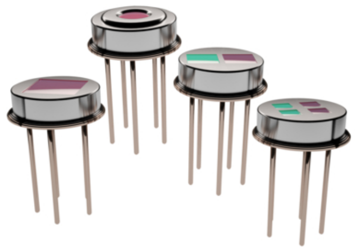
Broadcom

White Paper

A Guide to Choosing Sensor Technologies for Gas and Flame Detection and Analysis



Executive Summary

Mid-IR infrared sensing is widely used today in a broad range of detection and analysis applications, including flame and gas detection, fuel and oil analysis, food safety, and motion and gesture sensing. An innovative approach from both equipment designers and suppliers of core sensing technology is required to meet the technological challenges presented by the growing need for low-power, robust equipment with minimal calibration.

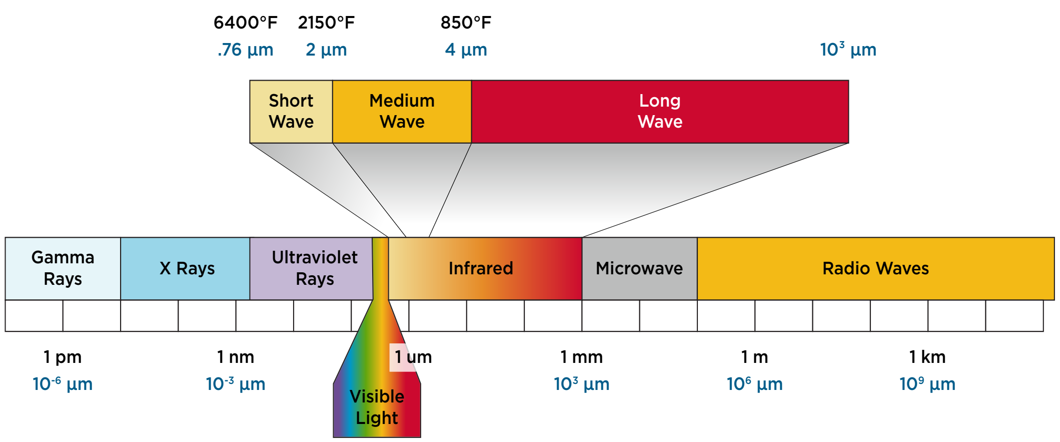
This white paper covers various infrared (IR) sensing techniques available to developers of gas and flame detection equipment, focusing on the characteristics and advantages of mid-IR sensors. Although for some applications robustness is critical, in others it is ultra-low power, cost, or the ability to digitally integrate multiple sensors in a complex monitoring environment or piece of equipment.

The choice of sensor format (analog or digital), filter options, and configurability is discussed with both flame detection and gas sensing applications in mind.

Introduction

In the electromagnetic spectrum, infrared radiation is found between visible light and microwaves. It is typically defined to span the region from 800 nm to 1 mm. See Figure 1.

Figure 1: Infrared radiation is found between visible light and microwaves. It is divided into three wavelength groups: near, mid, and far IR.



Infrared is itself divided into three distinct regions, based on the frequency of the IR radiation relative to the visible spectrum. Thus, near-IR is closest to visible light, typically 760 nm to 3 µm; mid-IR is from 3 µm to 14 µm; while far-IR is the broadest of the three, ranging from 14 µm to 1 mm.

Infrared sensors can be active (emitter and detector) or passive (detector only). Passive IR sensors in the mid-IR and far-IR regions are generally thermal IR detectors, whereas near IR-sensors are typically quantum detectors, also known as photodetectors. Photodetectors can have faster response times and greater sensitivity than thermal detectors, but they typically must be cooled in order to cut thermal noise, particularly when used for detecting longer wavelength radiation. This paper focuses on passive pyroelectric IR sensors, which do not need external cooling.

Passive IR sensors are particularly useful for analysis as they do not influence the samples or the environment within which they operate. Based on pyroelectric materials, typically crystals, they generate an electrical voltage when heated or cooled. In simple terms, IR sensors turn incoming IR radiation into an electrical signal.

A passive IR sensor may comprise one, two, four, or many individual detector cells, available in various package styles, including TO cans, for conventional through-hole boards or SMDs for direct mounting onto PCBs. The sensor's outputs can be very small, so an amplifier or pre-amplifier is typically integrated into the package with an internal voltage regulator. Outputs may be analog or digital or both, the latter incorporating an analog-to-digital converter.

Most IR sensors require integration with a microcontroller, either incorporated in the package or interfaced externally, via I^2C, USB, or other protocols, allowing for easy system integration.

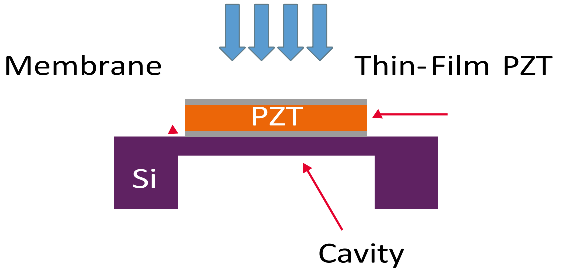
An optical filter or lens can be placed in front of the sensor, enabling it to select specific wavelengths. For some applications, a lens assembly may be incorporated to focus distant IR radiation onto the pyroelectric detector by extending the range of detection or increasing the field of view. In order to limit the spectral response, an optical band-pass filter can be used to block certain radiation wavelengths, to avoid false alarms, for example, or to detect specific substances. When multiple elements are integrated into a sensor array, the application may call for different wavelengths of IR light to be detected by each pixel. In this case, a device such as a linear variable filter (LVF) can be integrated.

IR Radiation Sensing

Passive IR sensors can be constructed from bulk or thin-film pyroelectric materials, which may be based on lead zirconate titanate (PZT) or lithium tantalate (LiTaO3). Alternatively, thermopile devices can be used. Thermopiles consist of a stack of thermocouples that form an electrical series of alternating materials. When a temperature difference is applied between the joints, an electrical voltage (signal) is produced.

While thermopiles are a mature technology that delivers a reasonably good signal-to-noise ratio (SNR) and small pixels in an SMD format if required, responsivity is low. Pyroelectric thin-film PZT, meanwhile, has a superior SNR, has high responsivity, and is faster and more accurate. In addition, PZT devices can be smaller with denser arrays. Manufacturing is scalable and transferable, and the technology offers strong potential for improved performance. See Figure 2.

Figure 2: Exploded Side View of the Structure of a Typical Thin-Film Pyroelectric PZT Mid-IR Sensor Device Delivering High Performance in a Robust Package



Conversely, pyroelectric LiTaO3-based IR detectors have comparable performance to thin film, with a good signal-to-noise ratio and high responsivity. However, resolution (both temporal and wavelength) of multipixel arrays may be lower, they generally feature large elements, and they are not available as SMDs. Devices are manufactured in dedicated fabs, and consequently they are often more expensive and supply is inflexible.

Bulk pyroelectric devices are typically characterized with poor SNR and low responsivity when compared to thin-film alternatives. Although they can cost less, sensing elements are larger, devices are manufactured in dedicated fabs, and they are typically not available in SMD format.

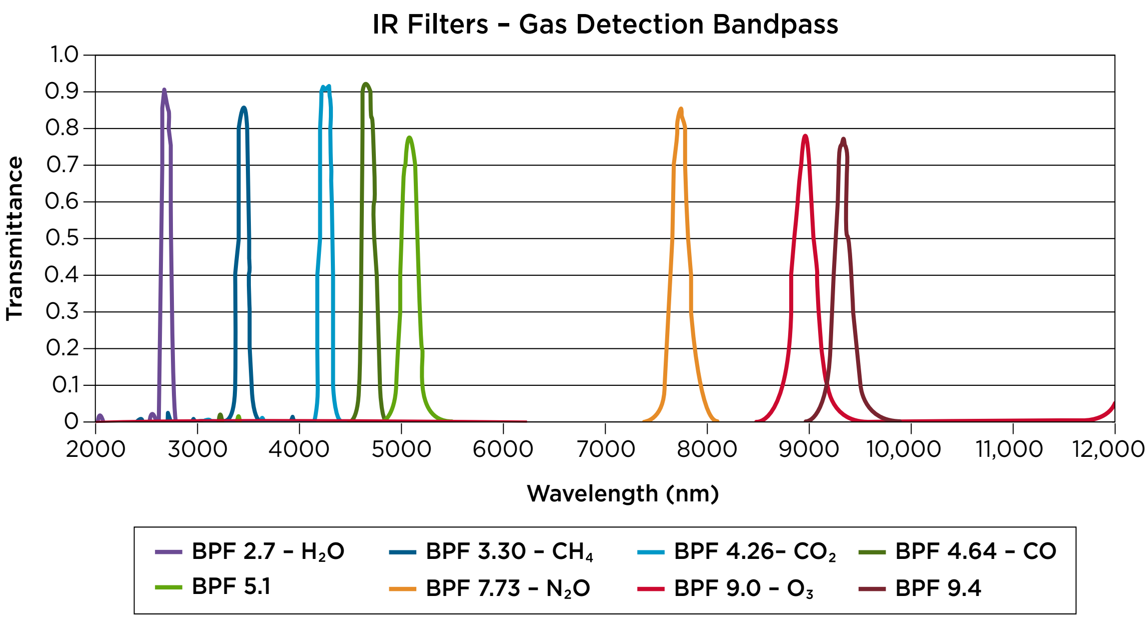
Mid-IR Techniques

All objects emit or absorb some form of thermal radiation, usually in the infrared spectrum, and different materials absorb different wavelengths of infrared energy. Thus, IR sensors are highly suitable for analyzing substances, including solids, liquids, and gases, and identifying specific elements within those substances. Additionally, they can be used to detect flames, as well as presence and motion.

IR energy from an emitter excites vibrational motions in the covalent bonds in molecules. In the case of a flame, IR energy is emitted as a function of the same molecular bonds. These vibrational modes have been proven to be unique to a specific chemical structure, thereby providing a “fingerprint” of the sample material for identification purposes.

The interaction of mid-IR radiation with a given sample has been shown to provide the most useful spectral fingerprint, being very specific to the chemical structure of the sample. So for gas sensing and flame detection, mid-IR sensors with gas-specific optical filters are the optimum choice to detect and identify the IR absorption peaks associated with different gases. See Figure 3.

Figure 3: IR Absorption Peaks Associated with Different Gases



Sensor Formats

Broadcom offers mid-IR sensors in a number of different formats, including discrete sensors and line arrays. At the heart of the company's core lies its unique thin-film PZT, mid-IR sensor technology, together with the required materials, deposition/ process, optics, sensor-level firmware, and applications knowledge. From this base, Broadcom has developed many compatible and complementary product ranges and can develop new pixel geometries and tailored designs to meet specific customer requirements.

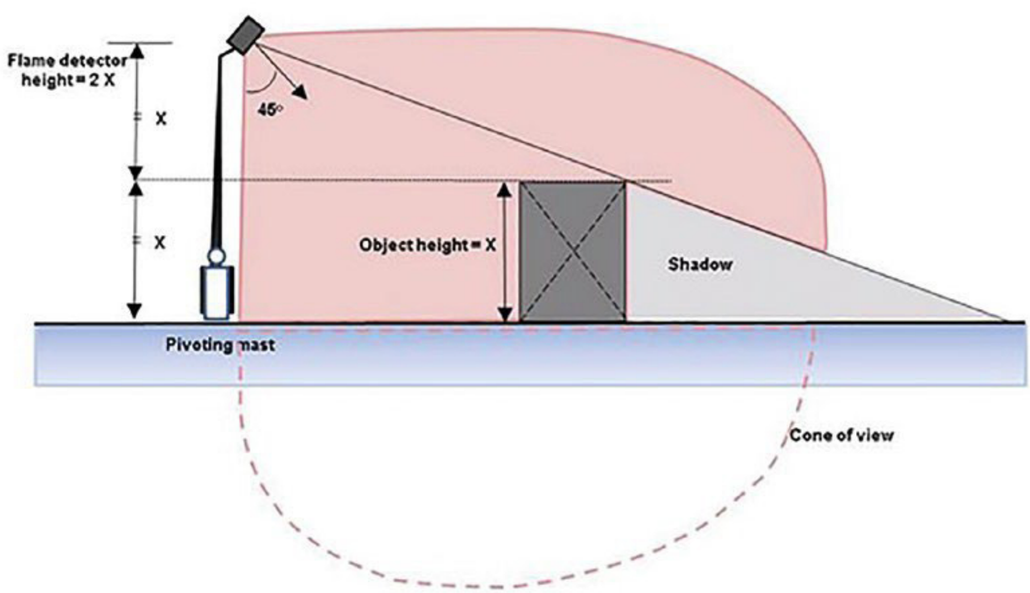
Catalog parts include analog single and dual IR detectors ("discrete wavelengths") packaged in TO-39 cans, single and 2x2 pixel digital IR sensors in an SMD format, plus linear IR sensor arrays in robust through-hole packages with no moving parts. While the linear arrays with 128 pixels best suit spectroscopy applications and very complex gas mixes, the discrete wavelength devices are eminently suitable for most gas and flame detection applications.

In terms of packaging, TO-39 cans (analog or digital) are better suited to challenging, long range outdoor environments requiring precision detection, such as heavy industrial, oil and gas, infrastructure and forest protection. They also typically feature a larger sensor area, accommodating more pixels to yield a higher SNR.

Flame Detection

IR sensing of flames finds application in many industries including oil and gas, chemical production, marine, transportation and logistics, energy and power, retail, healthcare, general manufacturing, and more recently, in home and commercial buildings. In operation, IR sensors measure the hot gases generated by a flame, in particular CO_2. SNR is an important characteristic for flame sensing, as well as field of view (FoV) and dynamic range, both being as large as possible in a single sensor. See Figure 4.

Figure 4: Field of view (FoV) is important in IR sensors for flame detection, covering as large an area as possible with a single device. (By Jan.Nijkamp - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5621925)



Companion IR sensors with appropriate filters are used to detect and reject other IR sources, such as sunlight and body heat, as well as application-specific sources, such as arc welding equipment, hot materials, or halogen lamps. Additional channels may also be used as reference channels, comparing the CO_2 signal with a channel unaffected by flames.

Both Broadcom® analog and digital mid-IR sensors are applicable to flame detection systems. The choice depends on critical performance factors, such as robustness, field of view, speed of response, and power consumption, as well as configuration criteria such as multisensor and digital system integration requirements.

Gas Sensing

Growing emphasis on environmental monitoring, including air quality, climate control, and toxic and combustible gas detection is generating new applications for gas sensing in homes, buildings, and the automotive/transportation sector. In the medical market, gas sensing is important for breath analysis for diagnostics, patient monitoring, ventilators, anesthesia, and breathalysers. In agriculture and horticulture, it is used to monitor food storage facilities, animal activity/consumption, and plant growth in greenhouses.

The four most common gases monitored are oxygen, carbon monoxide, carbon dioxide, and nitrogen oxide. The key advantages of IR sensing over alternative methods, such as electrochemical, MOS/MOX, and catalytic bead, are zero maintenance (no need for calibration), long lifetime (10 to 15 years), fast and accurate response, and the ability to detect and identify a wide range of gases. Low-power operation and a small SMD package enable portable, battery-powered detector devices.

Again, Broadcom offers both digital and analog IR sensors with a range of filter options, and the choice depends on the critical parameters of the end application, such as performance, the end equipment environment (indoor or outdoor), the gas or gases to be detected, system configuration or complexity, and digital integration requirements.

Analog Mid-IR Sensors

Broadcom analog sensors are simple, low-component count devices in single-pixel or dual-pixel formats. They are able to meet tough flame detection requirements. The high-performance features inherent in their thin-film, pyroelectric PZT construction include current mode sensing with 100 kV/W to 200 kV/W responsivity, stable response over the full flame flicker range of 3 Hz to 15 Hz, an ultra-short time constant of ~12 ms for fast flame detection, and a high dynamic range to detect nearby and distant flames.

Filter options include arc welding rejection, human motion rejection, and CO_2 in flame. In triple IR flame detection systems, flame sources can be accurately determined. An internal CMOS op-amp provides enhanced stability and reliability.

In gas detection applications, high responsivity enables lower power operating and extended emitter life. Optical filter options are available for all four common gases plus specialist anesthetic and refrigerant gases. The dual packages are particularly useful in gas sensing applications, and more information can be found at https://www.broadcom.com/products/optical-sensors/pyroelectric.

Digital Mid-IR Sensors

The ezPyro® digital IR sensor range is available in single-element and 2x2 pixel versions. Supplied with an integrated, configurable ASIC containing an I^2C interface, these ultra-low power devices are the smallest available in an SMD package measuring just 5.65 mm x 3.7 mm x 1.55 mm. ezPyro networks can replace conventional TO-39 packaged quads, with a similar PCB footprint and lower build height. For flame detection applications, the improved FoV is particularly important.

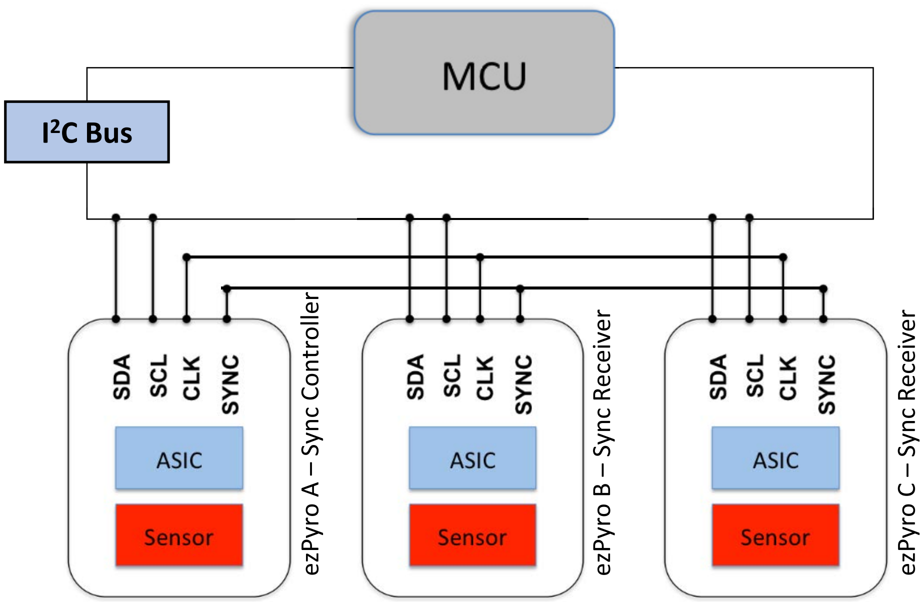
Featuring a current mode sensor readout, five-channel low-noise amplifier, and five-channel sigma-delta converter, the devices offer additional functionality including on-board clock and power management, enabling their use in energy harvesting applications.

Indeed, ezPyro technology offers various power saving modes. In normal active power mode, with four active channels at 1 kHz, power consumption is a comparatively low 60 µA. In low-power mode with four channels active at 166 Hz, consumption drops to 7.5 µA. With just one active channel at 166 Hz (enabling a wake-up signal), consumption is just 3.5 µA, while total power down mode, with wake-up by chip-select, is a mere 1.1 µA. In gas measurement applications, the ezPyro detector allows further system-level power consumption, as its high responsivity enables the use of shorter or lower-intensity IR source pulses.

The wake-up by signal feature turns off the I^2C digital output stream, while the sensor itself remains active. The wake-up signal is configurable by strength or duration, and it may be triggered by flame, for example, or a specific level of gas concentration, as well as by motion.

A further key advantage of digital IR sensors is the implementation of a full I^2C bus, allowing digital output, plus easy sensor configuration, not only for setup and power management, but also for complex systems operation. End systems might involve multiple sensors either networked or daisy-chained. For example, for flame detection using multiple rejection and reference channels, and in gas sensing for detecting multiple gases and reference channels. See Figure 5.

Figure 5: ezPyro digital IR sensors can be daisy-chained and networked using the I^2C bus, for multigas detection or flame detection with multiple rejection and reference channels.



An entire ecosystem for ezPyro detectors is developing fast, with an open API for application firmware and software development and re-use, based on an ARM Cortex M4 core. Broadcom also offers a range of evaluation boards and kits for a range of applications, including gas and flame sensing, plus backplanes and breakout boards for fast prototyping.

Key Specifications to Look For

While the end application generally determines which mid-IR sensors to use, there are some key specifications and features that engineers should look for when choosing and selecting sensor components for a new design, particularly for use in portable equipment.

- **Small size** – PZT thin-film processes produce the tiniest IR sensor components, enabling smaller and denser, high-resolution arrays and modules.
- **Physical robustness** – With no moving parts, the technology is innately rugged, withstanding shock and vibration and high operating temperatures.
- **No required cooling** – PZT can be easily patterned to provide individual sensor pixels on a thermally isolating membrane layer; simpler, more compact system options.
- **Minimal calibration** – Fit and forget: rugged, thin-film PTZ technology delivers stable and accurate operation, with no degradation over time or due to higher temperatures. Important in remote and energy harvesting applications.
- **High responsivity** – Current mode readout provides high responsivity over voltage mode types. Output signals do not depend on sensor capacitance, giving faster response times. See Table 1.

Table 1: Current mode sensing delivers higher, faster, and more stable responsivity than traditional voltage mode.

Parameter	Typical Voltage Mode Sensor	Broadcom Current Mode Sensor
Responsivity	< 5 kV/W	100–150 kV/W
Thermal Frequency Response	Peaks at 0.1–1.0 Hz	Stable up to 100 Hz
Time Constant	> 100 ms	~10 ms

- **Excellent signal-to-noise ratio and high sensitivity** – Thin-film pyroelectric IR sensors deliver the highest specifications.
- **Low power** – Passive devices offer the lowest power operation with lower duty cycle. Readout circuits can be as low as 0.9 µA, with wake-up via IR radiation. Important for all battery portable and energy harvesting applications.
- **Modularity** – Packaging options from chip to array, plus a range of filters, digital interfaces, and complementary products for easy systems integration. Re-use of technology (especially software and firmware) for variants and new products.
- **Integration** – Easy interfacing within even the simplest system to microcontroller. Also, the ability to daisy-chain and/or network for complex systems. Useful for systems where data is transferred to a central controller, such as in medical equipment, security monitoring, and so on.
- **Economy** – Manufactured in standard semiconductor foundries, taking advantage of competitive process options. Small, dense arrays enable lower-cost modules for portable systems.
- **Scalable production** – Technology is easily scalable for low or high volumes; particularly important for upcoming applications in the automotive and consumer markets.
- **Developing (yet proven) technology** – New R&D investment likely to lead to improved performance and broader application scope. Design flexibility for easy customization, important in the medical market.

Conclusion

This white paper has shown the key advantages of mid-IR sensor technology for flame and gas sensing applications. Mid-IR sensors are optimum for determining sample composition due to their ability to generate a clear “fingerprint” of components (specifically gases) detected. Thin-film PZT technology allows manufacturing of mid-IR sensors that are small and robust, both physically and thermally.

The technology delivers higher responsivity, superior signal-to-noise ratio, and lower power operation over alternative approaches. Easy interfacing to microcontrollers using industry-standard protocols, a wide range of filter options, and modular construction allow OEMs to build equipment that is easy to use and tailored for the specific end-user application.

Scalable manufacturing using standard semiconductor fabs ensures that the technology will suit a wide range of applications at low cost. Continued investment in R&D shows great potential for upcoming applications in new market sectors.