Temperature Behavior

1 Introduction

Detectors that measure radiation by means of the temperature change of an absorbing material are classified as thermal detectors. Thermal detectors respond to any wavelength radiation that is absorbed, and when an appropriate absorbing material or ‘blackening’ is applied to the detector element surface, they can be made to respond over a wide range of wavelengths.
Thermal detectors can be classified by their output into a number of categories. One of the most commonly used in infrared (IR) applications, is the pyroelectric detector type that derives its output from changes in the electrical polarization of certain crystals with temperature.

Commercially available single crystal pyroelectric materials have been developed which generate reasonable electric charges for small temperature changes, and at the same time they are stable, uniform and durable. It is this development that has made practical the large scale production and application of cost effective, high performance pyroelectric infrared detectors into a wide variety of commercial, industrial and military applications.
As the differing and diverse environmental conditions can adversely affect pyroelectric detector stability and performance, it is extremely important for IR system designers to understand how system requirements can best be translated to optimize detector specifications, and to acquire some basic knowledge of detector characteristics and construction.

As for any IR system, including those using pyroelectric detectors, system designers must determine the magnitude, as well as the spatial characteristics, spectral content and frequency of incoming radiation. An optical system that will deliver this radiation to the detector must then be designed. Making this basic information available to the detector manufacturer will generate the best suitable detector configuration regarding cost and performance.
Pyroelectric detectors can be used over a wide ambient temperature range without cooling or controlling the detector temperature. As they are typically manufactured from generally available single crystal materials, they are cost effective, and can readily be made into many detector configurations and sizes. In addition, detectors do not require special power supplies and detector signal processing and noise limited operation can be achieved readily with commercially available operational amplifiers (OpAmps) and relatively simple circuits.

Pyroelectric detectors will only respond to changes in incoming radiation levels. In addition, because they are constructed from piezoelectric materials, they will all respond to mechanical vibration to some extent although any resulting microphonic noise can be minimized by proper detector design and assembly techniques. Since pyroelectric detectors are often being used to detect small temperature changes, their performance can be affected by external temperature changes such as those caused by air movements. It is, therefore, particularly important for the system designer to understand how these changes affect detector performance.

This application note is offered to provide some insight into how temperature affects the various components that comprise a typical pyroelectric detector and how the effect of ambient temperature variations on detector performance can be minimized. Ambient temperature variations cause drift of detector signal and noise, and fluctuations or instability in detector output. These two effects should always be considered separately since they are caused by factors that require different corrective measures in detector design.

2 Temperature dependent Components within the Pyroelectric Detector

Figure 1 shows the basic commercial single element pyroelectric detector offered by InfraTec GmbH. In the figure there are the temperature dependent active and passive electrical and optical components indicated.

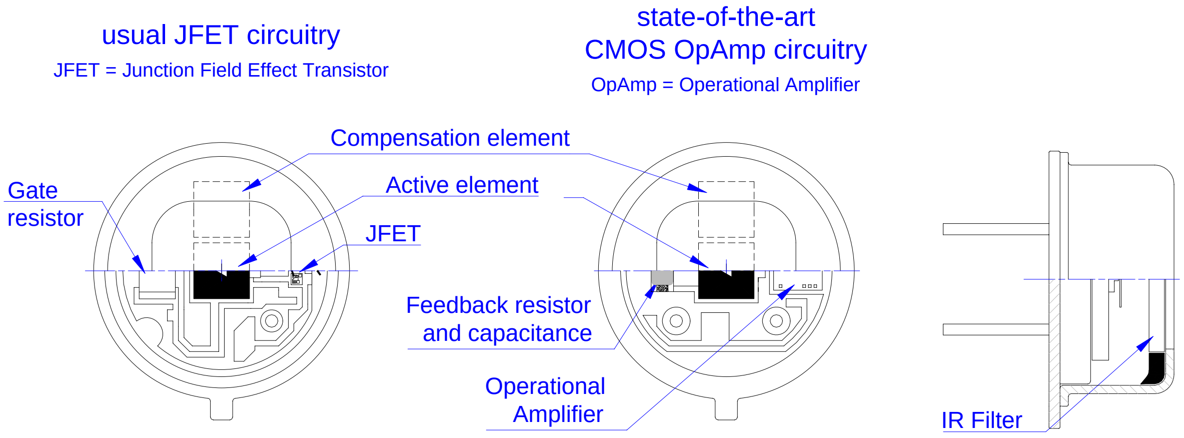

Fig 1: Typical InfraTec detector construction

2.1 Temperature dependence of the pyroelectric chip

To varying extents, components labeled in figure 1 contribute to both **drift** and **fluctuation**, although detector instability due to varying temperatures at fixed operating conditions can generally be attributed mainly to the physical qualities of the detector chip itself.

In a typical application, the active element of the pyroelectric detector is coated with an appropriate ‘black’ coating to enhance the absorption of chopped or modulated incoming radiation, in the wavelength range of interest defined by an IR filter, thus warming the pyroelectric crystal. Depending on the operating mode of the detector, the resulting current or voltage generated above the capacitance of the detector chip (typically 50 pF) is then converted into useful signal. The electrical charges (current) generated even by minimal increases in crystal temperature are on the order of pico- to nanoamperes. It is important to note that an increase in detector case/package temperature can produce ‘false’ signals.

Electrostatic peaks of up to 140 V, for example, have been measured from highly insulated detectors with case temperature increases as small as 10 °C.

2.1.1 Temperature drift/temperature coefficient

By definition, the Curie point is that temperature above and beyond which pyroelectric crystals cease to exhibit pyroelectric effects. The pyroelectric coefficient of these materials, which is a measure of eventual detector sensitivity, actually increases with increasing temperature up to the Curie point. In the case of Lithium Tantalate ($LiTaO_3$), from which almost all of InfraTec’s pyroelectric detectors are made, the Curie temperature is about 600 °C.
In most practical applications where operating ambient temperatures are substantially lower (<+120 °C), the intrinsic temperature coefficient (**TC**) of the pyroelectric current is approximately +1500 ppm/K (+0.15 %/K).

This is particularly important to know in system applications where the ambient temperature is changing, and this characteristic will manifest itself as detector ‘drift’. Since the compensation element in a thermally compensated detector does not contribute to signal, this **TC** also applies to compensated detectors.

Standard applications never analyze the pyroelectric current from the active element itself but the signal voltage generated by the pyroelectric current (voltage responsivity) is analyzed. Therefore the resulting **TC** of the pyroelectric chip depends on the operating mode of the detector either the element in the open-circuit-operation (voltage mode detectors, **JFET circuitry**) or as short circuit (current mode detectors, **OpAmp circuitry**). Only the **TC** of the pyroelectric current has an effect if the short circuit mode is applied but the **TC** will be overlaid by the relative permittivity of the Lithium Tantalate using the open-circuit operation.

2.1.2 Effects of temperature fluctuation on detector stability

As stated earlier, if not accounted for in the pyroelectric detector design, a change in the detector case temperature alone will usually generate a very low frequency signal, which can be of substantial magnitude. The commonly used voltage mode detectors with **JFET circuitry** are particularly susceptible to these temperature changes. Signals generated can cause detrimental effects to a chosen preamplifier by pushing the limits of its operational range. The longer the thermal and electrical time constants of these detectors, the more sensitive they are to these changes. The state-of-the-art **CMOS OpAmp** detectors present in temperature ramps a DC offset adjustment in the same dimension but the wanted signal is 100-times higher. That means that the ratio DC offset adjustment / signal will be lower than 1 % of the JFET circuitry and hence the dynamics range will not be limited anymore. Since thermal and electrical time constants are determined by detector construction, they can be reduced by design to attenuate, but not completely eliminate, the effects of expected case temperature changes in uncompensated detectors.

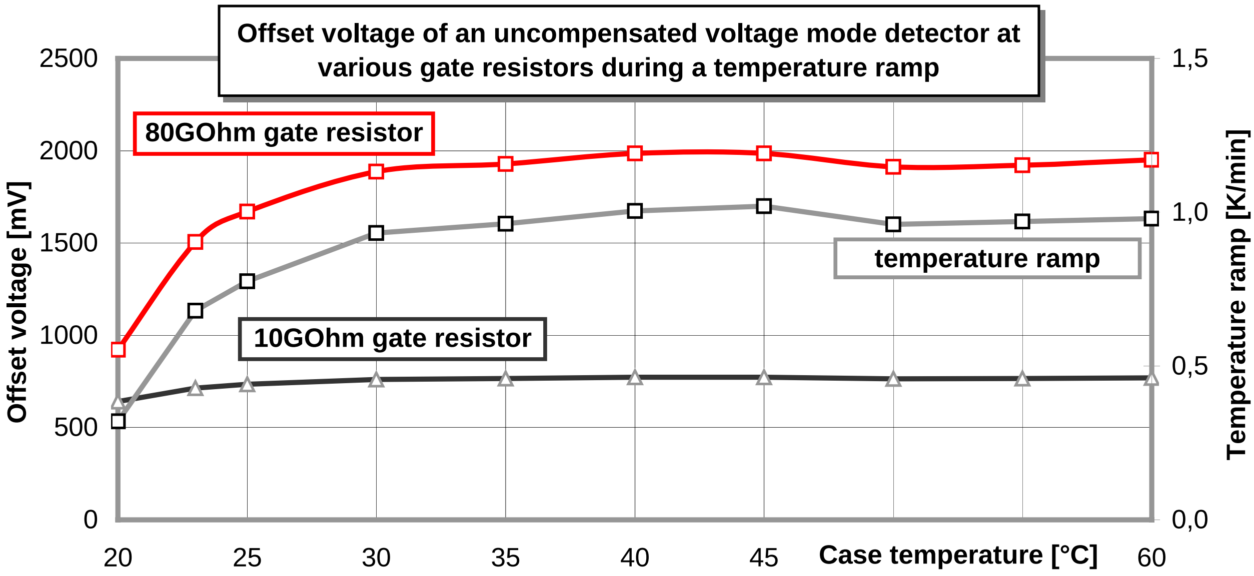

Fig 2: Offset voltage vs. temperature at various gate resistors (uncompensated voltage mode detector, JFET circuitry)

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Both can be tailored to meet specific operating conditions although it should be noted that varying the electrical time constant of a detector is not as complex as varying the thermal time constant of a detector. In the InfraTec product line there are only the extended detectors in series LIE-312 and LIE-332 offered with a thermal time constant other than standard.
Figure 2 shows the typical effect of temperature variation on detector offset voltage for uncompensated detectors with different gate resistors. Please note that the noise is inversely proportional to the sq. root of the intended resistor decrease, e.g. a 9-times higher stability will cause a decrease of detector detectivity down to 33 %.

To overcome the problems associated with detector instability due to case temperature changes, an additional optically inactive detector chip, known as the compensation element, may be added inside the package. The detector is then called a compensated detector. The compensation element will have negative (or the opposite) polarity of that of the active element. As case temperature varies, charges generated at the active and compensation element will essentially have the effect of canceling each other. Figure 3 showing the offset voltage vs. temperature of thermally compensated detectors, clearly presents the effectiveness of this arrangement.

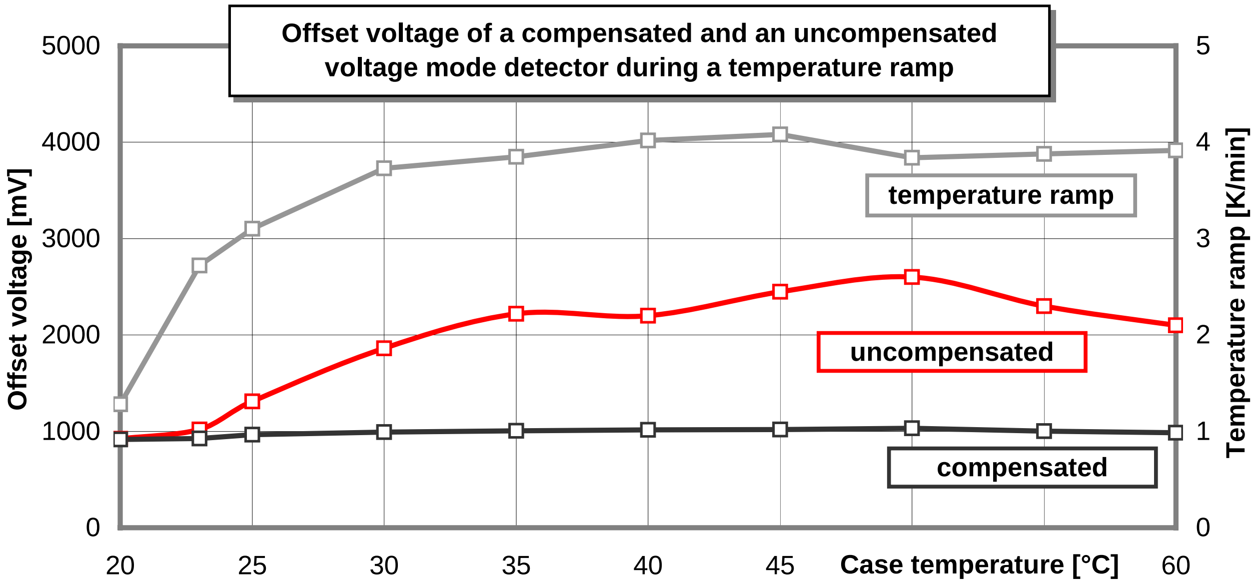
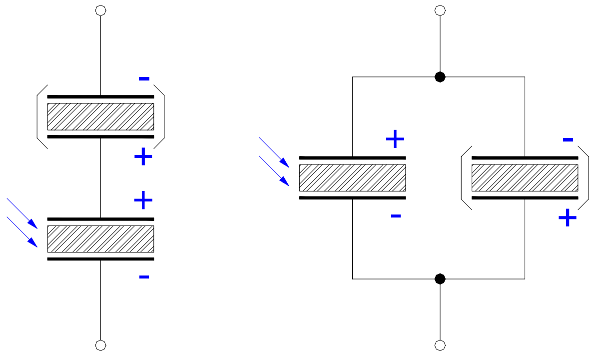


Fig 3: Offset voltage vs. temperature (compensated and uncompensated voltage mode detectors, JFET circuitry)

Thermally compensated pyroelectric detectors can be classified into two types: a) serial or b) parallel compensated, depending on the electrical connection of the active and the compensation element (see figure 4). The compensation element is completely optically shielded from incoming radiation, hence although optically inactive but still an electrically effective capacitor. The influence of the compensation element regarding signal and detectivity is different between the common **JFET circuitry** and the state-of-the-art **CMOS OpAmp circuitry**.

The net effect of compensation for usual **JFET circuitry** is reduction of detectivity to approximately 60 % for both compensation types, although signal and noise will be affected differently for each type. The approximate values of signal and noise for each type of compensated detector are shown as a percentage of those of an uncompensated detector in the figure above.
Due to the virtual short of compensation and pyroelectric element in the state-of-the-art **OpAmp circuitry** the parallel compensation neither causes signal nor detectivity losses.



Serial Compensation
Parallel Compensation

Serial Compensation
(Only with InfraTec's LIM-314)

JFET circuitry: 100 % signal; 170 % noise
OpAmp circuitry: not reasonable

Parallel Compensation

JFET circuitry: 50 % signal; 70 % noise
OpAmp circuitry: 100 % signal; 100 % noise

Fig 4: Serial and parallel compensation to increase the stability of the DC operating point of pyroelectric detectors in temperature ramps

The decision to use serial or parallel compensation is determined for **JFET** voltage mode detectors by the operating condition from the detector. Parallel-compensated detectors are more stable at strong (more than 2 K/min) or long time constant temperature ramps (longer than 1 hour). On the other hand the user may prefer the double signal of the serial-compensated detector. We always recommend testing parallel-compensation first. Due to the availability of the state-of-the-art **OpAmp detectors** it is no longer necessary to compromise between signal magnitude and stability.

2.2 Temperature dependence of gate resistor as well as feedback components

High value resistors used as gate resistor in **JFET circuitry** and feedback resistor in **OpAmp circuitry** are characterized by high negative temperature coefficients (i.e. resistance decreases with increasing temperature). (82 and 100) GOhm resistors that are routinely used with certain types of pyroelectric detectors, for example, typically have **TC'**s of (-1500 ... -2000) ppm/K.

NPO capacitors as well as printed strip lines are used in the feedback capacitance of the **OpAmp detectors** and hence there is no measurable temperature influence on the detector parameters.

2.3 Temperature dependence of integrated JFET and CMOS operation amplifier

The gate leakage current, as well as the current noise of integrated **JFETs**, increase substantially with increases in temperature. Particularly at the higher temperatures, this increase is exponential. The gate leakage current of a typical FET is normally less than 1 pA at +25 °C, but can increase to well over 100 pA at +125 °C.

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CMOS OpAmps use a insulated input which enables an ultra low input bias current and low noise. The **OpAmp circuitry** is best suited at high temperatures up to +100 °C (see figure 5).

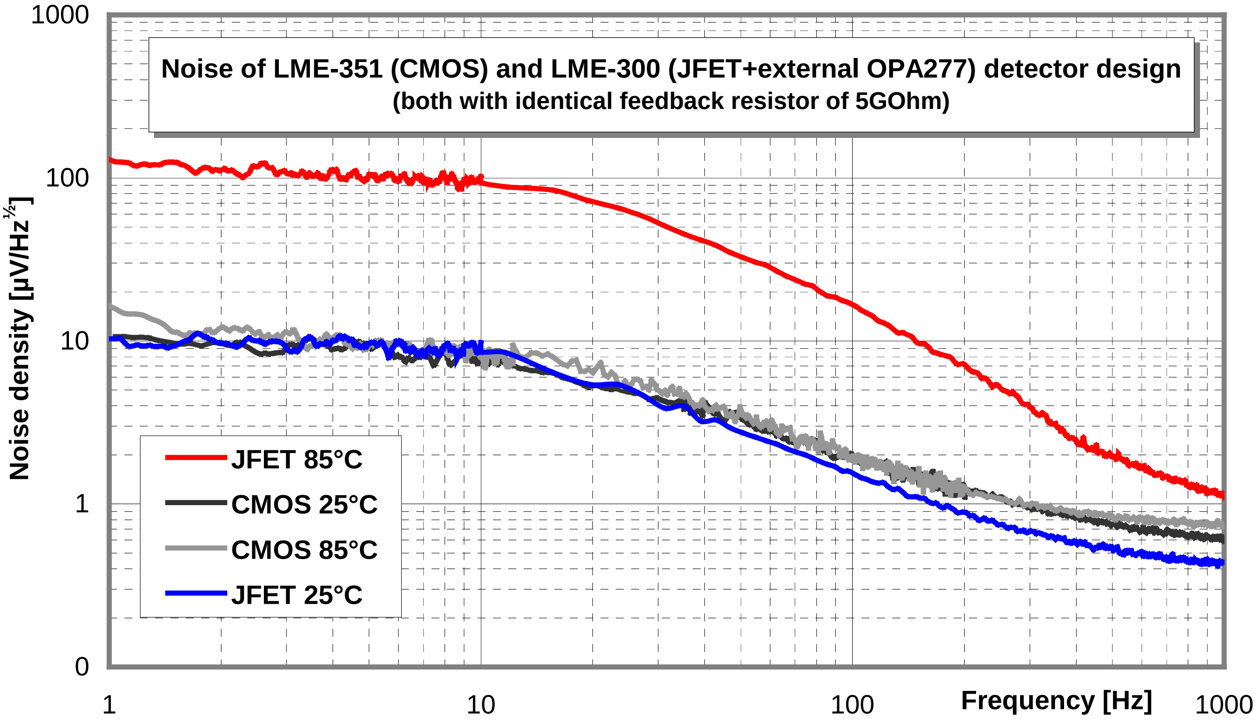

Fig 5: Different behavior of JFET and CMOS input transimpedance amplifiers at temperature increase

Another temperature effect can be created by the amplification drift of **JFET** or **OpAmp**. Increases in temperature will reduce the **JFET** common-source forward transconductance and increase the pinch-off voltage. Due to the high open-loop amplification and strong negative feedback of the **OpAmps** a drift of the **OpAmp circuitry** amplification determined by the temperature is not observed.

2.4 Temperature dependence of IR filters and windows

InfraTec pyroelectric detectors are coated with a black absorption coating whose spectral characteristics have been shown not to be temperature dependent in the storage and operating range. Please note that the maximum storage and operating temperature for detectors with metal black layer (applies only to LIE-312 and LIE-332 used for IR-spectrometer) is only 60 °C. Above this temperature the high absorption foamy structure of the metal black layer will irreversibly sinter, which will cause a reduced absorption capability.

To varying degrees, however, the spectral transmission of all windows and optical elements / filters fitted as part of detector package will vary with temperature.

For uncoated IR optical materials (e.g. CaF_2), temperature variation will mainly affect their transmission and absorption edge (hence their useful range). A signal drift up to -400 ppm arises e.g. for CaF_2 windows.

Temperature Behavior

The spectral thermal shift and changes in transmission characteristics of coated filters, however, is determined by the materials and coating design used to manufacture such filters, and therefore vary by the type of filter (e.g. narrow band pass - NBP, wide band pass - WBP), wavelength region and filter manufacturer.

Depending on the application InfraTec uses IR filters manufactured with a **low TC design** (typical temperature shift +0.22 nm/K, typical angle shift @ 15° -27 nm, see figure 6) or a **low angular shift design** (typical temperature shift +0.40 nm/K, typical angle shift @ 15° -12 nm, see figure 7). All integrated narrow bandpass filters in InfraTec pyroelectric detectors for the 3 to 5 micron region have been chosen for their stability in design and are typically deposited on silicon substrates.

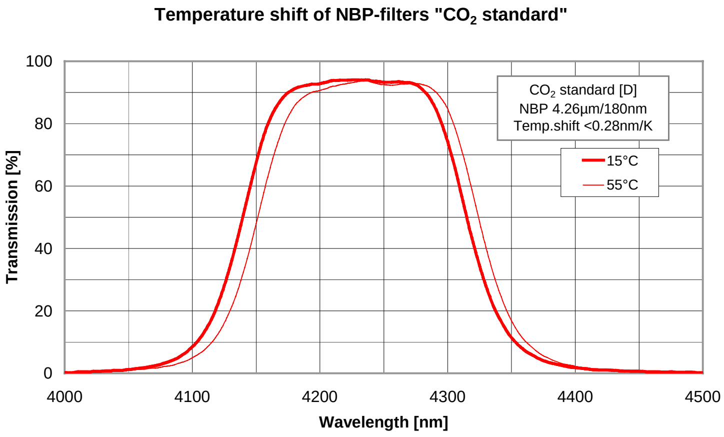

Fig 6: Temperature shift of NBP filter with low TC design

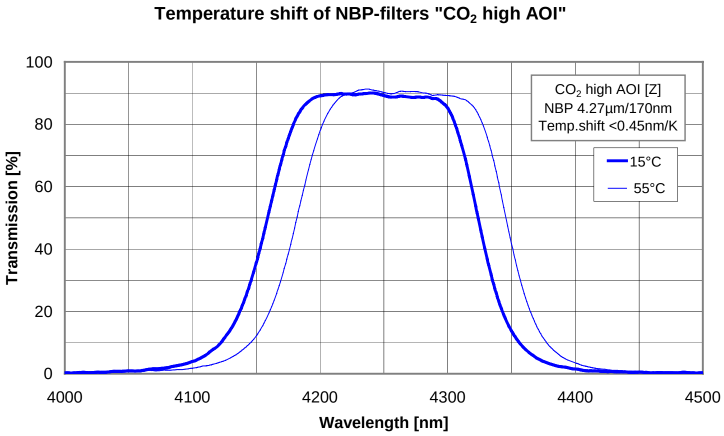

Fig 7: Temperature shift of NBP filter with low angular shift design

As a general rule, as temperature increases, IR bandpass filters will shift to longer wavelengths with some loss in band transmission. In addition, an angular shift results in a CWL shift to shorter wavelengths generally.

3 The Effects of Temperature Variation on overall Detector Performance

Accounting for the temperature dependence of the key components that constitute a complete detector assembly, some typical data can be offered on detector performance parameters that may be of particular interest to IR system designers.

3.1 Detector offset voltage (at a stabilized temperature – no temperature ramp)

Due to the increase in pinch-off voltage and gate leakage current, **higher temperatures will always increase the offset voltage** at the **JFET circuitry** because the negative **TC** of the gate resistor does not compensate this increase. Figure 8 shows the offset voltage vs. temperature of a typical, but representative, InfraTec detector with **JFET circuitry.**

The DC offset voltage of the **OpAmp circuitry** is determined by the offset voltage of the **OpAmp** itself (typical in the range of ±1 mV) together with input bias current and feedback resistor. The bias current is typically +3 pA at 85 °C. Figure 9 shows the offset voltage vs. temperature of a typical, but representative, InfraTec detector with **OpAmp circuitry.**

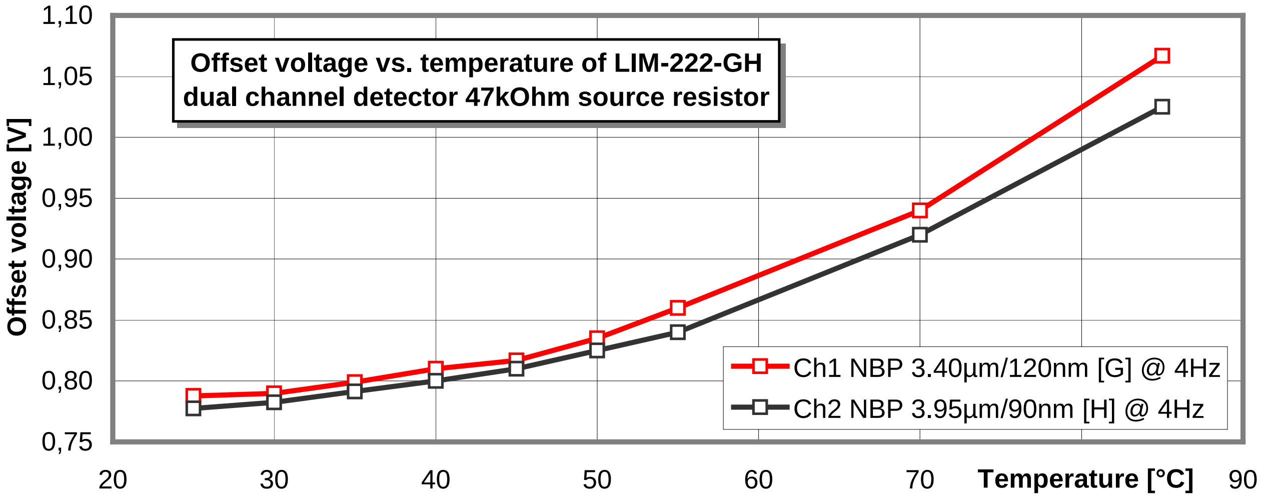

Fig 8: Offset voltage vs. temperature (JFET circuitry); after thermal transient period

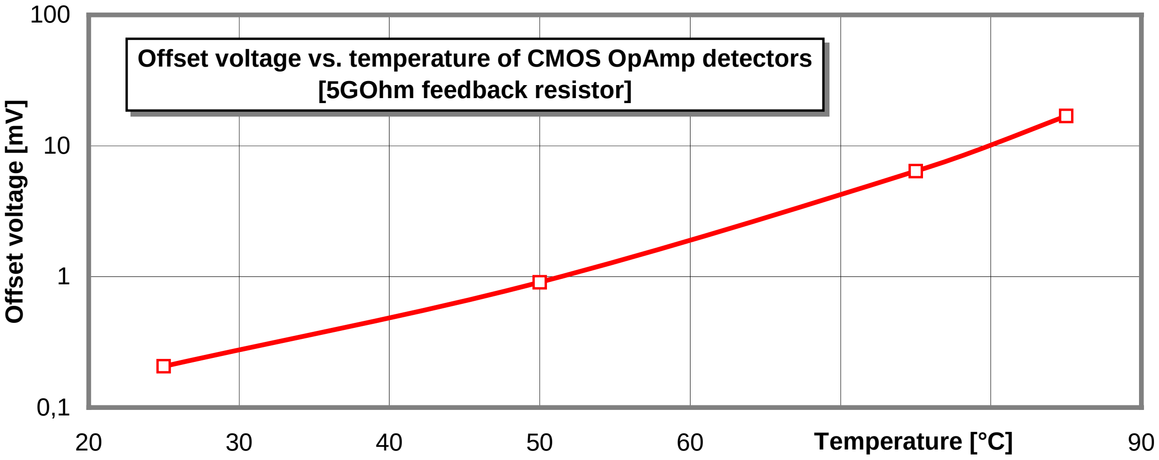

Fig 9: Offset voltage vs. temperature (OpAmp circuitry); after thermal transient period

3.2 Detector noise

An increase in gate leakage (**JFET**) or bias (**OpAmp**) current and the decrease in gate (**JFET**) or feedback (**OpAmp**) resistor value with an increase in temperature, results in higher detector noise. This increase in noise is particularly prominent at lower frequencies; see figure 10 below. As already discussed in 2.3 the noise arising from the **JFET** is considerably greater at higher temperatures compared to the **OpAmp**.

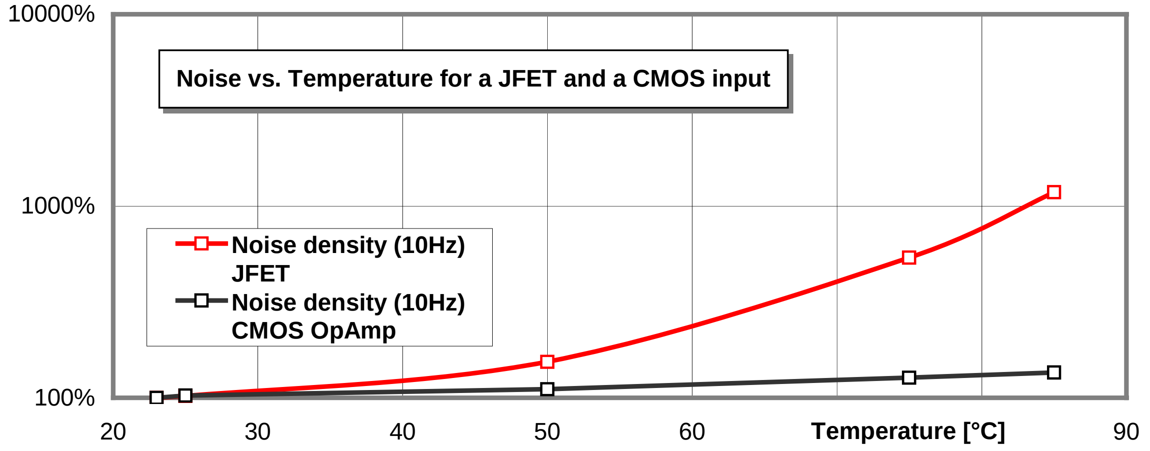

Fig 10: Noise of a JFET and a CMOS OpAmp circuitry at various temperatures

3.3 Signal voltage (responsivity)

InfraTec pyroelectric detector signals are nearly linear with temperature over the most common temperature range for many applications (see figure 11 for **JFET circuitry**). Please note for **TC** evaluation that a common CaF_2 window will create an additional **TC** of approx. -400 ppm/K.

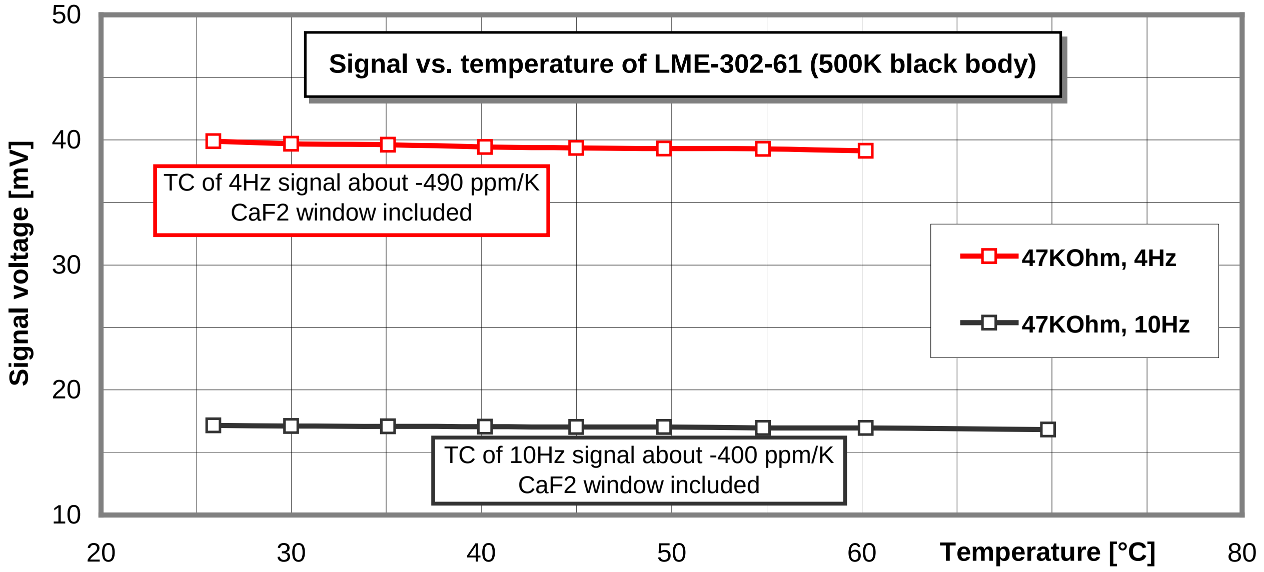

Fig 11: Signal voltage vs. temperature at JFET circuitry (LME-302-61: voltage mode with CaF_2 window)

Temperature Behavior

Detectors with **JFET circuitry** and without windows have typical **TC´s** in the range of (-200 ... 200) ppm/K, because the **TC´s** of the single components are almost compensated. A current source instead of the source resistor increases the signal voltage by (10 … 15) % but an influence on the temperature dependency cannot be detected. The negative **TC** of the detector as shown in figure 11 is mainly caused by the CaF_2 window. The temperature dependency of detectors with **OpAmp circuitry** is more significantly influenced by the modulation frequency. Above the electrical breakpoint the resulting **TC** becomes more and more positive and whereas below the breakpoint more and more negative. The detector LME-351-61 has a comparatively high electrical breakpoint of 160 Hz due to the feedback resistor of 5 GOhm. The modulation frequencies shown in figure 12 are much smaller than 160 Hz and cause without CaF_2 window a **TC** of the detector between +300 ppm/K (@ 60 Hz and -400 ppm/K @ 4.6 Hz). Including the CaF_2 window with a **TC** of -400 ppm/K the detector has a TC of -100 ppm/K @ 60 Hz and -800 ppm/K @ 4.6 Hz as shown in figure 12.

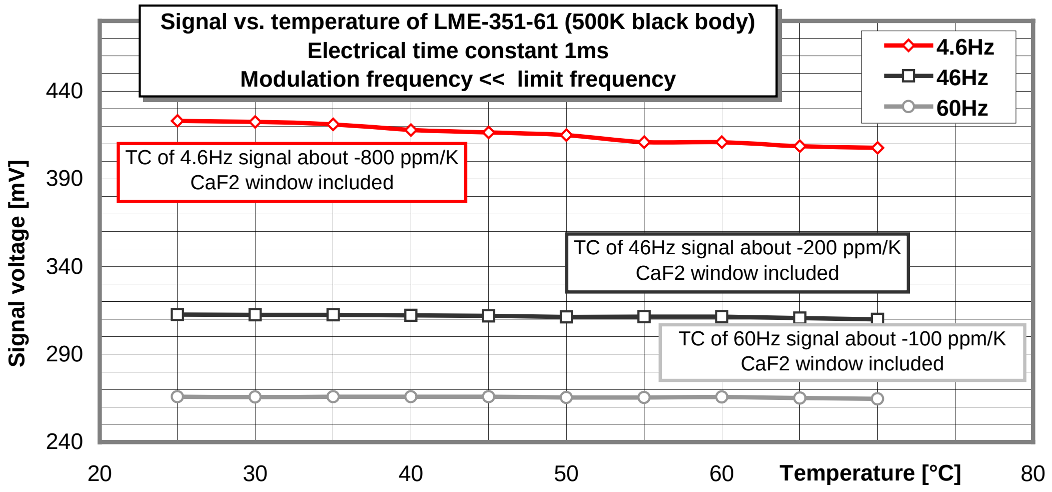

Fig 12: Responsivity vs. temperature at OpAmp circuitry (LME-351-61: current mode with CaF_2 window)

The detector LIE-245-10 has a noticeable greater electrical time constant of 16 ms (24 GOhm//0.68 pF). The electrical breakpoint is between 4.6 Hz and 10 Hz. TC behavior changes around these limits as shown in figure 13.

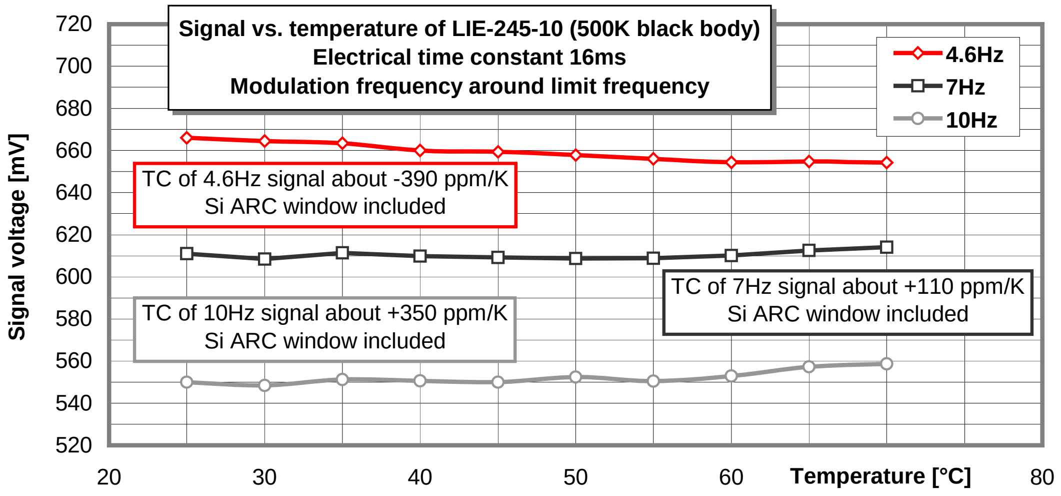

Fig 13: Responsivity vs. temperature at OpAmp circuitry (LIE-245-10: current mode with Si ARC window)

4 Summary

With this application note, InfraTec has attempted to provide IR system designers with some useful data regarding the effect of ambient temperature variation on pyroelectric detector performance due to the complex interaction of components that form just part of the detector assembly. As pyroelectric detectors are designed and incorporated into a specific application, however, designers must also consider how other system components (external to the detector) such as sources, optics etc. can also alter the expected detector performance. The interrelation of the temperature coefficients for single components of a detector are also influenced by the signal conditioning method of the software used.

Data from a simple set-up is included here to demonstrate the importance of understanding how system parameters interact. The temperature behavior of responsivity is presented in three figures (also applies to the signal voltage measured directly at the detector).

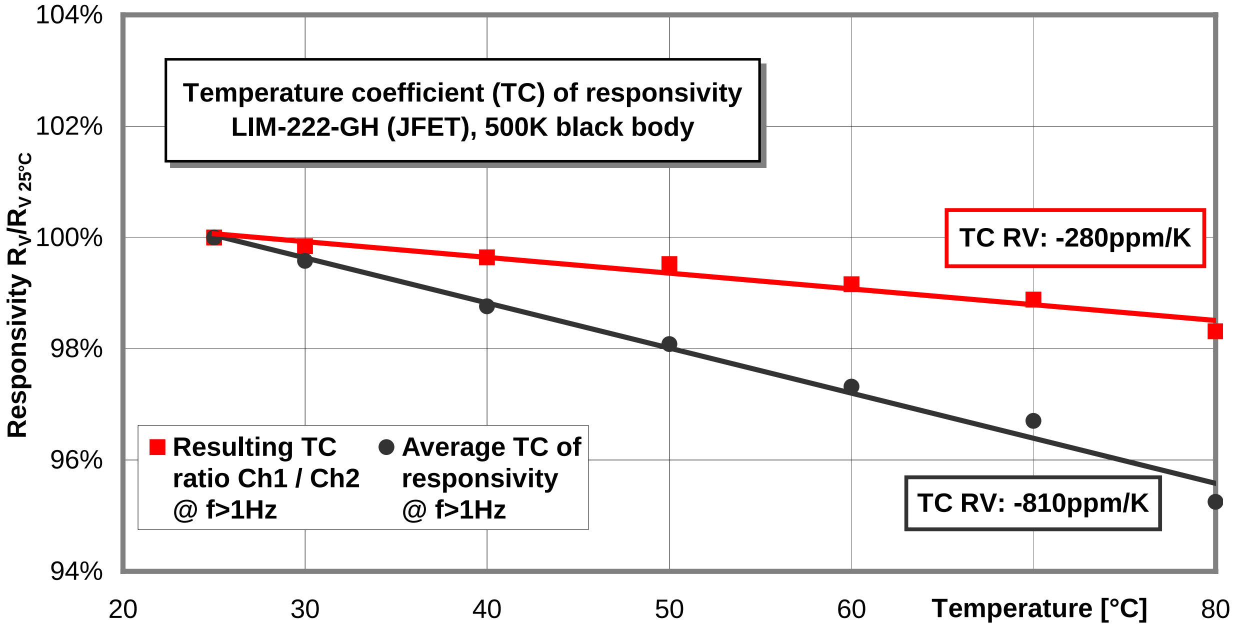

*Fig 14: Dual channel detector **LIM-222-GH** (TO39 housing; small chip size; thermal compensation; JFET; voltage mode; ch1: NBP 3.40 µm/120 nm HC; ch2: NBP 3.95 µm/90 nm Ref.), IR source 500 K black body.*

This figure illustrates a configuration which generates a slightly negative average TC of -810 ppm/K (channel 1 = -950 ppm/K, channel 2 = -670 ppm/K), at an operating temperature of 60 °C which results in a 3 % signal loss compared to room temperature (black curve).

Applying the ratio between the signal of the gas channel (channel 1) and the reference channel (channel 2) the impact of aging and pollution in the optical path of the gas being evaluated can be compensated (red curve). According to the Theory of Errors the resulting TC emerges from the ratio for TC_{ch1} - TC_{ch2} (in figure 14 (-950 ppm/K) - (-670 ppm/K) = -280 ppm/K). In principle, positive and negative values can emerge for the resulting TC through this ratio.

Temperature Behavior

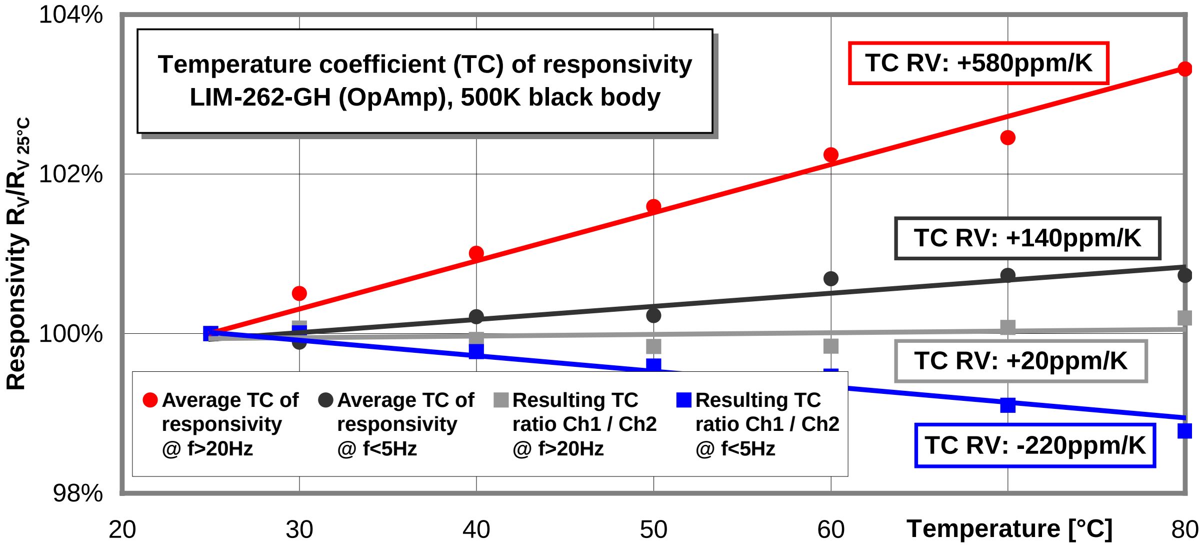

Fig 15: Dual channel detector LIM-262-GH (TO39 housing; small chip size; thermal compensation; OpAmp; current mode; feedback 100 GOhm; ch1: NBP 3.40 µm/120 nm HC; ch2: NBP 3.95 µm/90 nm Ref), identical filter placement and IR source as with the LIM-222-GH in figure 14.

The CMOS OpAmp equipped LIM-262-GH has been tested under the same arrangement and conditions as the LIM-222-GH. The current mode detector's typically positive TC of responsivity was measured. The TC is in the range of (+140 ... +580) ppm/K, depending on the modulation frequency. Again in this case, the resulting TC is calculated from the Channel 1/Channel 2 ratio as a difference of TC_{ch1} - TC_{ch2}. Depending on the TC value of the single channel, positive and negative values can emerge, based on the calculated difference.

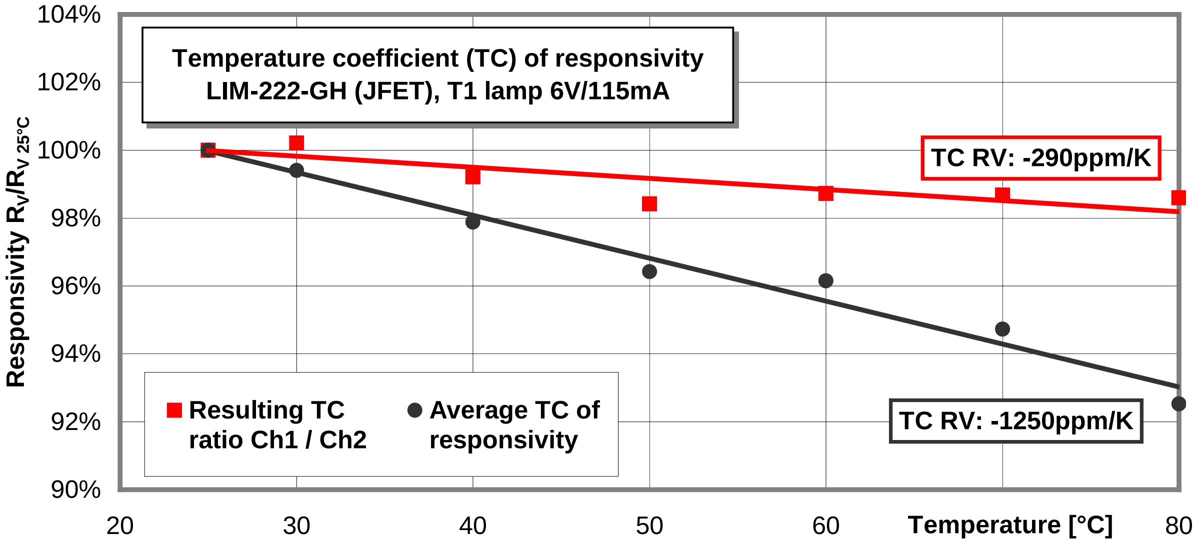

*Fig 16: Dual channel detector **LIM-222-GH** identical to figure 14 except for IR source which is a T1 lamp 6 V/115 mA*

Temperature Behavior

The temperature dependency of an identical dual channel detector LIM-222-GH when illuminated with a T1-type miniature light bulb 6 V/115 mA is presented in figure 16. This thin-walled light bulb is often used in gas analyzers. The modulation frequency is limited to 4 Hz by thermal time constant of the lamp filament. Only the single channels change with respect to the 500 K black body illumination (-1250 ppm/K instead of -810 ppm/K). Beside the lamp glass transmission, additional factors like modulation of the lamp and positioning accuracy of the optical channel influence the TC. The resulting TC (channel 1/channel 2) = $TC_{ch1} - TC_{ch2}$ is very comparable to the one with the 500 K black body irradiation (see figure 14). The additional temperature drift caused by the light bulb is being eliminated by the ratio.

From concept to production, InfraTec constantly strives to produce pyroelectric detectors with the highest quality and best performance on the market today for any application. All standard InfraTec pyroelectric detector packages are hermetically sealed and backfilled with very dry nitrogen for stability and long term reliability. Given the importance of translating system requirements into detector specifications, we take particular pride in our responsiveness and close technical interface with our customers.

We invite your inquiries.