Biospherical Instruments Inc.

APPLICATION NOTE:

How the Microradiometer System Produces a Calibrated Reading

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5340 Riley Street
San Diego, CA 92110-2621 USA

Vox: +1.619.686.1888
Fax: +1.619.686.1887

Net: sales@biospherical.com
Web: www.biospherical.com

How the Microradiometer System Produces a Calibrated Reading

This note describes how a microradiometer samples the photocurrent generated from the photodetector, and processes that reading into an offset-corrected, autoranging, scaled reading. This reading is then transmitted to the aggregator, and in turn, the aggregator transmitted this reading to the deckbox, which forwards it to the host computer. Readings generated in a microradiometer are not modified by the aggregator or deckbox, and these readings do not have the calibration factor applied, although this calibration factor is contained in the microradiometer and is normally read by the host computer where it is subsequently applied.

Readings from the 24-bit analog-to-digital converter (ADC) are internally produced in a 32 bit, unsigned, integer format ("reading"). These readings have a nominal count at 0 V of 8388608 counts. The internal scale factor is 1 count = 0.000000488 V derived from the nominal 4.096 V internal reference. During initial configuration and checkout of the microradiometers, the offset counts (unsigned integers) for all gains are determined in the dark, and stored replacing the nominal 8388608 count default. These offsets are recalled using the **`>tO!`** command, where "**`t`**" is the microradiometer tag.

Normally, the ADC in each microradiometer is continuously running at 125 Hz, collecting data and changing its range, if necessary, as described below. Assuming that the reading is stable (i.e., the gain has not changed in the last three cycles), the net reading is calculated as:

$$NetReading = Reading - Offset(gain),$$

where the *NetReading* is the difference between the *Reading* and the offset value determined at the current gain range. *NetReading* is a signed 32-bit integer. The **`Offset()`** values are recorded at the beginning of every profile, and are labeled as "**`offset _ High`**", "**`offset _ Medium`**", and "**`Offset _ low`**" (two-gain systems omit the medium offset).

Microradiometers report their reading in their "native" format, which is

$$ReportedReading = NetReading \times ADCscale(gain).$$

Because the microradiometers have multiple gains, there are *ADCscale* factors for each gain. For the highest gain setting, the *ADCscale* is the same as the nominal internal scale factor, or 0.000000488 V count^{-1}. Therefore, when the microradiometer is in high gain, the readings are in net volts, as measured by the ADC. In the case of other scale factors, multipliers of this factor are maintained, and although they are referred to as "volts," the saturation value of the microradiometer on low gain is 4.096 V × 40,000, or around 160,000, so the microradiometer never actually sees 160 kV. In the two-stage microradiometer, this is a single multiplier that is determined when the microradiometer is initially configured using the internal firmware command sequence. This is done by first maintaining the microradiometer in the dark and determining the offsets for each gain. Then, using a computer-controlled light source, a light signal is generated, which will be at the upper range of the most sensitive gain range (around 3.5 V). This large signal level is sufficient to also generate a signal in the lower gain range (around 3.5 mV for the two-stage radiometers).

The microradiometer repeatedly samples the light source at both gains and computes the net ratio of the signals produced. This net ratio is the "gain ratio" and is approximately 1000 in the case of the two-stage microradiometers. The product of this gain ratio and the *ADCscale* on high gain is the low gain *ADCscale*. The *GainRatio* is recorded in the *MicroRadiometerInfo* table produced at the start of every cast. In three-stage microradiometers, there are two gain ratios, each with a nominal value of 200. This means that on the most sensitive gain, the *ADCscale* is 1.0. On medium gain,

the *ADCscale* is around 200, and on the least sensitive scale, the nominal gain is 200×200.

The microradiometer has an automatic gain ranging system that is normally activated when the microradiometer attempts to use the gain that will yield the maximum resolution of the photodetector input current. This works by the microradiometer examining the ADC reading. If the reading is below a certain level—called *SwitchHigher*—and the gain is either medium or low, the microprocessor will switch the input amplifier to the next higher gain. This *SwitchHigher* ADC reading is a count of 31,000, which corresponds to a voltage at the ADC of 0.01513 V. In a similar fashion, if the ADC reading is nearing saturation (the maximum ADC input voltage of 4.096 V), then the microprocessor changes to a less sensitive gain. The point where this happens is *SwitchLower,* which is 7782400 counts, or 3.80 V. On two-gain systems, these switch points are 0.0034 V and 3.8 V.

It is possible to change the switch points, and also retrieve these points using the **>tJ!** command sequence. The exact values are recorded by these names in the *MicroRadiometerInfo* table produced at the start of a profile.

The switch points have been chosen to add hysteresis into the system to prevent rapid switching between gains when encountering noisy signals. This means that in a three-gain system, a signal that has declined in intensity and reaches the *SwitchHigher* point of 0.015 V, will produce an ADC reading of 3.03 V after the ranging switching. If the signal is held at that level, it would be below the *SwitchLower* point of 3.8 V and be stable. The same thing happens as a signal rises about the *SwitchLower* point.

Note that the *ReportedReading* is generated before any averaging inside the microradiometer. Because the ADC is running at 125 Hz, and most microradiometer applications call for sampling rates below 20 Hz, several ADC samples are obtained before data is reported. Microradiometers normally run in the polled mode with the aggregator first commanding all microradiometers under its control to start sampling. This resets the accumulator that holds the average of the *ReportedReadings,* and a new average begins. After the next command to start sampling this accumulator, the reading is transferred to a buffer and awaits the aggregator's request for data.

In the event that the light level changes sufficiently during an averaging period to cause the instrument gain to change settings, then a small number of readings after the gain change are discarded. This number is normally three and is set in the software. Assuming that the ADC is operating at 125 Hz, and that data is being transmitted at 15 Hz, then approximately eight ADC readings are averaged before transmission. If a range change happens, then this number may drop to four readings, which is still sufficient to produce an average. If the environment contains a lot of higher frequency optical "noise," such as very near the surface, then it is possible that the range may change more than once during the 70 ms sampling window. It may not be possible to average any readings because of frequent range changing. In this case, the data is reported as having a value of –999. During any normal profile, there will be very small regions where the reported data will be composed of readings averaged at two different gains, and will have two different offsets subtracted. It will not be possible to unambiguously recalculate the data using different offsets.

After transmission to the host PC, the readings normally have a scale factor and perhaps a "field offset" value applied:

$$Answer = \frac{TransmittedReading - Fieldoffset}{ScaleFactor}$$

Unwinding this computational sequence is fairly direct in most cases. The data should be divided into two groups (three groups in the case of three-gain microradiometers), data recorded on high gain, and data recorded on low gain. This is done by computing the radiometric level where gain switching occurs. As noted above, the switch levels are different depending on whether the signal is increasing or decreasing. This results in an additional middle group of data where the gain setting

is uncertain, or readings taken at both gains may be averaged into the data.

In the case where the data recorded in a cast shows a gap in readings as the instrument ascends or descends, then the most probable cause is that the gain ratio and/or offsets are incorrect. The gain ratio reported should be checked against the original factory calibration. Assuming that the original factory calibration is unchanged, the offsets should be compared against new offsets.

Optical Units

Optical channels are calibrated in μW cm^{-2} nm^{-1} for irradiance, and μW cm^{-2} nm^{-1} sr^{-1} for radiance.

Temperature and Pressure

Temperature and pressure channels are based on microradiometer circuitry, with the internal ADC supplying an instrumentation amplifier to condition the bridge circuitry of the temperature and pressure channels. In normal (optical) microradiometer channels, this amplifier is disabled—the parameter **`ADC _ gain`** is set to 1, but in the temperature channel, this is set to 128, meaning that a factor of 128x amplification is applied to the output of the pressure transducer bridge. In the case of pressure, the amplification (**`ADC _ gain`**) is set to 32. For both of these sensors, offsets are calculated in counts from the ADC, and the offsets are the same for both high and low gain. The offsets for pressure are calculated to give an output of 0 m at room pressure, acknowledging that there will be a field offset, or tare, calculated for the instrument on location to take account of atmospheric pressure changes. Temperature offsets are calculated to produce an output in degrees Celcius (°C) when the sensitivity factor is applied. Normally, autoranging is turned off and the gain ratios are set to 1.0.

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5340 Riley Street
San Diego, CA 92110-2621
Web: www.biospherical.com
E-mail: Support@biospherical.com
Vox: 1.619.686.1888
Fax: 1.619.686.1887