2. Microphonic Effect in Pyroelectric Detectors

2.1. Basics

All pyroelectric crystals are inherently piezoelectric. This effect is seen readily in Quartz. When a pyroelectric detector is mechanically excited through shock or vibration, an unwanted signal is produced. This behavior is called a microphonic effect or vibration response.

The interaction of mechanical and electrical variables in piezoelectric crystals can be expressed in an open-circuit operation by a simplified equation for the electrical field strength *E* and its dependence on stress *T* as shown in table 1. Depending on the orientation of the stress, two basic effects can be distinguished: the transverse effect (along the chip edges) and the longitudinal effect (through the thickness).

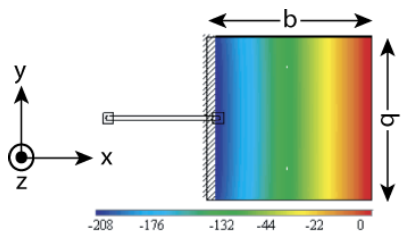
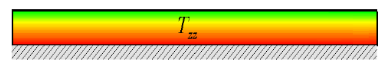
	Transverse Effect	***Longitudinal Effect***
Model	$\vec{T} \perp \vec{E}$ 	$\vec{T} \parallel \vec{E}$ 
Open-circuit voltage	$u_{vib} = -\frac{d_{31}}{\varepsilon_0 \varepsilon_{T33}} \frac{\rho b h}{2} \tilde{a}$	$u_{vib} = -\frac{d_{33}}{\varepsilon_0 \varepsilon_{T33}} \frac{\rho h^2}{2} \tilde{a}$
Open-circuit voltage of a 30µm thick $LiTaO_3$ chip, 3mm sq. element size, acceleration 9.81m/s² (b=3mm, h=30µm, a=1g)	$u_{vib} = 25\ \mu V$	$u_{vib} = 0.8\ \mu V$

Table 1: Comparison of transverse and longitudinal effect on a square thin chip

If the stress *T* is applied into the plane of the chip and transverse to the electric field strength *E* one can use the transversal model. The stress is a linear function in the X direction and exhibits its maximum value at the bearing point and zero-crossing at the right border. The mean stress is half of the maximum stress T_{XX}. A lithium tantalate element with a square electrode of 3mm x3mm and thickness of 30 µm would produce an open-circuit vibration voltage of about 25 µV at 1 g (9.81m/s²). If the acceleration acts longitudinal to the electrical field strength *E* and out of the plane of the chip the open-circuit vibration voltage per g is about 0.8 µV for a 30 µm thick lithium tantalate chip. This vibration voltage represents a limit for the reduction of the microphonic effect for a single element. Any further reduction could be achieved only by adding an anti-parallel / anti-serial compensating element.

2.2. Reduced microphonic voltage by “in-chip-compensation”

The simplest solution for reducing the stress caused by the transverse effect is the simultaneous clamping of the chip, both at the left and right borders. This results in tensile and compressive stress in the halves of the element and would counterbalance each other. A central fastening leads also to the compensation of stress. As shown in figure 1 the open-circuit vibration voltages are minimized by both the fastenings.

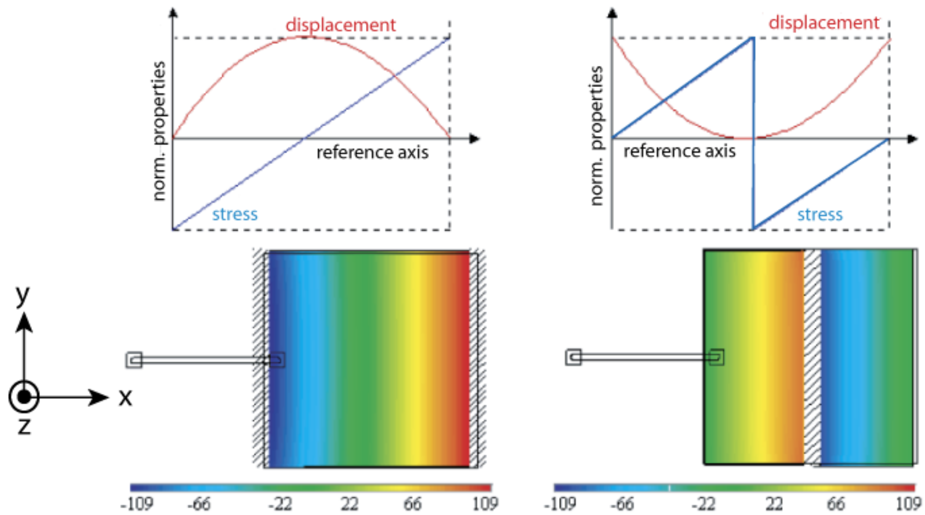


Fig. 1: Stress distribution on a double-sided (left), and center (right) clamped pyroelectric detector chip (3x3x0.03) mm³ with acceleration in the X direction

The analytical description of the microphonic effect shows that the transverse effects are minimized by an outer symmetrical mounting, or a central mounting and that the longitudinal effect is much lower. However, stress overshoot around the mounting points is produced, when the acceleration is applied out-of-plane. In this case the simplified analytical description of the longitudinal effect does not provide proper results, since the chip structure and chip mounting varies significantly from the ideal configuration. In contrast to the ideal configuration, the arrangement and thickness of the electrodes is different. Furthermore, an additional absorption layer displaces the neutral stress line out of the center line. The influence of an acceleration out-of-plane could only be described accurately by a numerical analysis, for example by the simulation software ANSYS Multiphysics.

As shown in figure 2, the base for the numerical analysis is a chip holder. The chip holder consists of a base plate with a central column surrounded by four symmetrically arranged columns. The pyroelectric chip is assembled on the chip holder by adhesive bonding.

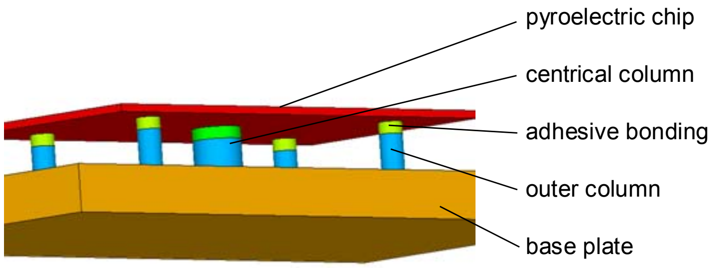


Fig. 2: Model of the assembly of chip holder and pyroelectric chip

In the plane of the pyroelectric chip the open-circuit vibration voltage is compensated by the symmetrical arrangement of all columns. If we look at the out-of-chip plane, the open-circuit vibration voltage is compensated by the arrangement of the outer surrounding columns in such a manner that convex and concave warpings are induced by mechanical excitation in the normal direction. These warpings produce tensile and compressive stress at one surface and the reversed at the opposite side of the pyroelectric chip as illustrated in figure 3. The positive and negative piezoelectric charges generated by the stress are compensated by the electrodes, which cover the top and the bottom sides. To achieve a stress compensation, the chip deformation can be optimized by modifying the arrangements of the mountings (see figure 4).

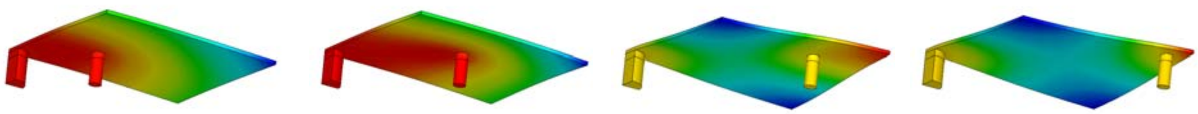


Fig. 3: Deformation and stress of a quarter of a pyroelectric chip assembled on a chip holder using different support positions along the chip diagonal

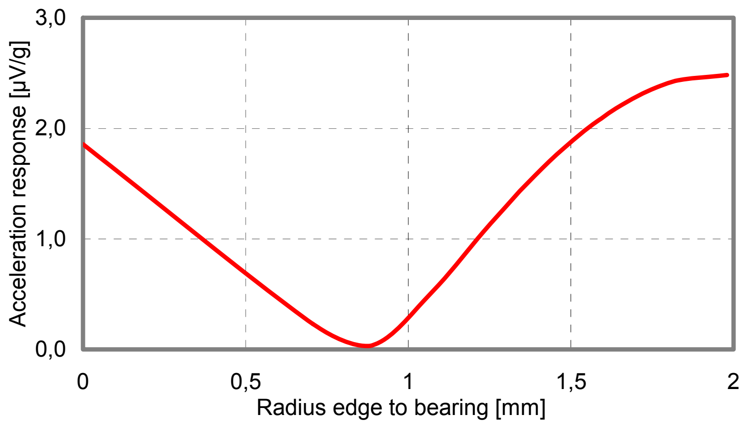


Fig. 4: Acceleration response of the chip shown in fig.3 as a function of the mounting point position

The stress distribution inside of a pyroelectric chip is also affected by the chip coating, technological parameters, as well as the elastic modulus of the adhesive by which the pyroelectric chip is bonded onto the chip holder. Nevertheless the statistics of sample measurements confirmed a good fitting of the test results and simulated values.

2.3. Microphonic effect at Voltage and Current mode operation

The operational mode of a pyroelectric detector and the frequency range affects the result of piezoelectricity at detector's output (see figure 5).

Voltage mode

The Open-circuit operation of a pyroelectric chip as described in the earlier BASICS section is given typically in voltage mode for frequencies higher than 0.5 Hz. The criteria for this is the electrical break point set by the product of chip capacity (30 ... 120 pF) and load resistor (5 ... 100 GOhm). In this frequency range the vibration or so called microphonic voltage at the detector output is identical with the open-circuit vibration voltage (see BASICS):

$$u'_{vib\,VM} = u_{vib} \quad (1)$$

A typical signal of a voltage mode detector is in the order of millivolts. A 100g acceleration (e.g. a shock) can produce a similar but disturbing signal of the mechanical vibration if its frequency fits the amplifier pass band.

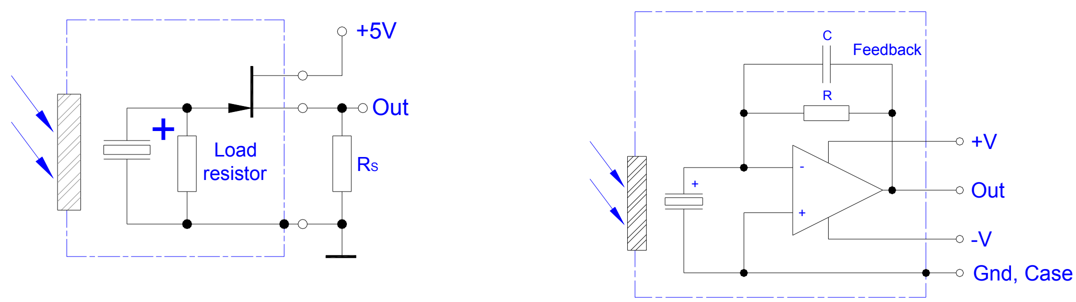


Fig. 5: Voltage mode operation (left) and current mode operation (right) of a pyroelectric detector

Current mode

State-of-the-art pyroelectric detectors make use of the current mode (see figure 5) more and more. From the open-circuit vibration voltage $\underline{u}_{vib}$ the short-circuit current i_{vib} is derived, which **increases in** a linear manner with the frequency. The short-circuit current flows in a preamplifier and generates a signal voltage *u'* at the output:

$$\tilde{u}'_{vib} = i_{vib} R \frac{1}{\left[1+(\varpi\tau_E)^2\right]^{1/2}} \tag{2}$$

As in voltage mode operation the microphonic voltage at detector's output is constant for frequencies well above the electrical cut-off frequency. Because the electrical time constant in current mode is defined by the feed back components *C* and *R* (this time constant is clearly shorter) this frequency range starts only from some 10 Hz. In this frequency range the vibration voltage at the detector output is created by the open-circuit vibration voltage (see Basics) but amplified by the quotient of the capacitance of the pyroelectric chip and of the feedback capacitance:

$$u'_{vib\,CM} = u_{vib} C_P C_{fb}^{-1} \tag{3}$$

Comparison

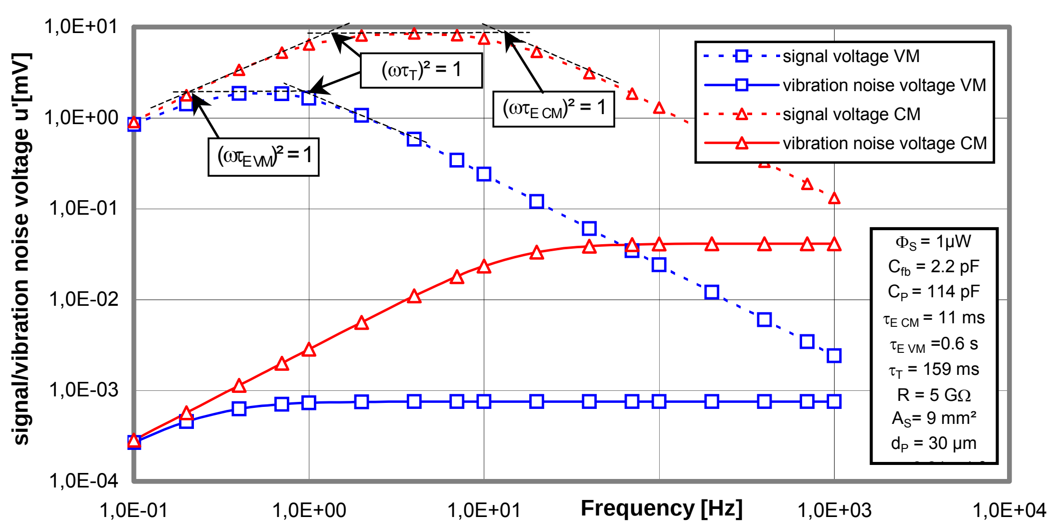


Fig. 6: Comparison of the signal voltage u'_S and of the vibration interference voltage $u'_{vib\,z}$ (longitudinal effect) in voltage mode and current mode

Figure 6 shows the frequency correlations with straight lines for the vibration voltage and dashed lines for signal voltage. The results are indicated with circles and squares for the current mode and the voltage mode respectively. Even if the vibration voltage behaves differently for current and voltage mode the ratio of signal to vibration voltage at a specific frequency (means the distance between the two red or the two blue lines in the diagram) is the same for current and voltage mode. There is no advantage from point of vibration responsivity by using current or voltage mode.

2.4. Introduction of the term “Microphonic-Equivalent Power (MEP)”

InfraTec introduced the Microphonic-Equivalent Power (MEP) for a simplified discussion:

$$MEP = \frac{R_{vib}}{R_V} \tag{4}$$

with

$$R_{vib} = \frac{u'_{vib}}{\tilde{a}} \tag{5}$$

The MEP is defined as the quotient of the vibration responsivity and voltage responsivity and indicates the incident radiation flux, required to generate an equivalent root-mean-square (RMS) signal voltage for a given vibration. It is expressed in the units of W/g (gravitational acceleration = 9.81m/s²). Table 2 summarizes vibration responsivity, voltage responsivity and MEP. Off course the MEP is more or less independent from the operation mode of the preamplifier. In the case of a standard detector, the vibration responsivity and hence the MEP strongly depend on the spatial direction of the applied vibration. In the case of microphonic reduced detectors (“low micro” type) with the novel chip holder, it is clearly demonstrated that the MEP value can be reduced to about 2 nW/g @ 10Hz in all three spatial directions.

Detector	Vibration Responsivity Rvib (10Hz, 25°C) in µV/g			Voltage Responsivity Rave (500K, 10Hz, 25°C) in V/W without window	Microphonic Equivalent Power MEP (10Hz, 25°C) in nW/g		
	x	y	z		x	y	z
LIE-502 (VM)	16	1,6	3,5	160	100	10	22
LIE-500 (CM)	550	55	120	5.500	100	100	22
LME-502 (VM)	0,5	0,5	0,4	160	3	3	2
LME-500 (CM)	65	65	50	22.000	3	3	2

Table 2: Vibration responsivity, voltage responsivity and microphonic-equivalent power of standard and “low micro” detectors

<u>Conclusion</u>

There are three ways to reduce the influence of the piezoelectric behavior on pyroelectric detectors in customer’s sensor modules:

- Suppress mechanical vibrations as good as possible by pulse damper (smooth rubber, flexible cables). Please note that the elongation [mm] at a constant acceleration [m/s²] is frequency dependent. A sinusoidal acceleration of 1g = 9.81m/s² is the result of a peak-to-peak elongation of:

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

  In a compact sensor module a mechanical damping can only be realized for frequencies higher than 100Hz.

Advanced Features of InfraTec Pyroelectric Detectors

- Limit the electrical pass band of the amplifier stages especially at the high frequency side by a steep low pass.
- Compensation of the microphonic voltage by sophisticated mounting of the pyroelectric chip.

InfraTec offers a variety of pyroelectric detectors of voltage mode (VM) or current mode (CM) operation with a reduced vibration response (so called "low micro") based on InfraTec's patented chip mounting technology. The reduction of the microphonic voltage is in the order of a twentieth (5%) of a conventional pyroelectric detector. Figure 7 shows their typical frequency response. Please note that the differing vibration voltage of the CMOS OpAmp detector series LME-351, -341 and -335 caused on a differing gain. LME-335 offers the highest responsivity (90,000 V/W @ 10Hz).

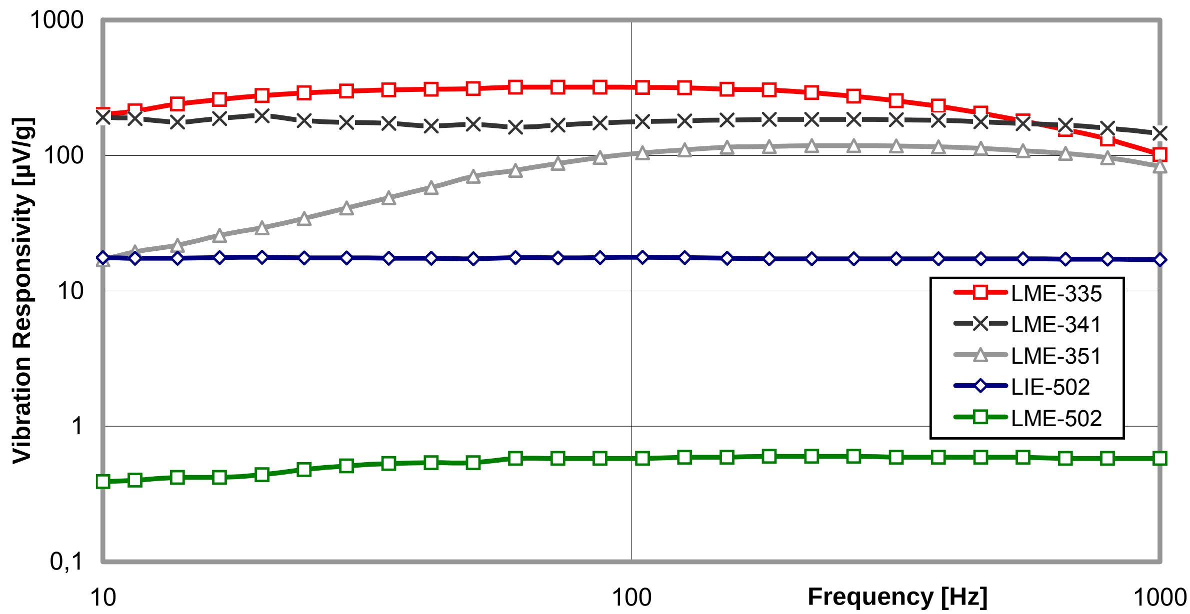


Fig. 7: Test results of microphonic effect
LME-502 (VM, 3x3mm², "low micro"), LIE-502 (VM, 3x3mm², conventional),
LME-351 (CM, 2x2mm², "low micro", 5GΩ//0.2pF), LME-341 (CM, 2x2mm², "low micro", 24GΩ//0.2pF),
LME-335 (CM, 2x2mm², "low micro", 100GΩ//0.2pF)

InfraTec's "low micro" technology is available for single element detectors such as LME-316 (VM) or LME-345 (CM) and multi-color detectors such as LMM-244 with an element size of 2x2 or 3x3 mm². These detectors can be identified at the part description by a "M" in the second digit (LME instead of LIE or LMM instead of LIM).