



ELTEC INSTRUMENTS, INC.

ELTECdata # 103

The Influence of Detector Active Area on Sensitivity and Noise Output of Pyroelectric Detectors

The information in this paper updates and expands basic technical information previously printed by ELTEC INSTRUMENTS, INC.

The purpose of ELTECdata # 103 is to define and delineate active area dimensions and give small area alternatives.

Definition:

The active area of a pyroelectric crystal is best defined as the area on which the detector exhibits radiation sensitivity. Occasionally, the active area is called "crystal size" or "electrode size" since these factors basically define the active area. However, these terms can be misleading. We're better off looking at the detector from the outside and testing where and in which area the detector is sensitive.

Photon detectors have light sensitive material (e.g. PbS) or a diode layer (photocell) and exhibit radiation sensitivity only in areas where sensitive material is deliberately deposited. There is absolutely no sensitivity outside this area.

The pyroelectric detector is a thermal detector, detecting a secondary effect (temperature change) from absorbed radiation. Because heat is transferred through materials and air, any radiation absorbed near the actual sensitive crystal will add to the magnitude of the signal produced, depending on the heat transfer efficiency.

With this in mind, we need to define a "sensitivity profile" telling us the sensitivity of any point on the detector, including the case, the wire connections (which also have some radiation sensitivity), etc. In short, no statement of "true responsivity" should be made without reference to experimental data.

Responsivity and Area Independence

Radiation sensitivity or responsivity of a detector is commonly defined in A/W (Amperes output per Watt impinging radiation). This fact holds true for pyroelectric detectors as well as for other detectors such as solar cells.

SINGLE ELEMENT DETECTORS - VOLTAGE MODE OPERATION

When using a pyroelectric crystal with a voltage follower or impedance buffer (integral or external), the output voltage is a function of the current responsivity and the lumped impedance. Current responsivity is given in Amps per Watt (typically on the order of one microamp). Lumped impedance is composed of the crystal capacitance, resistive load and stray capacitance associated with circuit wiring and the FET.

This is the most commonly used formula for measurement and instrumentation purposes where special detector size requirements arise:

$$R_V = R_i \cdot Z_{\text{eff}} \\ = A/W \cdot \Omega = V/W$$

$$Z_{\text{eff}} = \frac{R_L}{\sqrt{1 + (R_L C_T \omega)^2}}$$

where

R_V = voltage responsivity (V/W)

R_i = current responsivity (A/W)

Z_{eff} = lumped impedance (Ω)

where

R_L = load resistance

C_T = total capacitance

= $C_{\text{det}} + C_{\text{stray}}$

ω = angular frequency

= $2\pi f$

and

$$\tau_T > \tau_e$$

where

τ_T = thermal time constant

τ_e = electrical time constant

The current output of the pyro is independent of the active area for a given input power. The same output signal will be obtained if a certain input power falls on only a very small portion of the active area (such as from a narrow laser beam), or if the identical power is equally distributed over the whole area. In this context, the term input power is defined as radiation falling only onto the active area and not beside it. In the common situation of uniform power per area (uniform illumination when no focusing optics are used) or when the optics can only focus to a minimum spot size, the input power is proportional to the size of the active area. Refer to Figure A.

Conclusion

Current Responsivity is independent of the size of the active area as long as the active area is as large as or larger than the illuminated area.

Crystal Size & Electrode Size

Detectors are made of: a) a large crystal with a specific electrode pattern deposited on it or b) a crystal shaped to the desired size with both sides fully electroded.

Both approaches have been used. However, recent developments have shown (for lithium tantalate) approach b) is much better for dual element detectors. Why? Non-electroded areas act as a heat sink or as a short-circuit in the case of a dual element detector. This causes significant reduction of the sensitivity especially at low frequencies when there is enough time for the heat to spread out over the entire crystal.

This thermal loading becomes insignificant if operation frequencies are in the frequency range of 20 Hz or more, as is true for most arrays.

Voltage Responsivity versus Capacitance: Inverse

Momentarily ignoring stray capacitance, let's focus on the detector's capacitance and load resistor values. Detector capacitance is a function of a material's dielectric constant, the active area and the thickness of the crystal. If we go from a 2mm diameter electrode to a 1mm diameter electrode, the crystal's area will be reduced by a factor of four and crystal capacitance will be reduced by a factor of four.

$$C_{det.} = \frac{K\epsilon_0 A_{det.}}{d}$$

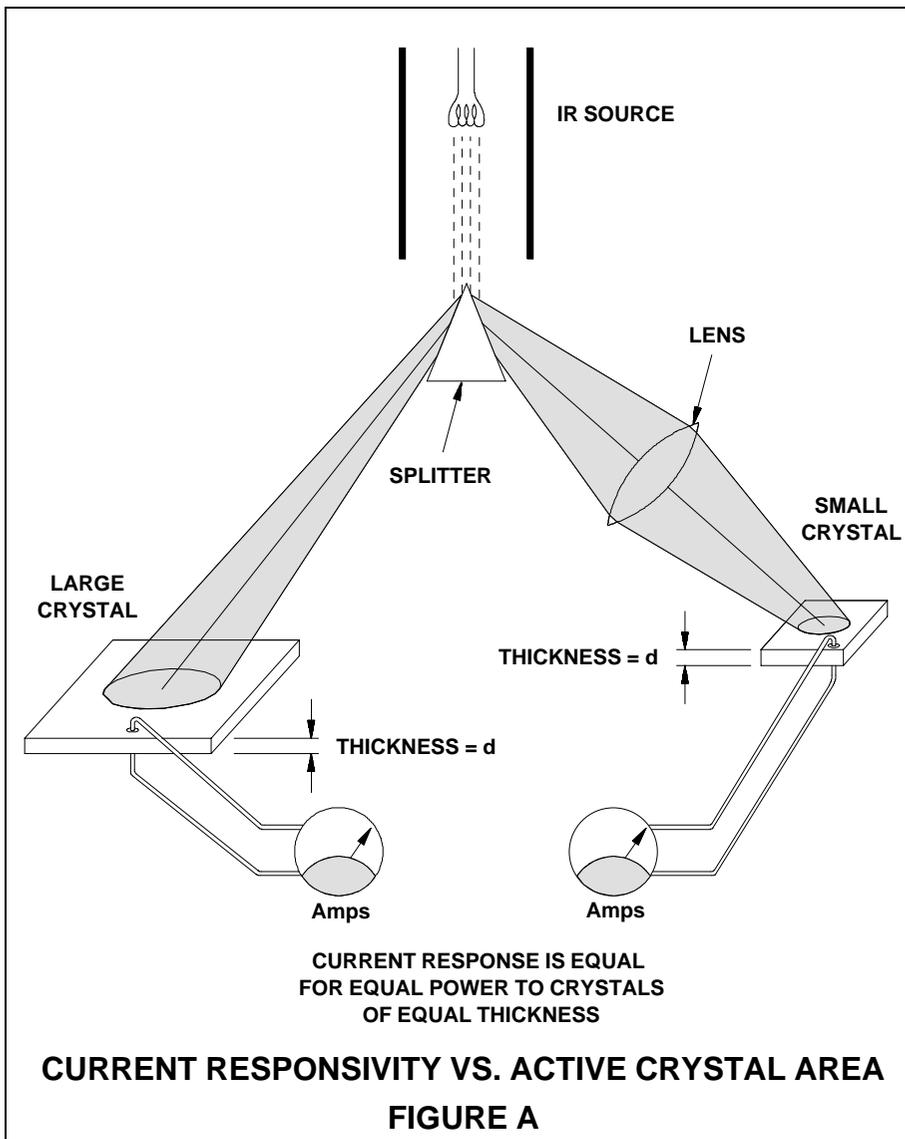
where

$A_{det.}$ = area of detector

K = dielectric constant

ϵ_0 = permittivity of free space

d = thickness of detector



Substituting the area-dependent impedance back into the equation defining the output voltage of a pyroelectric detector, we see that (keeping thickness constant) decreasing an area by a factor of four increased voltage responsivity by a factor of four.

There is a prevalent detector theory which advises making detectors as small as possible for best responsivity.

However, stray capacitance can set a lower limit on detector size. A common value for stray capacitance is equivalent to a lithium tantalate crystal with an area of approximately 0.5 mm sq. and a practical thickness. In a detector so defined, 50% of the signal would be lost into stray capacitance. Consequently, minimum size with acceptable loss (30%) is 1mm sq. assuming no special precautions, such as a thinner crystal is employed.

Although the voltage responsivity (R_V) is inversely proportional to capacitance, when sensing crystal size is decreased for higher responsivity, a point is reached where stray capacitance is equal to crystal size (typically 0.5mm sq.) and half the signal is lost to stray capacitance. Thus a crystal 1mm sq. is the minimum recommended.

Noise

FET current noise is the main noise source. Noise increases proportionally with responsivity when a detector crystal is made smaller as can be proven by the formula below:

$$V_N = I_N \cdot Z_{eff}$$

where

$$V_N = \text{noise voltage}$$

$$I_N = \text{FET noise current}$$

$$Z_{eff} = \text{lumped impedance}$$

The output noise signal is in complete analogy with voltage responsivity $V_N = I_N$ such that the noise voltage (V_N) = $I_N \cdot Z_{eff}$ with I_N as the FET noise current (which is to say that noise increases proportionally when a detector crystal is made smaller).

The real performance parameter, the signal-to-noise ratio (s/n) and also NEP and D^* remain essentially unchanged for any detector size.

Conclusion

Although the apparent signal can be made larger with smaller detector crystals, the real performance is not improved at all.

Below areas of approximately 1mm sq., stray capacitance becomes dominant and further reduces sensitivity and performance.

Including manufacturing problems, practical detectors will - in most cases - be limited to crystal size (equal to area size) between 1mm sq. and 3mm sq. in standard TO-5 housings.

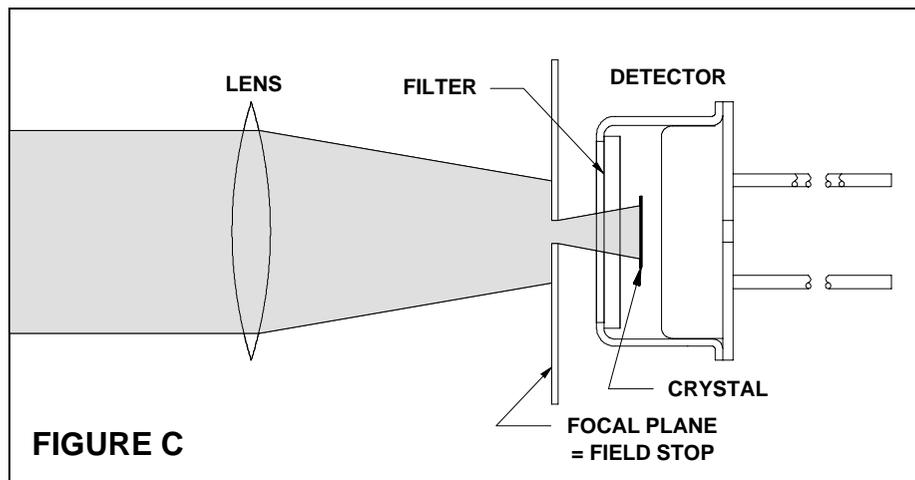
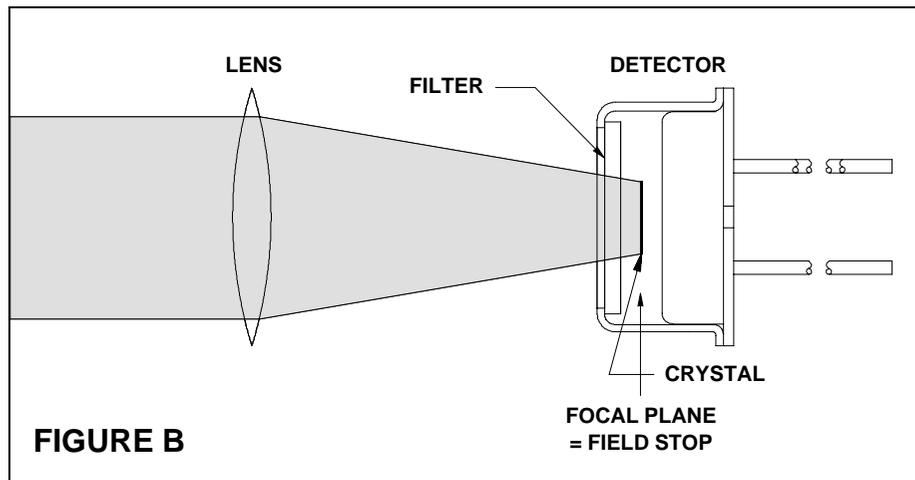
Small Geometry Alternative

In the non-common case we showed that performance is independent of area over a certain range. For small geometries, the parasitic capacitance effect decreases performance. There is a simple and effective alternative.

Definition: Field Stop

The field stop is the physical diameter limiting the optical system's angular field of view.

Small active areas are usually required to act as a field stop in a sys-



tem with a lens or other imaging optics such as radiometers. In our drawing (Figure B) the active area is identical with the field stop and determines the instrument's field of view e.g. the spot size in which the temperature is measured.

As an alternative, place an additional field stop (simple aperture) in front of the detector.

It is important that the field stop is now in the focal plane and not the crystal (Figure C). The crystal just catches any radiation coming through the aperture.

Now the field stop aperture acts as the "active area" and can be made to any desired shape and there is no limitation for minimum size. No matter where you put the aperture, the beam spreads out. However, no more energy can strike the crystal than comes through the aperture.

Detectors used in conjunction with a field stop must use a crystal with a minimum diameter of approximately twice the aperture's diameter - as in

ELTEC standard Model 406 which has a 2mm diameter electrode for apertures up to 1mm diameter. To maintain an adequate field of view for the previously noted configuration, the crystal must be big enough to catch all of the rays plus 20% tolerance.

With such a field stop placed in front of the detector, optical performance is now easier to determine.

- Radiation is focused onto the field stop aperture instead of the crystal. This aperture can be mounted exactly in the focal plane and mechanical detector tolerances such as the location of the crystal and diffraction of the detector window (window thickness and refractive index) no longer affects the accuracy of the system.
- A uniform sensitivity now exists over the "active area" - the aperture - as long as any ray impinging from the lens in the angle falls directly upon the crystal. This effect can be verified by raytracing.

- There are no more non-uniformities and reflections.

Note

This approach should be used in all instrument type applications of single-element detectors which are "image quality conscious". It cannot be extended to dual-element detectors or applications such as intruder alarms or similar "energy conscious" systems not requiring a defined active area.

Energy Conscious Systems

In intruder alarms or other motion detectors, the strength of the signal is much more important than the precise definition of the angular field of view. Here, no apertures are used and the crystal acts as the field stop. Crystal size is usually chosen as large as possible. However, the optimization has to be made in practical experiments using detectors with various crystal sizes to obtain best detection capability and lowest noise.

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ELTEC Instruments, Inc. P.O. Box 9610 Daytona Beach, Florida 32120-9610 U.S.A.
Tel (USA and Canada): (800) 874-7780 Tel (Outside USA): (386) 252-0411 Fax: (386) 258-3791
Web: www.eltecinstruments.com E-Mail: Sales@eltecinstruments.com