equipment and the system configuration. DTS systems can monitor the temperature in tunnels, in coal mines, along pipelines, in electrical cables, in gas sample line tubing assemblies, along conveyors, at bearings and motors, in Liquefied Natural Gas (LNG) operations, and in any application where variations in temperature indicate a change in the surrounding environment, leakage of gases or fluids, or degradation in equipment performance. DTS is used for fire detection, leakage detection, monitoring the current flowing through electrical cables, machinery health monitoring, and other situations where continuous temperature sensing is required over a distance or at multiple points using the same sensing device.

B.2 System Configuration:

The major elements of the system are:

<u>**Laser Light Source**</u>

- A solid state laser or laser diode generates a light pulse coupled into a multimode or single mode optical fiber.
- The backscatter reflected pulse is analyzed either through the Raman effect for shifts in wavelength of the return signal, or the Brillouin effect for changes in frequency (based on the DTS system).
- Systems with laser sources below 20 mW are available for applications where inherent safety of the system is required such as coal mines.

<u>**Optical Fiber Cable**</u>

- Standard communications grade single mode or multimode fibers (50/125 or 62.5/125).
- Some DTS systems use one (1) fiber per channel, 24 channels per system, with up to 256 sensing zones per channel.
- Other DTS systems use two (2) fibers per channel, with a loop-back at the far end for added accuracy and faster measurement rate.
- The sensing range can be up to 40 km per channel based on the fiber type and the system configuration.
- The fiber cable construction ranges from Fibers in Metal Tube (FIMT) for the most demanding applications to fibers with only a buffer for the more benign applications. Many constructions are available based on the mechanical and environmental requirements.

System Monitor

- A supervisory Programmable Logic Controller (PLC) based control system to monitor, process, and act upon the temperature data collected.
- The system has the capability to run control algorithms to characterize data, perform signature analysis, and correlate installed fiber locations to specific equipment locations.
- A Human Machine Interface is used to display the data, highlighting machine locations, cable routes, and pertinent equipment.

Various alarm schemes can be configured to look for abnormal temperature changes including rapid temperature rise, average temperatures above normal, as well as breaks in the sensing fiber, enabling for early detection of equipment problems such as bearing over-heating, lubrication issues, motors' malfunctions, and power cables' damage and wear.

The basic functions of the system are shown in Fig. B.1:

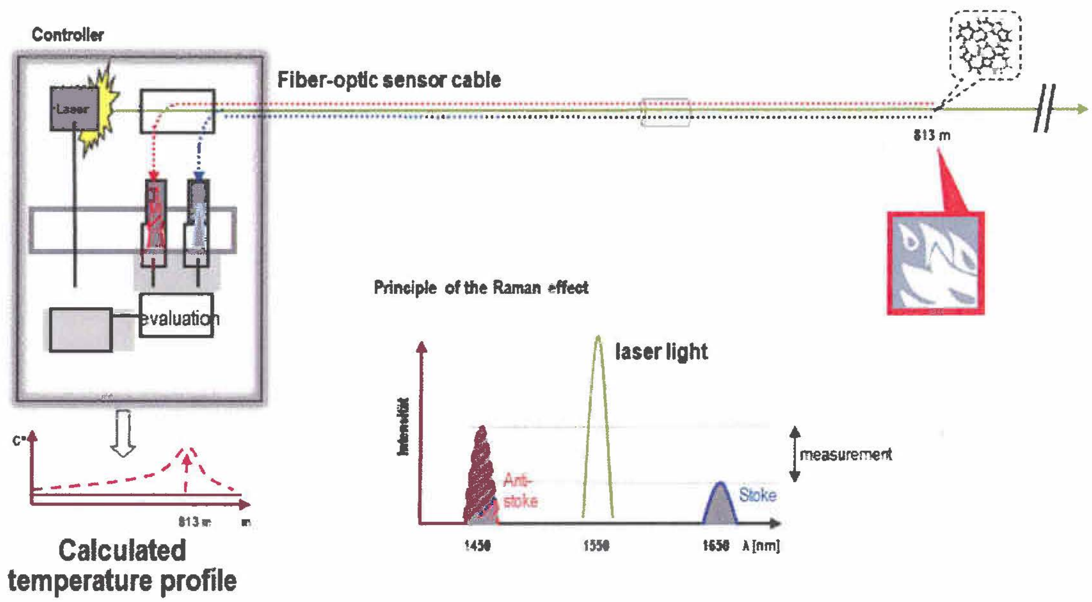

Figure B.1 –DTS System Components (© LIOS Technology)

B.3 System Description:

A typical dual channel system can provide up to 80 km of sensing capacity consisting of two 40 km cable runs with the capacity to detect temperature changes as little as 0.5°C, pinpointing the location to within 0.5 meters. Each sensor sub-systems can be placed in the areas or on the equipment to be monitored.

The supervisory control system is capable of interpreting the incoming data from the sensor network, matching the data with the installed location in the mine, tunnel, pipeline, building, or equipment and triggering the appropriate output (alarm or message) to the network or central monitoring system.

Fig. B.2 shows an example of a graphic control interface with status information, colored map, heat trace, and ratings results. Alarm and warning set points and displayed messages can be pre-programmed into the system.

Figure B.2 – Graphic Control Interface (© LIOS Technology)

B.4 Baseline Technologies

Optical fibers are made from doped quartz glass, a form of silicon dioxide (SiO_2) with amorphous solid structure. Thermal effects induce lattice oscillations within the solid. When light falls onto these thermally excited molecular oscillations, an interaction occurs between the light particles (photons) and the electrons of the molecule. Two approaches are used to measure changes in temperature in optical fibers: Raman scattering and Brillouin scattering.

<u>**Raman Scattering**</u>

When light falls on the thermally excited molecules in the optical fiber, **Raman scattering** occurs. Unlike incident light, the scattered light undergoes a spectral shift by an amount equivalent to the resonance frequency of the lattice oscillation. The light scattered back from the fiber optic therefore contains three different spectral shares:

- the Rayleigh scattering with the wavelength of the laser source used,
- the Stokes components with the higher wavelength in which photons are generated, and
- the Anti-Stokes components with a lower wavelength, in which photons are destroyed.

The Stokes and Anti-Stokes light components are the basis for fiber optic DTS. The ratio of these two return signals corresponds to a temperature change in the optical fiber. The position of the temperature reading is determined by measuring the arrival timing of the returning light pulse, utilizing Optical Time Domain Reflectometry (OTDR) or Optical Frequency Domain Reflectometry (OFDR) methods.

Brillouin Scattering

When the light falls on the excited molecules in the fiber, a fraction of this light changes its momentum, thus its frequency and energy.

The **Brillouin scattering** DTS exploits the sensitivity of the Brillouin frequency shift for temperature and strain sensing applications, using standard low-loss single mode optical fibers. This approach offers the longest distance range and a compatibility with standard telecommunication components.

Brillouin scattering can also be optically stimulated leading to the greatest intensity of the scattering mechanism and consequently an improved signal-to-noise ratio.

Stimulated Brillouin Scattering is especially suited for applications requiring speed, longer distance, or higher optical budget.

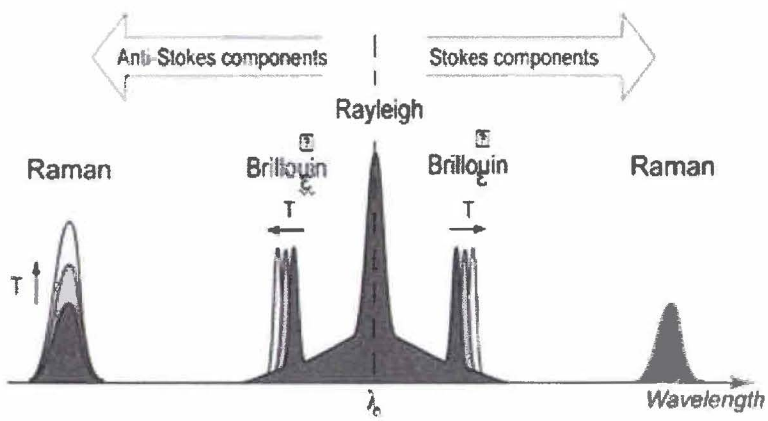

Figure B.3 – Brillouin and Raman Scattering