Application Brief 1: A Simple DC Radiometer

One of many applications of the thermopile detector is the remote measurement of temperature. In this Application brief we explain the basic principles of remote temperature measurement. Every object at temperature T (above absolute zero - 273.15℃) emits electro-magnetic radiation. The total amount of power or radiant flux (Φ) emitted per unit solid angle and per unit area over all wavelengths is given by the Stefan-Boltzman law [1]. Where the Stefan-Boltzman constant is given as:

$$\sigma = 5.6703 \cdot 10^{-12} \frac{W}{cm^2 K^4}$$

For a lambertian source the radiance (L) is:

$$L(\varepsilon, T) = \frac{\varepsilon}{\pi} \cdot \sigma \cdot T^4$$

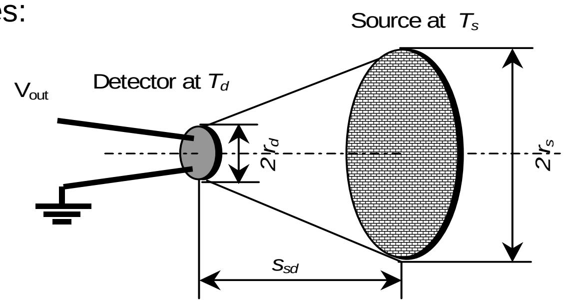
Where ε is the emmisivity of the object surface. Thermopile detectors respond to thermal energy emitted by any object in it's field of view by producing a voltage that is proportional to incident power. This response is called the responsivity (R) of the detector. As an example, Dexter Research's model 1M has a typical responsivity of:

$$R = 23.2 \frac{V}{W}$$

The net power exchange between an object (source or target) and a thermopile is influenced by the following factors:

- temperature of the source T_s and detector T_d;
- area of detector and source, as well as the shape, orientation, and distance between them;
- additional objects in the path (for example: optics);
- the radiative characteristics of all surfaces, such as emissivity;
- medium between detector and an object (for example: atmosphere and moisture).

Lets consider the simple case of a circular source and circular detector parallel to each other with a common optical axis, where the source does not fill the detector's FOV [2]. As an example, we will use the following values:



radius of the source: $r_s = \frac{10.6}{2} cm$

radius of detector: $r_d = \frac{1.0}{2} mm$

emissivity of source: $\varepsilon_s = 1.0$

emissivity of detector $\varepsilon_d = 1.0$

distance between the source and detector: $s_{sd} = 10cm$

The dimensions of the system in our example, are partly included in a "real body view factor", or *transfer factor* F_{sd} . Siegel and Howell [3] provide the calculations and a large catalog of transfer factors for different geometries. F_{sd} for the example above, can be calculated using the following expression [1,3]:

$$F_{sd} = \frac{2\pi \cdot r_d^2}{r_s^2 + r_d^2 + s_{sd}^2 + \sqrt{\left(r_s^2 + r_d^2 + s_{sd}^2\right)^2 - 4 \cdot r_s^2 r_d^2}}$$

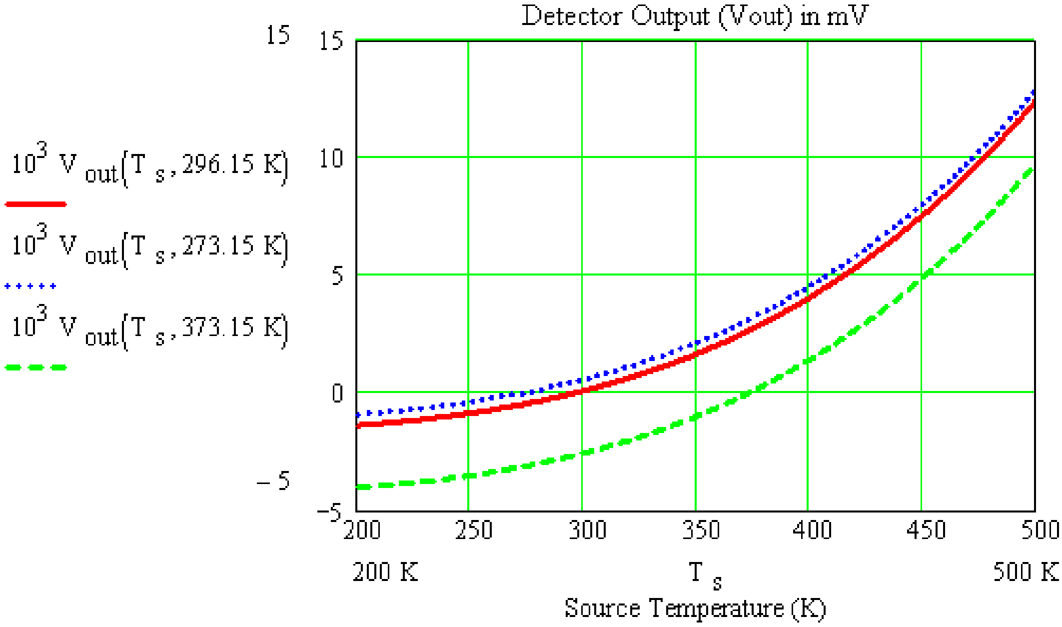
The net power exchange through radiation can be defined as in [4]:

$$\Phi\left(T_s, T_d\right) = \frac{\sigma \cdot \varepsilon_s \cdot \varepsilon_d \cdot A_s \cdot F_{sd}}{\pi} \cdot \left(T_s^4 - T_d^4\right)$$

Where A_s and A_d are the areas of source and detector respectively. For the case where the active area of the detector is square, use a circular detector of equal area. This will yield a close numerical solution. Knowing the responsivity of a detector and the net power exchange from the source, the output signal V_{out} can be estimated as:

$$V_{out}\left(T_s, T_d\right) = R \cdot \Phi\left(T_s, T_d\right) \qquad V_{out}(500K, 296.15K) = 12.418\,mV$$

In the figure below V_{out} is presented as a function of T_s for three detector temperatures:



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Above, we have shown an example of a simplified system. In reality the solution to the radiant power exchange problem is quite complex. However, to calibrate an actual instrument the following empirical formula can be used:

$$V_{out} = F \cdot \left(\varepsilon \cdot T_s^{\,n} + F1 \cdot T_{opt}^{\,n} - T_d^{\,n} \right)$$

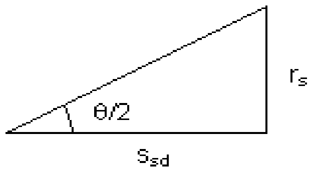
Where F and F1 are constants that depend on geometry, T_{opt} is the temperature of the optical components of the radiometer, and the power factor n is different from 4 due to the limited spectral range of a particular radiometer. Temperatures T_{opt} and T_d can be monitored by temperature sensors, for example LM20 from National Semiconductors. The other 3 constants: F, F1, and n can be determined by a 3 point calibration for each individual instrument.

<u>References</u>:

1. E.F. Zalewski, "Radiometry and Photometry," in M. Bass, editor in chief. Handbook of Optics, vol. II, 2nd ed., Optical Society of America, 1995, pp. 24.17, 24.26.

2. When the source fills the entire detector's FOV, please use the following equation to calculate r_s :

$$r_s = s_{sd} \cdot \tan\left(\frac{\theta}{2}\right)$$, where θ = Detector FOV



3. R. Siegel and J.R. Howell. "Thermal Radiative Heat Transfer", Hemisphere Publishing Corp., Washington, D.C., 3rd ed., 1992.

4. J.H Lienhard IV and J.H. Lienhard V, "A Heat Transfer Textbook", Phlogiston Press, Cambridge, Massachusetts, 2001, p. 531.

<u>Note</u>: *This application brief can be* ***downloaded*** *as a* ***Mathcad document*** *at www.DexterResearch.com (see the "Technical Briefs" tab, then click "**Download Mathcad Version**". You can then enter your own parameters into the boxed equations above and Mathcad will calculate the results. This download will require Mathcad 2001 or newer.*

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