BROADCOM

Application Note

AFBR-S6 Pyroelectric Detectors

System Design Consideration in a Mainstream Capnograph

Overview

Capnography is a clinical method of measuring a patients' CO_2 levels in their inhaled and exhaled breath. The concentration (or partial pressure) of CO_2 is measured in a form of a temporally well-resolved waveform. The amount of CO_2 as a function of time can be analyzed further in order to detect any present lung diseases, or as a diagnostic method in medical and emergency procedures. Exhaled CO_2 is the most definitive vital sign in a person.

The Broadcom® ezPyro® SMD is a world leading solution for digital infrared (IR) detection. Both our SMD and the TO-39 analogue IR pyroelectric gas sensors for capnography are used heavily by the main capnography manufacturers around the world: www.broadcom.com/products/optical-sensors/pyroelectric/ezpyro-smd-digital-pyroelectric-detectors

Features

The capnography customers, who use our IR detectors benefit from the following technological advantages:

- High speed of data readout (10 Hz to 30 Hz optimal)
- Low profile SMD package (3.7 mm x 5.6 mm x 1.3 mm)
- Instant start-up
- Low power consumption (1 µA to 23 µA)

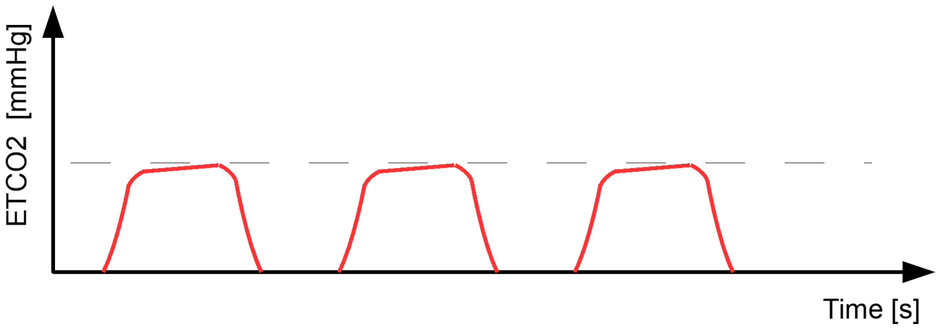
Infrared detector speed is particularly important to achieve a good temporal resolution of the measured CO_2 concentration waveform. When compared to a traditional TO-39 package, the low profile ezPyro SMD package might have an advantage if device size reduction is driving the system design process.

From a capnograph system design perspective, there are certain parameters that are important and need to be taken into account when making a system suitable for volume manufacturing. This application note will describe these parameters in detail.

What is Capnography?

Capnography is a method of measuring CO_2 content in the exhaled and inhaled breath. The concentration (or partial pressure) of CO_2 is measured. Information gathered from this measurement is represented on a graph of concentration as a function of time called a waveform, or a capnogram. See the example capnogram in the following figure.

Figure 1: Simplified sketch of a CO_2 Capnogram



The most important information gathered from a capnogram is the end-tidal CO_2 ($EtCO_2$). This measurement is the partial pressure at the end of an exhale process. Typically, a healthy person should produce a waveform represented by a quasi-square function. By analyzing deviations from that shape, you can learn about any present pulmonary diseases, the patient state, and any diagnostic or procedure problems such as the patient being incorrectly intubated.

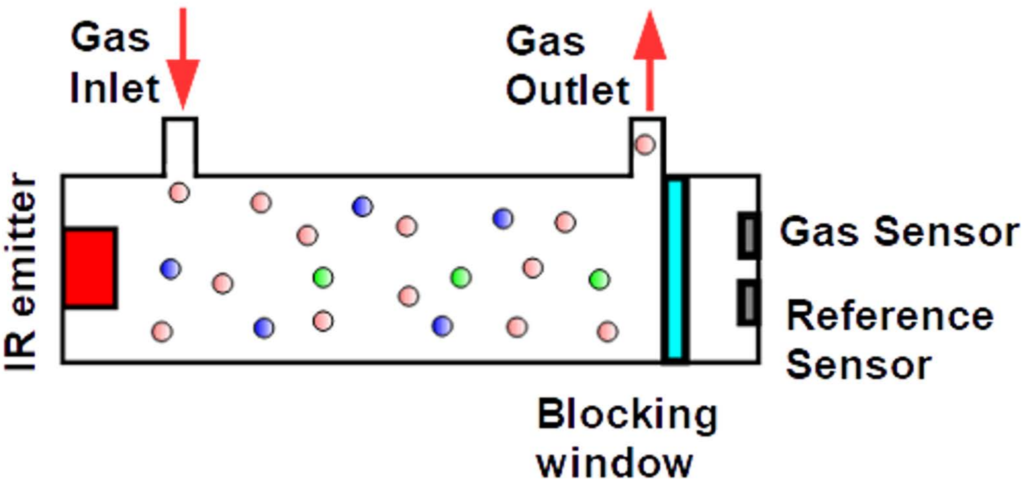
Capnography Systems

There are two main system designs used for capnography. These are: sidestream and mainstream systems. Both systems use a non-dispersive infrared (NDIR) spectroscopy method for measuring CO_2.

NDIR Spectroscopy

NDIR spectroscopy is based on a simple yet effective principle: the absorption of a wide spectral source by a chosen gas, and monitoring detector signal changes at a particular detection wavelength. The signal changes and wavelength correlate to the gas absorption characteristics. The following figure shows a simplified sketch of an NDIR spectroscopy system.

Figure 2: NDIR Spectroscopy System

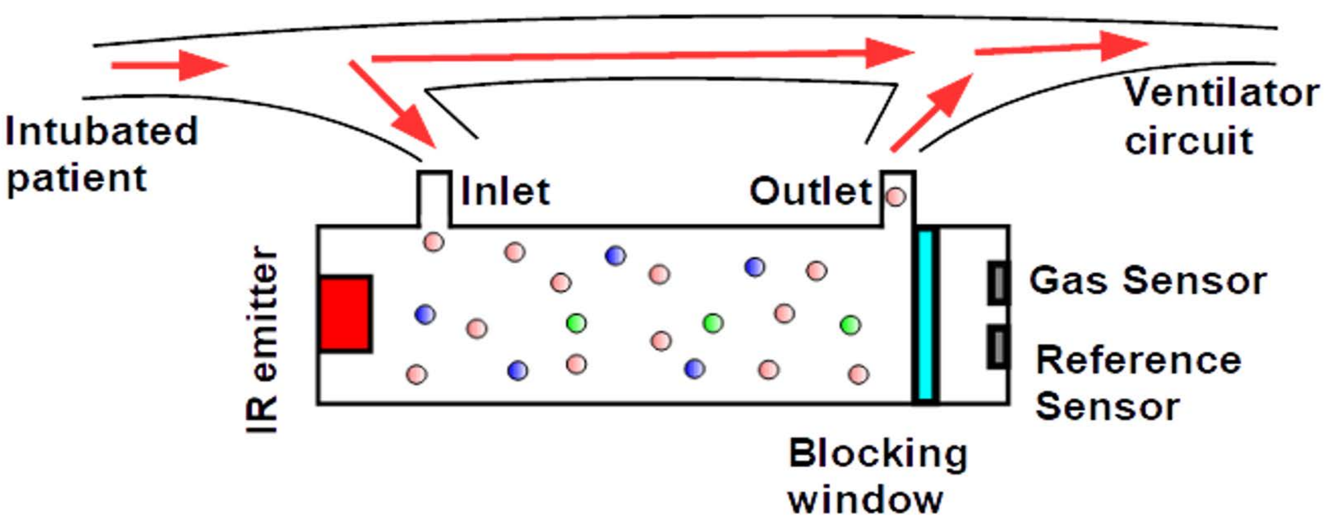


The IR emitter is usually a pulsed blackbody source which can be modulated at 30 Hz to 100 Hz rates, such as a MEMS based device. The emitter fills the gas tube with a broad range of wavelengths corresponding to the blackbody radiation. Some of these wavelengths will become absorbed by the gas. For example, CO_2 absorbs well at ~4.26 µm. If such a broad spectrum interacts directly with a detector, it would not be possible to measure changes at the gas absorption band. A narrowband filter is required to block everything but the gas absorption, such as 4.26/90 (CWL/FWHM) in the case of CO_2.

Sidestream Capnograph

In a sidestream capnograph, the measuring device is located away from a patient. In this system, the patient is intubated with a tube and a pumping mechanism is used to transport its breath sample (and often anaesthetic gases) for measurement. In this system a small part of the gas is taken away from the main tube and passed through the NDIR spectroscopy device. There, a Broadcom IR detector is used in order to create the $ETCO_2$ waveform which is then analyzed further. The following figure shows a simple sketch depicting a sidestream system for capnography.

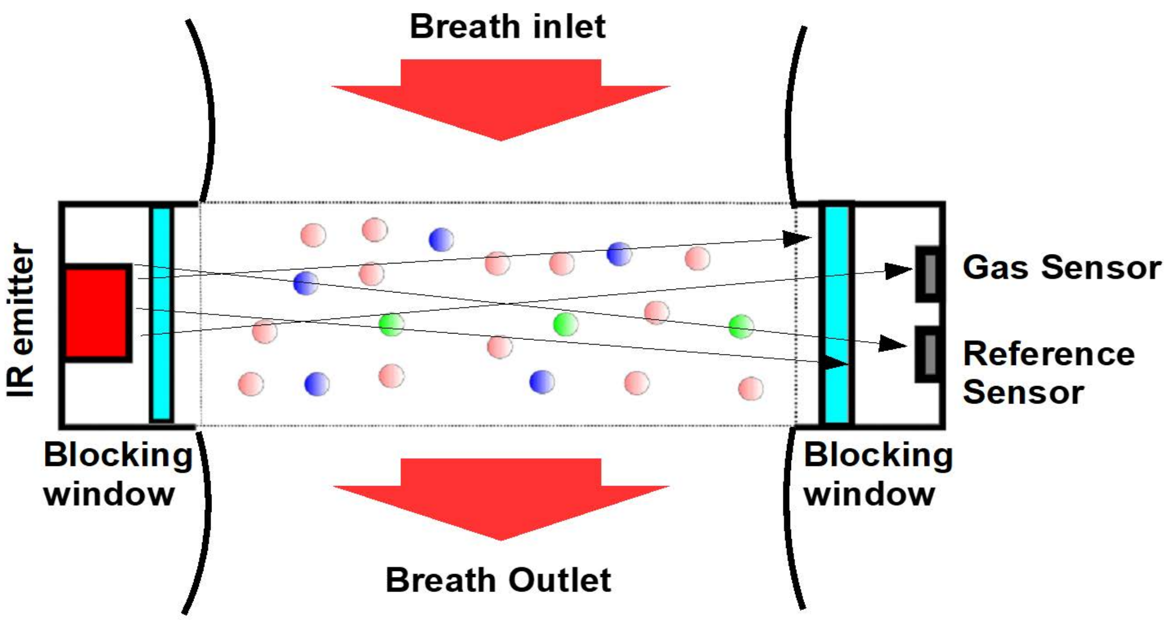
Figure 3: Sidestream Capnography



Mainstream Capnograph

In a mainstream capnograph the measuring device is located directly by the patient. In this system, exhaled breath is measured directly in the breath stream—in contrast to a partial measurement in the sidestream method. It allows for a more pronounced and real-time signal, since more CO_2 is present and the distance from the patient to the NDIR spectroscopy device is minimal. The following figure shows a simple sketch depicting a mainstream capnograph.

Figure 4: Mainstream Capnograph



Mainstream Capnograph Manufacturing

Mainstream capnographs are compact and direct measuring devices. They are typically better suited for a high volume and affordable manufacturing since they can be sold separately from the whole ventilation system.

Calibration

Two main steps for calibrating a mainstream capnograph exist. They are in fact not exclusive for capnography but are used widely for NDIR gas sensing systems.

The first step, a production step, uses an already calibrated environmental chamber located in a factory. Inside this chamber, gas is added at known concentrations while the temperature is varied. NDIR spectrometers (in this case, mainstream capnographs) are placed in the chamber, and calibration functions are derived from these readings while the concentration and temperature is varied.

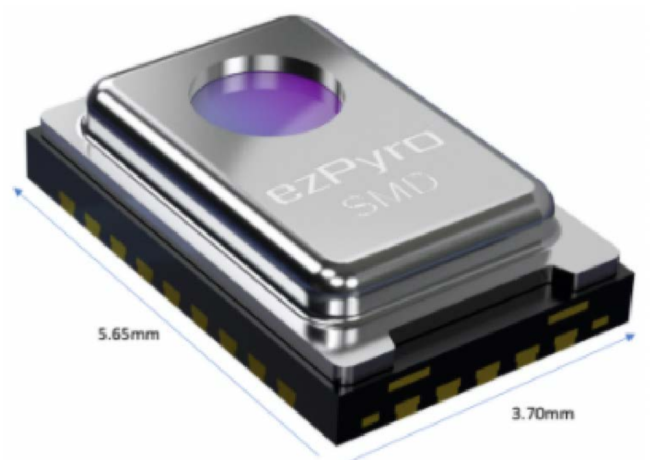
The second step consists of zeroing the already pre-calibrated capnograph in an open environment. This step can be performed where the concentration of CO_2 from breathing is close to atmospheric; such as in a hospital, in an open and non-crowded space, or outside.

For more details on procedural requirements for capnography systems, see ISO 80601-2-55:2018 Medical electrical equipment – Part 2-55: *Particular requirements for the basic safety and essential performance of respiratory gas monitors*.

Detector Speed and Size

You must have a fast detector to have a good quality and well resolved reading from a capnograph. A typical requirement for capnography systems is a detector that takes a reading at ~20 Hz to 30 Hz. Most pyro detectors are most efficient at around 2 Hz to 10 Hz, making them too slow for high quality capnography devices. Thanks to the Broadcom proprietary thin film technology of manufacturing, our detectors are faster than other competing technologies and therefore extremely well suited for capnography.

Figure 5: ezPyro SMD Infrared Detector



A standard package for an IR detector used in capnography is a TO-39. Most popular Broadcom analogue detectors are dual channel TO-39 detectors, where the second channel is used for a gas reference. Broadcom low profile SMD detectors, called ezPyro are becoming increasingly popular due to the miniaturization demand on mainstream capnographs. The ezPyro detector is significantly smaller than the TO-39 detector, and is ready for high volume manufacturing. These features makes them the detectors for capnography.

Tolerances

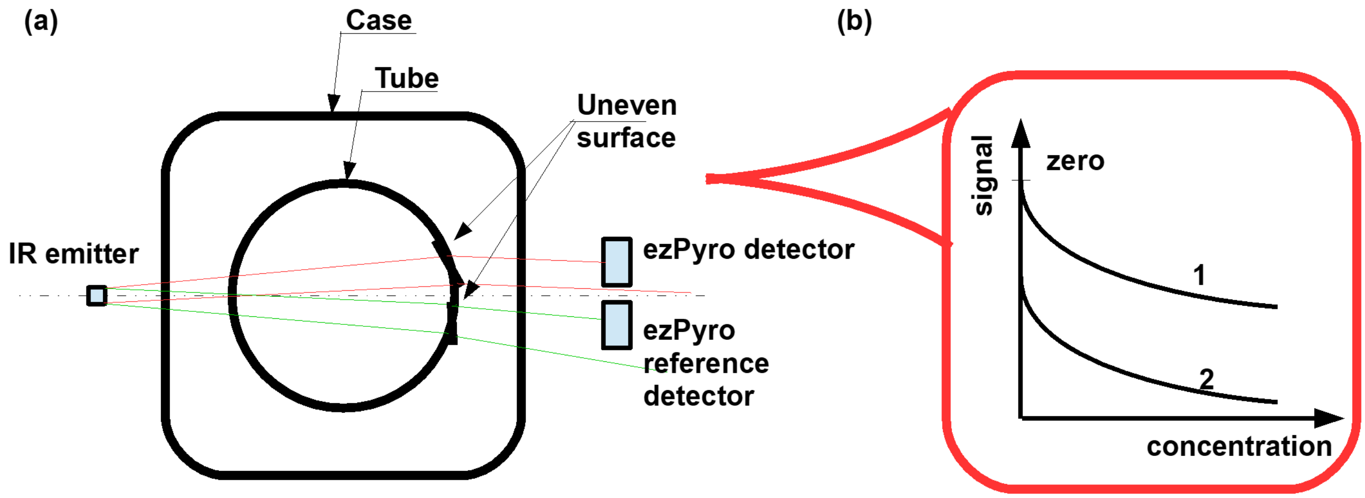
Since mainstream capnographs are manufactured in volume, tolerances on certain parts might be relaxed to reach an affordable cost level. A system designer should take care when defining these tolerances since they will be crucial in precise $ETCO_2$ measurements.

For example, mechanical tolerances on a tube inside of a mainstream capnograph will have a significant impact on the overall performance.

Tube Surface

An uneven or corrugated tube surface might result in skewing of the emitter light and a signal strength change on the detector as shown in the following figure.

Figure 6: (a) Side cross section of a mainstream capnograph. (b) The effect it may have on the calibration function 1 → 2.



Depending on the refractive index of the tube and the type and amount of deformation on the tube surface, a light ray may be skewed from the path toward the detector and lower the amount of signal reaching it.

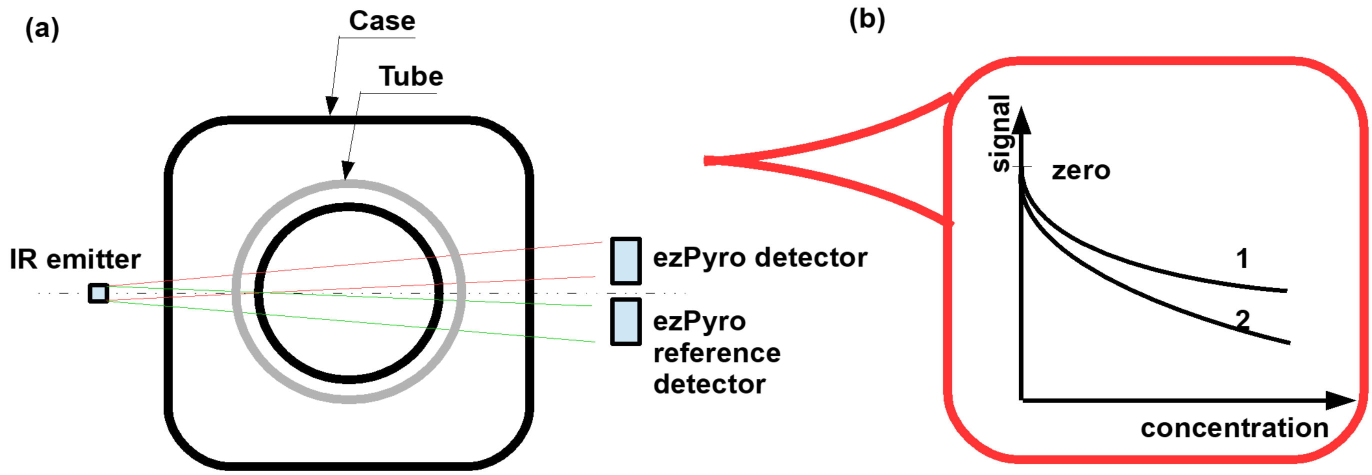
Tube Size

A tolerance on tube size and diameter is directly connected to the effective path length of each light ray going through the exhaled breath. NDIR spectroscopy is based on the Beer-Lambert law, which states that the signal change is exponentially proportionate to the path length of a gas cell, given by the equation:

$$I/I_o = e^{-\varepsilon L c}$$

Where I/I_O is the ratio of the signal absorbed by the gas to the undisrupted signal, ε is a constant depended on the absorption lines of a particular gas, c is the concentration of a gas, and L is the gas cell path length. Because of the exponential relationship described above, the path length change will have an impact on the calibration function shape. See the following figure for more information.

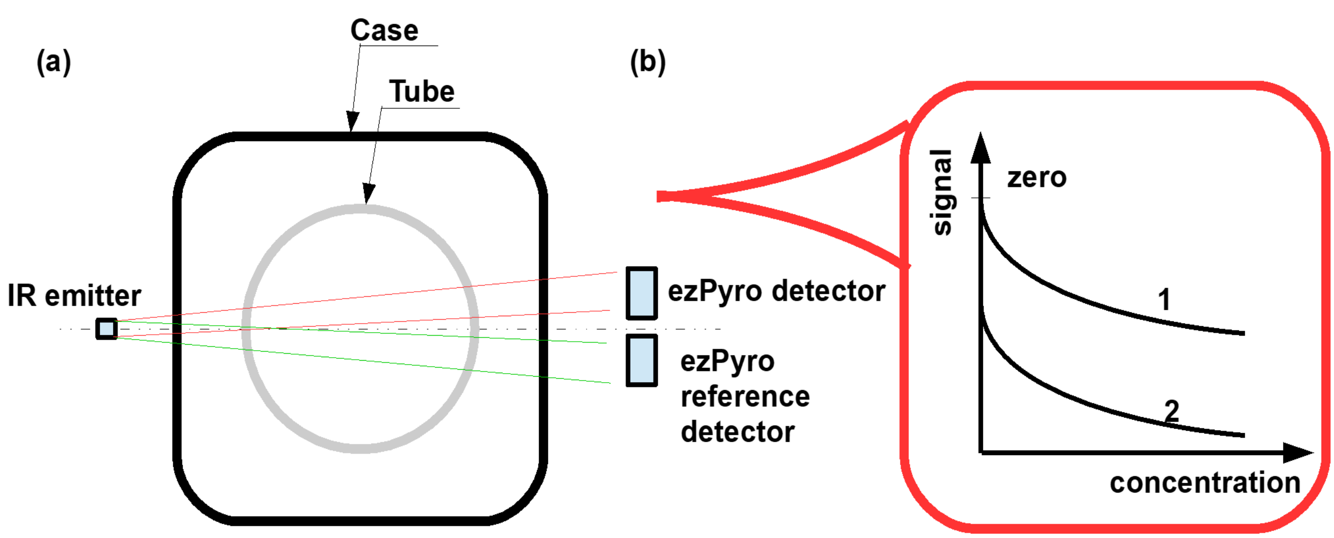
Figure 7: (a) Side cross section of a mainstream capnograph. The light gray circle indicates a diameter change of the tube. (b) The calibration function change as a result of the tube size variation 1 → 2.



Tube Material Variations

Tube material variation will not change the calibration function shape but its signal level (similar to Tube Surface), see Figure 8. This change is caused by a lower or higher amount of signal absorbed or transmitted by the tube material. Consistency of the tube material is therefore an important part of both tolerancing specifications as well as supplier quality checks.

Figure 8: (a) Side cross section of a mainstream capnograph. The light gray circle indicates a variation in the tube material. (b) The calibration function change as a result of the tube material variation 1 → 2.



Conclusions

Capnography is an exciting market with even more exciting technology behind it. It helps to improve people's health by giving a precise respiratory disease diagnosis. New applications for breath measurements are constantly being developed, and this data provides new methods for human health monitoring.

Broadcom manufactures detectors that are particularly well suited for capnography: continuous positive airway pressure (CPAP) machines, anesthesia systems, breath actuated metered-dose inhalers (MDI), and respiratory systems including ventilators. We have successfully provided detectors to many business partners world-wide and are expanding our presence in this market.