Patented *Virtual Reference*™ Infrared Gas Sensor

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For many years, gas sensing was only utilized for critical, cost insensitive industrial safety and processing applications. Recently, gas sensing has become feasible for consumer and commercial installations. Use of carbon monoxide gas detection for home safety and carbon dioxide sensing for building ventilation control has been continuously increasing. This has forced sensor designers to develop sensors that are both reliable and more cost effective. Here, reliability is taken to mean long life, sensitivity, selectivity, temperature stability and reduced calibration cycles.

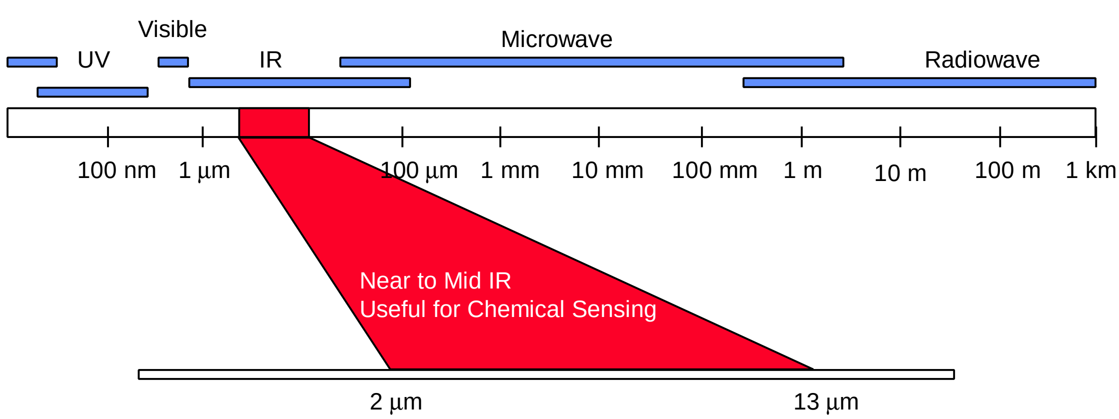
Gas detection technology traces its development to the early use of canary birds in mines. The canary's fast metabolism caused it to suffer more rapidly from the ill effects of toxic gases than the miner whose health was being protected. By watching the bird's alertness, the miner was forewarned of the presence of toxic gases.

Since then, gas sensing has evolved to include technologies such as electrochemical, catalytic pellistors, semiconductor and infrared. Most sensor technologies that have been developed over the years would be classified as "reactive"; that is, the analyte chemically interacts with the sensor element, providing an electrical signal that is proportional to the gas concentration. Reactive sensors suffer from a variety of drawbacks inherent to their nature: 1) the incomplete reversibility of the chemical changes at the end of the reaction, 2) depletion of the chemicals in the sensor element over time, 3) lack of specificity to the desired analyte and 4) interference from other environmental factors. For example, catalytic sensors used for hydrocarbon detection are poisoned by several common organic vapors and lose their sensitivity. An additional drawback is that reactive sensors that prematurely lose sensitivity typically

cannot be checked for operability unless they are exposed to the target gas. Therefore these types fail in an unsafe condition.

Infrared (IR) technology that is "non-reactive" in nature is becoming increasingly popular in gas detection. Long recognized for accurate identification of gases and reliable concentration measurements, this technology was previously used only in high-end instruments, and was not a choice for cost sensitive gas detection applications due to high cost. However, recent breakthroughs in sensor design have made it possible to apply this technology to cost sensitive applications.

Infrared gas sensors, which are comprised of solid state devices, do not chemically react with the gas. Further, they can be engineered to detect certain critical sensor element failures and then alert the user. In other words an IR sensor can fail-safe. The theory of infrared gas sensing and Texas Instrument's innovative sensor design are described below.



Infrared radiation is a part of the electromagnetic radiation spectrum, which also contains visible and ultraviolet radiation. Since electromagnetic radiation is wavelike, infrared radiation has wavelengths ranging from 0.8 to 100 microns. Gas molecules are made up of atoms that are bonded together. These bonds constantly undergo vibrations and rotations. The frequencies of these vibrational and rotational motions are a strong function of the size of the atoms and bond strengths. By nature, these

frequencies match with the frequency of the middle portion of the infrared spectrum (called mid IR). When exposed to a beam of infrared radiation, most gas molecules will absorb IR radiation at their vibration / rotation frequencies. The unique structure of each compound means that it will have a unique IR fingerprint which can often be used to identify it with an IR instrument

The ability of certain gases to absorb infrared radiation has been successfully utilized in developing instruments for gas sensing. An infrared gas sensor consists of an infrared source (emitting broadband radiation including the wavelength absorbed by the target gas) and an infrared detector that are separated by a gas cell. In non-dispersive IR (NDIR) sensors, an IR source and an IR detector are separated by a gas sample cell. An optical “band pass” filter is placed either in front of the source or the detector to screen out all radiation except for the wavelength that is absorbed by the target gas.

The characteristic output of the sensor element is called “absorption” and is the percentage loss between the IR radiation that reaches the detector with and without the target gas in the gas cell. The absorption is calculated from the infrared signals measured under zero gas (gas that does not have infrared absorption, e.g. nitrogen) I_0, and under the gas of interest I_G using the relationship,

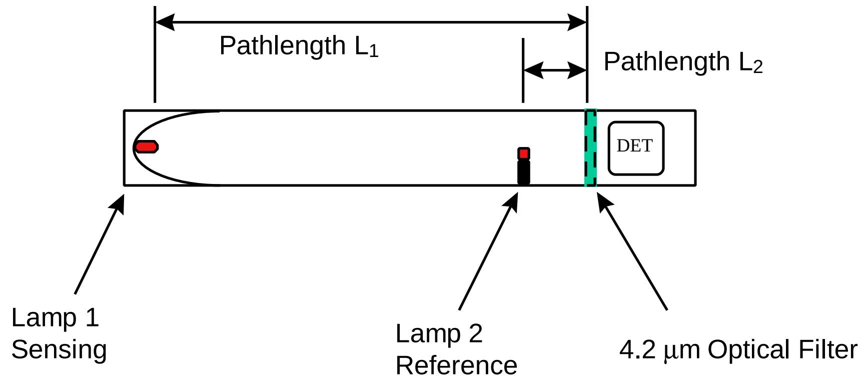
$$A = \frac{I_0 - I_G}{I_0}$$

Absorption increases with 1) increasing gas concentration and 2) increasing optical path length between the detector and the source. Knowing the dependence of absorption on the gas concentration for a given path length, a sensor will measure an unknown gas concentration based on the measured absorption.

A simple, single channel sensor interprets any loss in infrared signal as due to increasing absorption by the target gas. Therefore, the sensor design should ensure that the signal loss is not due to any other means such as infrared source or detector deterioration, changes in the optical assembly, or temperature variations. In practice, a reference channel is added to the sensor to correct for these potential problems. A reference channel is employed to optically measure changes in infrared radiation that are not caused by the gas of interest.

An ideal reference channel should use exactly the same optical path as the sensing channel and should not have any absorption by the target gas or by any other possible interfering gases. Commercially, there are several infrared gas sensors that use a reference channel. However, most do not satisfy the “ideal reference” conditions.

Texas Instrument’s new infrared gas sensor design utilizes a patented Virtual Reference™ channel at the absorbing wavelength that eliminates the need for locating a nonabsorbing infrared region for the reference channel. The optical design and the absorption theory are described in detail on the next page.



The sensor has two infrared sources (Lamp 1 and Lamp 2), one infrared detector and a narrow band optical filter that passes infrared radiation only at the wavelength absorbed by the gas of interest (4.2 microns for CO_2). Lamps 1 and 2 are placed in the gas cell at distances L_1 and L_2 respectively from the detector. When a gas concentration C is present in the gas cell, it will absorb the infrared radiation emitted by both the sources according to Beer's Law:

Sensing lamp signal	$S_1 = I_1 e^{(-KCL_1)}$
Reference lamp signal	$S_2 = I_2 e^{(-KCL_2)}$

K = absorption constant
C = gas concentration
I = IR Intensity emitted by the source

Ratio, $R = S_1/S_2 = (I_1/I_2)e^{\{-KC(L_1-L_2)\}}$

Since the radiation from Lamp 2 travels a much shorter path through the gas, it will be absorbed less than the radiation from Lamp 1. The ratio of these signals shows the same absorption characteristics with an equivalent cell length of (L_1-L_2). However, the signal from Lamp 2 will be equally effected by environmental factors, system aging and other unwanted factors. The absorption calculated from this ratio for the differential path system can be used to sense the gas concentration while referencing out non-signal impacts. Lamp 2 acts as the Virtual Reference™ to the system at the absorption wave length.

A key factor in traditional IR sensors is temperature dependency of the detector/filter pair. The use of single detector and single optical filter in calculating the absorption ratio in this design gives extremely good temperature performance to the sensor. Movements in output due to temperature dependency of the detector/filter pair are effectively referenced out.

Further, this is an optically efficient design. IR radiation is provided by incandescent lamps that are operated at a fraction of their recommended power. This provides the sensor with a long MTBF. It also adds stability since the heated elements age at an insignificant rate. Utilizing signal ratios and TI's proprietary signal processing schemes add higher resolution and stable output to the sensor. Fewer components and a simple optical design make it a low cost solution for many infrared gas sensing applications.

In summary, the technology of the TI-GS series of patented Virtual Reference™ designed gas sensors redefines the performance benchmark and price-point of infrared gas sensing. Whether your application centers on meeting a specific laboratory, Demand Control Ventilation, Indoor Air Quality, Controlled Atmosphere, refrigerant monitoring, HVACR installation, industrial instrumentation or Building System Controls requirement, TI has the dedicated staff of design and application engineers to support your immediate needs. TI Gas Sensors promises to continue focusing its research and development efforts on applying the advantages of non-reactive infrared gas sensing to many other existing and new gas sensing applications.