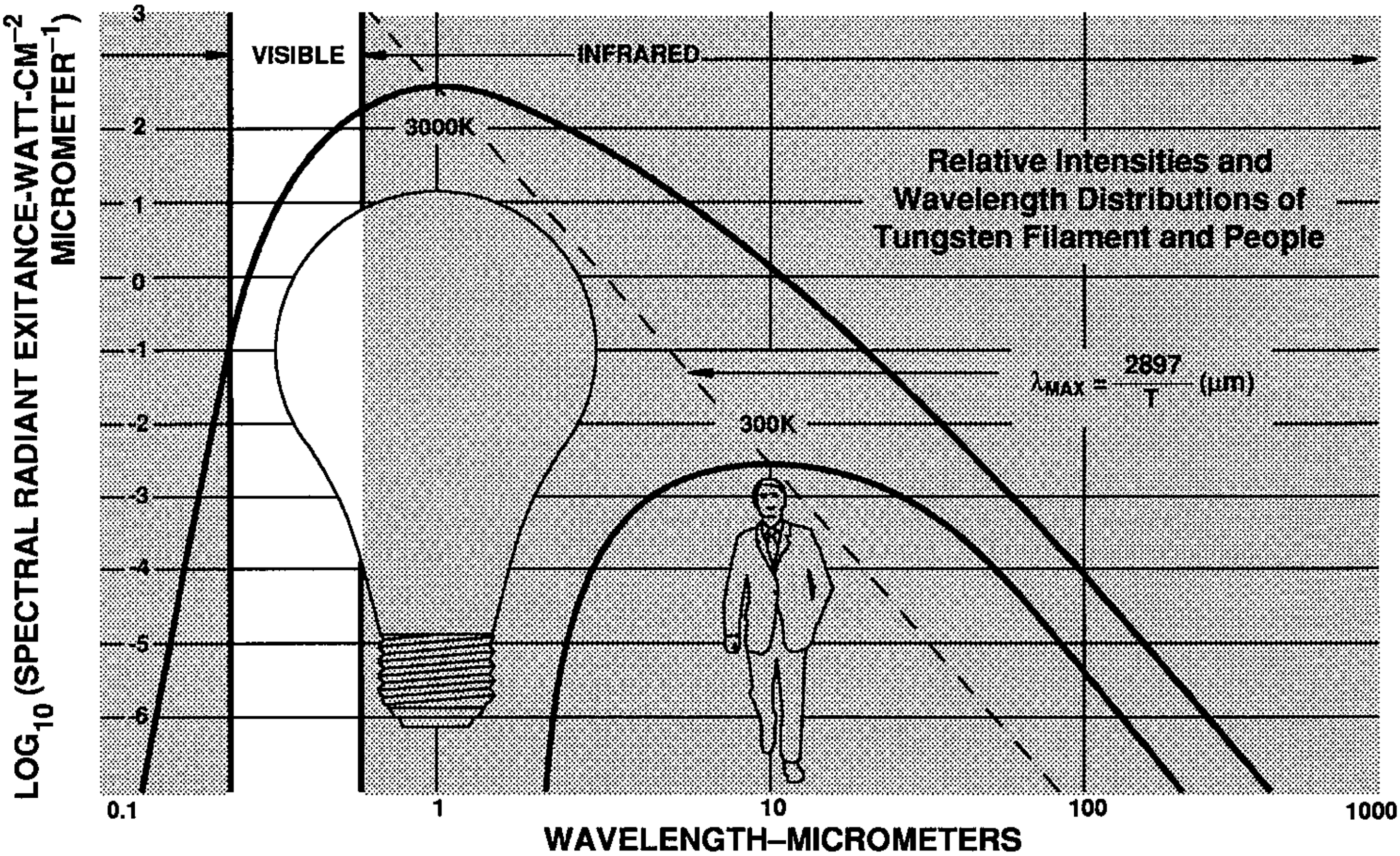
ELTECdata # 100

Introduction To Infrared Pyroelectric Detectors

ELTEC INSTRUMENTS, INC.



Use Infrared: It's Already There

Pyroelectric detectors make mid-range infrared affordable. You use what is already there — 100% natural and harmless.

You can use the invisible glow of objects and people to detect, count, monitor, locate, activate, conserve, protect, or warn. It is passive technology.

Beyond Photodiodes

Visible light goes from 0.4 to 0.7 micrometers on the wavelength spectrum. Beyond that is infrared. Photodiodes are inexpensive and practical even to 1 micrometer. But, 1 micrometer corresponds to the "wavelength of maximum energy" of a blackbody at about 2,900 Kelvin (4,700 F) which is the temperature of an incandescent bulb's white-hot filament.

To use the infrared emitted from ourselves or objects that we can touch, wavelengths well beyond 1 micrometer and especially those around 10 micrometers must be detected.

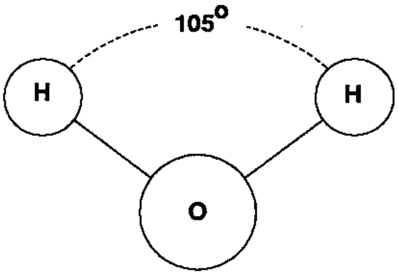
Pyroelectrics Are Practical

Detection of mid-range infrared is not new. Thermistors and thermopiles (thin-film thermocouples) have long been available. Although these components are relatively inexpensive, the circuitry required to make them work is not. Moreover, both thermistors and thermopiles are generally found wanting in terms of signal strength and speed of response.

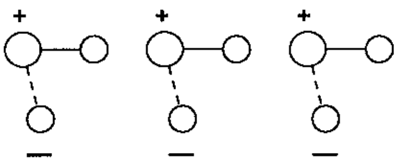
Pyroelectrics are today's practical choice for broad-band IR detection. Pyroelectrics offer technical advantages in signal strength and in minimizing interconnecting circuitry. And, as has happened with other components, use of more sophisticated production techniques pioneered at ELTEC INSTRUMENTS INC., has increased the availability of lithium tantalate pyroelectric detectors while lowering cost.

The Pyroelectric Effect: The Material

If a material has an internal electrical symmetry, it's neutral. If it's unsymmetrical — like water — it has a permanent electric dipole. Most unsymmetrical materials in bulk have a zero dipole effect because of a random or self-canceling arrangement.



Water is unsymmetrical



Dipoles acting in unison

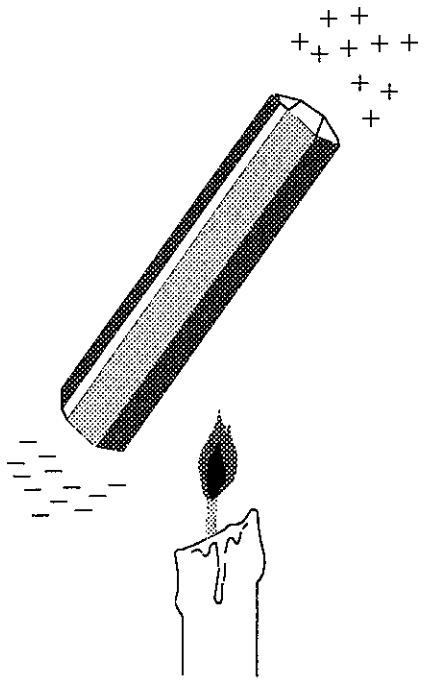
There are some unsymmetrical materials which maintain a net dipole orientation even in bulk. Heating such a material (within limits) doesn't randomize the dipoles, but rotates them in unison and thus maintains a polarization. Since this occurs in the absence of an external electric field, it is called a spontaneous polarization.

Dipoles will act in unison to an upper temperature point called the Curie Point. Lithium tantalate is a practical pyroelectric material because it has a Curie Point of 610 C. Also, lithium tantalate is a very responsive synthetic crystal with an established, long-term stability.

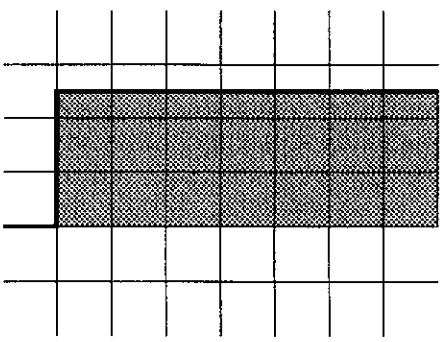
The Pyroelectric Effect: Simplified

The Greeks discovered the pyroelectric effect 23 centuries ago. They observed that when tourmaline was placed in hot ashes, it first attracted and then repelled them (charge generation ... attraction by induction ... contact/reversal ... repulsion of like charge). Hence "pyro", for fire, plus electric !

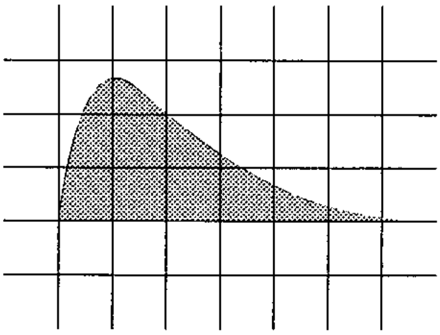
Pyroelectric isn't thermoelectric. In a thermoelectric device, like a thermocouple, a steady voltage is produced when two junctions of dissimilar metals are held at steady but different temperatures. In a pyroelectric device, a change in temperature creates a change in polarization. "Electrical polarization" is just another way of saying "electrical charge". And, by definition, change in charge with time is current. Thus, a pyroelectric device produces current only as it experiences a temperature change. When it's at a constant temperature, no current is produced.



Heated tourmaline develops electric charges



Infrared input to detector (step)

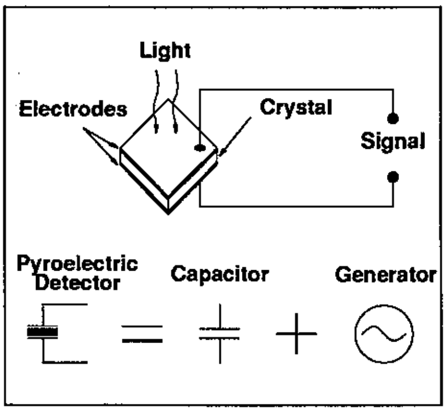


Response of pyroelectric detector

The nature of the pyroelectric detector makes it both fast and useful. Since every object is emitting infrared light, every object is a transmitter. And since the infrared detector responds to infrared, it is a receiver. An intruder entering a room is like an invisible light being turned on; the detector responds to the change in infrared light, generating a useful signal. A glass object (transparent in the visible and near-infrared) may pass right through a light beam undetected, but its infrared emissions will identify it every time. In short, wherever there's a change in infrared light, there's a potential pyroelectric application.

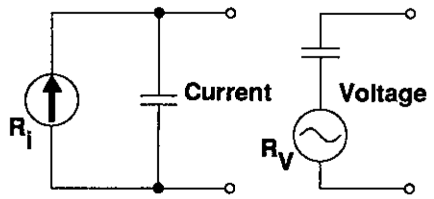
The Pyroelectric Detector

A thin wafer of lithium tantalate has electrodes deposited on both faces. The electrodes gather the charge which is unable to leak through because the material is such a good dielectric (insulator). In its simplest form, the pyroelectric detector is both a capacitor and a charge generator (in response to infrared light striking a face, being absorbed as heat, creating change in polarization). And all this at room tempera-



ture, without the need for cooling or electrical biasing.

The detector can be modeled as a current source with a parallel capacitance or as a voltage source with a series capacitance. Since the device does not have a resistive component, it will not exhibit resistor (Johnson) noise.



The detector can be modeled as either a voltage or current source

The absolute sensitivity or responsivity of a pyroelectric detector is expressed as a "current responsivity" or as a "voltage responsivity". The current response is independent of frequency once the time-rate of heat arrival is greater than the time-rate of material thermalization ("thermal time constant" - the time it takes for thermal equilibrium and thus a cessation of polarization change). The magnitude of current output is a function of the separation of the charge-gathering electrodes, the material parameters, and, at very low frequencies (1Hz), the thermal time constant. Thus the current response (for other than low frequencies) is expressed as:

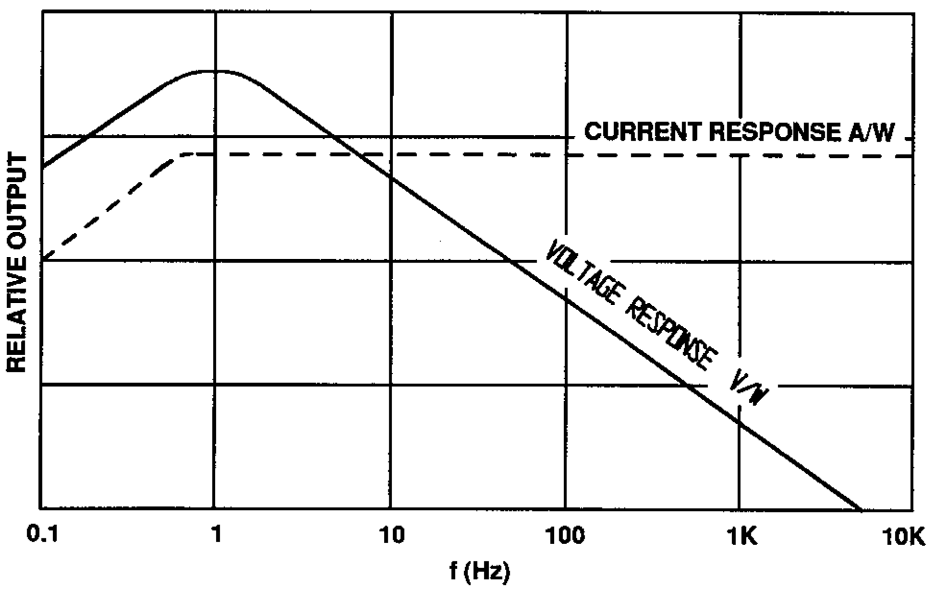
$$R_i = \frac{\Gamma}{d}$$

where R_i = current responsivity in A/W
r = material parameter (for lithium tantalate: $5.49 \times 10^{-9}\ \frac{A\ cm}{W}$)
d = electrode separation in cm

The voltage responsivity is dependent on the frequency of operation, the material parameters, the capacitance of the detector element, and at low frequencies, the thermal time constant. For frequencies between the thermal time constant and capacitive-break, the voltage responsivity is expressed as:

$$R_V = \frac{R_i}{\omega C_d}$$

where R_V = voltage responsivity in V/W
ω = angular frequency = $2\pi f$
C_d = detector capacitance in farads



Electrical response of a simple detector

The optical response (or bandwidth) is determined by the efficiency of the detector at absorbing thermal radiation (infrared light) and thereby heating the crystal. Obviously, a highly reflective electrode would be self-defeating. So special coatings are used to maximize absorption. Sometimes a black coating is applied over the electrode. However, the blackening can degrade high frequency performance because it introduces thermal diffusion time. If this time is too long relative to the input frequency, then the coating acts as a thermal cushion (or damper) and doesn't allow the detector crystal to accurately experience the thermal change.

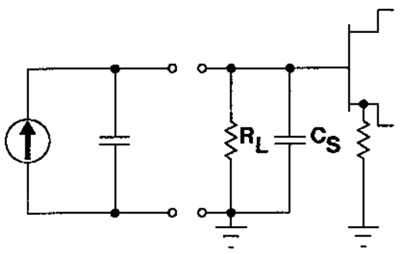
Electrical Considerations

As previously noted, the detector is effectively purely capacitive by virtue of its high DC resistance (10^{13} ohms). And since the capacitance is fairly small (typically 30 picofarads), the detector itself has a very high impedance. In most applications, this very high impedance must be converted to a more practical low impedance output. This can be done in two ways; a voltage follower or a current amplifier.

Both of these amplification schemes have positive and negative features. The voltage mode circuit will generally yield the best signal to noise ratio and it can operate at a very small supply voltage and current. However, it does not have a large output responsivity and output response will be frequency dependent (unless a low value R_L is used). The current mode offers a substantial increase in output signal. It can have a "flatter" frequency response and that response can be set independent of the crystal. Unfortunately, the noise characteristics of the operational amplifier limit the signal-to-noise ratio and the operating voltage and current requirements are greater.

NOTE: Although the voltage (Field Effect Transistor) or current (Op Amp) circuits can be added externally to the basic detector package, it is accomplished with the addition of stray capacitance, susceptibility to EMI, testing problems, expense and possibly a compromise in reliability. To circumvent these problems, detectors are offered with the FET and appropriate load resistor or op amp and appropriate feedback resistor in the detector package.

Detector connected with source follower



The voltage follower is basically a FET connected as a source follower.

In this configuration, the voltage output will be:

$R_V = R_i \times Z_{eff} \times A_o$

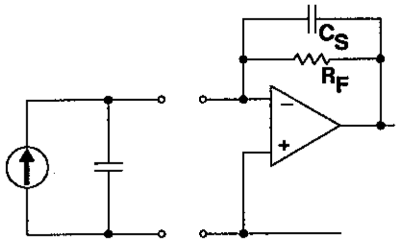
where R_V = voltage response in V/W

R_i = current responsivity

Z_{eff} = lumped impedance of crystal, R_L, and stray capacitance at the input

A_o = follower gain (approx. 0.8)

Detector connected with a current to voltage converter



The current to voltage converter can be an operational amplifier connected as shown.

In this configuration the voltage output will be:

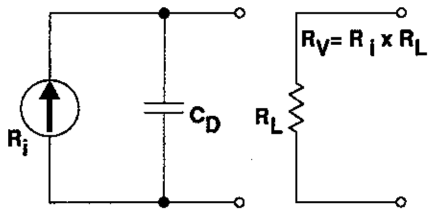
$R_V = R_i \times Z_F$

where Z_F = lumped impedance of feedback loop including R_F and C_S stray feedback loop

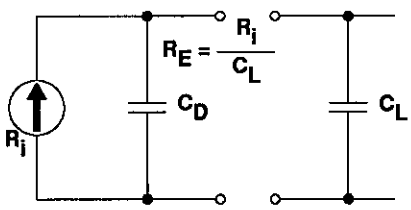
Laser Applications

In high speed or fast pulse applications with a great deal of incident power, the detector can be operated without an impedance converter. If pulse resolution is required, the detector can be loaded with a resistor – the value of which is determined by the speed of the event to be monitored. The detector can also be used as an energy monitor by loading the output with a capacitor. In this case, responsivity is:

$$R_E = \frac{R_i}{C_L}$$



Circuit for pulse resolution in high power applications



Circuit for energy monitor of high power pulses

Demystifying D-Star

The ultimate sensitivity of an infrared detector is determined by the signal-to-noise ratio. No matter how precise or noise-free the amplification scheme, there is a point where the output signal cannot be distinguished from background noise. This point, when related back to the responsivity of the detector gives the minimum detectable power level. In IR jargon, this is called "Noise Equivalent Power" or NEP. It is defined as:

$$NEP = \frac{\text{Noise}}{\text{Responsivity}} = \frac{\text{watts}}{\sqrt{\text{Hz}}}$$

Note that the NEP for any given detector is dependent on wavelength, operating frequency, noise center frequency, noise bandwidth (usually 1 Hz), and temperature.

$$NEP = 2.2 \times 10^{-10} \frac{W}{\sqrt{\text{Hz}}}$$

(500K, 20Hz, 1 Hz, RT)

The source temperature is 500K and implies the optical bandwidth; 20 Hz is the operating frequency and noise center frequency; 1 Hz is the noise bandwidth; RT (25C) is the temperature of the sensor.

Since minimum noise power is desired, the smaller the NEP the better. Unfortunately, sensor manufacturers want to complicate sensor performance factors even further by also specifying a parameter called D-Star (D*). This parameter normalizes the NEPs to a given constant detector area. This permits all detectors to be compared on an equivalent basis.

$$D^* = \frac{\sqrt{A_d}}{NEP}$$

where A_d = area of detector in cm^2.

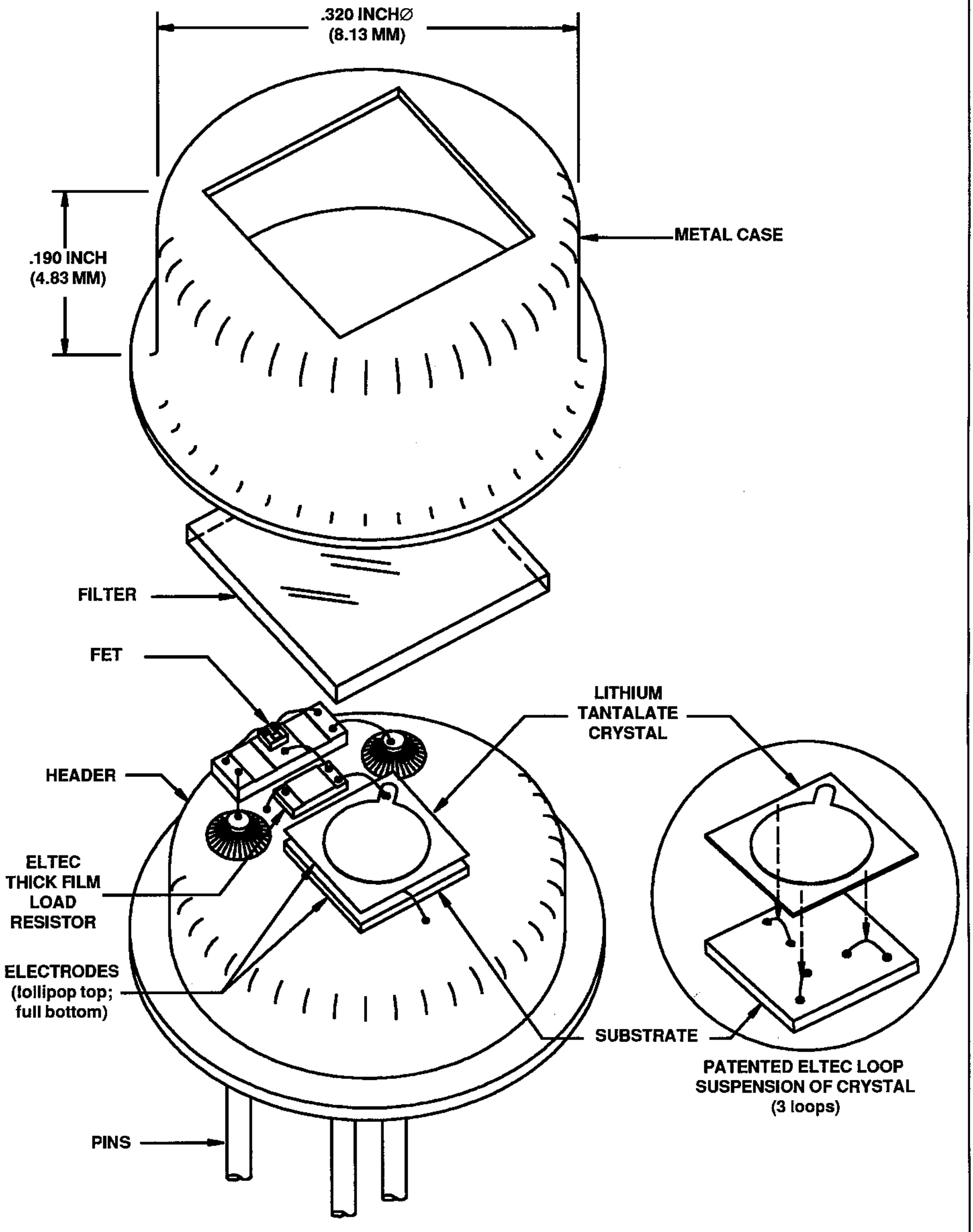
The larger the D* the better.

As with NEP, D* must be specified for wavelength, frequency, noise bandwidth and temperature. For example:

$$D^* = 2.8 \times 10^8 \frac{cm\sqrt{\text{Hz}}}{\text{Watt}}$$

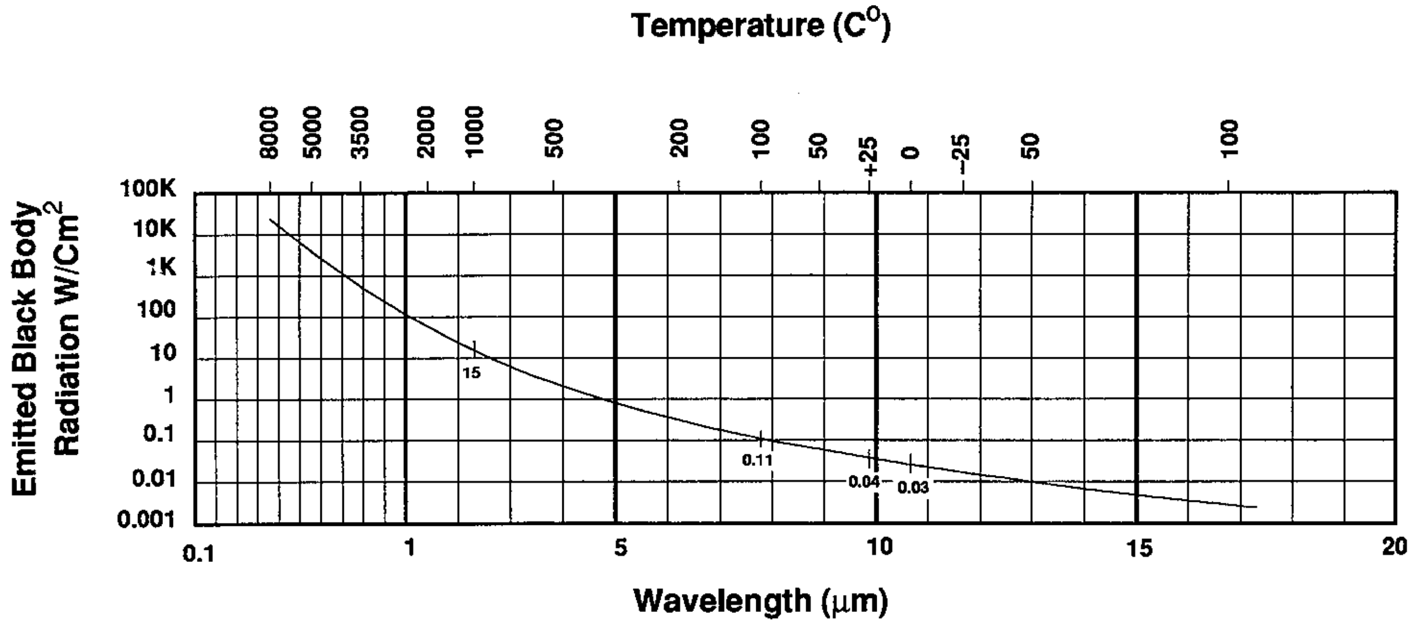
(10.6 µm, 10 Hz, 1 Hz BW, RT)

Even though the concepts of NEP and D* were created to facilitate apples-to-apples comparisons, practical pyroelectric detector performance is area-dependent rather than square-root-of-the-area-dependent (see ELTECdata #103). Consequently, direct comparison of different detectors with different sizes is still difficult. Also, the temperature of the sensor is often not specified (and some other types of IR sensors are very temperature dependent) and also some devices have outputs which are not linear with input power.



PYROELECTRIC DETECTOR WITH INTEGRATED ELECTRONICS

OBJECT TEMPERATURE VS. WAVELENGTH



The top abscissa on the curve above shows an object's temperature while the bottom abscissa shows the wavelength of the maximum energy for an object at the corresponding temperature. Note that there is always a distribution of energy over all wavelengths for any object with about 25% of all energy in wavelengths shorter than the wavelength of maximum energy and 75% in the longer wavelengths.

The curve within the coordinate system relates the temperature/maximum wavelength to the total emitted energy given in watts per square centimeter of surface on the ordinate axis. The value given are for a true blackbody and the value for any real object will be a percentage representing the ratio of the actual radiation emitted to the energy emitted by a blackbody at the same temperature.

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Silverlight Ltd., Technoparkstr. 2, CH-8406 Winterthur, Switzerland
info@silverlight.ch www.silverlight.ch