# Crystal Technology, Inc.

# AOTF Controllers and Temperature Compensation

**Revision 1.2**

**2010/08/10**

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| Revision History | | | |
|---|---|---|---|
| **Revision** | **Date** | **Who** | **Comments** |
| 1.0 | 2008/12/01 | Calvin Hwung | Genesis. |
| 1.1 | 2008/12/05 | Dale Gifford | Release 2008-12-05. |
| 1,2 | 2010/08/10 | Dale Gifford | Updated logo, fixed typos. Release 2010-08. |

**Table 1: Revision History**

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# 1. Introduction

## 1.1. Purpose

Temperature Tracking is the process of adjusting the RF Frequency output of the AOTF Controller to maintain optimum diffracted light intensity. The diffracted light intensity is a function of the RF Frequency injected into the AOTF Crystal. The optimum frequency varies with the temperature of the AOTF Crystal, so it becomes important to compensate for changes in the temperature of the AOTF Crystal by adjusting the RF Frequency. The compensation algorithm can be based on measuring the light intensity directly or by measuring the temperature of the AOTF crystal. This document contains information about using Crystal Technology's *Acousto-Optic Tunable Filter (AOTF) Controllers* in environments that utilize Temperature Compensation. This document provides guidelines for configuring and operating *AOTF Controllers* in a Temperature Compensation mode of operation.

## 1.2. Related Documents

The following references may be useful in fully understanding and utilizing the *AOTF Controller*:

- Octal Channel AOTF Controller Integration Guide, Revision 1.1, 2010/08/10, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- Quad Channel AOTF Controller Integration Guide, Revision 1.1, 2010/08/10, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- Single Channel AOTF Controller Integration Guide, Revision 1.1, 2010/08/10, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- AOTF Controller Command Reference, Revision 1.3, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- AOTF Controllers and FSK Operation, Revision 1.3, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- AOTF Controllers and Light Intensity Tracking, Revision 1.2, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- AotfManager User's Guide, Revision 1.1, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.
- AotfCmd User's Guide, Revision 1.1, www.CrystalTechnology.com, Crystal Technology, Inc. 1040 East Meadow Circle, Palo Alto, CA 94303-4230.

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### *1.3. Notation*

- Numbers with an "h" suffix or "0x" prefix are hexadecimal. All other numbers are decimal.
- Register and bit names ending in "**[#]**" and "**[#:#]**" signify selection of a subset of the register (e.g. **I2CS[0]** represents bit 0 of the **I2CS** register, and **I2CS[5:3]** represents bit 5 through 3 of the **I2CS** register).
- Signal names ending with '#' (e.g. **INT0#**) indicates an active low signal.
- N/A is an abbreviation for Not Applicable.
- Register bits are either set (1) or cleared (0).

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## 2. Temperature Compensation

Temperature Compensation is the process of adjusting the RF Frequency output of the *AOTF Controller* to maintain optimum diffracted light intensity. The diffracted light intensity is a function of the RF Frequency injected into the AOTF Crystal. The optimum frequency varies with the temperature of the AOTF Crystal, so it becomes important to compensate for changes in the temperature of the AOTF Crystal by adjusting the RF Frequency.

All host environments are not identical, and there is more than one way a host environment might deal with variations in AOTF Crystal temperature. To facilitate these various host environments *AOTF Controllers* have algorithms embedded in the firmware that can be utilized in different temperature compensation schemes.

The algorithms in *AOTF Controllers* have been divided into two broad categories:

- **Average Temperature Tracking**
  These algorithms monitor the temperature of the AOTF Crystal. They consist of averaging mechanisms across intervals of temperature samples.
- **Frequency Tracking Adjustments**
  These algorithms provide flexibility for the host environment for making the adjustments to the RF Frequency.

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## 3. Average Temperature Tracking

The Average Temperature Tracking algorithm is a running average of the temperature over time. The algorithm is controlled by three parameters:

- **Average**
  The *Average* is the number of rapidly sampled conversions of the Analog to Digital Converter (ADC) that are averaged together to represent the instantaneously sampled temperature. The ADC is sampled at 1KHz (i.e. every 1ms apart). Because the temperature sensor for the AOTF Crystal is typically located a few feet from the ADC, there is unwanted noise injected into the temperature readings. The *Average* is used as a low pass filter to attempt to smooth out the readings and ignore the injected noise. The default value for *Average* is 0, which disables the low pass filter function. When the low pass filter function is disabled only a single conversion from the ADC is used for the *Average*.

- **Interval**
  The *Interval* is the time delay between *Averages*. The Interval is expressed in milliseconds.

  NOTE: *Interval* should be greater than *Average*, otherwise there isn't enough time to collect the samples in the *Average* before the next *Interval* begins.

- **Count**
  The *Count* is the number of *Intervals* that will be averaged together to create the final running average of the AOTF Crystal temperature.

*Figure 1* shows how these elements are related.

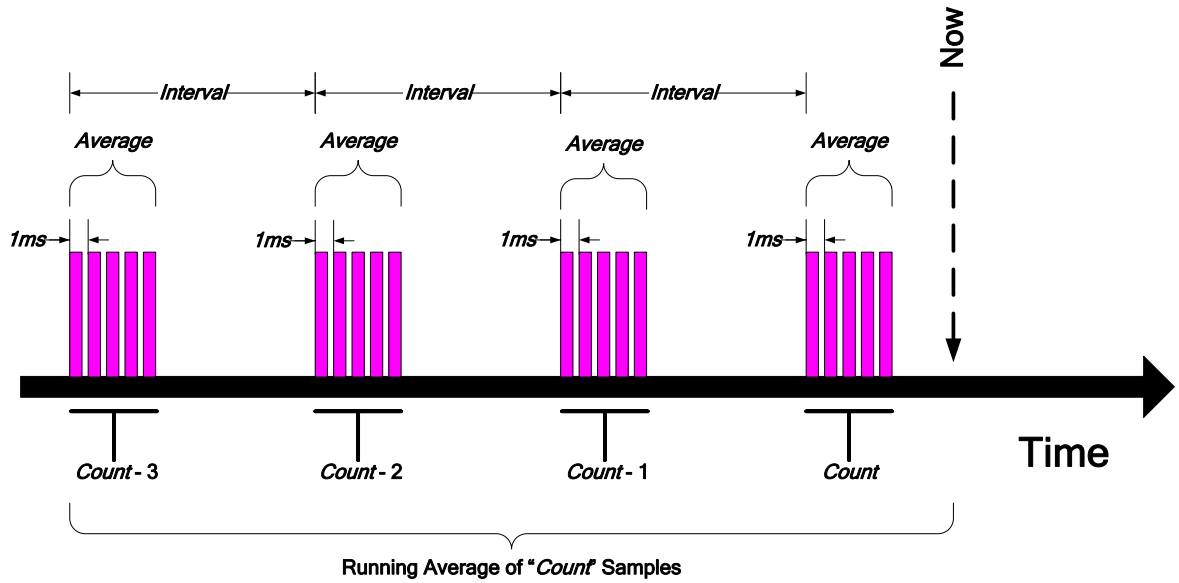


**Figure 1: Average Temperature Tracking**

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The Average Temperature Tracking parameters can be configured with these firmware commands:

- **Average**

  `Adc Average Channel* [Count]`

  `Channel*` is the ADC channel of the temperature sensor. For the AOTF Crystal temperature the ADC channel is 1. Other ADC channels are used for other temperature sensors, such as the Oscillator and RF Amplifier temperature sensors.

  `Count` is the number of samples for the *Average*.

- **Interval**

  `Temp Interval Sensor* [Ms]`

  `Sensor*` is the temperature sensor. For the AOTF Crystal temperature the `Sensor` is "Crystal".

  `Ms` is the number of milliseconds for the *Interval*.

- **Count**

  `Temperature Count Sensor* [Count]`

  `Sensor*` is the temperature sensor. For the AOTF Crystal temperature the `Sensor` is "Crystal".

  `Count` is the number of *Intervals* in the running average.

Alternatively the Average Temperature Tracking parameters can be configured via the AODS Controller software, which provides a Graphical User Interface (GUI) for configuring the *AOTF Controllers*, as shown in Figure 2.

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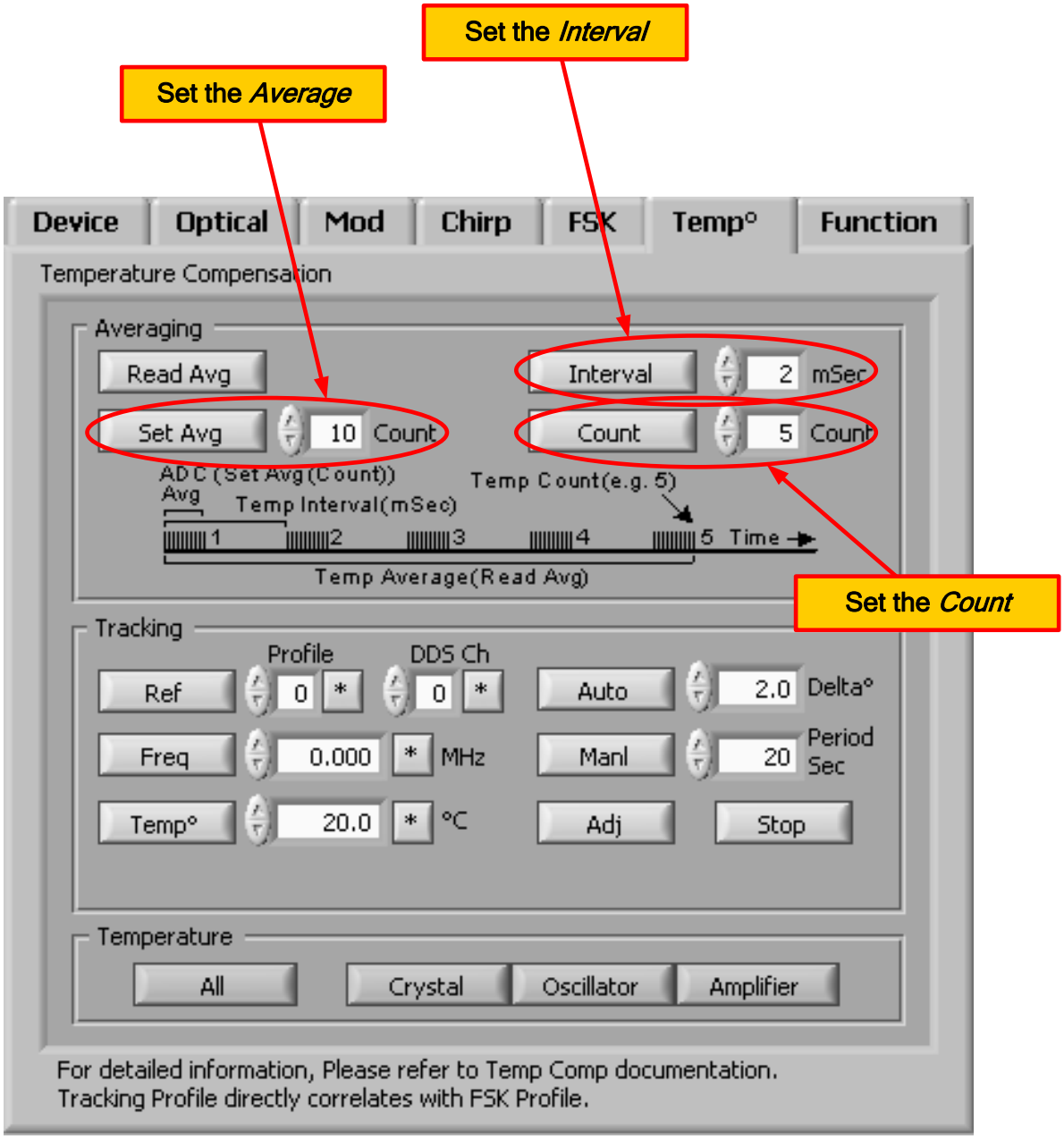


**Figure 2: Average Temperature Tracking**


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## 4. Frequency Tracking Adjustments

Frequency Tracking Adjustments are based on an algorithm that models the behavior of the AOTF Crystal with respect to temperature. The coefficients used by the algorithm are characterized by Crystal Technology at the time the AOTF Crystal is manufactured. The coefficients are stored in the EEPROM inside the AOTF Crystal housing. The *AOTF Controller* reads the coefficients whenever necessary.

To use the algorithm it is necessary to establish a reference frequency $f_0$ and reference temperature $t_0$. $f_0$ and $t_0$ together form a point ($f_0, t_0$) that serves as a reference point for anchoring the algorithm.

There are two common scenarios for ($f_0, t_0$):

- Zero degrees C
  If the AOTF Crystal has been characterized at 0°C and the corresponding frequency is known then it can be used as the reference frequency along with 0°C for frequency tracking adjustments.

- Host environment operating temperature
  The most common reference point is to choose any ($f_0, t_0$) that is known to be correct for the AOTF Crystal in use. This turns out to be relatively easy if the host environment contains a light intensity sensor connected to the *AOTF Controller*. Use the "Peak Light Intensity" algorithms of the *AOTF Controller* to find the frequency where the diffracted light intensity is maximized. The "Peak Frequency" can be used as the reference frequency for the current temperature of the AOTF Crystal. See *Section 5* for more information about using the Peak Light Intensity to determine a reference frequency.

Once ($f_0, t_0$) are known, the Frequency Tracking Adjustments can be done.

Establish the reference point ($f_0, t_0$) with the following commands:

```
Track Frequency 0 f0
Track Temperature 0 t0
```

A short cut exists if the *AOTF Controller* is at the Peak Light Intensity frequency and the temperature is stable by issuing the following command:

```
Track Reference 0 * *
```

This will establish the current frequency of channel 0 as the reference frequency and the current temperature as the reference temperature.

Alternatively, the AODS Controller application can accomplish the same commands as shown in *Figure 3*:

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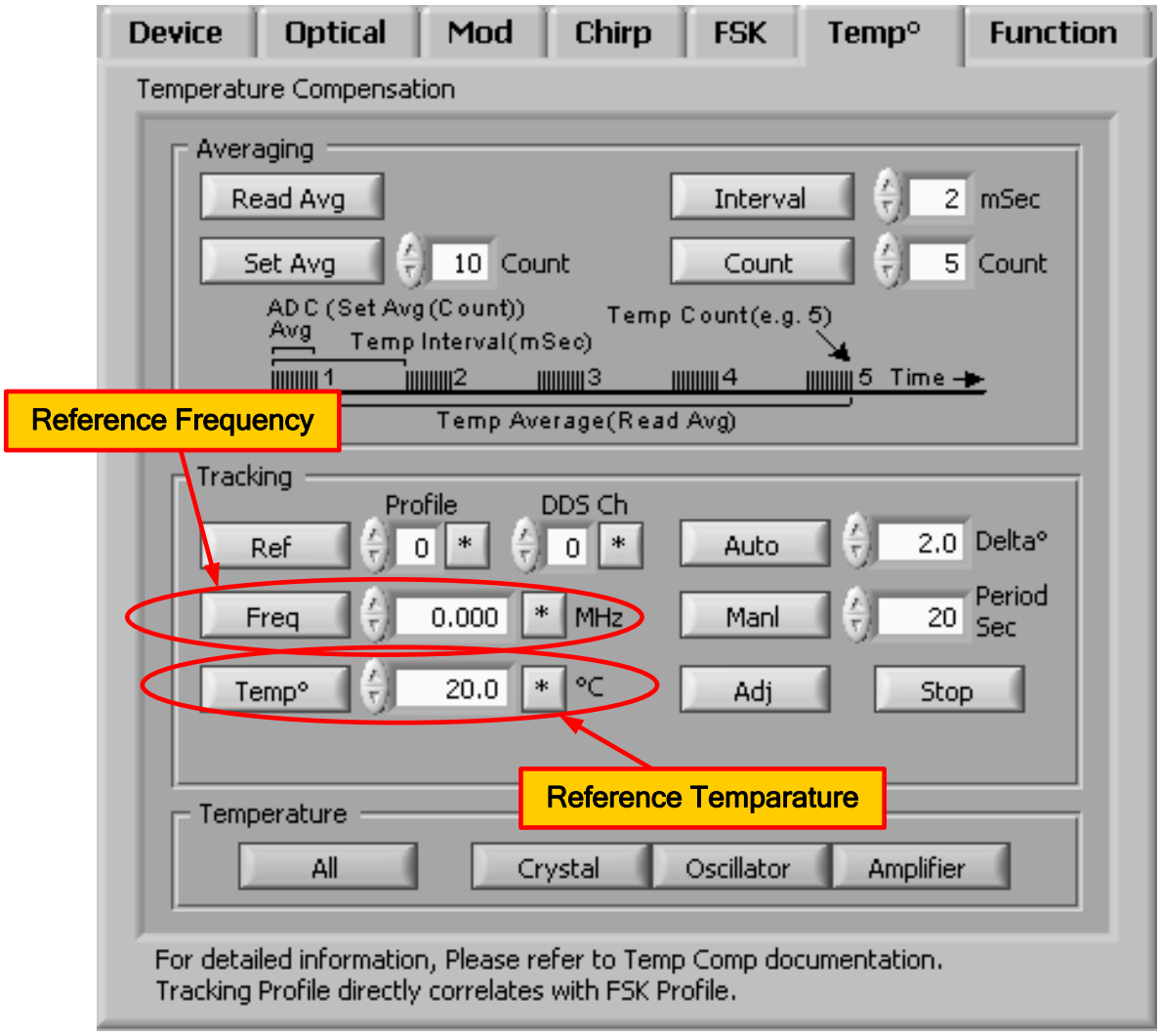


**Figure 3: Reference Frequency and Reference Temperature**


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Frequency Tracking Adjustments are divided into two modes of operation:

- **Auto**
  Auto Frequency Tracking uses an interval timer to periodically make adjustments to the frequency. Each interval period the frequency is adjusted to compensate for any changes in the temperature. If the change in temperature is below the minimum threshold, no adjustment will be performed. This is to compensate for minor fluctuations in the temperature.
- **Manual**
  Manual Frequency Tracking only performs adjustments when the host invokes the adjustment command. This is to allow the host the ability to decide when frequency adjustments can be tolerated.

To configure the *AOTF Controller* for Auto Frequency Tracking issue this command:

```
Track Auto -t 0 2.0 20
```

This will enable Auto Temperature Frequency Tracking for channel 0 every 20 seconds. The temperature must change by 2ºC before any adjustments will be performed. To terminate the Temperature Tracking issue the following command:

```
Track stop 0
```

To configure the *AOTF Controller* for Manual Frequency Tracking issue this command:

```
Track Manual -t 0 2.0
```

This will enable Manual Temperature Frequency Tracking for channel 0. No adjustments will be made until the following command is issued:

```
Track Adjust
```

The temperature must change by 2ºC before any adjustments will be performed. To terminate the Temperature Tracking issue the following command:

```
Track stop 0
```

Alternatively, the AODS Controller application can accomplish the same commands as shown in *Figure 4:*

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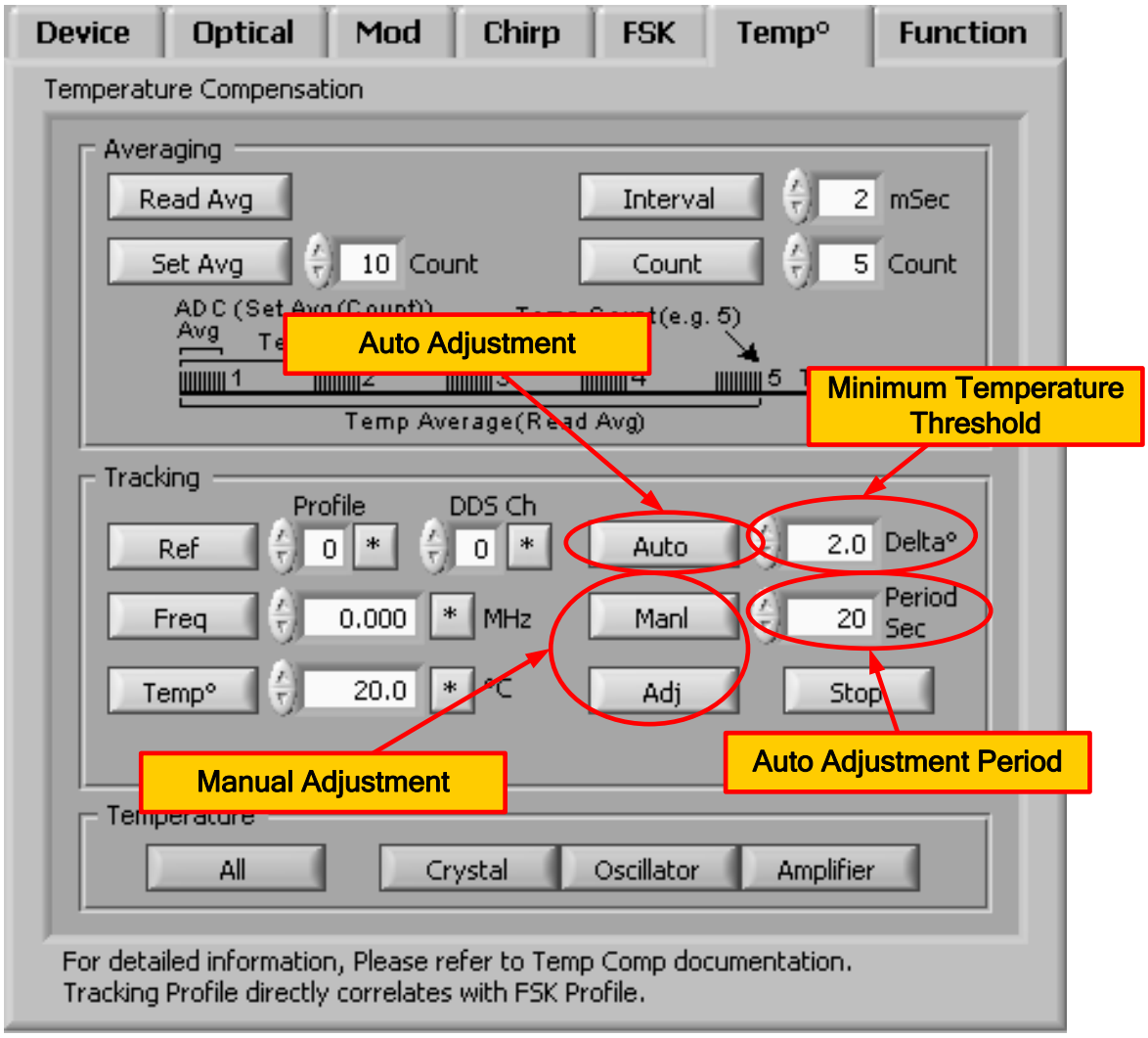


**Figure 4: Auto and Manual Frequency Adjustments**


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## 5. Using the Peak Light Intensity to determine a Reference Frequency

To use the "Peak Light Intensity" algorithms of the *AOTF Controller* to determine a Reference Frequency for Temperature Compensation by following the procedure outlined below.

The Peak Light Intensity algorithms require a Light Intensity meter connected to the Light Intensity sensor input of the *AOTF Controller*. Configure the host environment as shown in *Figure 5*:

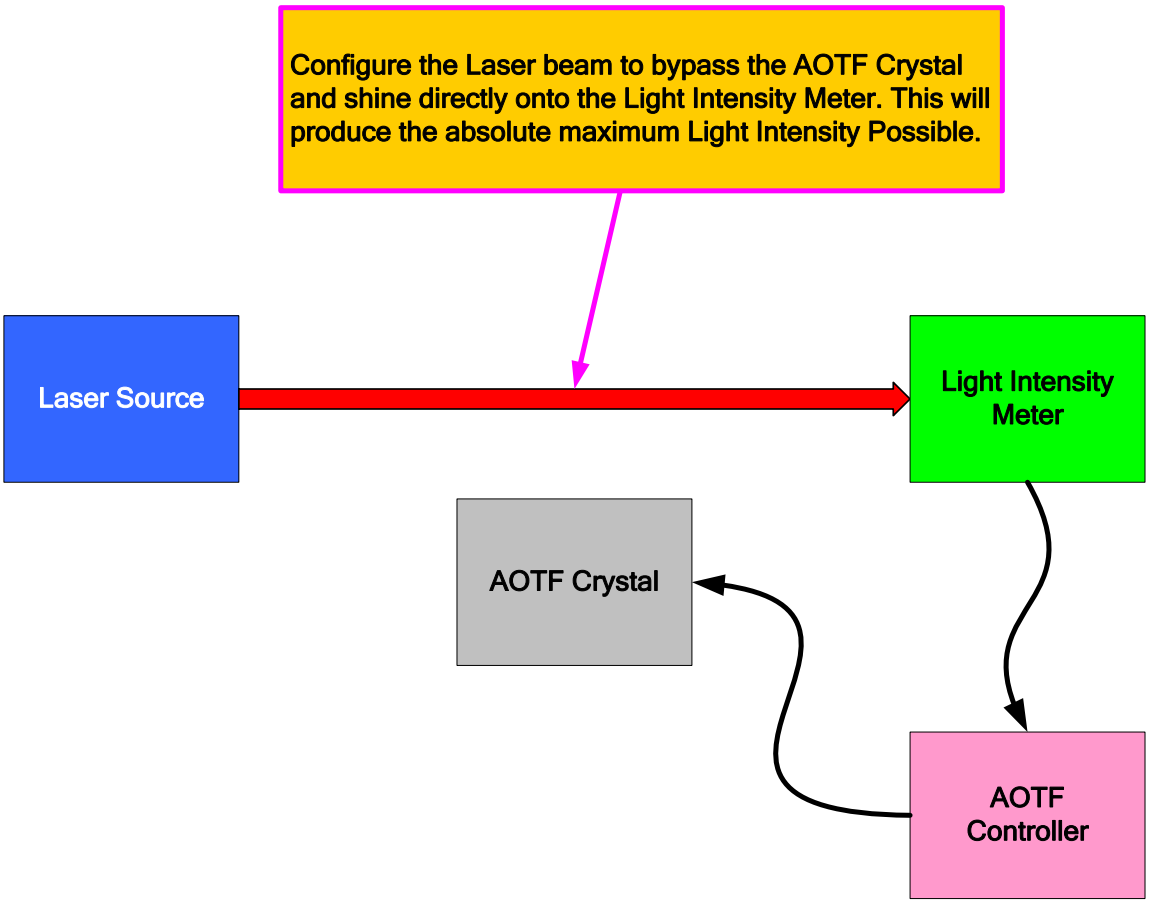


**Figure 5: Peak Light Intensity Calibration**

This phase of the Peak Light Intensity calibration should be performed with the modulation amplitude configured for maximum intensity. The modulation amplitude can be either Analog Modulation or Digital Modulation, depending on the configuration of the *AOTF Controller*. NOTE: It's possible to overdrive the AOTF Crystal, and the final phase of the Peak Light Intensity calibration will attempt to compensate for the overdrive. For now adjust the modulation for maximum intensity.

This configuration will allow the *AOTF Controller's* sensor input to be calibrated for the correct amount of gain to produce the optimum range for the sensor input. With the host environment correctly configured, issue this command:

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```
Adc Peak 2
```

The "`Adc Peak`" command will adjust the gain of sensor input 2, which is the Light Intensity sensor input, for a full scale reading. This will make the full range of the ADC available for the next phase of the Peak Light Intensity algorithm.

Alternatively, the AODS Controller application can accomplish the same command as shown in *Figure 6*:

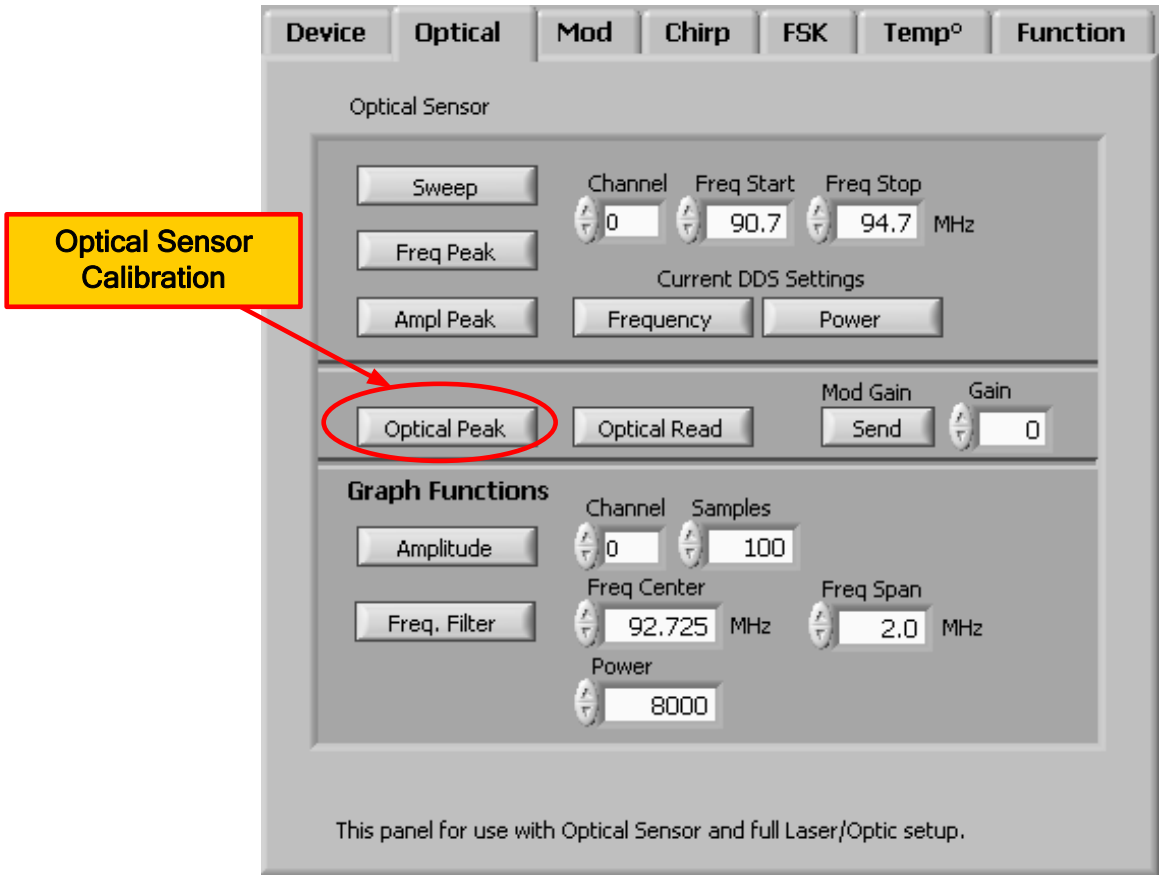


**Figure 6: ADC Optical Sensor Calibration**


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Reconfigure the host environment as shown in *Figure 7*:

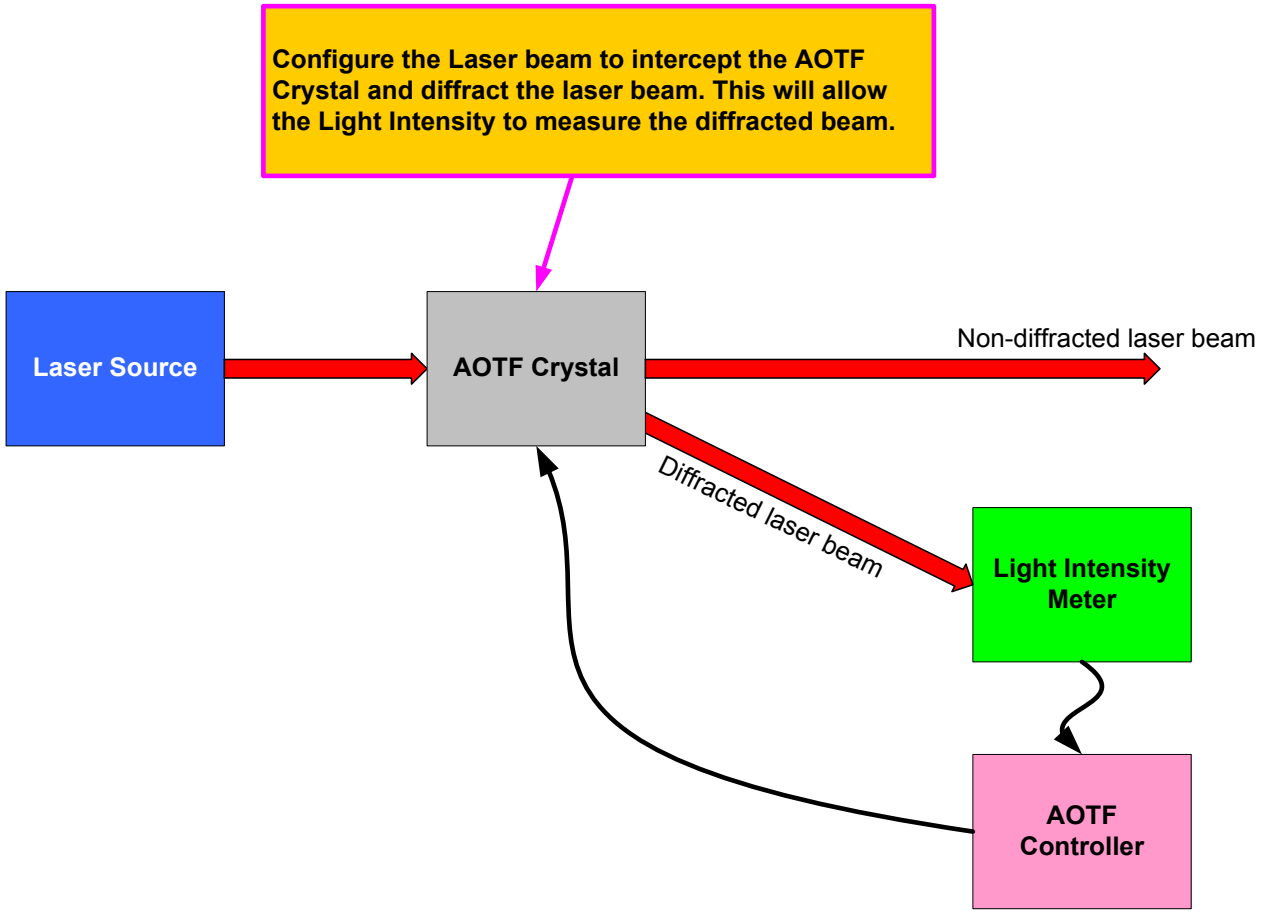


**Figure 7: Peak Light Intensity**

With the host environment configured like *Figure 7* issue this command:

```
Dds Peak 0 50 150
```

This will use channel 0 of the *AOTF Controller* to sweep through the RF spectrum from 50MHz to 150MHz and search for the Peak Light Intensity of the diffracted beam. When the algorithm completes the frequency of channel 0 will be positioned on the frequency that provided the Peak Light Intensity.

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Alternatively, the AODS Controller application can accomplish the same command as shown in *Figure 6*:

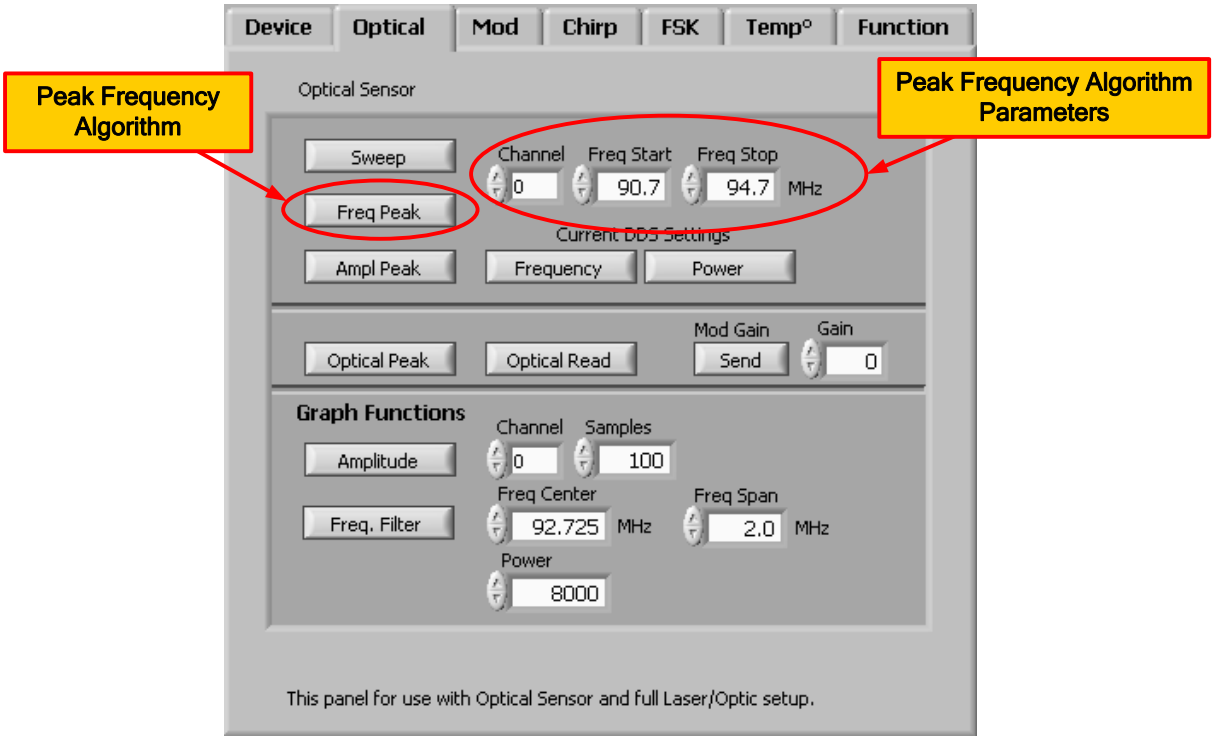


**Figure 8: Peak Frequency Algorithm**

For Frequency Tracking adjustments both a reference frequency and the temperature of the Crystal are required to create the ( $f_0$ , $t_0$ ) reference point. The above procedure has located $f_0$ ; to locate $t_0$ issue this command:

```
Temperature Read Crystal
```

The temperature read is $t_0$ , the temperature of the AOTF Crystal at the time that the Peak Light Intensity is measured.


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Alternatively, the AODS Controller application can accomplish the same command as shown in *Figure 9*:

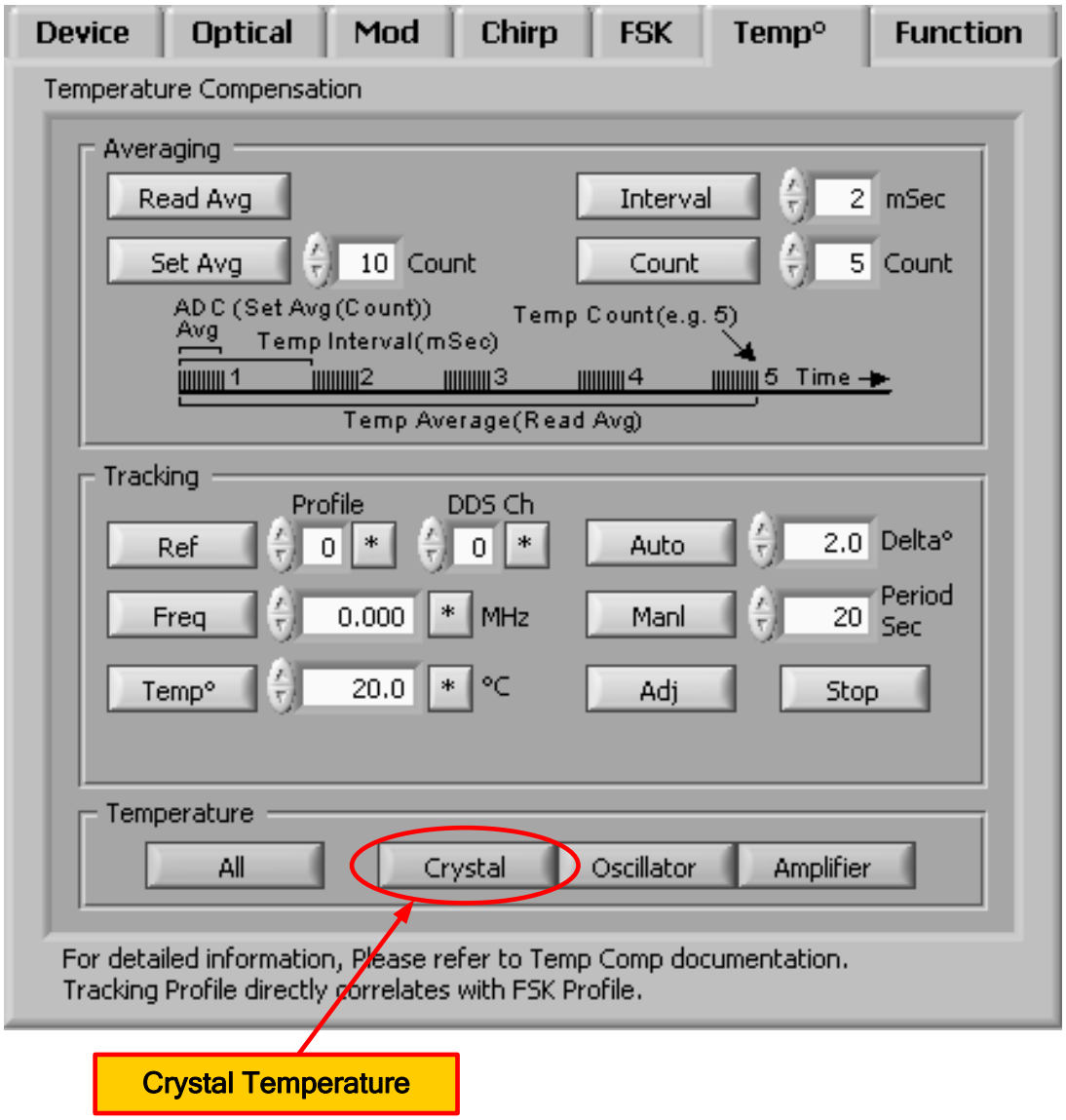


**Figure 9: Crystal Temperature**

Now that the Peak Frequency has been determined, the optimum modulation can be configured. It's possible to overdrive the AOTF Crystal, which results in less diffracted light as the modulation voltage increases beyond the optimum. There are two ways to optimize the modulation voltage:

- **Adjust the Modulation Voltage**
  This is accomplished by having the host environment reduce the modulation voltage to 0 and then slowly raising the modulation voltage to maximum while tracking the Peak Light Intensity on the light intensity meter. This calibration step requires that the host perform the modulation voltage adjustments while using the *AOTF Controller's* "`Adc Read`" command to track the


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light intensity meter sensor input and record the modulation voltage setting that results in the maximum light intensity. This is the preferred technique because it preserves the maximum range for the SIN wave generator, and allows the DDS chip to produce the best possible SIN wave with the most number of points along the SIN wave curve.

- **Adjust the Amplitude Scale Factor**
  The Amplitude Scale Factor (ASF) of the DDS chip can be adjusted to reduce the amplitude output, and thereby reducing the RF power output from the DDS chip. The ASF can be adjusted manually with the "`dds amplitude`" command. Alternatively the "`dds amppeak`" command can perform an automatic adjustment of the ASF to optimize the Peak Light Intensity. The "`dds amppeak`" command increments the ASF from 0 to the maximum and observes the light intensity sensor input. When the command completes the ASF will be set to the value that produced the maximum light intensity.

It's important that this procedure be performed in a relatively stable temperature environment.

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