

Reflecting Cavity Blackbodies for Radiometry

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Abstract Nearly 20 years ago Quinn and Martin presented a novel blackbody design with an absorbing end face and highly reflecting side walls. This blackbody had the considerable advantage of being less sensitive to temperature gradients along the side walls (potentially of several degrees Celsius) compared to an all-black cavity. Recent work at NPL has developed this concept further, laying out the conceptual framework in simple terms, analyzing potential pitfalls such as diffraction, and describing a design which closely matches the theoretical best performance.

Summary

Blackbody sources with reflecting side walls are, when designed correctly, less sensitive than absorbing cavities to thermal gradients along the cavity length. This fact offers benefits for primary standard instruments, since these tend to be long and require the highest and most uniform emissivities. Furthermore, since a reflecting cavity design allows thermal engineering requirements to be relaxed, mass and size reductions for high emissivity transfer standard sources for both laboratory and space flight applications is possible.

The rationale for having a blackbody with reflecting rather than absorbing side walls was established in 1986 [Quinn]. The argument can be summarised as follows. Suppose the rear wall of the cavity is thermally uniform and has an emissivity ε_0 . Here “rear wall” refers to the section of the cavity interior which can be directly viewed by a detector. Suppose further that a temperature gradient exists along the length of the cavity, i.e. along the side walls. Then as Quinn and Martin show (assuming, for simplicity, an arbitrarily small cavity aperture) the deviation from 1 of the effective emissivity of a reflecting side wall cavity is $(n \varepsilon_1)$ times that of an absorbing side wall cavity. Here n is the number of reflections a typical ray emitted by the rear wall experiences within the cavity before impinging again on the rear wall; ε_1 is the emissivity of the reflecting side wall, equal to one minus the wall reflectivity and hence much less than one. Thus for small n , the reflecting side wall cavity has an effective emissivity closer to one than does an absorbing side wall cavity.

This argument breaks down as the thermal gradient along the cavity length approaches zero. An isothermal cavity with absorbing walls has a higher emissivity than one with partly reflecting walls. This paper will discuss, for the first time, the conditions for which a reflecting cavity is advantageous. We will answer the question: for what thermal gradients does the reflecting cavity outperform the absorbing cavity?

Since the optimal reflecting cavity reflects radiation

emitted by the cavity rear plate back onto the plate after one bounce, the optimal design is a spherical reflector with a high emissivity rear plate positioned to overlap with the center of the sphere. The output aperture is a hole in the reflector, so that only the absorbing plate is directly visible to a radiometer. Radiation emitted by the plate either directly exits the aperture or returns to the plate after a single reflection from the cavity wall.

An estimate of the cavity absorptivity, and hence, by invoking the Kirchoff Law and the reciprocity theorem, the cavity emissivity, can easily be made by calculating the fractional loss of diffuse radiation from the plate through the aperture. For a fixed aperture size, increasing the distance from the plate to the aperture increases the emissivity. However, as this distance is also the radius of the spherical reflector, the size of a high emissivity blackbody can easily become unwieldy. In earlier designs, a “Christmas tree” shaped reflector was used to approximate the spherical reflector. This paper will describe our recent work, employing better ray tracing techniques than originally available, which establishes an optimum shape for a reflecting cavity which maintains practical dimensions.

An absorbing cavity absorbs and, therefore emits, radiation over a full hemisphere with an approximately lambertian distribution. This ensures that diffraction at the blackbody aperture can be neglected. For a reflecting cavity, however, the directional emissivity is sensitive to the reflector design and may be very far from lambertian. In this case diffraction cannot be neglected. Recent work on diffraction in radiometry has shown that the Fresnel and paraxial approximations used in nearly all diffraction loss calculations to date may introduce errors of several tenths of a percent [Edwards]. Therefore careful design which either creates lambertian emission over the full hemisphere or enables an accurate diffraction loss calculation is critical for reflecting cavity blackbodies. This paper will discuss the diffraction problem in some detail and include design solutions which minimise or eliminate it.

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References

- Quinn, T. J., J. E. Martin, A Black-body cavity for total radiation thermometry, *Metrologia*, 23, 111-114, 1986.
- Edwards, P. J., *Diffraction Theory and Radiometry*, PhD Thesis, Imperial College, 2004.