THE INFLUENCE OF DETECTOR ACTIVE AREA ON SENSITIVITY AND NOISE OUTPUT OF PYROELECTRIC DETECTORS

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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.

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.

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.

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 comprised 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:

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

where
R_V = voltage responsivity (V/W)
R_i = current responsivity (A/W)
Z_{eff} = lumped impedance (Ω)

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

where
R_L = load resistance
C_T = total capacitance = $C_{det.} + C_{stray}$
ω = angular frequency = $2\pi f$

and

$$\tau_t \gg \tau_e$$

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 square 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.

Conclusion

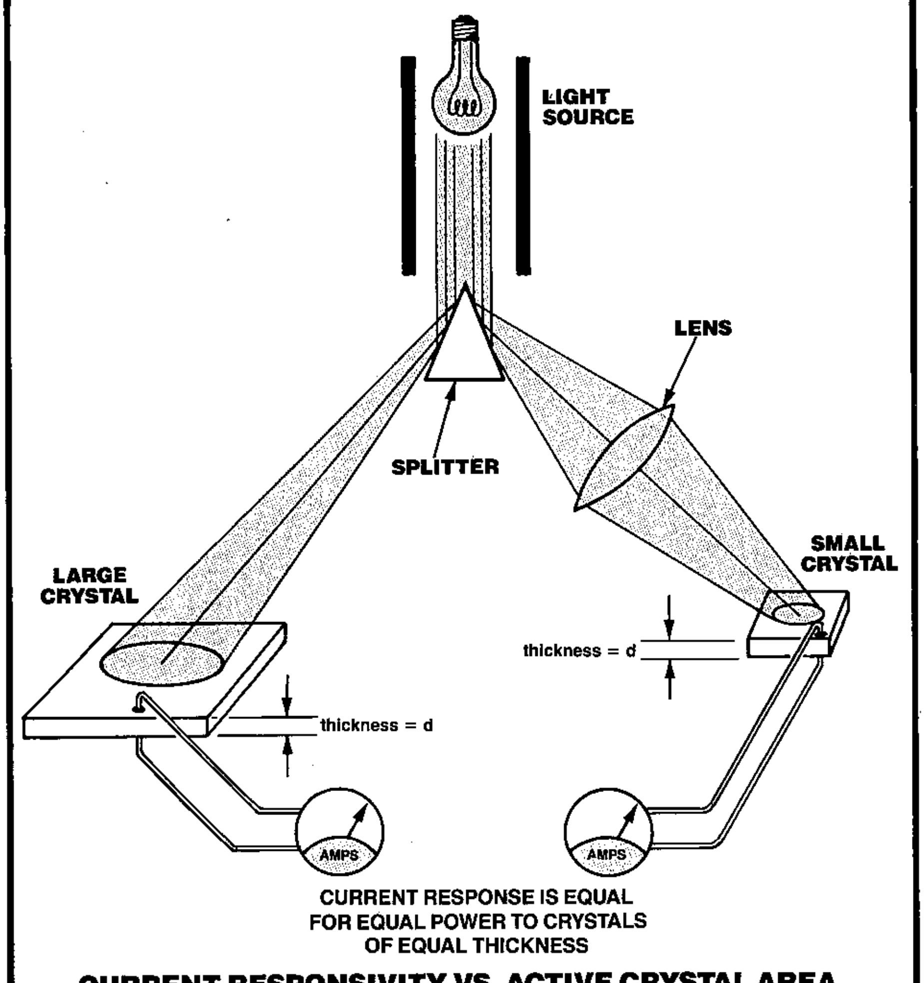
Current Responsivity is independent of the size of the active area as long as the active area is as large as or larger than the illuminated area.

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.



CURRENT RESPONSIVITY VS. ACTIVE CRYSTAL AREA

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.

$$C_{det.} = \frac{K\varepsilon_0 A_{det.}}{d}$$

where
$A_{det.}$ = area of detector
$= \pi r^2$
r = radius of detector
K = dielectric constant
ε_0 = permitivity of free space
d = thickness of detector

Substituting the area dependant 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 increases 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 capicitance can set a lower limit on detector size. A common value for stray capicitance is equivalent to a lithium tantalate crystal of approximately 0.5sq. mm area with 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,

Although the voltage responsivity (Rv) 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 1 x 1mm is the minimum recommended.

such as thinner crystal or an active guard, are employed.

Noise

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

$U_N = I_N \times Z_{eff}$
where
U_N = Current Noise
I_N = FET noise current
Z_{eff} = lumped impedance

The output noise signal is in complete analogy with voltage responsivity $U_N = I_N$ such that the noise voltage $(U_N) = I_N \times Z_{eff}$ with I_N as the FET noise current (which is to say that noise increases proportionally with the responsivity when a detector 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 small detectors, 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 1 × 1 mm and 2.5 × 2.5 mm.

Small Geometry Alternative

In our 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

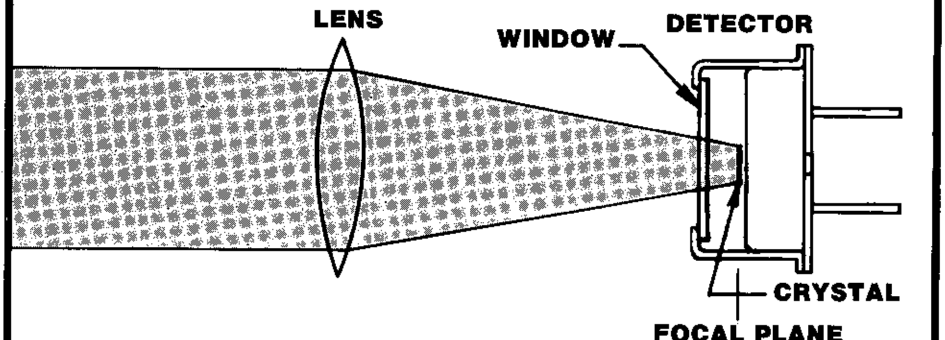


FIGURE X

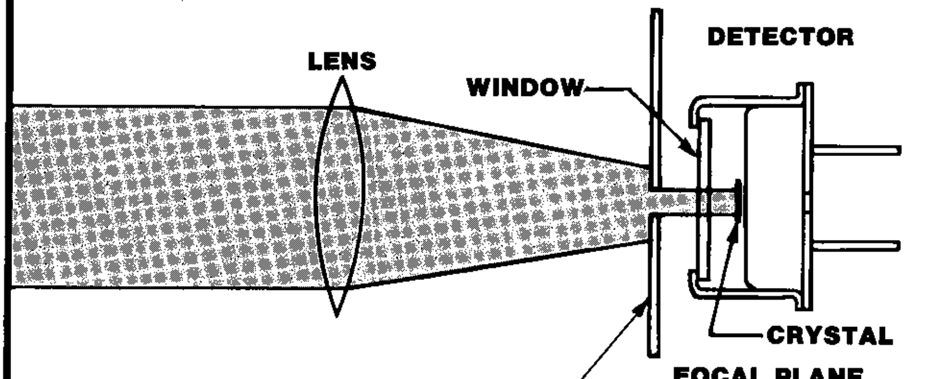


FIGURE Y

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 system with a lens or other imaging optics such as in radiometers. In our drawing, (Figure X) 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 Y). 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.

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 the full bundle of rays plus a 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.