TECHNICAL SOLUTIONS
TS102
IRCON

Temperature Errors Due to Background Radiation

This article examines how background sources of radiation affect measurements taken with infrared brightness thermometers. Other articles in this Temperature Error Series discuss errors caused by uncertainties in target emissivity and path transmission. The last remaining error source will be covered in the fourth Error Series article on unavoidable error sources within the instrument itself.

PROBLEM OF BACKGROUND SOURCES

The basic relationship used in infrared thermometry is that the intensity, or “brightness,” of infrared radiation emitted by an object increases predictably with its temperature. Unfortunately an infrared brightness thermometer cannot distinguish between radiation which the target emits and radiation which originates from other sources. If the detected radiation includes not only the radiation from the target but also an additional component originating from background sources, the indicated temperature is higher than the target’s true temperature.*

All of space is filled with the radiation emitted by the physical matter in the environment. Any radiation emitted by sources other than the chosen target object is referred to as “background radiation” It can have component wavelengths throughout the electromagnetic spectrum, including the visible and the infrared. The intensities at the infrared wavelengths (as with all the other wavelengths) are determined by the temperatures and emissivities of the objects in the surroundings, as well as by the presence of absorbing materials in the transmission paths.

Yet background radiation does not present a problem to temperature measurement unless it has a significant intensity. The intensity is significant when the brightness of the background sources at the detected wavelength is comparable to or greater than that of the target. Then the extra contribution from the background may “make enough of a difference” to increase the indicated temperature. As an analogy, it is easy to see that a flashlight beam adds significantly to the light from a match, but makes no real difference when added to the beam from a searchlight. The brightness of the flashlight is not significant if the “target source” is much brighter.

Since we can’t see infrared radiation ourselves, how can we know if the background radiation is significant enough to produce an error? We can estimate the significance of the background’s radiance relative to the target’s simply by comparing the approximate temperature of the target and background sources. Although many other facts affect how much background radiation is actually detected, this basic relationship still provides a good way to identify potential background interferences.

For example, consider the case where a target is heated well above room temperature. Then the radiation emitted by room temperature objects is hardly noticeable in comparison to the detected radiation from the target. If the room is lit with tungsten filament bulbs, however, the radiation produced by the high-temperature filaments could add significantly to the detected target radiation. Similarly, intense plant lighting or inspection lighting can cause problems. Other hot surfaces and hot objects near the target are also important sources of background interferences.

DETECTION OF BACKGROUND RADIATION

Under what circumstances does the detected radiation include an added component from background sources? An obvious case is when the target does not completely fill the instrument’s field of view. Then the unit also “sees” beyond the target into the “background.”

However, a correctly operated brightness thermometer is aimed so that the target does completely fill its field of view. Under these conditions, no background radiation can be detected unless the target has transmissive or reflective properties. That is, background radiation can be a problem only if the target acts something like a mirror, or a window, or both, in the detected infrared spectral region. Note that an object which is reflective or transparent to visible radiation is not necessarily reflective or transparent to infrared radiation, and vice versa.

The target’s reflectivity (R) and transmittance (τ) factors at the detected wavelength affect the size of the contribution made by background radiation to the detected energy. As shown in Fig. 1, these factors can take on values from zero to one, representing the fraction of incident background radiation that is reflected or transmitted. Thus, even when there is a relatively large

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*We are assuming in this article that target emissivity and path transmission are known and compensated for using the thermometer’s emissivity dial (see other Error Series articles.)

amount of background radiation, there still might be very little error in the temperature measurement. The target may reflect or transmit only a small fraction of the background radiation to the detector within the thermometer's sensing head.

The target's emissivity value is the indicator of how susceptible it is to background interferences. This is because an object's emissivity (ε) is related to its transmissive (τ) and reflective (R) properties by the formula

$$\varepsilon = 1 - R - \tau^* \qquad (1)$$

For instance, a "blackbody" is a perfect radiator and has an emissivity of 1. When the emissivity value equals one, both the reflectivity and transmittance must be zero.

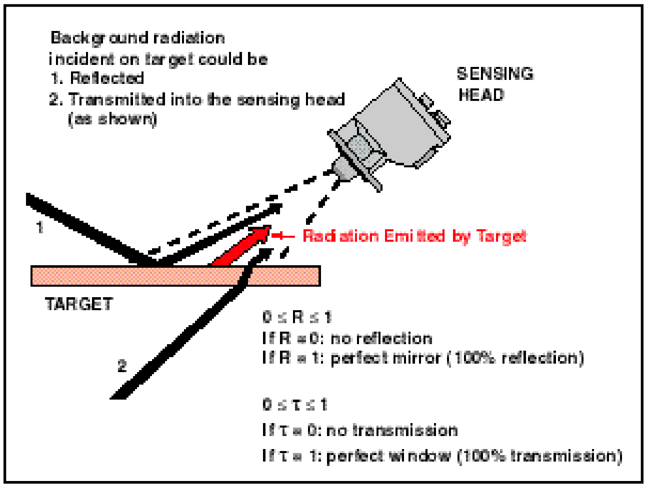

Fig. 1 Background radiation can contribute to detected radiation if τ_{TARGET} or R_{TARGET} is greater than zero. (The target absorbs the portion of incident background radiation which is neither reflected nor transmitted.)

Because such a target does not reflect or transmit any radiation, the measurements contain no error due to background radiation. This is true no matter how much background radiation there is. However nearly all real targets have emissivity values which are less than one. Because of this, the detected radiant energy usually has at least some contribution (due to reflection and/or transmission) from the background.

It is clearly beneficial to detect radiation in a spectral region where the target has a high emissivity. This is one of the reasons that IRCON offers such a wide range of instruments with different spectral responses. Generally instruments are chosen so that the target has no transmission and as little reflection as possible in the detected spectral region. As you will see in the next topic, This makes the problem of avoiding significant background radiation a little easier.

To summarize the preceding discussion, the lower the target emissivity, the greater the fraction of radiation the target reflects and/or transmits from the background. But if there is not much radiation in the background to begin with, the "extra" contribution to the detected energy is very small. If there is a significant amount of background radiation, there may be enough energy detected to cause an erroneously high temperature indication.

GEOMETRY OF VIEWING ARRANGEMENT

The actual contribution of background radiation to the detected energy is determined by the geometry of the viewing arrangement. That is, the position of the target and the sensing head with respect to significant background sources determines how much of the background radiation is actually reflected or transmitted into the instrument's optical system. If the sensing head can be positioned to avoid the reflected or transmitted radiation, temperature measurement errors can be avoided as well.

Two examples of this area shown in Fig. 2. Both targets illustrated have some reflectivity but no transmittance, as is often the case in real applications. For each example, the instrument in position 1 receives radiation with a component from the background and indicates a temperature that is too high. Each instrument in position 2 avoids reflections from the background source.

In Fig. 2 (a), the unit in position 2 is simply aimed so that none of the background reflections enter its optical system, In fig. 2 (b) the unit in position 2 is shielded from the background radiation by the target itself, since it has no transmittance. If this target had some transmittance at the detected wavelength, the sensing head could "see through" it to some extent. Then there would be less error if the instrument were aimed so that it looked through the target in the direction of a cooler background.

The kind of reflections depicted in Fig. 2 are specular reflections, for which the angle of incidence equals the angle of reflection. As shown in Fig. 3, an uneven or rough surface can also produce diffuse reflections which scatter some of the radiation in other directions. If the target material in Fig. 2 (a) produces diffuse reflections the brightness thermometer in location 2 is not completely safe from background reflections.

Because specular reflections are generally the most significant, consequently they are the most important to avoid. Note that although the reflectivity may be different for the visible and infrared regions, it still may be possible to observe visually the direction of the reflected energy if the background source is incandescent. If the background source is not hot enough to radiate at visible wavelengths, the angles of incidence and reflection must be visually estimated.

In some applications it is impossible to position the instrument so that it avoids background radiation. When this is the case, a final possible solution is to use some form of shielding to eliminate the problem. An opaque shielding material that is appropriately placed between the background source and the target can be used to

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*Technically, this expression should take into account internal reflections. However, this is unnecessarily complicated for our present purpose.

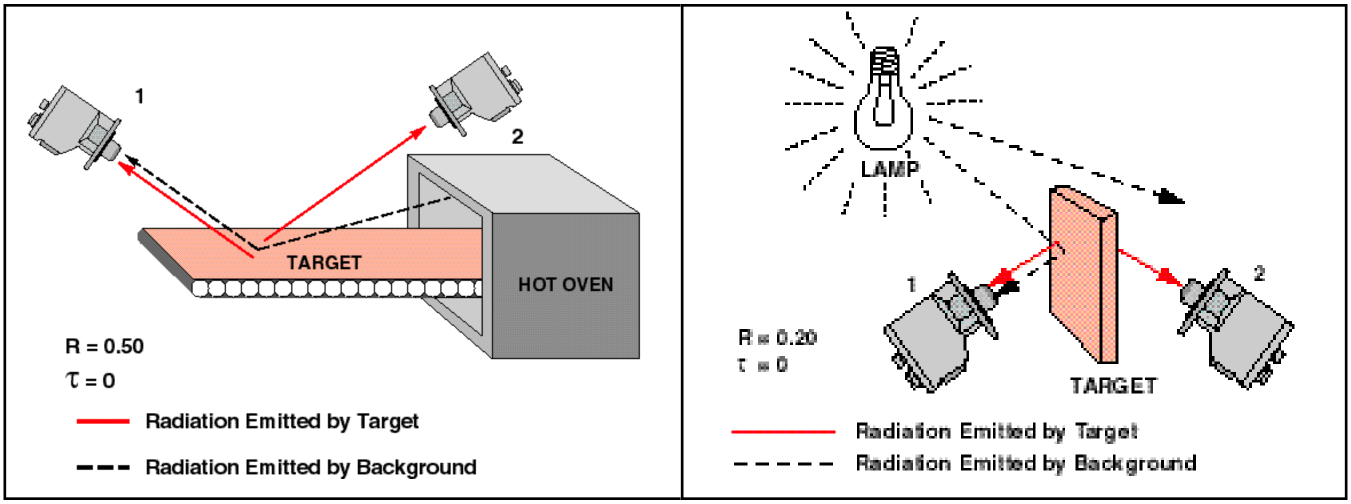

Fig. 2 Proper positioning of the sensing head can avoid significant background errors. (a) Unit 2 avoids first-order reflections; unit 1 receives 50% of the significant radiation from the heated oven. (b) Unit 2 is shielded by the target; unit 1 receives 20% of the incident radiation from the high-intensity lamp.

block the background radiation before it can be reflected off (or transmitted through) the target. Of course, geometrical considerations are still important here, since it is necessary to know the path of potential reflections (or transmissions) in order to shield properly.

In particularly difficult situations, a cooled sight tube accessory can greatly improve the accuracy of temperature measurements. This tube is attached to the sensing head to provide an almost completely shielded view path. Reflections from the background that would have entered the optical system are blocked by the presence of the tube, as shown in Fig. 4. It is imperative however, that the sight tube be kept cooler than the target. Otherwise, the hot tube itself would emit a significant amount of radiation, defeating its shielding action.

PUTTING THE PIECES TOGETHER

Background interferences can get quite complex due to multiple reflections, multiple sources and the like. Other complications can arise when hot gases or sooty flames lie between the sensing head and the target. Then the hot molecules in the transmission path have the effect of both reducing and adding to the detected energy. They do this by absorbing or scattering some of the radiation emitted by the target as well as by emitting a significant amount of radiation themselves. Some applications, however, lend themselves to a relatively simple analysis. Although we recommend against viewing directly into an oven in certain circumstances, it is an application which will allow us to examine more rigorously how error is produced.

We will be assuming known conditions to determine the effect of the background on the detected radiance. To arrive at actual numerical temperature error values requires a knowledge of precisely how radiance (which we will call N) depends on temperature. Since this relationship, given by the Planck equation, involves mathematics beyond the scope of this article, we will simply show the results of translating our values, calculated in terms of radiance, back into temperature.

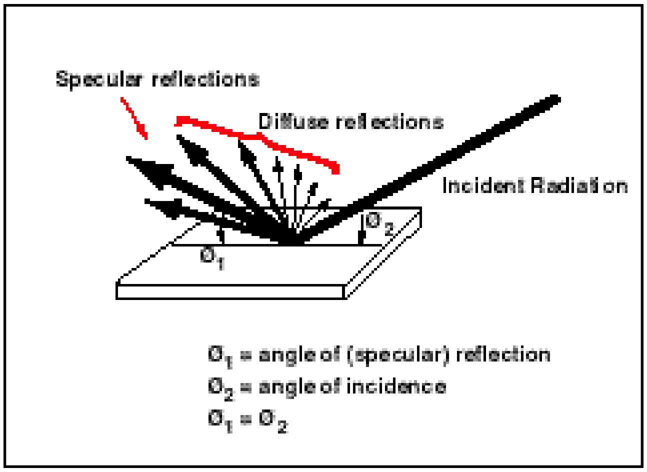

Fig. 3 Specular reflections leave the reflecting surface at the same angle the incident radiation makes when striking the surface. Diffuse reflections, which result from roughness in the surface, are scattered in other directions.

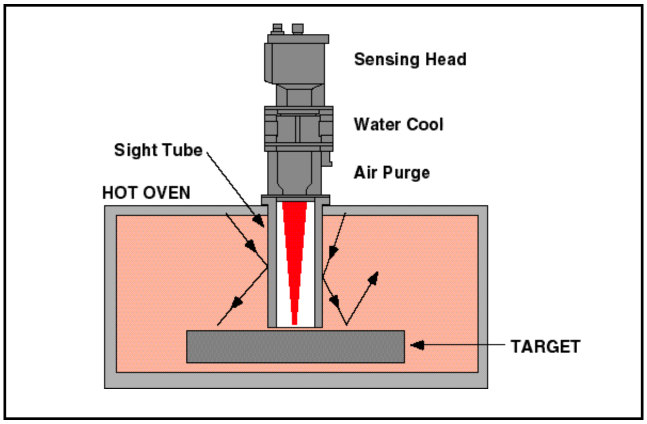

Fig. 4 A cooled sight tube accessory can be used to prevent background reflections from entering the optical system.

Example: VIEWING INTO AN OVEN

A MODLINE 3, 600 Series brightness thermometer is used to measure the temperature of a target which is contained within a heated oven. In order to do this, the unit must be aimed directly into the oven. The instrument responds to wavelengths of 2.0 to 2.6 µm, and the target has an emissivity of 0.75 and no transmittance in this spectral region. (a) if the target temperature is 700°F and the background temperature is 1000°F, how much of the detected radiance is emitted by the background and how much of it is emitted by the target? (b) What is the detected radiance if the target is removed from the oven and viewed in a much cooler environment?

Answer: (a) The total detected radiation is given by

$$N_{\text{TOTAL}} = N_{\text{FROMTARGET}} + N_{\text{FROMBACKGROUND}} \qquad (2)$$

Because the target has an emissivity of 0.75, it radiates 75% of the energy that would be emitted by a blackbody at 700°F. So

$$N_{\text{TOTAL}} = N_{\text{EMITTED}} = 0.75\, N_{700}$$

We will assume that the oven is much larger than the target so that it approximates blackbody characteristics. Then its radiance equals that of a blackbody at 1000°F, or N_{1000}. Since the target is essentially surrounded by the oven walls, it is not possible to position the sensing head to avoid error. Radiation is reflected and/or transmitted in every direction according to the target's R and τ characteristics. So the detected radiance from the background is given by

$$N_{\text{FROMBACKGROUND}} = N_{\text{REFLECTED}} + {}_{\text{TRANSMITTED}}$$
$$= R\, N_{\text{REFLECTED}} + \tau\, N_{1000} \qquad (3)$$

Since the target has zero transmittance, we know from equation (1) that the reflectivity must equal 0.25. Substituting these values into equation (3) gives

$$N_{\text{FROMBACKGROUND}} = 0.25\, N_{1000}$$

Therefore equation (2) becomes

$$N_{\text{TOTAL}} = 0.75\, N_{700} + 0.25\, N_{1000} \qquad (4)$$

(b) When the background's temperature is much lower than the target's, the contribution from the background becomes negligible. That is, the second term in equation (4) would be ◀ 0.75 N_{700}, so we can say that the total detected radiation is just 0.75 N_{700}.

Table 1 shows that when the background is 1000°F. Notice in the table that the error in this example diminishes quickly as the background temperature falls below the target temperature.

TABLE 1 BACKGROUND ERRORS (ΔT)

MODLINE 3 600 SERIES (2.0 TO 2.6 µm)

$\varepsilon_{\text{TARGET}} = 0.75$ $T_{\text{TARGET}} = 700°\text{F}$

T BACKGROUND (°F)	ΔT ($T_{\text{INDICATED}} - T_{\text{TARGET}}$)
400	1°
500	5°
600	15°
700	36°
800	69°
900	114°
1000	169°

Fig. 3 Specular reflections leave the reflecting surface at the same angle the incident radiation makes when striking the surface. Diffuse reflections, which result from roughness in the surface, are scattered in other directions.

MINIMIZING BACKGROUND ERROR

Various methods of minimizing background errors have been mentioned throughout this article. The following summarizes the most important points:

- Use a spectral region where the target emissivity is high.
- Avoid significant reflections (and transmissions) through positioning or shielding.

Although we have considered the general causes of background error, our discussion has been by no means complete. We encourage you to bring us the details of your application. IRCON's application engineering staff has the expertise to help you most effectively maintain the accuracy of your temperature measurements.

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