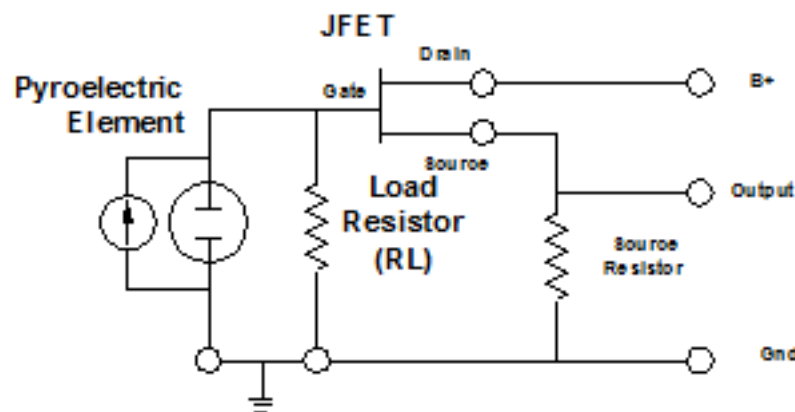


## Noise in Pyroelectric IR Detectors

Over the years pyroelectric detectors have found a place in many IR detection applications including Non Dispersive Infrared (NDIR), Fourier Transform IR Spectroscopy (FTIR), Non Contact Temperature Measurement (NCTM), Passive Infrared Motion Sensing (PIR), Laser Pulse measurement and other diverse scientific applications. The key to the performance of these detector applications is the signal to noise of the sensing element or detector. The signal to noise requirements are often specified as the Noise Equivalent Power (NEP) or Dstar (Specific Detectivity or  $D^*$ ) of the detector. Pyroelectrics are high output thermal detectors and as such the noise output is often the limiting item to performance. Here we present the various sources of noise in these devices and how it can affect the performance in their applications.

Pyroelectric detectors are defined electrically as current sources in parallel with a capacitance. As such they have a very high impedance which must be converted to a lower impedance to make them useful. This is commonly done with a JFET transistor operated as a voltage follower. Most of the noise sources are associated with this impedance converter circuit. Other circuits such as current to voltage converters are also used but which have slightly different noise mechanisms. These are discussed later.



The input load resistor  $R_L$  is a major contributor of noise as it produces Johnson noise ( $V_nR$ ) which is defined as:

$$V_nR = \sqrt{4KTRB} \text{ Volts}/\sqrt{\text{Hz.}}$$

Where:

$K$  = Boltzmann's Constant  $1.38 \times 10^{-23}$  W-sec/K

$T$  = Temperature in Kelvins

$R$  = Resistance in Ohms

$B$  = Bandwidth of the measurement in Hz.

Although Johnson noise is noted as a voltage it is often easier to refer to this noise source as a noise current especially with these devices as will be shown later.

$$I_{nr} = \frac{V_nR}{R} \text{ amps}/\sqrt{\text{Hz.}}$$

A second major contributor to noise is the leakage current (often called shot noise) in the JFET which is defined as:

$$I_{ns} = \sqrt{2qBi} \text{ amps}/\sqrt{\text{Hz.}}$$

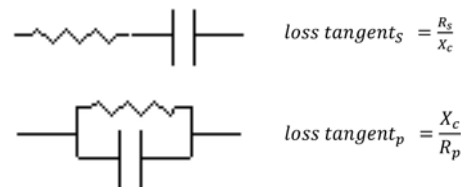
Where:

$q$  = Charge on the electron  $1.6 \cdot 10^{-19}$  Coul

$i_l$  = Gate leakage current in amp.

Note: The  $i_l$  term is temperature dependent and approximately doubles for every 10 degrees above room ambient

The ideal pyroelectric element is noiseless as it ideally only possesses capacitance. However the "purity" of this capacitance causes some value of AC resistivity (either series or parallel) which in turn produces Johnson noise. This "purity" is defined as the loss tangent which is the tangent of the angle between the conductance and capacitance reactance vector. The value of loss tangent is a function of the detector material's morphology, purity, the resistance of the electrode structure and any leakage across the capacitor's plates. Below you can see the difference between series resistance and parallel (or leakage) connection of a less than ideal capacitor. Loss tangent is measured with an instrument which simultaneously measures the dielectric and electric vector at a given frequency and computes its value.



The noise current generated from the loss tangent in a capacitor (pyroelectric element) is defined:

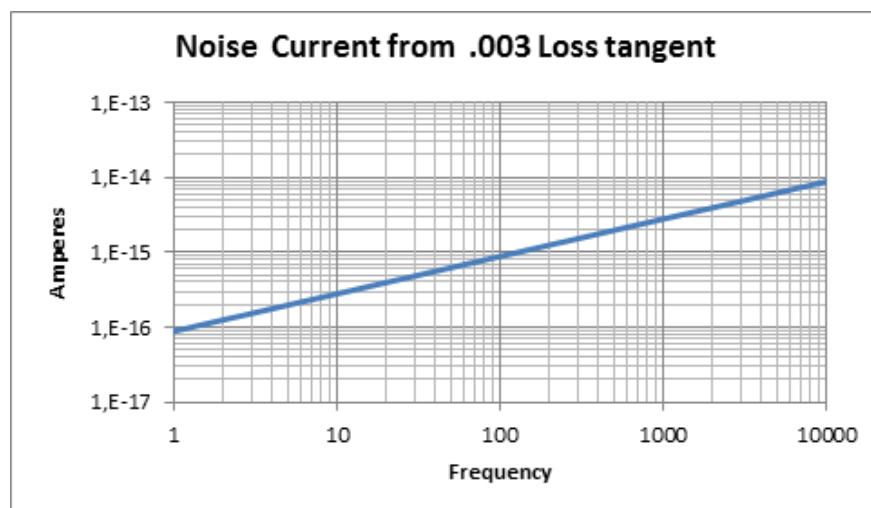
$$I_{nl} = \sqrt{8KT\pi Cd f L B} \text{ amps}/\sqrt{Hz}.$$

Where:

$L$  = Loss Tangent

$f$  = Measurement Frequency

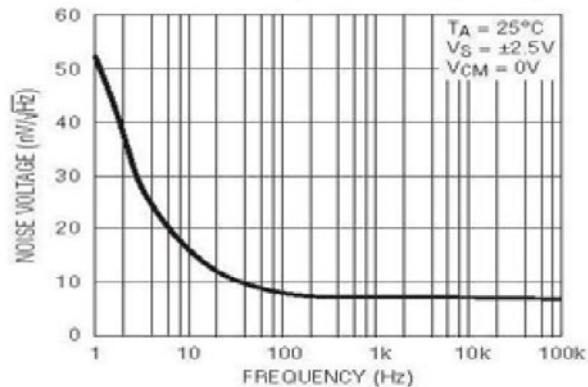
$Cd$  = Detector Capacitance



Note the change of the loss tangent noise with frequency. As the frequency increases the noise increases as the square root of the frequency. This shows that the loss tangent noise is more important at higher frequencies.

The final contributor to detector noise is the voltage noise ( $e_n$ ) from the JFET. This varies by JFET design (geometry) and operating frequency. The JFET's  $e_n$  is related to its transconductance at its operating point. Lower voltage noise parts have larger geometries and thus have a larger transconductance but higher leakage currents while JFETs which have very low leakage currents have very small geometries and are typically higher in voltage noise than a JFET due to their small geometries providing lower transconductance ( $e_n \propto 1/g_{fs}$ ). Voltage noise from the JFET only becomes important at higher operating frequencies where it can influence the total noise output. Curves from measurements showing the  $e_n$  as a function of drain current ( $I_d$ ), frequency and temperature are provided by the suppliers of the JFET and are fairly accurate. These can be used to determine  $e_n$  at any frequency.

Noise Voltage ( $e_n$ ) vs. Frequency



The graph above shows the  $e_n$  voltage noise as a function of frequency of a JFET which would be used in a detector for a high frequency application. Note the  $e_n$  at 1.0 kHz is about 6 nV

The frequency spectrum of the  $e_n$  can be determined from the graph with some curve fitting. Typically the curve displayed above can be calculated by knowing a value of noise at one frequency and by the shape of the curve. ( $e_{nf}$  is  $e_n$  as a function of frequency)

$$e_{nf} = e_{n_{1000}} \sqrt{1 + \left(\frac{NC}{fIf}\right)^2}$$

Where:

$e_{n_{1000}}$  = Specified noise at a given frequency (6 nV from vendor data)

NC = Noise corner frequency (~40Hz.)

If = Inflection factor (~ 1.35)

The total noise voltage in a detector is the RMS sum of all the previously described noise sources.

The RMS summation of the noise current from the resistor, current noise from the JFET and the current noise from the loss tangent are:

$$I_n = \sqrt{I_{nR}^2 I_{nS}^2 I_{nL}^2}$$

The voltage noise from these three noise sources is a function of the detector's impedance (Z) which is defined:

$$Z = \frac{Rl}{\sqrt{1 + (2\pi f RlCd)^2}}$$

Where:

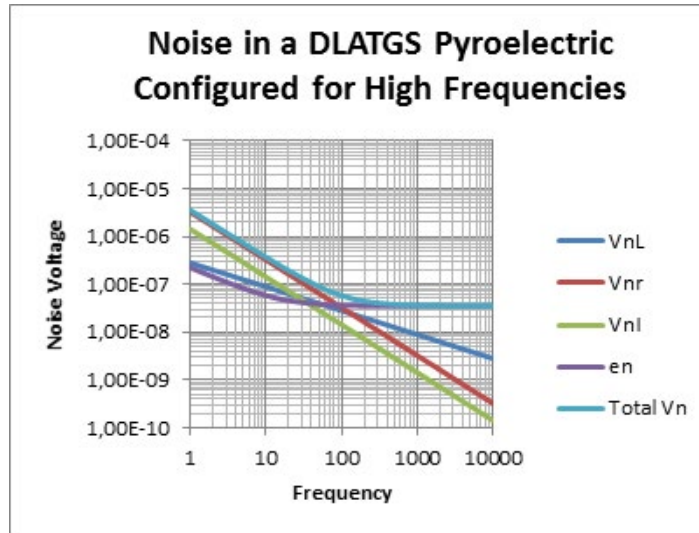
Rl = Load Resistor (Ohms)

Cd = Detector Capacitance (Farads)

Considering all these noise sources (Resistor JFET Shot noise, Loss tangent noise and JFET voltage noise) the total Noise Voltage ( $V_n$ ) from all sources is:

$$V_n = \sqrt{(ZIn)^2 + en_f^2}$$

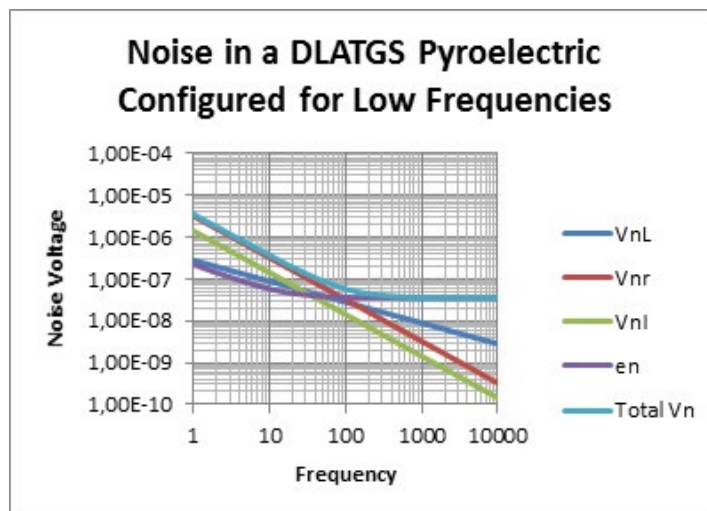
These can all be shown on the following graph:



Notice that the noise in this configuration is dominated by the load resistor at the low frequencies and at the high frequencies by the loss tangent of the detector element and the JFETs voltage noise

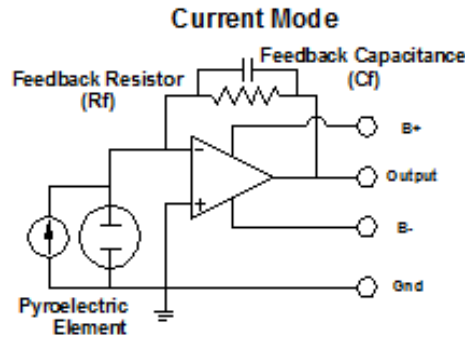
This example is for a device has been optimized for high frequencies applications such as FTIR

Below is the same device optimized for low frequencies notice the noise voltage @10 Hz is substantially lower than the device above but substantially higher at the higher frequencies.



The noise mechanisms discussed above are for the case where the impedance conversion is made with a JFET connected as a source follower. We now discuss the case where the impedance conversion is made with a current to voltage converter or transimpedance amplifier.

Today there are quite a good number of opamps which have very low input bias currents and low voltage noise which can be used with pyroelectric detectors with the added benefit of providing much higher output voltages (V/W) than can be produced with followers. A typical circuit is shown in figure 3 below



The higher output comes about by the fact that in the CM the Opamp's feedback loop impedance is much greater than that of the VM. The only capacitance in this loop is the very minimal stray capacitance (~0.2 pF) where in the VM the capacitance could be 10 to 100 times larger.

For comparison the output voltage as measured by the JFET follower in "Voltage Mode" is:

$$V/W (VM) = I(A/W) Z_d(\Omega)$$

And the output voltage as measured with a current mode amplifier in "Current Mode" is:

$$V/W (IM) = I(A/W) Z_f(\Omega)$$

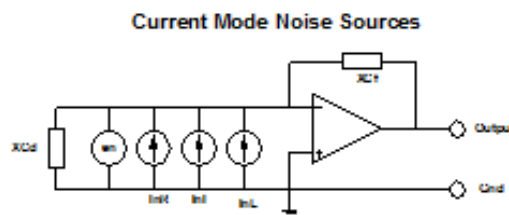
Where:

$$Z_d = \text{Detector impedance (Ohms)} = \frac{R_L}{\sqrt{1+(2\pi f R_L C_d)^2}}$$

$$Z_f = \text{Impedance of the Opamp feedback loop (Ohms)} = \frac{R_f}{\sqrt{1+(2\pi f R_f C_f)^2}}$$

One can see that the output signal difference between the VM and the CM is proportional to the ratio of the detector to the feedback capacitance. For large area detectors where the detector capacitance is quite large the output can be substantially increased with the CM circuit.

The noise sources in the CM are the same as those in the VM but instead of the Johnson noise coming from the load resistor ( $R_L$ ) we have the Johnson noise from the feedback resistor ( $R_f$ ). The input bias current or shot noise in the opamp is equivalent to the input leakage current in the JFET. The loss tangent noise current from the pyroelectric element is same and the voltage noise ( $e_n$ ) from the opamp is equivalent to the JFET as discussed above. See figure below:



However the CM approach has another noise mechanism which can be significant. In this configuration the Opamp has an inverting voltage gain which amplifies its voltage noise. This inverting amplifier gain is given by:

$$A_v = 1 + \frac{Z_f}{Z_d}$$

This gain is frequency dependent rising from "1" at DC where  $Z_f$  and  $Z_d$  are essentially the value of the feedback resistor and the leakage in the detector. ( $Z_d$  is much larger than  $Z_f$ ). The frequency dependent voltage noise in CM amplifier is given by:

$$en_f = en \left( 1 + \frac{Z_f}{Z_d} \right)$$

To summarize the CM approach does give higher output signals than VM but the noise is also increased basically by the ratio of the capacitances. The best case is to use this approach with a low capacitance detector at the lower frequencies.

The plot below shows the noise output for voltage and current mode detectors

