

# **ELDS - Enhanced Laser Diode Spectroscopy**

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## **KEYWORDS**

Laser Diode Spectroscopy, Gas Detection, ELDS.

## **ABSTRACT**

Laser Diode Spectroscopy (LDS) is a well known method for the sensitive detection and measurement of gases, with techniques including WMS (Wavelength Modulation Spectroscopy), FMS (Frequency Modulation Spectroscopy) and TTFMS (Two Tone Frequency Modulation Spectroscopy) being successfully employed in a variety of applications. However, due to a number of significant shortcomings, LDS has not seen widespread application in the detection of hazardous gases for safety related applications. Enhanced Laser Diode Spectroscopy (ELDS) has been developed to overcome the shortcomings of previous LDS techniques, enabling it to be used in the most demanding safety related gas detection applications.

## **INTRODUCTION**

Laser diode spectroscopy techniques have been widely used in instrumentation to measure gases in industrial processes and to monitor atmospheric pollutants. However, equipment using LDS techniques has only enjoyed limited success in the detection of toxic or flammable gases for safety related applications. The main reason that LDS based equipment has not been widely employed for the detection of toxic or flammable gases for safety related applications is that such applications demand an extremely high level of reliability and in particular very low false alarm rates.

The repercussions of false alarms from gas detectors can include the shutting down of industrial or petrochemical plants, personnel donning safety equipment and commencing evacuation procedures; and a loss of confidence in a gas detection system. Consequently, users of fixed gas detection equipment are looking for false alarm rates for each gas detector of lower than 1 per 100 years. While existing LDS based equipment might be able to detect or measure fractional absorbances of the order of  $1 \times 10^{-4}$  to  $1 \times 10^{-5}$  with reliability acceptable for process control or atmospheric monitoring applications, such small fractional absorbances cannot be detected with an acceptably low false alarm rate for safety applications.

When attempting to reliably detect fractional absorbances of  $1 \times 10^{-4}$  to  $1 \times 10^{-5}$  using conventional LDS techniques, the designer encounters three main problems, these being system noise, absorption(s) by atmospheric gases and coherence / fringe effects.

## **NOISE**

System noise is introduced by virtually all of the active components used in an LDS system, including the laser diode drive circuit, laser diode, detector(s) and amplifiers. These differing noise sources exhibit complex frequency and probability distributions, making it practically impossible to determine their influence upon overall false alarm rates in a regime where effects with probabilities as low as once in a thousand years are potentially significant. It can be stated with confidence that for an LDS based system to experience a system noise induced signal deviation of less than  $1 \times 10^{-5}$  for a period long enough to cause a false alarm just once in one hundred years of operation requires an exceptionally high system signal to noise ratio ( $>1 \times 10^6 : 1$ ). In practice, even with careful design and selection of components, sub-systems and signal processing routines, achieving such a high system signal to noise ratio is not possible. Furthermore, even if it were possible to achieve such a high system signal to noise ratio in ideal conditions, the signal losses associated with the operation of an LDS system outdoors over a useful path-length preclude achieving such a signal to noise ratio in operational service. Therefore, any LDS based system looking to detect fractional absorbances of  $1 \times 10^{-5}$  with an acceptably low probability of false alarms for use in safety related applications must address the problem of the signal to noise ratio requirement associated with conventional LDS systems.

## **ABSORPTION BY ATMOSPHERIC GASES**

When making optical measurements along an open path through the atmosphere it is essential to consider the effects of absorption by the gases which constitute the atmosphere. In particular, atmospheric gases such as water vapour, carbon dioxide and oxygen exhibit strong optical absorption at wavelengths from the near infrared to the far infrared, which is the wavelength region of main interest for LDS systems. When assessing wavelengths at which to make measurements of a particular target gas it is necessary to ensure that there are no strong atmospheric absorption lines at wavelengths very close to that of the target gas' absorption line. Also, any continuum absorption by atmospheric gases must not attenuate radiation at the candidate wavelength to such an extent that the system's signal to noise ratio is unduly compromised. Additionally, when looking to detect fractional absorbances as low as  $1 \times 10^{-5}$ , it is necessary to consider the effects introduced when making measurements in the far wings of strong atmospheric absorption lines. This is necessary because even if the line is relatively distant and the atmospheric transmission is acceptably high, the curvature of the transmission in the far wings of a strong absorption line can produce effects similar to those produced by a small absorption by the target gas.

For atmospheric gases such as oxygen and nitrogen which have relatively stable atmospheric concentrations, it is possible to compensate for any small reading offsets that

their absorptions might introduce, either by zeroing the instrument or detector when it is installed, or by applying a correction calculated for the length of the monitored space. However, for atmospheric gases such as water vapour, carbon dioxide and carbon monoxide which exhibit significant variation in concentration depending upon weather, geography and any local emissions of these gases, such compensation is not possible. Therefore, when designing an LDS system to make high sensitivity measurements along an open atmospheric path it is necessary to pay particular attention to the effects of absorption by water vapour, carbon dioxide and carbon monoxide; and any technique which can reduce the potential for such absorptions to interfere with equipment using LDS would be highly beneficial.

## **COHERENCE / FRINGE EFFECTS**

The diode lasers used in LDS systems exhibit a high degree of spatial and temporal coherence, which means that light reflected or scattered from virtually anywhere within the LDS system or monitored space can interact in a coherent manner with the light proceeding directly along the intended measurement path. The consequence of such coherent interactions is unwanted amplitude modulation of the light proceeding along the measurement path, such modulations being particularly undesirable if they produce features similar to those produced when the laser's wavelength is scanned across the target gas' absorption line. This problem is exacerbated by the fact that the amplitude of any such modulation is dependant upon the field strength of a particular reflection or scattering source, not upon the intensity of such a source. This means that amplitude modulations of  $1 \times 10^{-5}$  can be produced by reflected or scattered light of  $1 \times 10^{-10}$  intensity relative to that of the beam with which they are interacting. In effect, reflected or scattered light is capable of modulating the intensity of the light proceeding along the intended measurement path by far more than its own intensity!

With relative intensities of  $1 \times 10^{-10}$  capable of producing amplitude modulations of  $1 \times 10^{-5}$ , coherence / fringe effects are a very significant problem in LDS based systems. Indeed, much work upon the enhancement of systems using LDS has revolved around developing techniques to reduce the magnitude or overall impact of coherence / fringe effects upon such systems. This work has included the development of a number of patented techniques to combat coherence / fringe effects, such as those described in US 4,684,258 [1] and US 4,934,816 [2].

Despite the success of techniques developed to reduce the significance of coherence / fringe effects upon LDS systems, in many instances, coherence / fringe effects still set the limit of detection or measurement for such systems. Also, whilst these techniques work successfully in relatively benign, controlled environments, they work less well in outdoor or uncontrolled environments and are not sufficient to deal with the challenges presented by extreme environments. Consequently, if an LDS system is to be used to detect fractional absorbances of  $1 \times 10^{-5}$  in industrial safety applications its design must address the coherence / fringe problem in a manner that works with the highest reliability even when exposed to extreme environmental conditions.

## ENHANCED LASER DIODE SPECTROSCOPY (ELDS)

Enhanced Laser Diode Spectroscopy (ELDS) has been developed to enable fractional absorbances of  $1 \times 10^{-4}$  to  $1 \times 10^{-5}$  to be detected or measured with sufficient reliability to enable products employing this technique to be used in the most demanding safety related gas detection applications.

ELDS addresses the problems of system noise, absorption(s) by atmospheric gases and coherence / fringe effects by a combination of approaches which significantly enhance the ability of a system to detect small fractional absorbances with a low false alarm rate.

### NOISE

The first approach which forms part of the ELDS technique addresses the problems associated with system noise and the signal to noise ratio requirements for low false alarm rates.

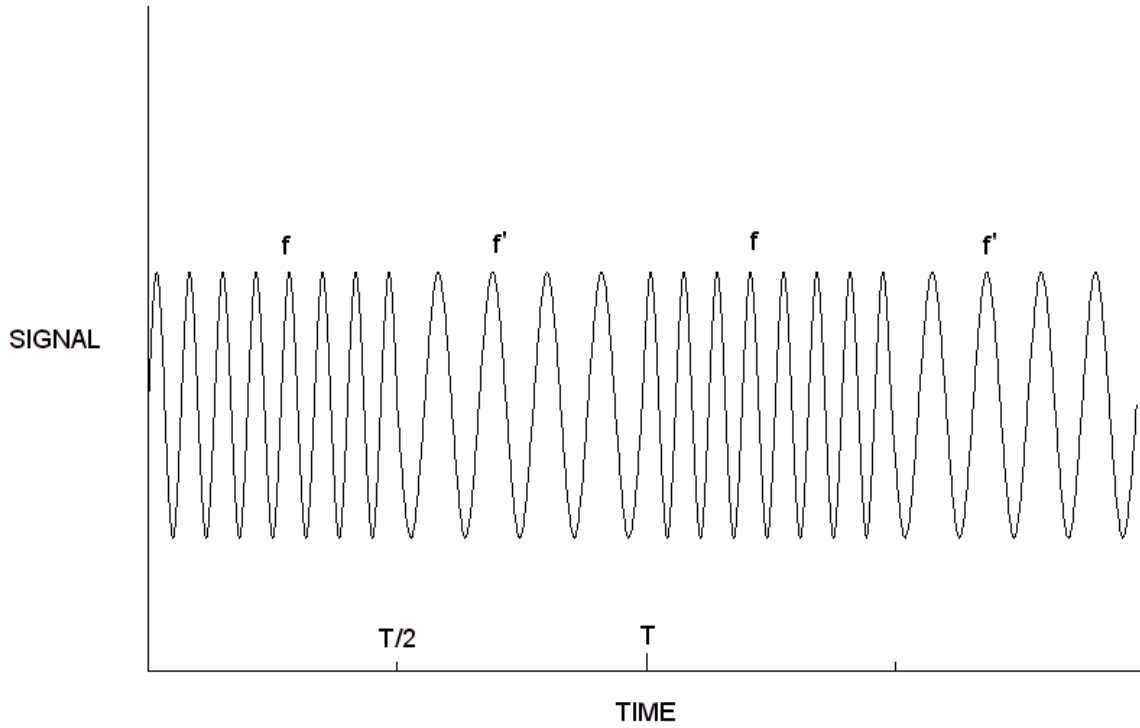
For a conventional LDS system, modulating the laser at a frequency  $f$  and measuring target gas absorption at harmonic frequency  $f_1$ , the probability of system noise  $N(f_1)$  producing a false alarm size deviation  $\Delta(f_1)$  in a given measurement interval  $T$ , can be described by an equation of the form below, where  $k_1$  is a constant for the system relating noise to probability of deviation  $P(\Delta(f_1(T)))$ :-

$$P(\Delta(f_1(T))) = k_1 \cdot N(f_1) \cdot T^{-1/2} \quad (1)$$

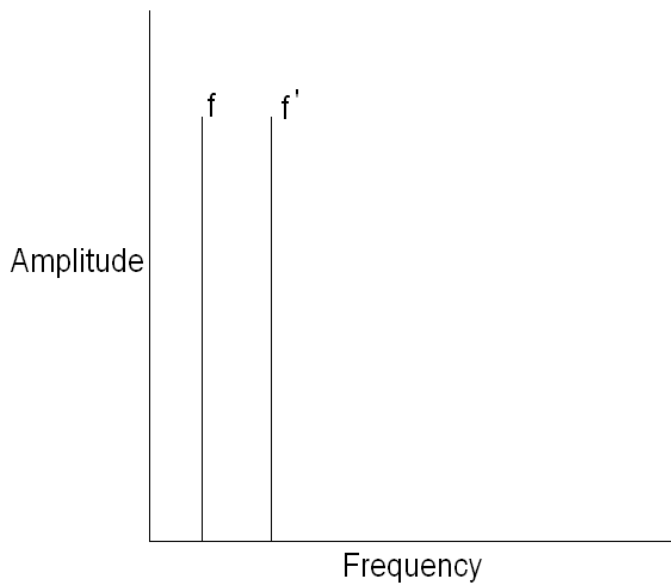
In the first approach which forms part of the ELDS technique, the laser diode is driven by a current as shown in Figure 1, comprising two components, a bias component and a sinusoidal component. The bias component is chosen to operate the laser diode at a mean wavelength  $\Lambda_1$ , close to a chosen optical absorption line of the target gas; whilst the sinusoidal component alternates between two, non-harmonically related electrical frequencies  $f$  and  $f'$ , at each of which frequencies the laser's wavelength is alternately scanned across the chosen absorption line for an interval  $T/2$ . When there is no gas present in the measurement path, the combined Fourier transform of the detector signal for a total interval  $T$  (where  $T \gg 1/f_1$ ) will look like Figure 2, with just two frequency components  $f$  and  $f'$ . When there is a substantial quantity of target gas in the monitored space, the combined Fourier transform of the detector signal will look like Figure 3, with sets of harmonics of both  $f$  and  $f'$ . When measured at frequencies  $f_1$  and  $f_2$  for intervals of  $T/2$ , the probability of system noise producing a false alarm size deviation ( $\Delta(f)$ ) during each separate  $T/2$  interval is as follows:-

$$P(\Delta(f_1(T/2))) = k_1 \cdot N(f_1) \cdot T^{-1/2} \cdot \sqrt{2} \quad (2)$$

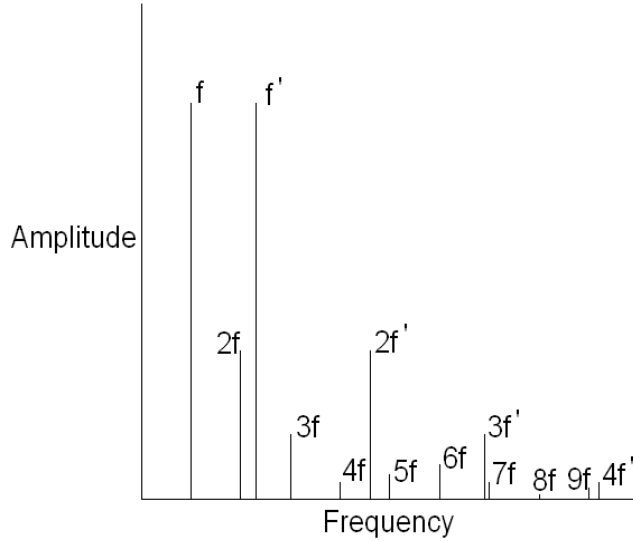
$$P(\Delta(f_2(T/2))) = k_2 \cdot N(f_2) \cdot T^{-1/2} \cdot \sqrt{2} \quad (3)$$



**FIG. 1 LASER DIODE DRIVE WAVEFORM INCLUDING TWO, NON-HARMONICALLY RELATED, WAVELENGTH MODULATION FREQUENCIES**



**FIG. 2 FOURIER TRANSFORM OF ZERO GAS SIGNAL FOR INTERVAL T**



**FIG. 3 FOURIER TRANSFORM OF POSITIVE GAS SIGNAL FOR INTERVAL T**

If measurement frequencies  $f_1$  and  $f_2$  are chosen to be the same order harmonics of  $f$  and  $f'$  and the system noise at  $f_1$  and  $f_2$  is the same, the probability that during a combined measurement interval  $(T/2 + T/2)$  the quantities of target gas  $Q_1$  and  $Q_2$  calculated to be present in the measurement path will exceed a false alarm size deviation  $(\Delta(f))$  due to system noise is:-

$$P(\Delta(f_1(T/2))) \& P(\Delta(f_2(T/2))) = k_1 \cdot N(f_1) \cdot T^{-1/2} \cdot \sqrt{2} \times k_2 \cdot N(f_2) \cdot T^{-1/2} \cdot \sqrt{2} \quad (4)$$

Which for  $N(f_1) = N(f_2)$  simplifies to:-

$$P(\Delta(f_1(T/2))) \& P(\Delta(f_2(T/2))) = 2 \cdot k_1 \cdot k_2 \cdot N(f_1)^2 \cdot T^{-1} \quad (5)$$

Since in most instances  $P(\Delta(f_1(T/2)))$  and  $P(\Delta(f_2(T/2)))$  are small, the probability of both measurements suffering noise induced deviations sufficient to exceed an alarm threshold during interval  $T$  is very small. By way of example, a system with a noise floor sufficient to achieve an average false alarm rate of 1 in 2 days when modulating at a single frequency could be improved to achieve an average false alarm rate lower than 1 in 100 years by measuring at an additional frequency and using the second measurement to confirm the first.

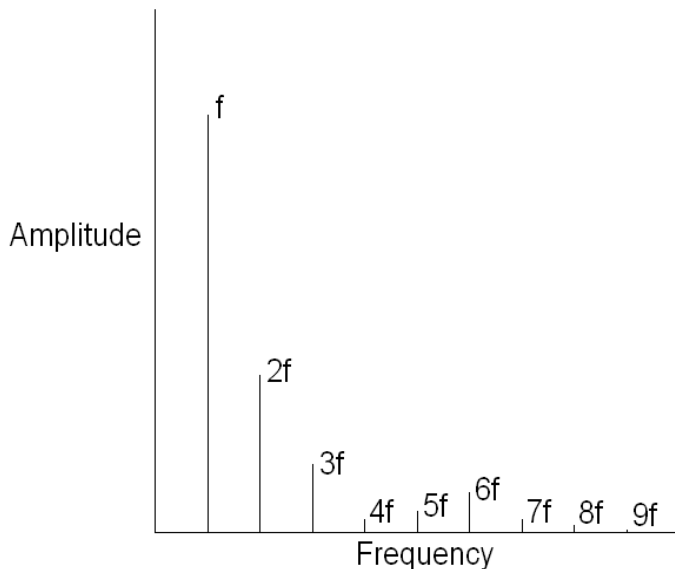
The benefits of modulation and measurement at multiple, non-harmonically related electrical frequencies are not limited to reducing the impact of classic, thermal noise. Electronic systems are often required to operate in environments affected by electromagnetic interference. Unlike classic, thermal noise, electromagnetic interference tends to be at frequencies which are harmonically related to the frequencies of operation of the equipment which are the source of the interference. Therefore, the use of modulation at a number of non-harmonically related frequencies reduces the likelihood

that electromagnetic interference will affect all measurement frequencies simultaneously, enabling false alarms due to electromagnetic interference to be reduced.

## **ABSORPTION BY ATMOSPHERIC GASES**

The second approach which forms part of the ELDS technique addresses the problems associated with absorption(s) by atmospheric gases when measuring along open paths.

In a system operating with an open path through the atmosphere it is usually possible to find one or more target gas absorption lines which do not coincide with absorption lines of atmospheric gases. The worst-case scenario tends to be the presence of strong atmospheric absorption lines at wavelengths near to the target gas absorption line, but not coinciding. These nearby atmospheric lines cause problems to conventional LDS systems because they can generate significant harmonics of the wavelength scanning frequency. Figure 4 shows the typical Fourier transform produced as a result of scanning a target gas absorption region close to a strong atmospheric absorption line, with no target gas present. Note the significant second harmonic component generated by the presence of the nearby strong atmospheric absorption line and the smaller but still significant third and fourth harmonics. Provided that the target gas absorption line is being scanned over a region which does not contain the maxima of the strong atmospheric absorption line, the harmonic pattern of Figure 4 is produced, with the third and fourth harmonics always smaller than the second harmonic.

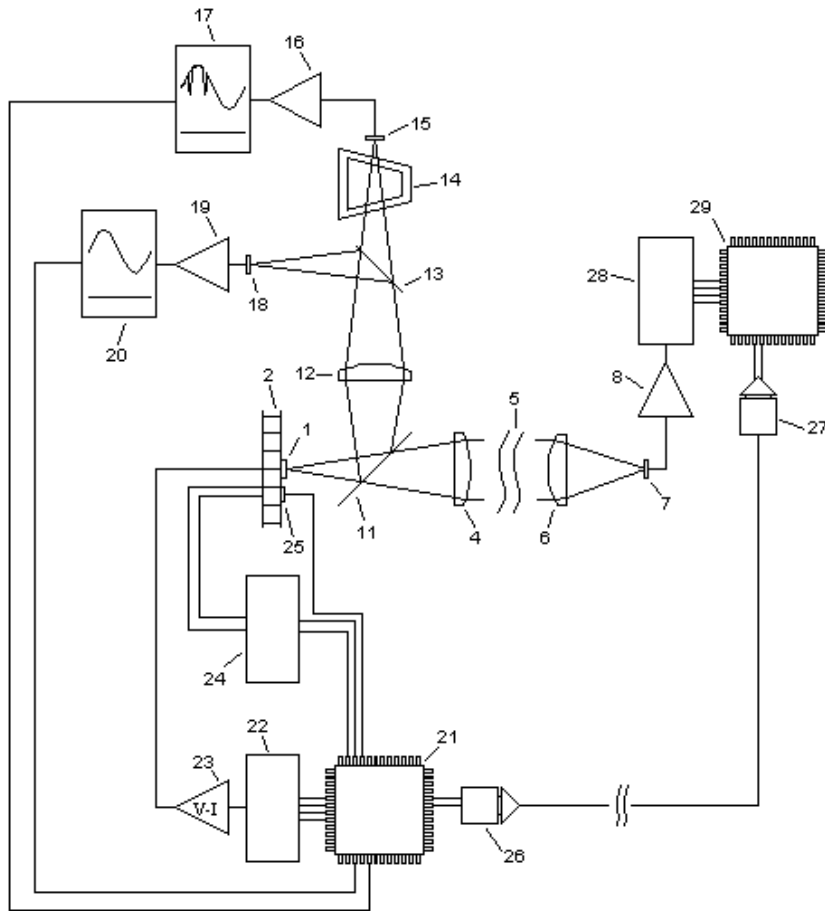


**FIG. 4 FOURIER TRANSFORM OF SIGNAL IN THE WINGS OF A STRONG 'INTERFERING' ATMOSPHERIC ABSORPTION LINE**

A basic ELDS system is shown in Figure 5. A laser diode is mounted on a temperature controlled mount in a transmitter. The optical radiation emitted by the laser diode is sampled by a beam-sampler, with the majority of the radiation passing the beam-sampler to be transmitted through a monitored space and concentrated onto an optical detector D1 in a receiver. The sampled laser diode radiation passes through a retained target gas sample before being detected by optical detector D2. The signal from detector D2 is amplified and digitised, with the digitised waveform being passed to a microcontroller. This digitised waveform contains information regarding the effect of absorption of laser diode radiation by the retained target gas sample. The microcontroller processes the digitised waveform from optical detector D2 to determine the magnitudes and phases of the fundamental and harmonic components of the wavelength scanning frequency present in this waveform. This information is then used by the microcontroller to actively control the precise operating conditions of the laser diode, such that absorption of laser diode radiation by target gas produces a known distortion 'harmonic fingerprint' with very specific harmonic characteristics. Controlling the operating and drive conditions of the laser diode such that absorption of its radiation by target gas produces a very specific 'harmonic fingerprint' is the key to this technique.

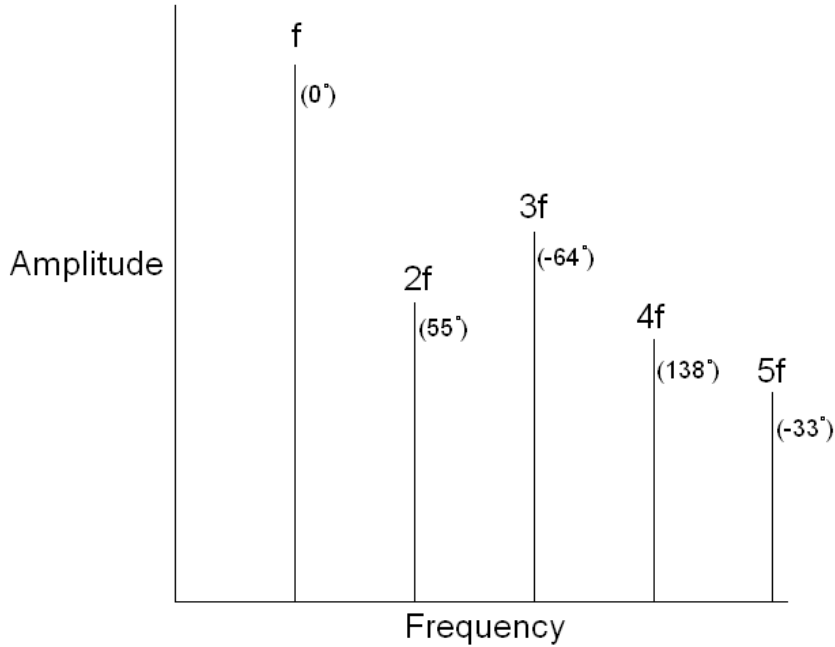
The signal from receiver optical detector D1 is amplified and digitised, the resulting digitised waveform being passed to the receiver microcontroller. The receiver microcontroller processes the received waveform to determine the magnitudes and phases of the fundamental and harmonic components of the wavelength scanning frequency present in this waveform. These harmonics are compared to the known 'harmonic fingerprint' produced by target gas absorption, and provided that the magnitudes and phases of the harmonics exhibit a good correlation with the 'harmonic fingerprint', the magnitudes of the harmonics are used to calculate the amount of target gas present in the monitored space. If the harmonics do not exhibit a good correlation with the target gas 'harmonic fingerprint' it is most likely that they are the result of absorption by interfering atmospheric gases or coherence / fringe effects and such data is rejected.

Figure 6 shows a 'harmonic fingerprint' which has been generated by precisely controlling the operating and drive conditions of a laser diode set up to probe / measure the absorption line of hydrogen sulphide at 1589.97nm. Note that the second, third and fourth harmonics all have significant and similar magnitudes. Absorption by atmospheric carbon dioxide at 1590.15nm and / or water vapour at 1590.26 produces second harmonics, but any third or fourth harmonics are always substantially smaller than the second, making it easy to reject these potential sources of interference using the 'harmonic fingerprint' shown in Figure 6, the conditions for generation of which are being actively maintained by the ELDS transmitter.



- |                        |                                 |                         |
|------------------------|---------------------------------|-------------------------|
| 1. Laser diode         | 2. Temperature controlled mount | 4. Output collimator    |
| 5. Monitored space     | 6. Receiver collecting element  | 7. Optical detector D1  |
| 8. Amplifier           | 11. Beam-sampler                | 12. Sampling element    |
| 13. Beam-splitter      | 14. Retained target gas sample  | 15. Optical detector D2 |
| 16. Amplifier          | 17. Target gas waveform ADC     | 18. Optical detector    |
| 19. Amplifier          | 20. Zero gas waveform ADC       | 21. TX microcontroller  |
| 22. Laser drive DAC    | 23. V:I converter               | 24. Temp. control drive |
| 25. Temperature sensor | 26. TX comm's link              | 27. RX comm's link      |
| 28. Receiver ADC       | 29. RX microcontroller          |                         |

**FIG. 5 A BASIC ELDS SYSTEM**



**FIG. 6 EXAMPLE OF A ‘HARMONIC FINGERPRINT’ GENERATED BY CONTROLLED SCANNING OF A H<sub>2</sub>S ABSORPTION LINE AT 1589.97nm**

### COHERENCE / FRINGE EFFECTS

The third approach which forms part of the ELDS technique mainly addresses the problems associated with coherence / fringe effects, these effects often setting the minimum measurement or detection limit in LDS based instrumentation or detection equipment. However, it should be appreciated that this technique also reduces the potential for interference by atmospheric gases; whilst the ‘harmonic fingerprint’ technique described earlier also has benefits with respect to coherence / fringe effects.

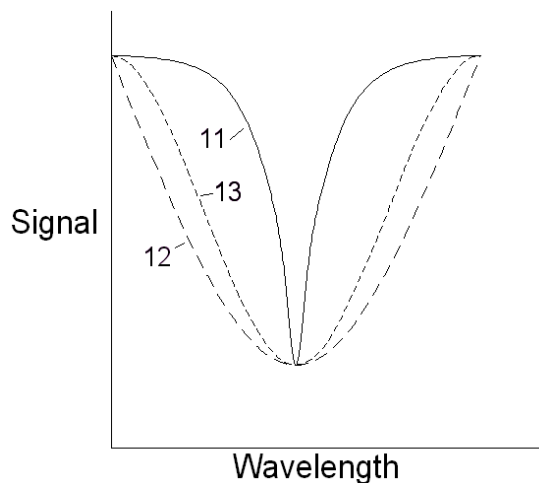
The amplitude modulation produced by coherent interference exhibits a sinusoidal variation with wavelength. For coherent light of wavelength  $\Lambda$ , the phase difference expressed as a number of wave cycles  $\Phi_n$ , between light leaving an optical surface and light returning having been reflected at a distance D from this optical surface is given by:-

$$\Phi_n = 2D / \Lambda \quad (6)$$

The amplitude modulation produced by coherent interference between light leaving an optical surface and light returning from reflection at a distance D from an optical surface will go through a single sinusoidal cycle for a change in wavelength  $\partial\Lambda$ , is given by equation:-

$$(\Lambda + \partial\Lambda) = 2D / (\Phi_n - 1) \quad (7)$$

Figure 7 shows the amplitude modulation produced when a laser diode's wavelength is scanned over a target gas absorption line, a half cycle of a sinusoid and a full cycle of a sinusoid, all fitted to the same wavelength interval. It can be seen from Figure 7 that if the period of the sinusoidal modulation produced by coherence / fringe effects is of approximately the same width as the target gas absorption line, there is a probability that such modulation will start to correlate and / or interfere with the measurement or detection of the target gas absorption line.



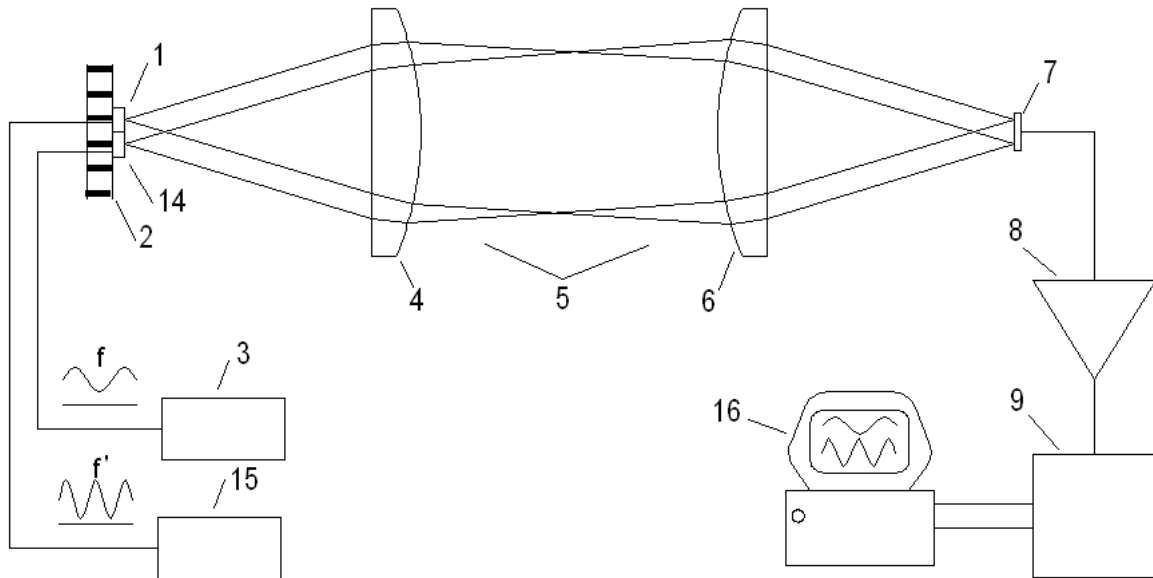
- 11. Gas absorption line
- 12. Half cycle of sinusoid
- 13. Full cycle of sinusoid

**FIG. 7 COMPARISON OF ABSORPTION LINE PROFILE WITH SINUSOIDAL CYCLES**

Even with extremely careful design and engineering of an LDS system it is not possible to completely eliminate coherence / fringe effects from such systems, it is only possible to reduce their size or impact upon system performance. For LDS systems making measurements through open atmospheric paths, the situation is made considerably worse by the fact that the designer cannot control what happens in the open part of the system. Light can be scattered or reflected in the open path by rain-drops, snow, fog, mist, people or vehicles moving through the path. This results in light being scattered or reflected at distances and intensities over which the designer has little or no control. For an LDS system making measurements along an open path therefore, there is always the possibility of light being reflected or scattered at a distance which will create coherent fringes with a period which will correlate and interfere with the measurement of a target gas absorption line.

Whilst it is not possible to eliminate coherence / fringe effects from an LDS system, especially one operating along an open measurement path, it is possible to reduce the rate of false alarms arising from such effects by using a system configuration as shown in Figure 8. The LDS system shown in Figure 8 contains two laser diodes, operating at

mean wavelengths  $\Lambda_1$  and  $\Lambda_2$ , these wavelengths corresponding to two different absorption lines of the same target gas. These lasers are on a common temperature stabilised mount and are driven at electrical frequencies  $f$  and  $f'$  and scanned over wavelength ranges  $\partial\Lambda_1$  and  $\partial\Lambda_2$  respectively. The outputs from the lasers are collimated by a common optical element, aligned such that optical radiation from both lasers reaches the receiver after passing through the monitored space. Optical radiation from both lasers is concentrated onto a receiver detector, at which point the optical signals are effectively combined into a single electrical signal with principal frequency components  $f$  and  $f'$ .



- |                           |                                 |                       |
|---------------------------|---------------------------------|-----------------------|
| 1. Laser diode            | 2. Temperature controlled mount | 3. Laser drive        |
| 4. Transmitter collimator | 5. Monitored space              | 6. Receiver lens      |
| 7. Optical detector       | 8. Amplifier                    | 9. Receiver ADC       |
| 14. Laser diode           | 15. Laser drive                 | 16. Signal processing |

**FIG. 8 DUAL LASER ELDS BASED GAS DETECTION SYSTEM**

The electrical signal from the receiver detector contains two sets of independent frequency components proportional to the amount of target gas present in the measurement path. A quantity of target gas  $Q_1$  is calculated from the amplitude of frequency component  $f_1$  for measurements made around wavelength  $\Lambda_1$  whilst scanning over a range  $\partial\Lambda_1$ ; and a quantity of target gas  $Q_2$  is calculated from the amplitude of frequency component  $f_2$  for measurements made around wavelength  $\Lambda_2$  whilst scanning over a range  $\partial\Lambda_2$ . These effectively independent measurements of the quantity of target gas in the monitored space can then be compared and used to confidently determine the quantity of target gas present in the monitored space, if any.

When addressing the problems associated with coherence / fringe effects, the use of two laser diodes in a configuration as illustrated by Figure 8 has the following benefits:-

1. Wavelengths  $\Lambda_1$  and  $\Lambda_2$  can be chosen independently, enabling a larger difference between these wavelengths to be realised than would ordinarily be possible when scanning a single laser. This larger wavelength difference results in significantly different coherence / fringe modulation periods when light from the two lasers is scattered or reflected by a common surface at a distance large compared to their wavelength ( $\gg 1000 \times \Lambda$ ). Consequently, the probability of coherence / fringe effects due to scattering or reflection simultaneously producing the same net interference effect at both measurement wavelengths is greatly reduced.
2. The lasers can be scanned over significantly different wavelength ranges, making it possible to ensure that light scattered or reflected from a single surface at a distance  $D$  cannot produce a sinusoidal amplitude modulation with a period closely correlated to that of the target gas absorption line for both of the lasers. In effect, there are two characteristic distances  $D$  and  $D'$  corresponding to  $\partial\Lambda_1$  and  $\partial\Lambda_2$  respectively, at which scattering or reflection could be a problem for one laser but not the other. By deliberately spacing these characteristic distances such that they never coincide and are not harmonically related, scattering or reflection from a single surface cannot equally interfere with both measurements at the same time.
3. The physical separation in  $x$ ,  $y$  and  $z$  between the two lasers reduces the probability that light scattered or reflected from a common surface will introduce modulation with the same amplitude and phase onto both laser outputs. If necessary, the lasers can be deliberately mounted in positions at which common-mode interference will be further reduced.

In addition to the above benefits with relation to coherence / fringe effects, the use of two lasers operating at mean wavelengths  $\Lambda_1$  and  $\Lambda_2$ , scanning ranges  $\partial\Lambda_1$  and  $\partial\Lambda_2$  at frequencies  $f$  and  $f'$ , with measurement of frequency components  $f_1$  and  $f_2$  has the following benefits:-

1. Since each laser is scanning their target gas absorption line at one frequency, one hundred percent of the time, there is no system signal to noise reduction such as that associated with scanning a single laser alternately at two frequencies.
2. The use of two lasers, scanning different wavelengths at different electrical frequencies makes it possible to treat each measurement as being completely independent of the other. Statistical calculations of the improvement in false alarm rate achieved can be relied upon when used to calculate false alarm probabilities that are too low to be practically measured.

## **ELECTRONIC FUNCTIONAL TESTING**

In an ELDS system similar to that shown in Figures 5 and 8, the transmitter's microcontroller has direct control of the digital synthesis of the laser diode drive waveform(s) and access to the 'harmonic fingerprint'(s) being produced by absorption of

laser diode radiation by the retained sample of target gas. Consequently, the transmitter has sufficient information to know how the signal reaching the receiver will be affected by a given quantity of target gas in the monitored space, and the means of synthesising this affect. Upon receiving a command instruction from an operator or control system, the microcontroller can calculate the size and phase of the harmonic components to be added to the laser diode drive waveform(s) in order to simulate the presence of a given quantity of target gas in the monitored space. By adding these harmonic components to the drive waveform(s) being applied to the laser diode(s), the optical radiation leaving these devices will contain the 'harmonic fingerprint'(s) of the given quantity of target gas being simulated by the transmitter.

When the receiver processes the signal that it is receiving from the transmitter during the transmitter's gas simulation, the receiver will not be able to distinguish the 'harmonic fingerprint'(s) injected by the transmitter from those produced by target gas being present in the monitored space, and will calculate and output the corresponding quantity of target gas. By comparing the output from the receiver to the quantity of target gas that the transmitter was instructed to simulate, it is possible to verify that the gas detector is operational and will respond correctly to gas in the event of a leak.

Compared to the conventional techniques currently used to test gas detectors, electronic functional testing has the following advantages:-

1. Functional testing can be performed remotely, without operators needing to gain access to the gas detectors.
2. Gas detectors can be functionally tested much more frequently, providing greater safety integrity.
3. The results of functional testing can be gathered and logged completely electronically.
4. There is no need for operators to carry cylinders of hazardous gases around in order to test gas detectors.
5. The operation and maintenance costs for a gas detection system are considerably reduced.

## **DETECTION OF MULTIPLE HAZARDOUS GAS SPECIES BY A SINGLE UNIT**

The multiple laser approach shown in Figure 8 is also applicable to the detection of multiple gas species, including both toxic and flammable gases. For example, a Vertical Cavity Surface Emitting Laser (VCSEL) operated in the region of 1684nm to 1687nm can be used to detect methane, ethane, propane, ethylene and propylene; whilst a VCSEL laser diode operated at 1589.97nm can be used to detect hydrogen sulphide. Since in most oil and gas applications, where hydrogen sulphide is present it is intimately mixed in solution gas, which predominantly comprises methane, the presence of methane detected at 1684nm can be used to validate the detection of a leak of hydrogen sulphide based upon measurements at 1589.97nm. The resulting detector is capable of reliably detecting the major flammable and toxic gas hazards encountered by the oil and gas industry, in a single open path unit.

## **CONCLUSION**

Enhanced Laser Diode Spectroscopy (ELDS) makes possible the sensitive detection of hazardous gases with the reliability required by demanding safety related applications. Additionally, ELDS provides remote, electronic functional testing of gas detectors, a feature with considerable safety integrity and cost of ownership benefits for users of fixed gas detection equipment. As a consequence of its significant advantages compared to existing gas detection technologies, ELDS based gas detection has the potential to significantly improve the safety of operations where hazardous gases are produced or encountered.

## **REFERENCES**

1. Webster, C., Method and apparatus for enhancing laser absorption sensitivity, US Patent 4,684,258, 1987
2. Silver, J.A. and Stanton, A. C., Laser absorption detection enhancing apparatus and method, US Patent 4,934,816, 1990