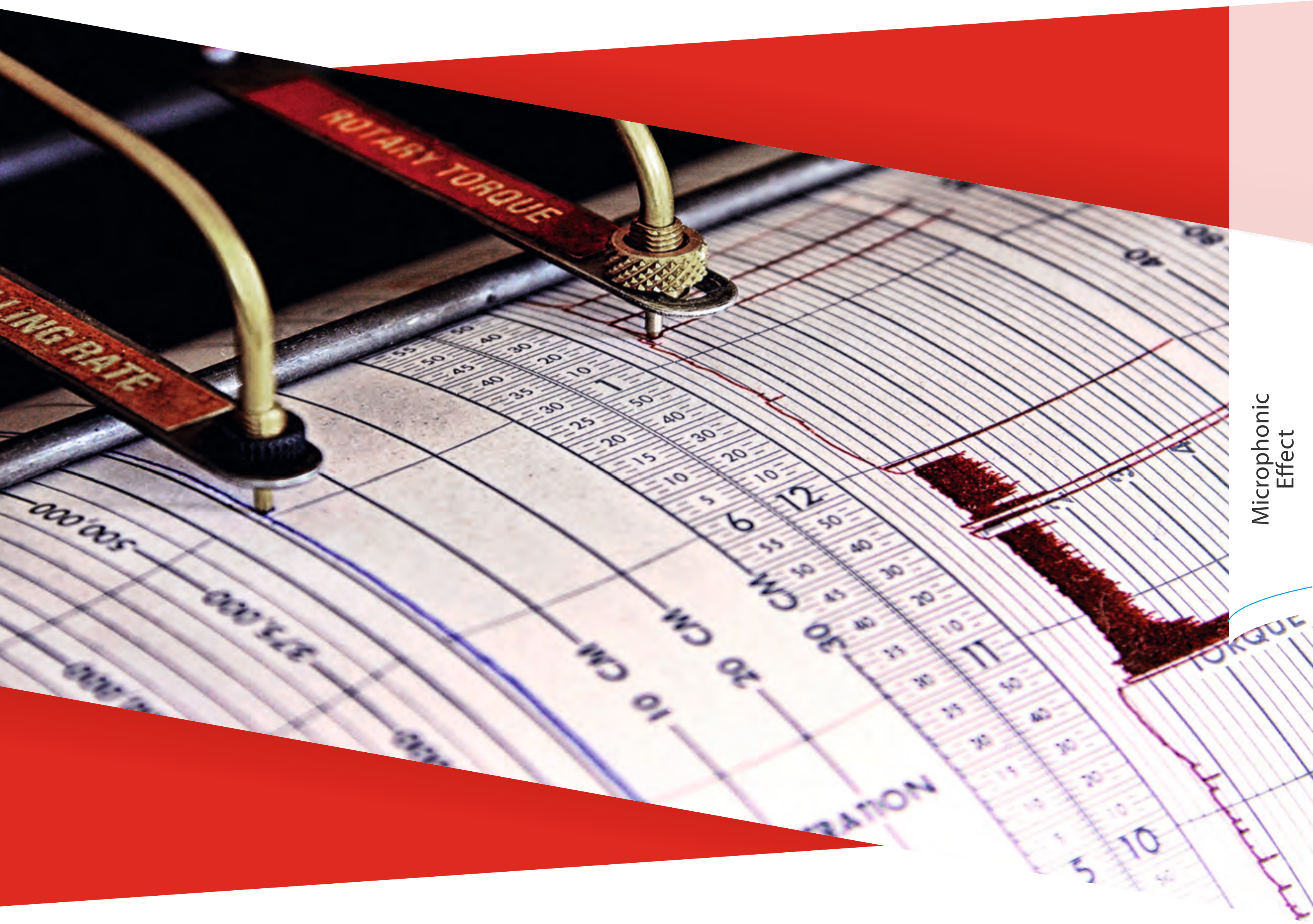
Microphonic Effect

Impact of mechanic vibration on detectors and how it can be minimised



Microphonic Effect in Pyroelectric Detectors

Each pyroelectric material always has piezoelectric properties, too. Therefore, dependencies of the signal voltage on mechanical stress applied to the pyroelectric chip may play a role in addition to the desired measuring effect that is caused by temperature changes of the crystal. The following chapter discusses how these dependencies can be described, how strong they are and which measures can be taken to counteract them in practice.

4.1 Basic Principles

If pyroelectric materials are exposed to external forces e.g. mechanical shock or vibration, their crystal lattice is deformed. If, as a result, the centres of charge in the crystal shift vertically to the metal plated surface of the material, surface charges are generated.

Thus, the surface charges generated by the pyroelectric effect and the undesired effects of the piezoelectricity interfere with each other. The piezoelectric share in the signal is referred to as microphonic effect or vibration response.

The piezoelectrically generated voltage $\mathrm{u_{vib}}$ of the pyroelectric chip is used as the fundamental value for our considerations. In the exemplary case of a LIE-501 in which a pyroelectric chip with a surface area of 3 × 3 mm² is clamped on one side, the disturb signal caused by microphonics is up to 25 µV at 1 g acceleration (1 g = 9.81 m/s²).

4.2 MEP – Microphonic Equivalent Power

For the purpose of comparison, InfraTec has introduced the microphonic equivalent power (MEP) by analogy to the noise equivalent radiant power (NEP cf. section 1).

$$\mathrm{MEP} = \frac{\mathrm{R_{vib}}}{\mathrm{R_V}} \tag{40}$$

with

$$\mathrm{R_{vib}} = \frac{\mathrm{u_{vib}}}{\tilde{\mathrm{a}}} \tag{41}$$

MEP indicates how much radiant power must impinge on a detector to generate the equivalent signal caused by an acceleration of 1 g acting on the detector. Small numerical values stand for a low vibration response of the respective detector.

4.3 Measurements

The pyroelectric as well as the piezoelectric effect occur in certain crystals. Both effects are strongly dependent on the orientation of the crystal (anisotropy). Pyroelectric crystals form a sub-group of piezoelectric crystals. Therefore, every pyroelectric crystal has piezoelectric properties, too. For pyroelectric detectors the crystal orientation is chosen in a way to maximize the pyroelectric effect. The resulting sensitivity to accelerations cannot be avoided. Its influence on the measurement signal of the pyroelectric detector can be minimized by the customer by mechanical decoupling of the detector from its environment or effective vibration dampening. Specific measures can also be taken inside the detector to dramatically reduce the effects of critical vibration modes and therefore their scale of interference on the output signal.

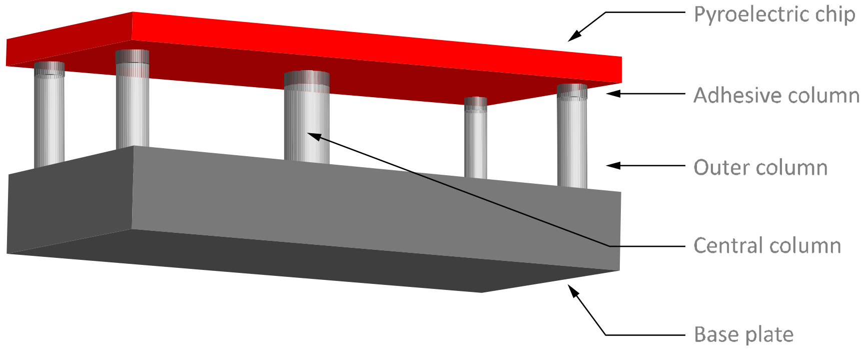


Figure 27: Chip holder for reducing the microphonic effect, design model from FEM simulation

Based on finite element method (FEM) simulations, InfraTec has developed a special chip holder (Figure 27) and has successfully introduced it. By means of this patented mounting of the pyroelectric chip in conjunction with a sophisticated combination of fixed and flexible mounting points

- the deformation of the pyroelectric chip is significantly reduced,
- the remaining vibrations are dampened effectively and
- the excitation of critical vibration modes is suppressed effectively.

Thus, the vibrations of the pyroelectric chip can be significantly reduced for the typical modulation frequencies of the pyroelectric detector at approx. 10 Hz. The disturb signal generated by mechanical forces is reduced to one twentieth (5 %) compared to a conventional pyroelectric detector.

These chip holders can be used in many single and multi channel detectors with a chip size of 2 × 2 mm² or 3 × 3 mm². The second character in the product description of detectors with reduced microphonic effect is an "M" in the prefix of the part number such as “LME”.

4.4 Effects on the Detector Behaviour

The effects of the voltage generated by piezoelectric effects on the detector signal will be discussed below both for voltage mode and current mode. A comparison of the measurement results will illustrate as to when a reduction of the microphonic effect makes sense and which additional measures are recommended for further reducing the influence due to piezoelectric effects.

4.4.1 Voltage Mode

The current generated by the pyroelectric chip leads to a voltage drop at the low-pass filter which is formed by $\mathrm{C_P}$ and $\mathrm{R_G}$. A JFET aligns this voltage to the impedance of the subsequent amplifier stage.

At mechanical excitation frequencies above the electrical corner frequency (typically 0.025 … 0.16 Hz), the voltage of the unconnected pyroelectric element at the detector output is given by:

$$\mathrm{u_{vibVM}} = \mathrm{u_{vib}} \tag{42}$$

In voltage mode a mechanical shock of 100 g (1 g = 9.81 m/s²) generates a disturb signal in the range of several millivolts which is of a similar level to a typical detector signal.

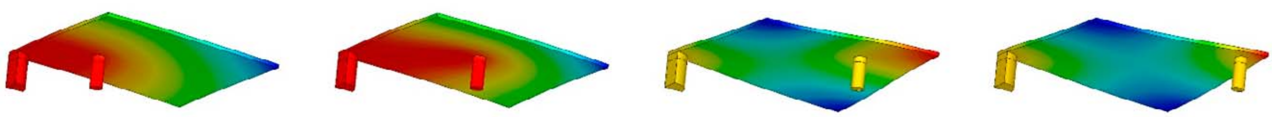


Figure 28: Results of FEM simulation

4.4.2 Current Mode

In current mode the current generated by the pyroelectric chip is converted into a voltage by a transimpedance converter (TIA). The voltage $\mathrm{u_{vib}}$ generated by mechanical excitation can be converted to a piezoelectrically generated current which increases linearly with the frequency of the mechanical excitation. Above the electrical corner frequency of a current mode detector (typically 10 … 30 Hz), the amplification of the vibration noise voltage $\frac{\mathrm{u_{vibCM}}}{\mathrm{u_{vib}}}$ is equal to the ratio between the pyroelectric chip capacitance and feedback capacitance. The output voltage of the detector results from

$$\mathrm{u_{vibCM}} = \mathrm{u_{vib}} \cdot \frac{\mathrm{C_p}}{\mathrm{C_{fb}}}. \tag{43}$$

4.4.3 Comparison of Both Operation Modes

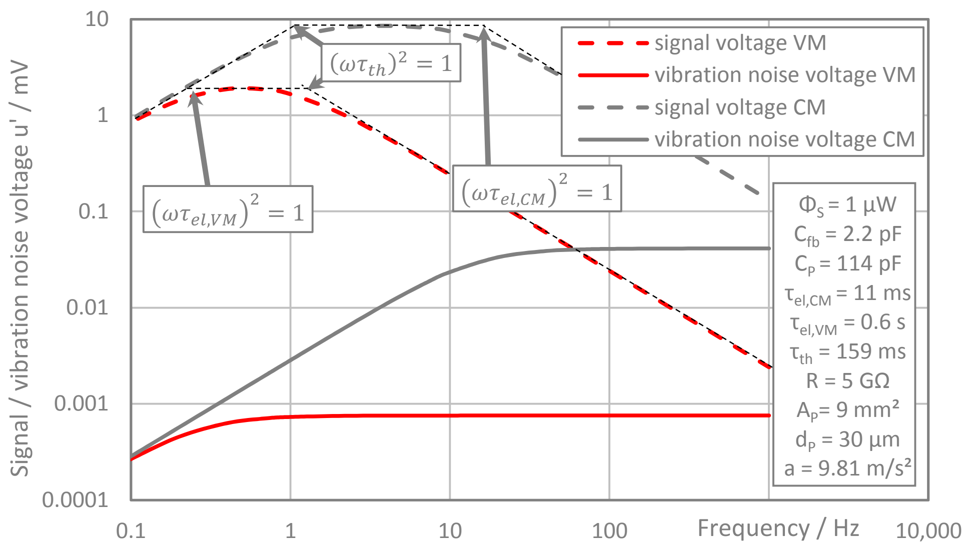


Figure 29: Comparison of desired signal and vibration noise voltage in voltage mode (VM) and current mode (CM)

In both operating modes the voltage generated by mechanical excitation above the electrical corner frequency reaches a constant value. In voltage mode this corner frequency is already reached at a few millihertz. In current mode the range of constant vibration noise voltage begins at a much higher frequency of approx. 10 Hz. Desired signals as well as disturb signals are amplified in the same way. Figure 29 shows the typical desired detector signal across the optical modulation frequency (dashed lines) and the disturb signal caused by the microphonic effect across the mechanical excitation frequency (continuous lines). The distance between the respective curves in the diagram represents the ratio between the desired signal and disturb signal. It becomes clear that this ratio is the same for both operating modes above the thermal corner frequency. It, however, decreases with increasing frequency. For this reason, the choice of the operating mode does not have any influence on the suppression of piezoelectrically generated disturb signals.

4.5 Measured Values and Summary

4.5.1 Measured Values

Figure 30 shows the measured frequency responses of different detectors with mechanical excitation. The different vibration noise voltages of the detectors in current mode (LME-335, LME-341 and LME-351) result from different amplifications and compensations. Therefore, the LME-335 has the greatest sensitivity both to the microphonic effect and to infrared radiation.

Figure 30 also illustrates the lower vibration response in voltage mode with the LIE-502 and its significant reduction by using the InfraTec patented chip holder in the LME-502.

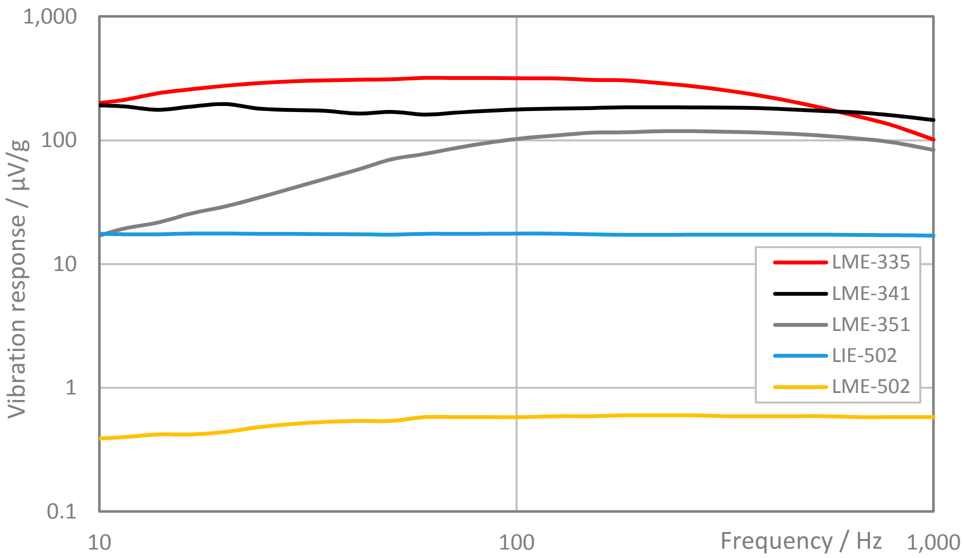


Figure 30: Measurement results of the vibration response across the mechanical excitation frequency:
LME-335 (CM, (2 × 2) mm², 'low micro', 100 GΩ || 0,2 pF),
LME-341 (CM, (2 × 2) mm², 'low micro', 24 GΩ || 0.2 pF),
LME-351 (CM, (2 × 2) mm², 'low micro', 5 GΩ || 0.2 pF),
LIE-502 (VM, (3 × 3) mm², conventional),
LME-502 (VM, (3 × 3) mm², 'low micro')

Table 7 shows some typical measurement results of selected detectors as an example. The higher vibration response of detectors in current mode (CM) compared with those in voltage mode (VM) is clearly evident. For assessing the influence of the microphonic effect, however, only the MEP is of interest. The positive impact of the chip holders which reduce the microphonic effect in the LME detectors is perfectly obvious and independent of the operating mode.

Detector	**Vibration response R_{vib} (10 Hz, 25°C) in µV/g**	**Voltage responsivity R_V (500 K, 10 Hz, 25 °C) in V/W without window**	**Microphonic Equivalent Power MEP (10 Hz, 25 °C) in nW/g**
LIE-502 (VM)	16	160	100
LIE-500 (CM)	550	5,500	100
LME-502 (VM)	0.5	160	3
LME-500 (CM)	65	20,000	3

Table 7: Comparison of vibration response, voltage responsivity and MEP for selected voltage and current mode detectors with and without a chip holder for the reduction of the microphonic effect

4.5.2 Summary

The unavoidable piezoelectric interference of the signal of pyroelectric detectors cannot be reduced by choosing a certain operating mode but only by mechanical countermeasures. As a manufacturer of pyroelectric detectors, InfraTec uses a sophisticated mechanical design which significantly reduce the impact of mechanical excitation.

In addition, the following measure can be taken to reduce the vibration-induced disturb signal in the subsequent application even further:

- The use of vibration dampers minimizes mechanical vibrations (rubber connector, elastic cable, etc.). Please note that the deformation due to constant acceleration is frequency dependent. A sinusoidal acceleration of 1 g (=9.81 m/s²) results in a peak-to-peak deformation of:

70 cm at 1 Hz	7 mm at 10 Hz	70 µm at 100 Hz	0.7 µm at 1 kHz

What are the implications? In practice effective mechanical damping in a compact sensor module can only be achieved for vibration frequencies above 100 Hz.

- Interferences of significantly higher frequency than the measurement frequency should be suppressed by choosing a suitable electrical bandpass e.g. a low-pass of higher order with a corner frequency of at least three times the measurement frequency.

InfraTec’s wide range of voltage mode and current mode detectors with various combinations of compensating elements, electrical time constants and amplifications makes it possible to choose a suitable detector for any application even with regard to the vibration response of the detectors.