Precision Flash Lamp Current Measurement –Thermal Sensitivity and Analytic Compensation Techniques

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Abstract:

For multiple-beam direct-drive laser fusion to occur it is essential that each laser beam hits the target with the same force. To help achieve this, the pump power provided to the flash lamps within the laser amplifiers is precisely monitored using a waveform digitizer module (WDM) designed at the University of Rochester's Laboratory for Laser Energetics (LLE). Temperature changes within the WDM induce errors. In order to measure and reduce these errors a test stand has been constructed to accurately and automatically measure the effects of temperature on the digitizer. The test results provide a basis for the development of an analytic temperature compensation code for the WDM's onboard FPGA (Field Programmable Gate Array), which is expected to greatly improve the accuracy of pump power readings at varying temperatures.

Background:

All electronic devices have a certain degree of sensitivity to temperature changes, referred to as their temperature coefficient. All precise electronic measurement devices require some level of compensation for this. This applies to the precise measurement of the current provided to the flash lamps in the laser amplifiers in the Omega EP laser system (see figure 1). It is essential that each amplifier receive the same amount of pump energy so that it produces a consistent output. Without precise control of the output from each amplifier, some of the laser beams may be more powerful than others.

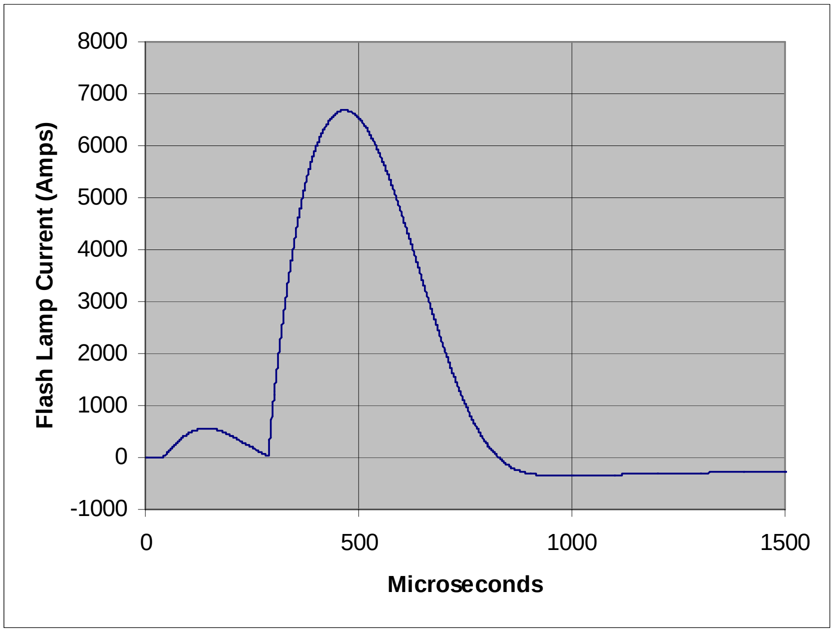

Figure 1:
A typical measurement illustrating the current waveform provided to the flash lamps.

The waveform digitizer module, or WDM (see figure 2), is the device that measures the current waveform provided by the power conditioning units (PCU's) to the flash lamps. This device comprises seventeen, fourteen-bit analog-to-digital converters which are controlled by a field-programmable gate array (FPGA). These analog-to-digital converters measure the voltage collected by current sense transformers on the flash lamp power cables in order to determine the current being supplied. The FPGA processes and records the data being collected to the memory. This data is then collected by a single board computer for later analysis. The WDM was designed to contribute no more than a 1% error in the flash lamp waveform current measurement.

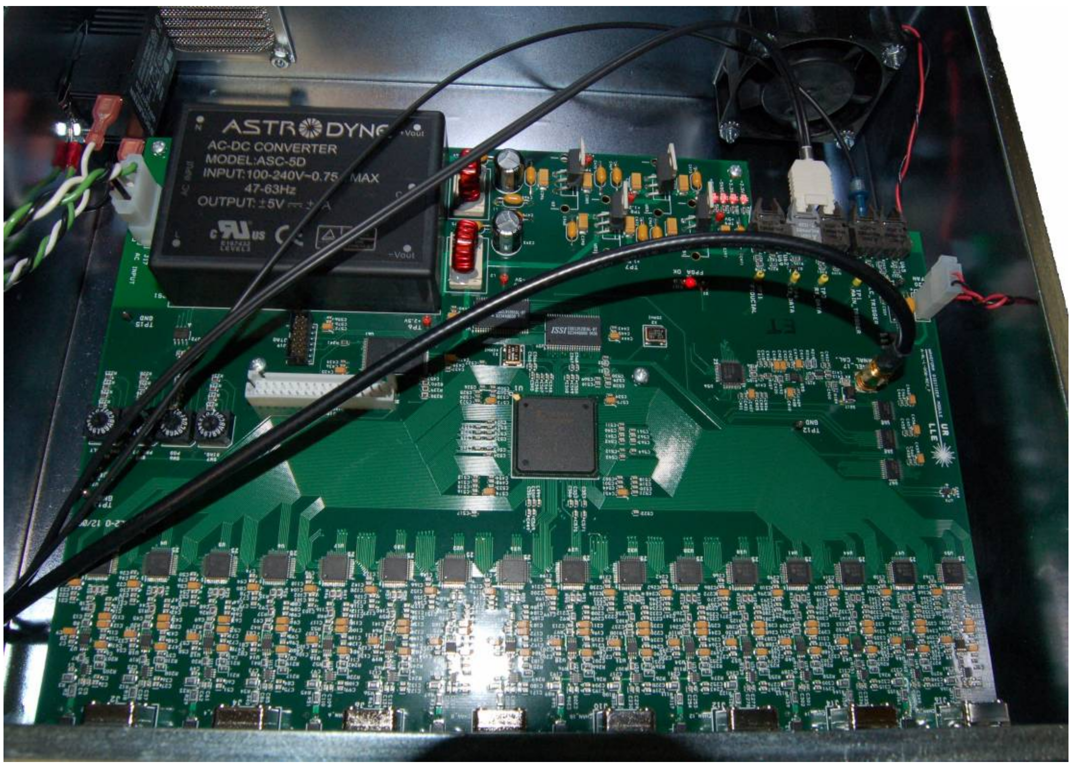

Figure 2:
The waveform digitizer module (WDM) is used to digitize and store measurements of the current provided to the laser amplifiers from the power conditioning units.

Procedure

In order to characterize and compensate the WDM for temperature changes, a test stand is needed. To develop a test stand a few major components are required: a way to regulate temperature, a test waveform, and a way of analyzing the result. In order to efficiently characterize the WDM the process also has to be automated since a large number of boards need to be tested.

The centerpiece of the test stand is a PC104 single board computer, of the same type that controls the WDMs installed in the laser system. This computer runs custom code, written in C as part of this research project, which controls the entire test without user intervention. To regulate the ambient temperature the WDM under test is placed in an environmental chamber and connected to an amplified arbitrary waveform generator output which simulates the PCU signals. The PC104 computer sets the environmental chamber to the desired temperature through an RS-232 (serial) connection. After the WDM has had time to reach thermal equilibrium, data is automatically collected from both a control WDM at room temperature and the WDM in the chamber. The arbitrary waveform generator is then turned off and the process is repeated at another temperature. The software also takes into account a correction factor to correct for environmental chamber errors. This factor was calculated early in the test stand development using a LabView program and sensors similar to those used on the WDM which were mounted throughout the chamber. In order to accurately find the effect that temperature has on the WDM it is tested at a wide range of temperatures, from about 10°C to about 70°C. It takes approximately 24 hours to test a single WDM throughout the full range of temperatures. In order to maximize the amount of thermal characterization data being collected the test waveform is a collection of sine waves with varying frequencies and amplitudes which emulate most of the possible input signals a WDM could be expected to measure.

To help troubleshoot any problems that might occur, the test stand has some built-in debugging features. While running, the PC104 computer acquires a screenshot of an oscilloscope connected to the test stand. The oscilloscope triggers off the same trigger controlling the WDMs and test waveform generator and provides an image of both the trigger and the test waveform at each side of the test waveform amplifier. While the program is running it also displays some diagnostic information on the display of the PC104 such as the current, temperature and data storage file being written.

The WDM produces a spreadsheet containing the waveform being digitized on a sixteen-bit scale. The large number of sample points makes any sort of non-graphical analysis tedious. As a result, as much analysis as possible has been automated. A C parsing program has been written to reduce the data by extracting the amplitudes of each waveform and calculating the deviation from the control data. To calculate the effect temperature has on the WDM's DC offset (measurement with no signal), a script was written for the UNIX utility GAWK.

Results:

While additional WDM's need to be tested, there are some encouraging early results shown in figure 3. In terms of both DC offset and gain, the WDM's error seems to change linearly. On average, the DC offset changes by 1.35 amps per degree Celsius.

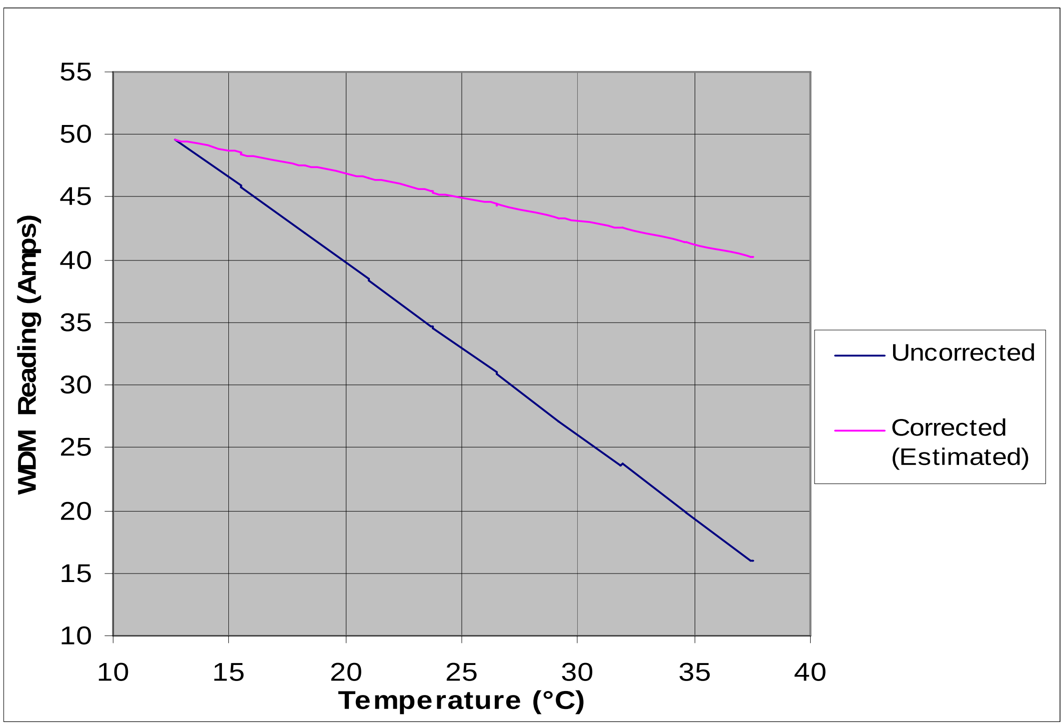

Figure 3:
This graph shows the WDM's DC offset at different temperatures. The pink line shows the WDM corrected with an average correction factor. The average correction factor is not perfect due to variations between boards.

Similarly, the signal sensitivity of the WDM when it is driven with sine waves (based on peak amplitude), is a linear result, with a slope of about -1.5 amps per degree Celsius (see figure 4).

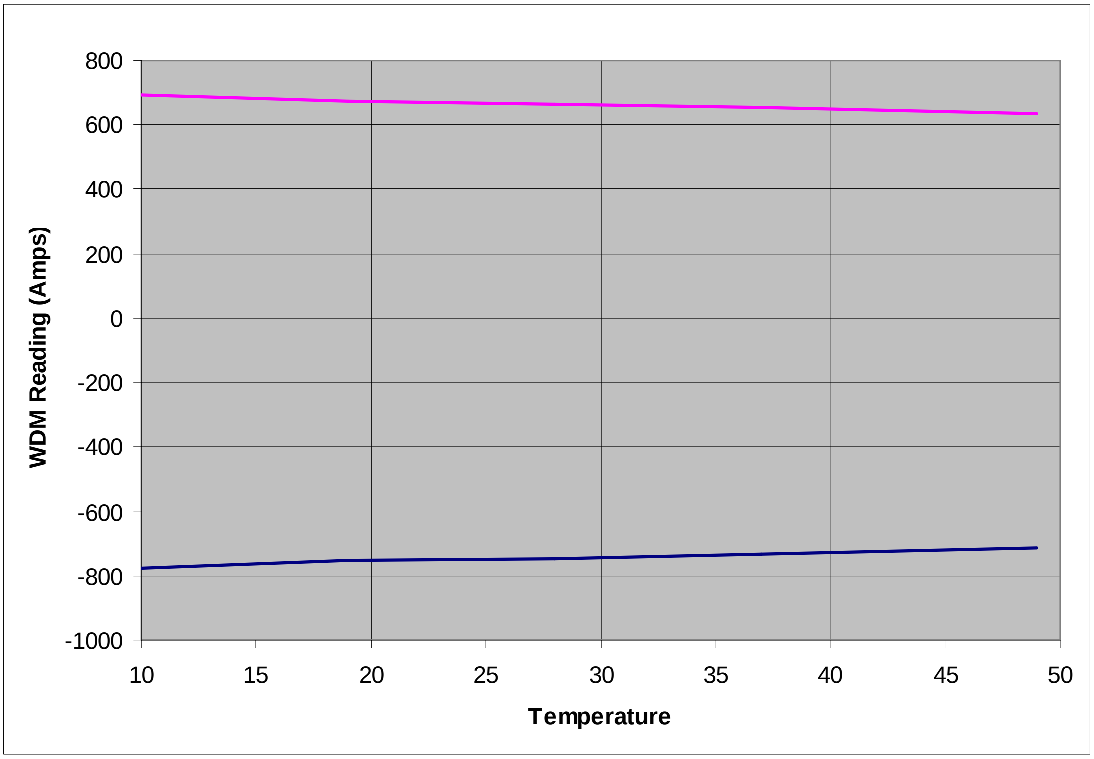

Figure 4:
This graph shows the amplitude measurement deviation of the test WDM from a room temperature WDM at both positive and negative peaks. The large deviation is caused by differences in calibration between the two devices. The slope of the lines is all that is of concern.

Compensation:

Since the temperature-induced error experienced by the WDM is linear with temperature, it is easy to correct for. To correct for DC offset drift, a code module has been written for the WDM's onboard FPGA. The algorithm is simply to add to the current reading the product of a calibration coefficient and the difference between the actual and calibration temperatures. Because an FPGA is used instead of a microcontroller this compensation can be performed in real time, needing to be computed only once per laser shot. The code to implement this compensation routine was written in the high level description language VHDL.

An algorithm and code for correction of gain changes versus temperature that affect the precise measurement of time varying waveforms by the WDM has not yet been written. This should be straightforward resulting from the linear nature of this thermal effect on the WDM. This will likely be a C program run by the PC104 PCU control computer to post-process the data coming from the WDM.

The WDM assemblies tested as part of this project seem to behave similarly with respect to thermal dependence. However the number of boards sampled is small, making it difficult to know whether a single compensation constant can be used or whether it will be necessary to test and compensate each board individually. If it turns out that each board must be compensated individually, it is possible to compute a correction factor for each board and store it in the PCU control PC104 computer's storage for correction during post-processing after laser shots.

Discussion:

Prior to the start of this project, the effect that temperature would have on the WDM was uncharacterized. The WDM is required to have no more than 1% error, making its thermal characterization of great importance. While the temperature in the capacitor bays, where the WDMs are located, rarely changes more than a few degrees, the WDMs can not be calibrated in place. The room where they are calibrated may be at a different temperature. Thus characterization and compensation of the WDM thermal effects is required. Thermal effect correction also has the potential to reduce the thermal stabilization time required for the WDMs to be within specification. Even though the error caused by temperature turned out to be only a fraction of a percent as determined in this project, it combines with other factors increasing the total error. As a result, it is important that the WDMs be characterized and compensated for any temperature effects that may occur.

Conclusion:

The waveform digitizer, or WDM, is a highly precise current measurement device. It is absolutely necessary that the flash lamp current measured by the WDM is accurate in order to achieve uniform laser energy and pressure on the target. One factor contributing to errors in the WDM measurements is the effect of temperature. In this project it was determined that the DC offset linearly drifts with temperature by as much as 1.3 amps per degree Celsius in addition to the 1.5 amps per degree Celsius of drift measured on a time varying waveform. As a result, it is important to take temperature effects into account, either as data is being collected or in post processing. A compensation routine was successfully written to correct DC offset drift in collected data within the WDM FPGA.