Applications and design ideas with IR Sensors

Smart Home

Private homes are an ideal application space for smart sensing products. Outdoor applications include automatic safety lighting to illuminate driveways, pathways and entrances, as well as motion-activated surveillance cameras and smart door bell cameras for home security and property surveillance.

Indoor applications can sense a car in the garage, trigger stairway lighting, and activate TV and PC monitors. Motion and presence activated heating, room air conditioners, and automatic wall switches for room lights require suited IR Sensors.

In the Kitchen

Modern kitchens are suited with many sophisticated devices and appliances for smart food preparation and storage. In addition to being a part of smart home infrastructure, the kitchen may be linked onto LAN or KNX bus. The equipment with it's electronic control circuitry is perfectly suited to accomplish added functionalities by adding sensors. In refrigerators and freezers, food temperature can be controlled without probes to ensure optimal preservation. With microwave ovens, defrost and heating functions can be monitored and controlled with similar IR sensor applications. Stove-top cooking can also be monitored by various sensors and exhaust fans can be automatically activated for safety and comfort. Gas detectors alert us of dangerous gas concentrations for added safety in smart home infrastructures.

Home Health

One of the most popular IR sensing devices in our homes is fever temperature measuring using ear thermometers. The function is realized by a non-contact IR sensor measurement looking at the ear canal. A similar sensor is applied for a more easy measurement. The forehead thermometer is well suited to quicktest a baby's temperature without putting harm to the infant. In more clinical applications, IR sensor based gas monitors help during surgery to provide suitable breathing support.

Distributor
AZPECT part of amsTECHNOLOGIES
where technologies meet solutions
nordics@amstechnologies.com
azpect.amstechnologies.com
Contact us

For these applications Excelitas DigiPyro® and CaliPile® IR Sensors provide motion activiation and presence monitoring to optimize energy usage in real time based upon human presence.

Public Buildings

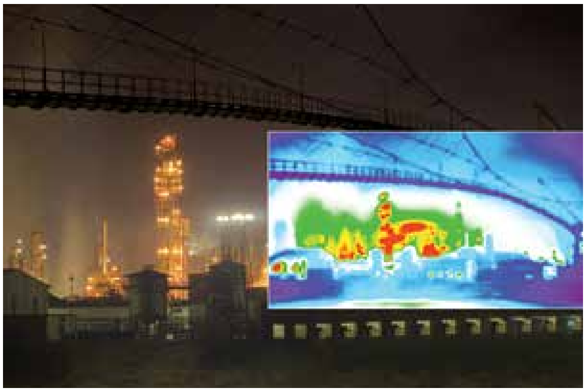
Public facilities and buildings are an ideal space for smart sensing applications. As a more effective alternative to pre-defined clock dusk-to-dawn set lights, motion activated light controls offer the forefront of energy conservation and reduce light pollution. In storage buildings, high bay luminaire control saves signifcant amounts of power and money by activating lights only when a person is present in that sector.

In the Office

Offices require ample lighting to maximize efficient work spaces during operating hours. Often enough these lights are manually operated, or may be left on when work spaces are not in use. This presents a significant opportunity for power savings and economy gains if controlled by IR based presence sensors.

Motion detection, presence monitoring and high-bay luminaire controls represent the future of energy-efficient work environments. Monitor displays, PCs and AV equipment may be hibernated when users depart their terminals or meeting space and even HVAC can be sensor controlled for intelligent and dynamic room temperature controls based upon presence, sunlight shift and ambient temperatures.

Industry



All industrial processes require sensor-based supervision and control. Whenever heating processes are applied, non contact temperature measurement is the preferred method of collecting process data.

Gas monitors of various physical principles contribute to safe and controlled areas. Among critical gases, the infrared based NDIR gas sensor modules provide long-term stable measurement and reliability.

Infrared Basics

All solid bodies when having temperatures above the absolute zero (-273 °C) emit electromagnetic waves. The range of longer wave lengths beyond the visual spectrum is referenced as infrared radiation. Scientist Wilhelm Wien (1864–1928) has described the relation between a solid body's temperature and its emitting peak wave length by following equation:

$\lambda_{max} = 2898 / T$
T = Temperature in K (Kelvin)
λ = Wavelength in µm

With this formula the peak emission wave length of any material may be calculated.

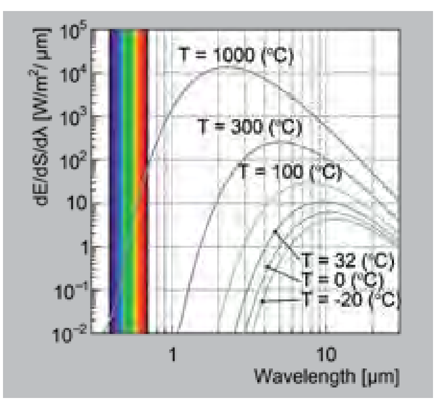


Fig 1:Radiated Energy vs. Wavelength

Max Planck (1858–1947) has described the relation between a solid body's surface temperature and its emitting wave length.

According to Max Planck, the intensity curve of all emitted wave lengths for a solid body is rather broad. For the case of an ideal emitting body the emission spectrum is shown in Figure 1 for selected surface temperatures. Ideal emitters are called "black body".

With the naked eye we can see hot objects at about 1000°C glow red and we can feel the heat, whereas colder objects that cannot be seen glowing, still may emit heat. The human eye's sensitivity is limited to the so-called visible range of 300 to 750 nm. To detect the non-visible infrared-radiation, we need sensors that work in the range beyond, which is 1µm and further. Typical sensors for motion detection use windows 5µm to 14µm.

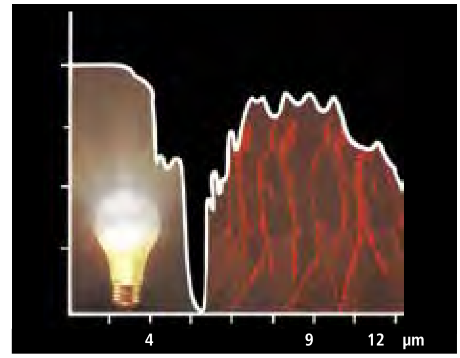
Temperature Dependence

The radiation sent from emitting bodies is temperature dependent. There is another parameter which determines the body's surface property. With this Emissivity factor we can estimate the total emitted radiation power P of a warm object:

$$P_{net} \sim \varepsilon T^4_{obj} + (1-\varepsilon)\, T^4_{amb}$$

The radiated Power is proportional to its surface temperature T [Kelvin] to the Power of 4 and its emissivity. The emissivity ε of the surface of an ideal black body is 1. An opaque object with an emissivity lower than 1 (gray body) will additionally reflect the temperature of the ambient.

Hot objects generally dominate any total radiation over cold objects due to the power of 4 dependence.



Spectral working range versus visible light

The Real World

The human skin as well as water have a very high emissivity in the far infrared of above 0.9. The peak emission for human skin temperature is around 10µm and it is barely radiating below 3µm.

Typically, specular objects are highly reflective in the infrared region and contribute less to the total radiation received from the objects surface temperature. Diffuse objects can have a high emissivity and are better suited for measuring their surface radiation.
We further need to consider that properties in the visible spectrum may totally differ from the properties in the IR spectrum.

A human head with a surface temperature of approx. 35°C or 308 K calculates into a peak wavelength of 9.4 µm; the body of a cat at 38°C temperature calculates to 9.3 µm. Pets like cat or dogs have similar body temperature. By this, their radiation is very similar to human, and it is not possible to distinguish humans from cats or dogs by their infrared spectrum.

Infrared Detectors

With detectors for the infrared spectrum there are two major classes by their physical principles: Photon Detectors and Thermal Detectors. Photon Detectors convert radiation directly into free electrons. Thermal Detectors receive radiation, transfer it to raising temperature of the sensing material which changes its electrical property in response to the temperature rise. Photon Detectors such as Photodiodes and Phototransistors range from visible to near infrared.

To detect the radiation of objects at typical ambient temperatures, and slightly above, simple photonic detectors based on PN-doped silicon structures such as CCD or CMOS will not work. Advanced technologies, specific for that use, separate into two major classes: **Photon Detectors** and **Thermal Detectors**. Photon Detectors convert radiation directly into electrons and are typically made from cooled exotic semiconducting materials - these detectors are not the scope of this overview.

Thermal Detectors receive radiation, transfer it to raising temperature of the sensing material which changes its electrical property. The spectral range is also dependant from the absorbtion of the material. These detectors have a broad response from below visible light up to over 100µm. Thermal Detectors are sensitive to the net radiation.

$$P_{net} \sim \varepsilon T^4_{obj} + (1-\varepsilon)\, T^4_{amb} - T^4_{sens}$$

Fitted with special infrared windows as spectral filters they work in the mid to far infrared range without ambient visible light interference. Excelitas offers a variety of thermal detectors, including Pyrodetectors and Thermopile Detectors. Pyroelectric sensors require a modulated radiation over time in order to respond with a charge flow. While the response of pyroelectric sensors is generally higher than response of Thermopiles, Thermopiles provide a constant voltage output, which is proportional to the net radiation.

Both technologies respond to radiation changes within several milliseconds making them optimal to detect fast temperature modulations. Details are discussed in the corresponding sections.

Filters for Infrared Sensors

Material used for filters and windows must be transparent in the wavelength of interest. Glass for example is generally not suited to sense the temperature of human skin since it absorbs wavelengths above 4µm. Common materials with a broad transmission range are Germanium and Silicon for being used as the internal filter window for IR Sensors. For outside protection only few materials are suitable. Among many plastics, only PP or HD-PE can be used as protection or as fresnel structured optics for presence and motion detection.

Detectors by Excelitas Technologies are fitted with special infrared windows used as spectral filters. They work in the mid to far infrared range and usually block the visible range. Common applications in infrared reference wavelengths from 2 to 20µm. Thus the many windows allow transmission from 5-14µm. Infrared windows for pyrometric applications are defined for the atmospheric window. To avoid atmospheric absorption long range pyrometers apply a sharp cut-on/cut-off window of 8-14µm (G9).

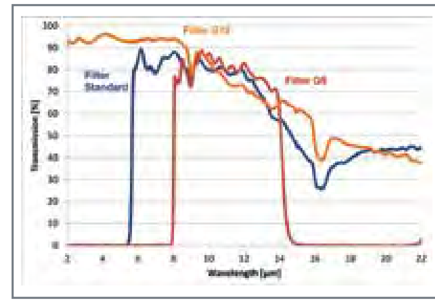


Fig.2

In Fig.2 we show the graph for standard infrared window and the "G9" window. For the special application of Gas Sensing by non-dispersive infrared absorption (NDIR) of a modulated radiation source we offer narrow band filters. The appropriate narrow band optical filters enable detection of Carbon Monoxide, Carbon Dioxide, Natural Gas and other environmental gases, as well as some technical gases. Please refer to the section dedicated to Gas Sensing for details.

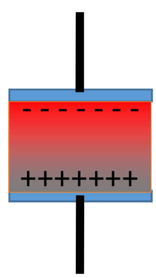
Environmental Remarks

Thermal Detectors achieve best results at thermally stable conditions. This applies not only to the detector but also to the environmental conditions. Temperature gradients and temperature changes through direct and indirect heat transfer as well as other thermal influences shall be minimized in order to obtain best measurement results.

Pyroelectric Effect

Since ancient times the pyroelectric effect has been known as a property of ferroelectric materials. It is based on a specific behavior of dielectric materials, the phenomenon of a permanent electrical polarization. When changing temperature of such materials, this polarization will increase or decrease. We observe a charge displacement when applying electrodes to the surface.

This pyroelectric effect is the basic principle for detectors that can recognize temperature variations. The characteristic value for the permanent polarization, called pyroelectric coefficient, disappears above the Curie point.

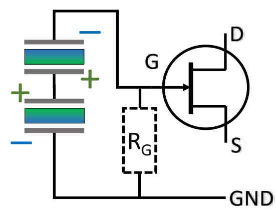


The Curie temperature limits the operation temperature range for such detectors. Pyroelectric detectors do not require cooling in order to operate.

Detector Design

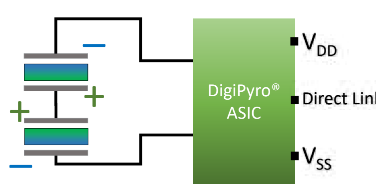
Within our detectors, a thin slice of pyroelectric material is fitted with electrodes to form a capacitor. To compensate for ambient temperature changes, typically pairs of capacitors in opposed orientation are used.

Incoming radiation on one of the two paired elements will generate extremely low levels of thermal energy, so the pyroelectric current flow is rather small. It needs an amplification circuit to convert this small current into a convenient signal. Traditional analog detectors apply a high ohmic resistor and a dedicated low-leakage current FET in order to transform the high impedance of the detector material to a common output resistance. The pyroelectric element's capacitance and the high gate resistance of the FET form an RC circuit with a time constant of about 1 second.
At very low frequencies the self-discharge dominates: with the electrical and thermal time constants the detector forms a band-pass like transfer function.



Dual Element Analog Detector with source follower cuircuit

Excelitas is the first to have introduced digital technology to Pyroelectric Detectors with its DigiPyro® family. A high-resolution ADC circuit provides direct analog to digital conversion. DigiPyro will drastically reduce your development and testing time. No further amplification chain is required and electro-magnetic interference (EMI) is significantly less severe.



Motion Detection

The most typical application of pyroelectric sensors is motion detection. Since only one of two compensating elements must be irradiated to generate a signal, pyroelectric sensors are placed behind optical components such as mirrors or multi-faceted Fresnel lenses.

A lens or mirror projects the thermal signature of the object onto the elements. Generally for long distance sensing long focal lengths are recommended.

For wall (horizontally) mounted applications, dual-element sensors (PYD) will give the best signal-to-noise performance. Optionally four (PYQ) element sensors with dual output can be used allowing an advanced differential signal analysis.

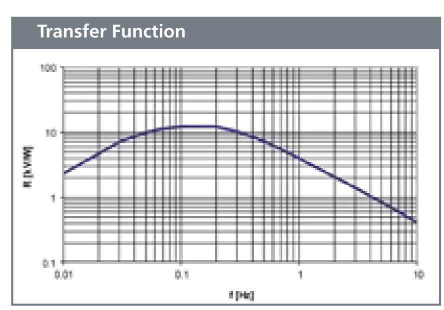
Ceiling mounted applications require four element sensors with diagonally oriented elements. Best signal-to-noise performance is achieved with two separate channels, one for each element pair. As a cost effective alternative, a design with all four elements in a row with a single output can be used.

Detector Characteristics

The most important electrical data of the IR-Sensor are its responsivity, match and noise. Some special applications refer to NEP or D*.

Responsivity

As shown before, responsivity features a natural band-pass behavior with a maximum at about 0.1Hz radiation modulation. Excelitas measures the responsivity in front of a modulated black body while covering one of the two compensated elements. The result is provided as a voltage per radiation power V/W at a 1Hz modulation frequency, unless specified differently. That unit is not normalized to the active sensor area, which means that small element sizes will provide larger responsivity values as compared to large elements when using the same pyroelectric material.

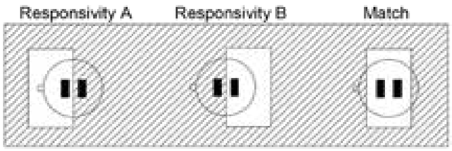


Example of transfer function of Dual Element Pyro

Match/ Common Mode Balance

The match between compensating elements of a pyroelectric detector indicates the ability for the "so-called" common mode rejection.

It is an important value for the performance of detectors, which are used for motion detection. It measures how well a signal can be suppressed when the origin is changing its temperature but not its position in the field-of-view. Stationary objects such as heaters will be rejected well when the match is low. The match is typically given as a signal by all illuminated elements of a detector relative to the responsivity of one element.

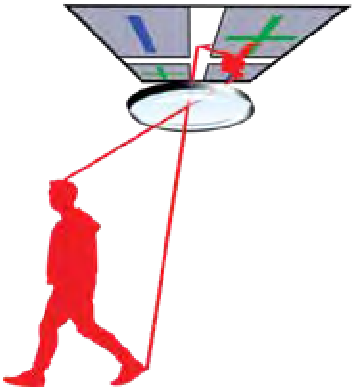


Noise

The noise of the sensor consists of three parts: the basic thermal noise of the sensing material, the (Johnson) noise of the high ohmic resistor and the input noise of the FET. The total output of these three parts is rather stable for temperatures below 40°C. Above this temperature, noise increases exponentially as a function of the temperature like it can be observed with typical other active electronic components. Noise is given in µV peak-to-peak or zero-peak.

Environmental Conditions

High humidity, condensation, dust or other radiation absorbing residuals will influence the detector performance.
For the application of remote temperature measurement, generally it is required to have the sensor and all components around it at the same temperature as the ambient in order to calculate the correct absolute object temperature.



Example for a Four Element Detector

For the application of motion detection, the objects temperature must differ from the ambient in order to modulate the net radiation power over time.

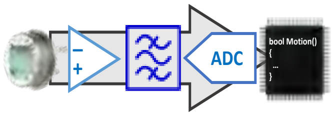
Electro-Magnetic Interference

Like in any other component with small signals, EMI can influence the measurement results of thermal detectors. Metal TO-cans perform the best in difficult conditions. Excelitas digital solutions achieve the highest EMI tolerance since they do not require any additional amplification of analog signals.

The Analog Approach

A typical motion detection layout consist of five components. The analog detector signal requires an amplification stage in order to be processed. The amplification factor is typically above 1000 and is very sensitive to any electro-magnetic interference. It requires a very careful design and is very often the topic of last minute design changes when it comes to testing for conformity with international regulations.

Moreover, the signal is floating when ambient conditions change even slightly. Hence, a band-pass filter of typically 0.4 Hz to 10 Hz is applied prior to digitization with an ADC input stage. Finally, the signal analyzed for motion signatures meeting user defined criteria.



Generally Applied IR Windows

Material used for filters and windows must be transparent in the wavelength of interest. Glass for example is generally not suited to sense the temperature of human skin since it absorbs wavelengths above 4µm. Common materials with a broad transmission range are Germanium and Silicon for the filter windows of IR Sensors. For outside protection only few materials are suitable. Among many plastics, only PP or HD-PE can be used as protection or as fresnel structured optics for presence and motion detection.

Detecting Gases

In the early days of the mining industry, the common method for gas detection was to take a bird in a cage along.

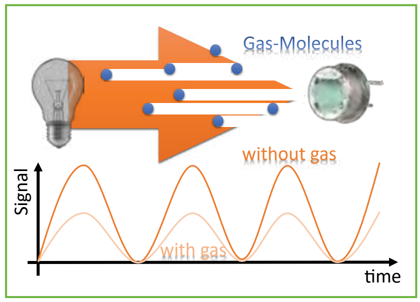
Canary birds were well known as an early warning system for toxic gases. If the bird went unconscious, it was high time to get out. Today electonic sensors have replaced the ancient system.

The now applied NDIR principle requires a combination of Thermal Radiation Source and Infrared Sensor. The selection of source strongly depends on spectral range. For range below 5m popular incandescent miniature lamps can be applied, for long-range thermal sources are required.

When designing NDIR-based gas sensors the selction of available Detectors is split between Pyrodetectors and Thermopile Sensors. Since NDIR usually applies modulated sources to prevent overheating, the engineer has the choice of preference. Both sensor priciples can be called equally suitable when fit with the narrow band window necessary for the speciffic gas absorption.

Special Application Detectors for Gas Sensing

Environmental protection is one of our most serious concerns. Features and instrumentation are required to measure and monitor all kinds of gas in

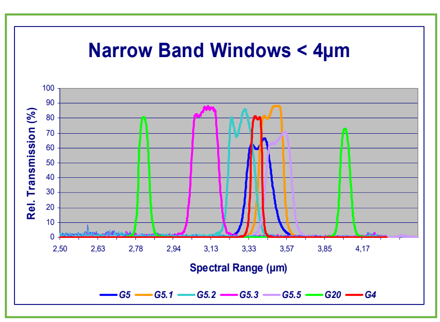


our environment. One of the methods applied is the NDIR technique, a principle of measuring gas concentration by its absorption properties in the infrared range.

Filters for Gas Sensors

The spectral sensitive range of the detectors is defined by a filter window. Common applications in infrared reference wavelengths from 2 to 20 µm. Long-range pyrometers apply a sharp cut-on/cut-off window of 9-14µm (G9) .

Excelitas offers single-channel detectors with such windows as well as Dual-Channel Detectors. When choosing Dual-Channel, typically one channel works as reference fit with a window that will have

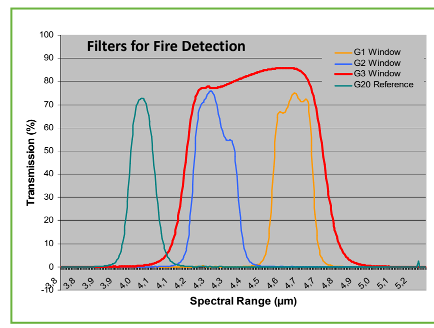


no gas absorption band (G20).
For sensing one specific gas by infrared absorption we offer narrow-band filters to detect specific gas absorption lines. The appropriate narrow band optical filters enable detection of Carbon Monoxide, Carbon Dioxide, Natural Gas and other environmental gases, as well as some technical gases. Please see the range of available filters and specifications.

Fire Detection

Since the exhaust of fire is mainly a hot emission of CO and CO_2, the infrared sensor may also be used for fire detection when fit with a suitable filter.

Our Detectors are applied in single- or dual-channel configurations. With the suited specific narrow-band spectral window our detectors and sensors are a vital part of making our environment more safe, secure and healthy.



Narrow Bands Filter Table

Filter type	Application	CWL	HPB
G1	CO	4.64µm	180nm
G2	CO_2	4.26µm	180nm
G2.2	CO_2	4.43µm	60nm
G2.5	CO_2	4,33µm	160 nm
G2.6	N_2O	4.53µm	85nm
G3	$CO+CO_2$	4.48µm	620nm
G4	NO	5.3µm	180nm
G5	HC	3.35µm-3,4µm	190nm
G5.1	HC	3.46µm	163nm
G5.2	HC	3,28-3,31µm	160nm
G5.3	HC	3.09µm	160nm
G5.5	HC	3,32-3,34µm	160nm
G5.6	HC	3.42µm-3,451µm	160nm
G5.7	HC	3,30-3,32µm	160nm
G5.9	HC	3.375µm-3,4µm	190nm
G7.1	R12	11.3µm	200nm
G7.2	R134a	10.27µm	210nm
G7.3		12.4µm	180nm
G20	Reference	3,95µm	90nm