Boson Image Non-Uniformities (INUs)

Application Note

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1.1 Revision History

Version	Date	Comments
1.0	September 2017	Initial release
1.1	November 2017	Minor corrections and clarifications
1.2	June 2018	Added INU specification for 640
1.3	April 2019	Updated export footer, minor reformatting

The FLIR website will have the newest version of this document as well as many other supplemental resources: **https://www.flir.com/products/boson/**

There is also a large amount of information in the Frequently Asked Questions (FAQ) section on the FLIR website: **https://flir.custhelp.com/app/answers/list**.

1.2 Scope

An image non-uniformity (INU) is defined as a group of pixels which are prone to varying slightly from their local neighborhood under certain imaging conditions. Two examples are shown in Figure 1. This document provides a detailed explanation of INUs, the camera features for minimizing their appearance, the conditions under which they are most likely to manifest, and recommended practices for system design & integration aimed at minimizing their appearance. It is organized into the following sections:

- Section 2.0: Root Cause of INUs (and Examples)
- Section 3.0: Mitigation Features
- Section 4.0: Operating Conditions to Avoid
- Section 5.0: Guidelines for System Design & Integration

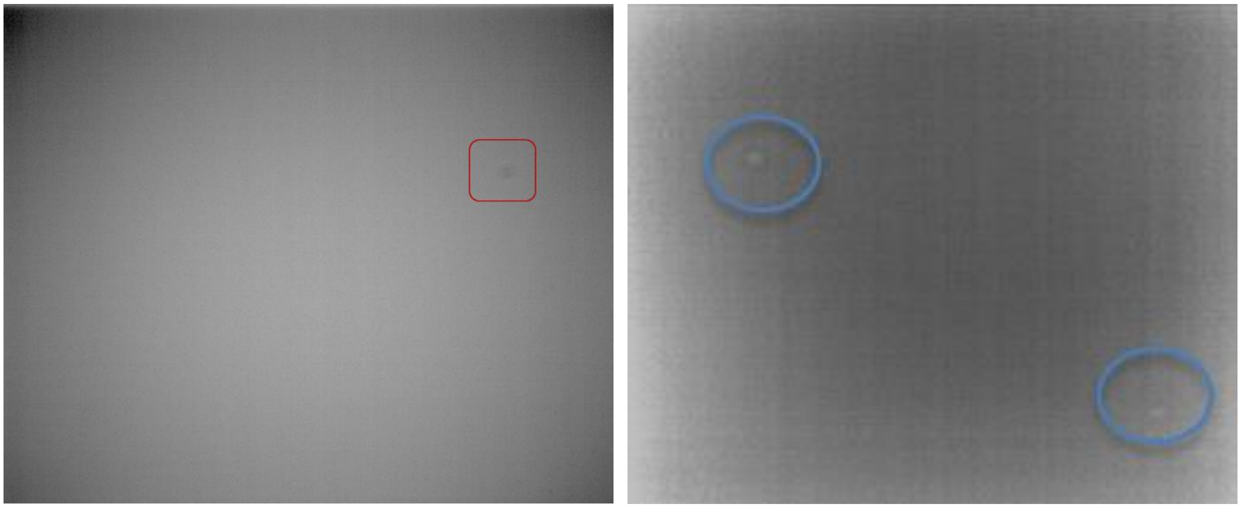


Figure 1: INU examples

2 Root Cause of INUs (and Examples)

The Boson sensor is highly sensitive to microscopic defects on its window coating and also to any debris contaminating the window surface. Any such obscuration creates a "shadow" which is in relatively sharp focus. The result is referred to as an Image Non-Uniformity (INU). Fortunately, Boson includes two correction terms intended to compensate for INUs. The first is lens-gain correction and the second is referred to as Supplemental Flat-Field Correction (FFC). SFFC compensates for irradiance generated from within the camera, such as the radiative heat from the camera's own housing. This unwanted source is referred to as out-of-field irradiance, signifying that it is not originating from sources within the camera's optical field of view.

Figures 2-4 show 3 example Boson images, all with the camera imaging a uniform scene temperature. Figure 2 is with gain correction and SFFC disabled. (Note: the number of INUs shown in this example is *not* representative of one which would be shipped to a customer. It is deliberately shown as an extreme case.) The many large INUs, such as the one circled in gray, are from blemishes on the outer window surface, while the smaller one circled in yellow is from a defect on the interior window surface. Figure 3 shows a similar image except gain correction is now enabled but SFFC remains disabled. The INUs remain visible because out-of-field irradiance is not corrected. Finally, Figure 4 illustrates the case when both gain correction and SFFC are enabled. Notice that INUs are no longer visible.

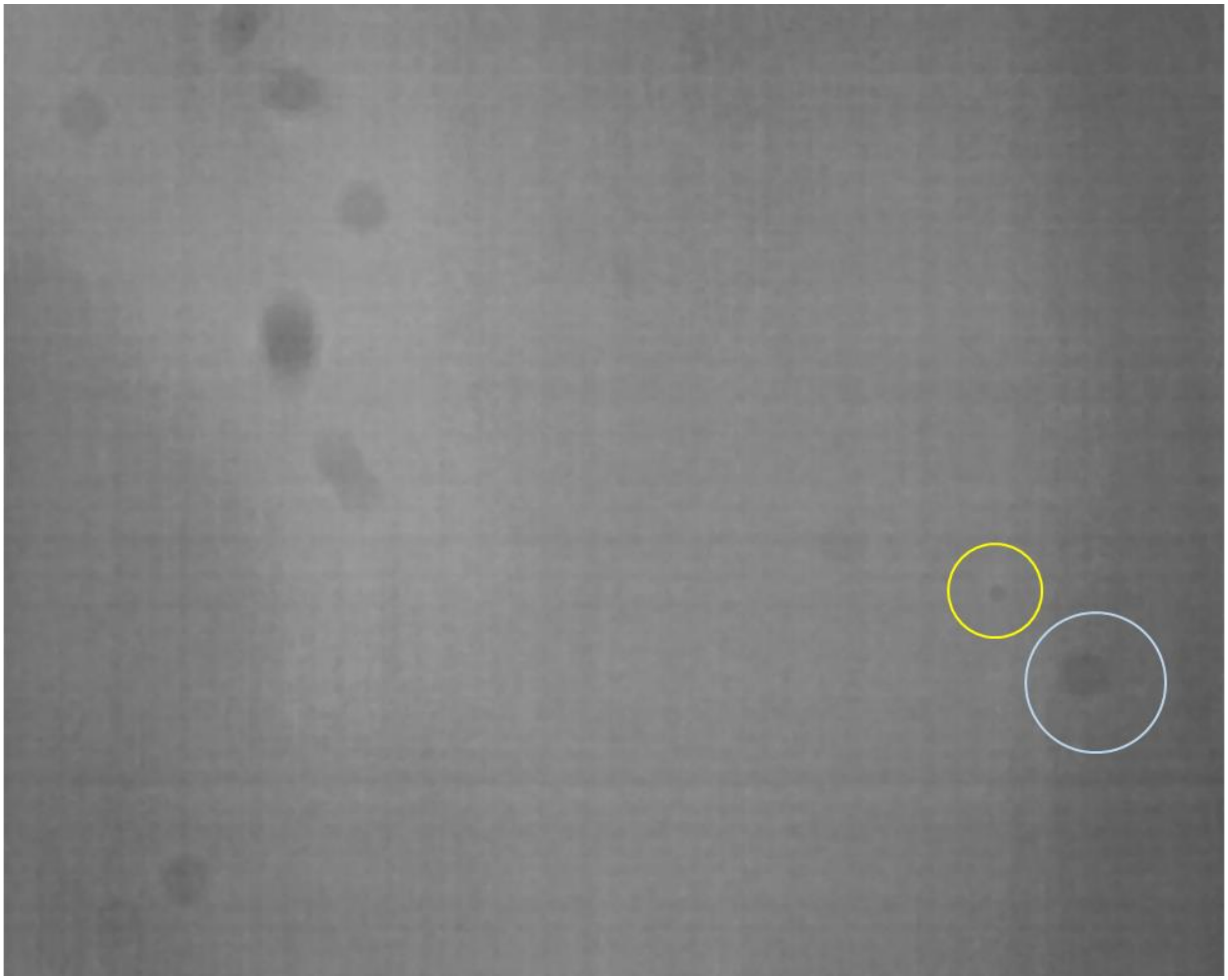


Figure 2: Example image with both gain-correction and SFFC disabled.

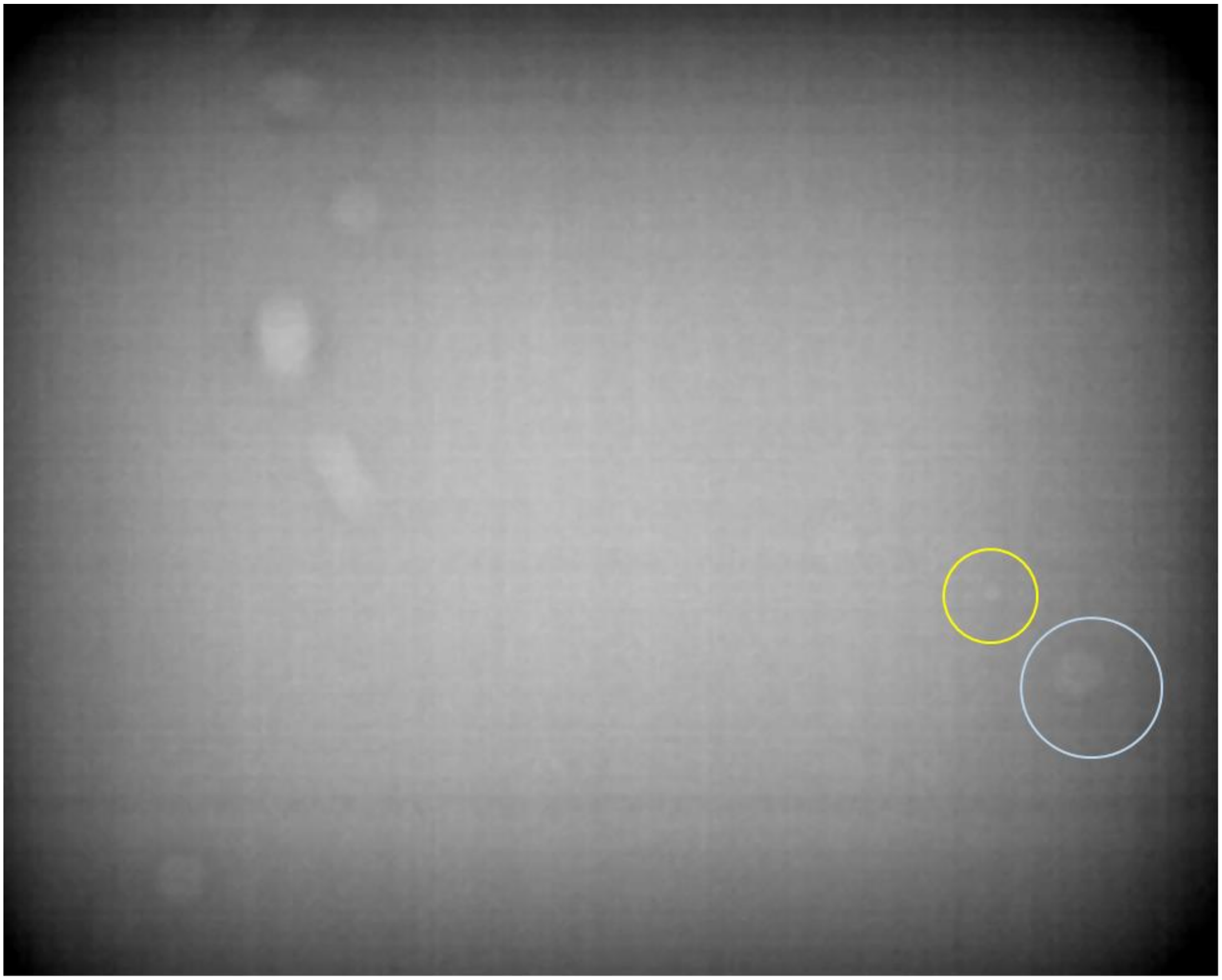


Figure 3: Example image with gain-correction enabled but SFFC disabled.

Figure 4: Example image with both gain-correction and SFFC enabled.

Generally speaking, there are four important variables which describe the appearance of INUs:

- Size: this is mostly a function of whether the imperfection causing the INU is on the inner or external surface of the sensor window. The size of the imperfection is also a consideration.
- Number and location: these two variables are a function of the sensor grade. The consumer grade of Boson is the lowest cost, and it also has the least stringent requirements pertaining to the number of INUs, as shown in Table 1 below. The professional and industrial grades have identical requirements regarding number and location of INUs. (It is NEDT and operability which distinguish industrial grade from professional grade.) Note that the number and location of allowed INUs refers to the number of allowed INUs when a camera is shipped from FLIR. If proper handling procedures are not followed as described later in this document, it is quite possible for additional INUs to be introduced by the user as the result of contamination of the outer surface of the WLP (e.g., a dust particle or a scratch from removing a particle).

- Magnitude: this variable is mostly a function of the size and type of defect (inner or outer). This variable is harder to quantify than the others because mitigation techniques (described in the next section) and operating conditions (described in the section after next) have a very strong effect on the magnitude of INUs.

Table 1: Size and Location Allowance for INUs for each Boson Grade

(Shown for reference only. Refer to the product datasheet for up-to-date INU allowances.)

320 configuration

Camera Grade	In Central 160x120	Outside Central 160x120
Industrial	0	≤1 Type A ≤1 Type B
Professional	0	≤1 Type A ≤1 Type B
Consumer	≤3 Type A ≤1 Type B	≤3 Type A ≤2 Type B

A type A INU is defined as one with radius < 10 pixels, and it is caused by an inner defect. A Type B INU is defined as one with radius >10 pixels, and it is caused by an outer defect or contamination.

640 configuration

Camera Grade	In Central 320x240	Outside Central 320x240
Industrial	0	≤2 Type A ≤2 Type B
Professional	0	≤2 Type A ≤2 Type B
Consumer	≤6 Type A ≤2 Type B	≤6 Type A ≤4 Type B

3 Mitigation Features

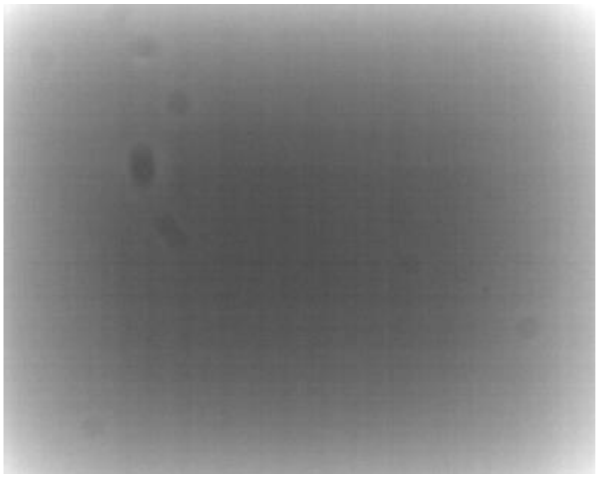
3.1 Lens-Gain Calibration

For all Boson configurations except lens-less, the camera is delivered with a factory-calibrated lens-gain map. However, it is highly recommended to repeat the calibration if the Boson is integrated with any additional optical components (e.g. behind a protective window, a filter, a secondary lens, etc). It is also recommended to recalibrate lens gain if the focus of the lens is significantly altered from its factory condition (e.g., changed from infinity focus to a close-in focus). Calibrating lens gain is accomplished by exposing the camera to two different uniform scene temperatures, which facilitates a determination of relative optical throughput at every point on the FPA. A detailed set of instructions for lens-gain calibration are provided in a separate App Note entitled "Boson Lens Calibration / Lens-less Core" (102-2013-100-02). See Section 1 for a link to a FLIR website where this App Note can be found. Three important points stressed in that App Note are worth repeating in this one:

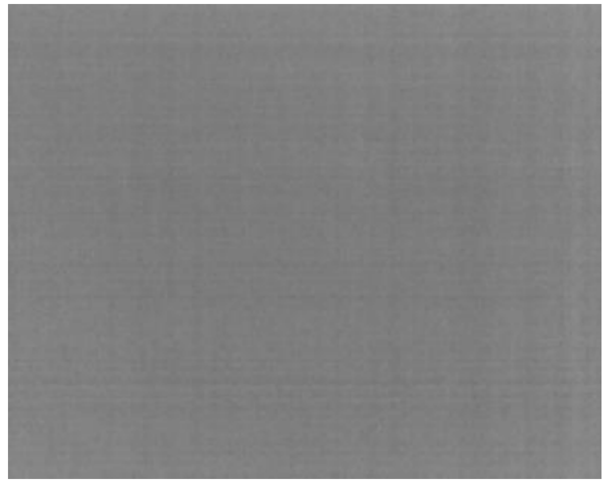
- Prior to lens calibration, the Boson should be integrated with its final system hardware, particularly all optical components, to ensure the infield radiation is representative of its condition during system use.
- The camera should be focused as it is to be used and *not* refocused on the blackbodies used for calibration. Changing focus can have a subtle effect on the infield irradiance pattern.
- The blackbodies used for calibration must subtend the entire field-of-view. Failure to fully subtend the field of view will misrepresent the irradiance pattern to the FPA.

3.2 Supplemental FFC (SFFC)

In most applications, FFC will be performed using the camera's internal shutter assembly, which inserts or retracts a paddle into the optical path. When FFC is performed using the internal shutter, best image quality is obtained with the additional correction term called Supplemental FFC (SFFC). When properly calibrated and applied, SFFC significantly improves uniformity and minimizes the appearance of INUs, as illustrated in Figure 5.



(a) SFFC disabled



(b) SFFC enabled

Figure 5. Image uniformity following internal FFC, with and without SFFC.

For all Boson configurations except lens-less, the camera is delivered with a factory-calibrated SFFC map. However, it is highly recommended to recalibrate SFFC after the Boson core is integrated by the user into the end system with all heatsinking in place. That is because the internal heating of the camera will differ in this condition compared to the FLIR-factory-calibration conditions. SFFC calibration is a simple process which requires only a single external blackbody or other uniform source. A detailed set of instructions for SFFC calibration is provided in a separate App Note entitled “Boson Lens Calibration / Lens-less Core” (102-2013-100-02). See Section 1 for a link to a FLIR website where this App Note can be found. Three important points stressed in that App Note are worth repeating in this one:

1) Lens gain must be calibrated prior to SFFC calibration.
2) Before calibration, the camera should be integrated into the end system, which includes the enclosure, optical components, and heatsinks and heat loads (including other system electronics, if possible). The goal is to mimic as closely as possible the steady-state temperature conditions within the end system.
3) The exact temperature of the blackbody source used for SFFC calibration is not terribly important since it is performed with lens-gain correction applied. What is important is that the blackbody subtends the entire field of view of the camera.

3.3 External FFC

Unlike internal FFC which uses the camera's internal shutter assembly as the uniform reference, Boson also provides the option to perform FFC against an external source. (For external FFC, the user must first ensure the camera is viewing a uniform source external to the camera lens, one which completely subtends the entire field of view.) Because the reference is located outside the camera, none of the out-of-field irradiance from within the camera is blocked during the FFC event. Consequently, the FFC itself compensates for those sources.

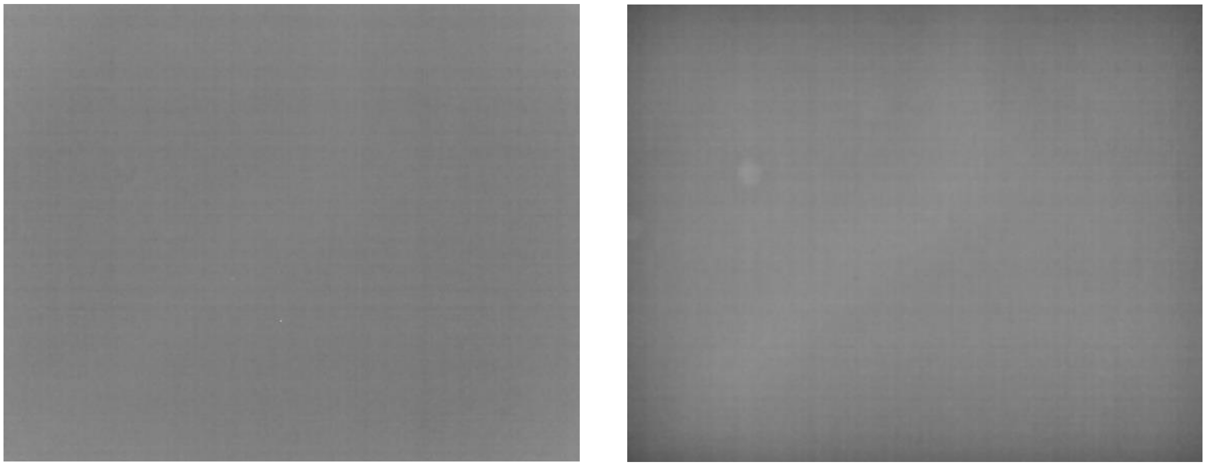
Note: SFFC correction, described in the previous section, should always be disabled when using external FFC for uniformity correction. Enabling SFFC after external FFC will actually *cause* non-uniformity since doing so resulting in out-of-field irradiance being doubly compensated (once by FFC, once by SFFC).

4 Operating Conditions to Avoid

Section 2 described the root cause of INUs, and Section 3 described correction terms which mitigate the root cause. This section describes operating conditions which present challenges to these mitigation techniques. While it may be impossible to completely prevent all such conditions in every application of a Boson camera, they should be avoided whenever possible.

4.1 Thermal Shock

When a camera is rapidly transitioned from one temperature environment to another (for example, taken from an air-conditioned room to an outside location on a scorching hot or frigid cold day), the temperatures of various internal components tend to change at slightly different rates. As temperature differences between internal camera components vary, so too does the out-of-field irradiance. Because SFFC is optimized for steady-state conditions, image uniformity is likely to worsen and INUs to be more visible during a thermal shock event, as exemplified in Figure 6. Consequently, it is recommended to isolate the camera core from such events to the extent possible. While rapid temperature change is inevitable in many applications of thermal imaging (e.g., firefighting as a particularly harsh case in point), Section 5.1 provides recommendations for thermal management intended to minimize the adverse effects of thermal shock.



(a) Before thermal shock (at steady state)   (b) During thermal shock

Figure 6: Example imagery before and during a thermal shock event

4.2 Frequent Power Cycling

A Boson camera dissipates a relatively large amount of power (> 500 mW for most configurations) into a relatively small thermal mass (as low as 15g for some configurations). As with most power-dissipating devices, proper heatsinking is required to prevent significant self-heating during operation. But even with adequate heatsinking, it is not uncommon for the temperature of Boson's internal components to increase by several Celsius degrees from start-up to steady-state operation – each incidence of power-up is a thermal-shock event of sorts. The SFFC correction algorithm automatically compensates for internal temperature variations during the start-up transient to achieve good uniformity throughout. However, frequent power toggles can lead to atypical thermal conditions inside the camera, which in turn can result in less effective correction of out-of-field irradiance. It is therefore recommended to avoid rapid power cycling to allow for best imaging performance.

4.3 Excessive FFC Events

It may seem counterintuitive at first blush, but performing internal FFC too frequently can actually *degrade* image quality. The reason is that actuating the shutter causes additional power dissipation (albeit for a very short time), and doing so too frequently can lead to two undesirable conditions:

(1) non-uniform heating of the shutter paddle, which in turn impresses non-uniformity into the FFC correction
(2) excessive internal heating, which in turn changes the out-of-field irradiance pattern

Under most circumstances, it is recommended to operate the camera in "automatic FFC mode" with factory-default settings. Doing so causes FFC events to happen automatically at a cadence controlled by the camera. However, it is undesirable in some applications to have an FFC event take place automatically without intervention by host electronics. In such cases, the camera should be put in "manual FFC mode" such that FFC only takes place when explicitly commanded. When operating in that mode, it is recommended to avoid FFC at a rate more frequent than every 30 seconds. (This recommendation refers to the *average* frequency, and occasional exceptions such as during extreme thermal shock are not discouraged.) As guidance, the camera provides an "FFC Desired" flag (provided through the optional telemetry line and also via an optional on-screen symbol) to signal when it would perform FFC if operating in automatic FFC mode.

5 Guidelines for System Design & Integration

5.1 Thermal Management

When integrating a Boson core into a higher-level system, perhaps the most important consideration affecting performance (especially with respect to minimizing INUs) is thermal management. Minimizing temperature gradients within the camera is important, but even more critical than an isothermal out-of-field condition is a *stable* out-of-field condition. That is because SFFC is calibrated against a specific out-of-field irradiance pattern. When the pattern strays from its calibration state, SFFC will be less effective. To prevent the pattern from varying, the camera (and especially the optical path / sensor) should be isolated as much as possible from any sources of transient thermal loading/ heatsinking. Specific examples are provided in the paragraphs which follow.

In most applications, it is assumed the Boson core will be installed within a sealed enclosure. Two options exist for environmentally sealing the camera – protruding the lens assembly through the enclosure[1] (depicted in Figure 7a) and encapsulating the entire camera behind an LWIR-transparent window (depicted in Figure 7b). From the standpoint of thermal management, placing the entire camera within an enclosure better insulates it from the external environment, thereby reducing susceptibility to gradients caused by thermal shock, solar loading, convection currents, and other forms of non-symmetrical heat-loading / heatsinking. For many use cases, the benefit of fully enclosing the camera is relatively minor; however, for systems which must operate in cold-weather conditions, a second and far more significant reason to select the fully-enclosed option is the need to de-ice. As shown in Figure 8, heating a lens assembly is far more likely to produce gradients in the camera than heating a window. It is nearly impossible to heat a lens without also heating the mechanics which hold it, thereby altering the out-of-field irradiance pattern and instigating non-uniformity and INUs.

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[1] All but the smallest Boson lens options provide an o-ring groove on the lens barrel to facilitate a clamp seal.

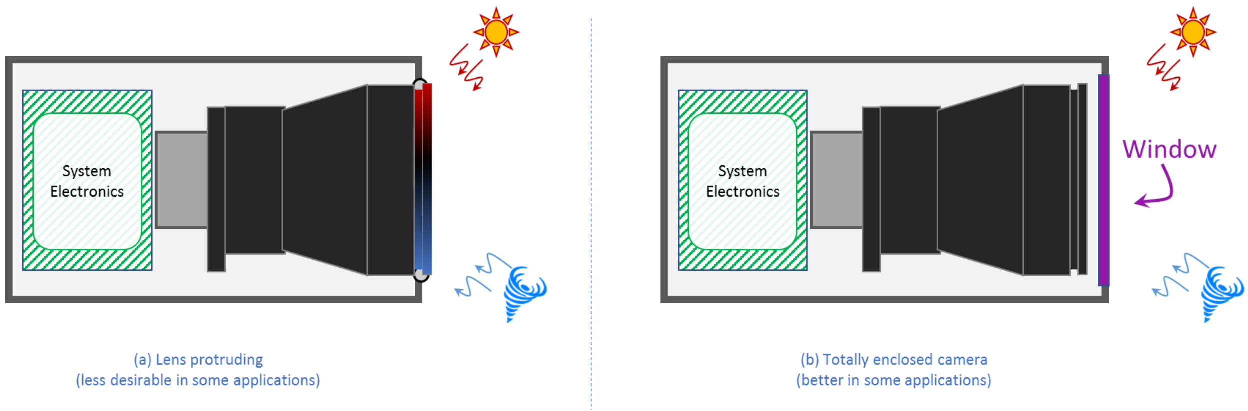


Figure 7: Two system-enclosure options

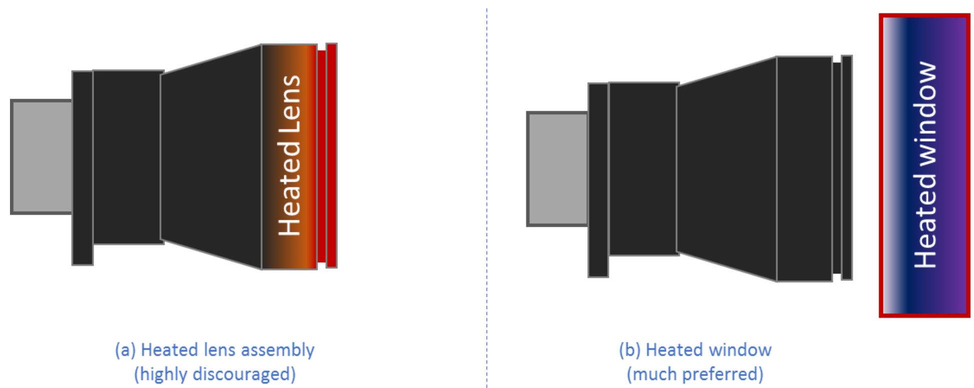


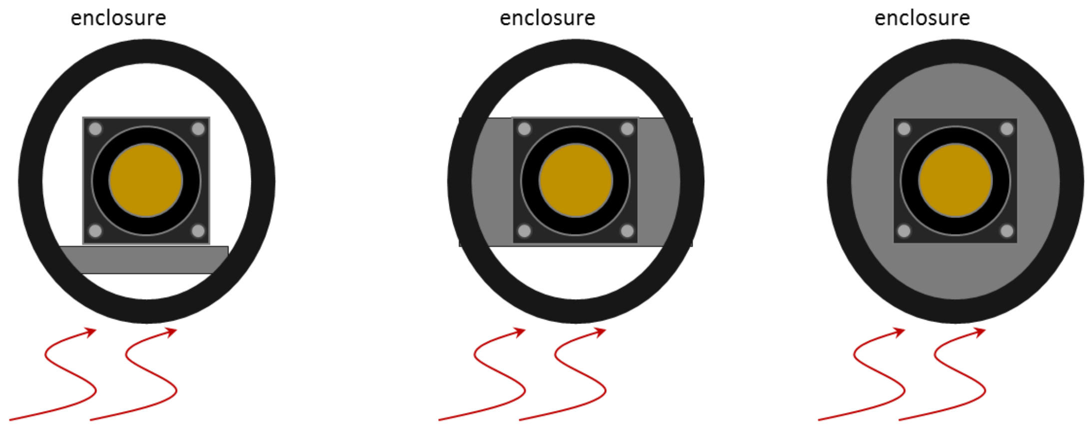
Figure 8: Two de-icing options

As described previously in this App Note, it is essential to provide adequate heatsinking when integrating a Boson core into a system. The purpose of heatsinking is not just to prevent an overheat condition but also to minimize thermal gradients within the core. Because most of the camera's power is dissipated by its electronics assembly at the rear, it is important to provide some means of conducting heat away from this surface. For small-lens configurations of Boson (i.e., those in which the mass of the lens assembly is less than the mass of the camera body), the recommended mounting strategy is to fasten a suitable heatsink to the rear-facing surface of the camera via its 4 threaded holes. The Boson tripod adapter, shown in Figure 9, is a worthy example in that it provides excellent thermal conduction from the rear of the camera (via ample surface-area contact) to a large thermal mass (i.e., the metal base of the adapter).

Figure 9: Heatsinking example

For large-lens configurations, the preferred mounting approach from a structural standpoint is to clamp the lens barrel. But even for that mounting approach, it is still expected that some means of conducting heat from the back surface of the camera will be provided. While a rigid connection to the rear surface may not be feasible with the front of the camera rigidly mounted, many options exist for connecting a heatsink via a compliant interface (e.g., thermal pad, copper braid, spring-loaded contact, etc).

In some applications, the temperature of the system enclosure may be highly dynamic due to inconsistent thermal loading or heatsinking. For example, a small handheld scope might change temperature by several degrees depending upon whether it is being handled or dangling from a lanyard. Another example is a system operating in a variable airstream, such as a camera installed on a moving vehicle. For such scenarios, the best thermal-management approach may be to insulate the Boson core from the enclosure. However, not every application can support this option; for example, systems required to operate at temperatures approaching 80C may need to directly couple Boson to the enclosure as a means of dissipating its heat and averting an overtemp condition. In that case, symmetric coupling is preferred over asymmetric for minimizing gradients influenced by the enclosure. This recommendation is illustrated in Figure 10, which depicts cross-sectional views of a hypothetical tube enclosure with various approaches for coupling a Boson core (viewed from the direction of its optical axis).



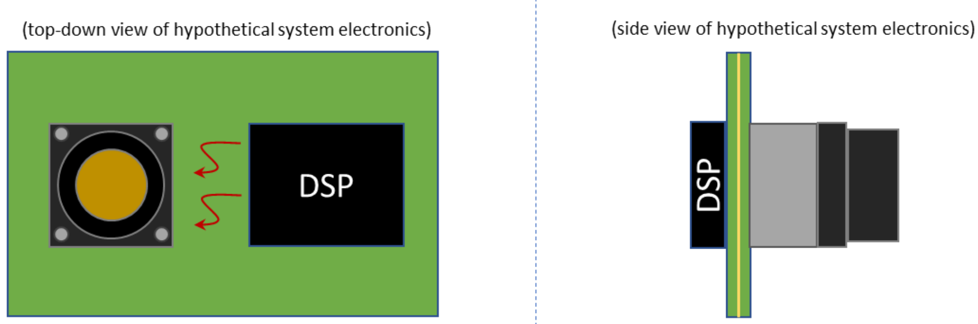
(a) Asymmetrically coupled (not recommended)

(b) Symmetric in one axis (better)

(c) Symmetric in both axes (best)

Figure 10: Examples of coupling a Boson core to a system enclosure

Another potential source of dynamic thermal loading is a neighboring component / device which dissipates a significant amount of power, such as a DSP, ARM, or SoC. Especially if power dissipation of the device is variable and/or if it requires convective cooling, care should be exercised to prevent temperature fluctuations of the nearby Boson core. As illustrated in Figure 11, locating such devices immediately adjacent to the camera is less ideal than thermally isolating them (e.g., by mounting on opposite sides of a circuit-card assembly).



(a) Asymmetric thermal loading from a high-powered device (not recommended)

(b) Thermal isolation between the two devices (preferred)

Figure 11: Examples of locating high-powered devices relative to a Boson core in an end system

5.2 Optical Design

Because the theoretical ratio of out-of-field irradiance to infield irradiance increases with f/#, as depicted in Figure 12, a slow optical system is more susceptible to INUs than a fast one. All standard Boson lenses are nominally f/1 designs. Users who intend to integrate their own optical system to a lensless Boson core are advised against selecting an f/# much slower than that, particularly if the camera is intended to be used in a highly dynamic thermal environment. Designs which utilize a variable f-stop or other means to vary f-number are also highly discouraged since varying the f/# affects both the infield and out-of-field irradiance patterns (invalidating both the lens-gain calibration and the SFFC calibration).

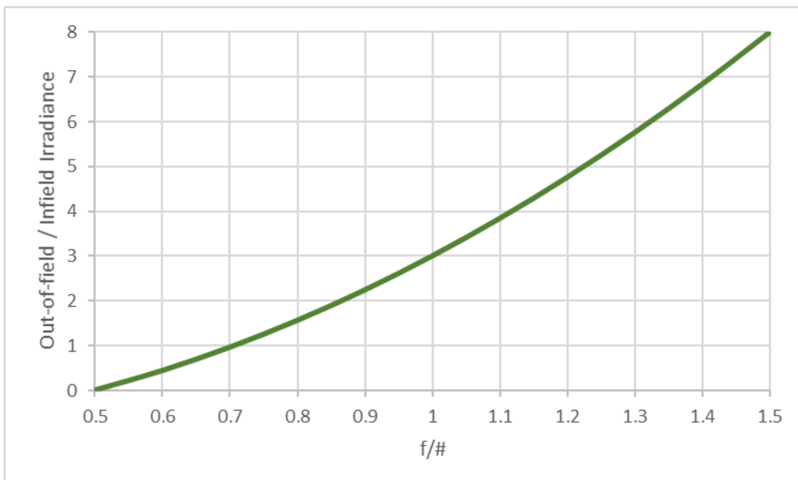


Figure 12: Ratio of out-of-field to infield irradiance vs. f/#.

Boson provides the capability to store two sets of lens-correction terms (where each set is comprised of a lens-gain map and a SFFC map). For dual-FOV lens designs, it is recommended to calibrate one set of terms using the first FOV and the other set with the second FOV. During operation, the applied set of correction terms should be changed (selectable via the command & control interface) whenever the FOV is changed.

5.3 Cleanliness

Any dust particle which finds its way to the sensor window will create a new INU. Performing lens-gain calibration and SFFC calibration might mitigate the appearance temporarily, but a dust particle is prone to moving. When it does, the location where it formerly resided will be falsely corrected and the its new location falsely uncorrected. The best mitigation against this source of INU is prevention. Great care is taken in the FLIR factory to produce a camera free of dust and debris in the sealed area between the lens assembly and the sensor assembly. For most Boson users, there is no reason to ever remove the lens assembly and risk the possibility of contamination. (Doing so also voids the warranty.) Debris removal is a very delicate process, one likely to bring about further contamination or possible damage if done improperly. If debris contamination is suspected, FLIR strongly recommends contacting a customer-service representative to arrange a Return Merchandise Authorization (RMA) so that proper dispositioning and repair can be conducted in the FLIR factory by a qualified operator.

Lensless configurations of Boson are shipped with a factory-installed protective cap. Removal of the cap and installation of a lens assembly should be performed in a certified clean room (Class 1000 / ISO 6 or cleaner), preferably under a laminar flow hood (e.g. Class 100 / ISO 5).