

APPLICATION NOTE

MEASURE PULSE-TO-PULSE ENERGY UP TO 130 kHz WITH THE MACH 5 kHz ENERGY METER



It wasn't long ago that you had no choice but to grab a Thermal Power Meter, fast photodiode, a set of ND filters, a fast Digital Scope and Data Acquisition software to be able to try to measure the pulse energy performance of your 100 kHz laser in real time. And you had to have considerable expertise and time to make this work repeatedly, and you still didn't get accurate pulse to pulse energy.

Stop! You don't have to do this anymore. We've just completed our development work on the world's first 130 kHz Energy Meter, the [Mach 5](#). This is today's way, and the most accurate way of measuring the real time performance of your pulsed DPSS or Fiber Laser.

Mach 5 started with a challenge from several of our customers who were using pulsed DPSS lasers at 30 and 50 kHz and didn't have a good way of measuring pulse energy in real time, other than the method described above. Many of the applications for these lasers required accurate delivery of pulse-to-pulse energy and a need to know that every pulse was above a process energy threshold and that none were missing.

So we got to work on this challenge. It all started with the task of designing and verifying performance of a family of fast pyroelectric probes. They had to be sensitive enough to measure from 10 nJ, fast enough to measure at greater than 100 kHz, and accurate to a few percent over a wide range of average powers and wavelengths. We accomplished this by designing three fast probes, one featuring a silicon PIN photodiode, one a InGaAs photodiode and the other a Pyroelectric detector. Each was mated to a small integrating sphere, with flat spectral reflectance which helped keep the sensors small, enhanced the spatial uniformity and offered some attenuation to avoid saturation and/or damage due to high peak power levels. Our pyroelectric probes include a miniature thermistor mounted inside to monitor the sensor temperature as it changes with average power. This allows Mach 5 to thermally compensate the sensor response. You've got to have it!

Next, we had to develop fast digital electronics that could capture every pulse at 100 kHz, digitize and process them for accurate peak, baseline, period and temperature measurement. The new instrument had to be able to store a bunch of data in real time, about 4 million data points in 40 seconds. Then it had to be able to download this data to a PC in a hurry to make room for the next set, so a full speed 2.0 USB was required. Our Mach 5 just plain fly's (no pun intended)! Before we start to describe the particular attributes of one detector versus the other, it makes sense to spend a little time giving some general technical information about what each is and how they work.

And finally, we wanted the Mach 5 to be simple to operate but have plenty of powerful laser diagnostic capabilities and features. We chose to write our Applications Software in the almost universal laboratory language, National Instrument's LabView. Our software is standalone (you don't need to own LabView) and includes a set of very useful drivers for those who want to integrate Mach 5 into their existing test set ups.

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Now let's get into the meat of the story; how you can use [Mach 5](#) to measure and analyze your high repetition rate pulsed laser. Here's a partial list of things you can do with Mach 5:

- Accurately measure every pulse at greater than 100,000 Hz
- Capture and store up to 4 million plus pulses, 40 seconds of data at 100 kHz
- Measure pulse energy, frequency, and jitter
- Measure the number and timing of missing pulses, or pulses below an energy threshold that you set
- Display your energy data in a strip chart, histogram or statistics window
- Log test data to a file for analysis later
- Use the FFT (fast fourier transform) feature to look for periodic phenomena you'd otherwise not see
- Set up an automated "Life Test" for your laser, just push start and walk away
- Calibrate the M5 probe against your in house standard Thermal Power Meter in a couple of simple steps (User Probe Cal)

Let's look at a few examples of how we were able to use the Mach 5 system to analyze the performance of our pulsed 10 nsec, 100 kHz, Nd:YLF laser.

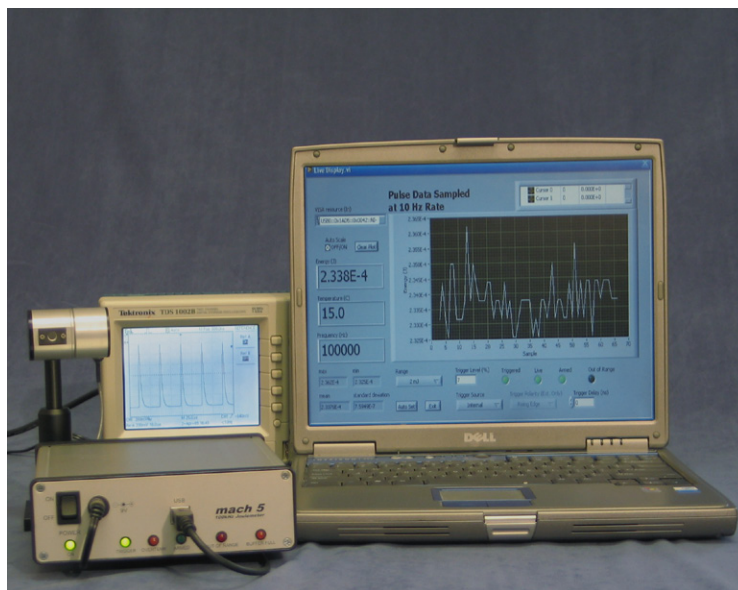
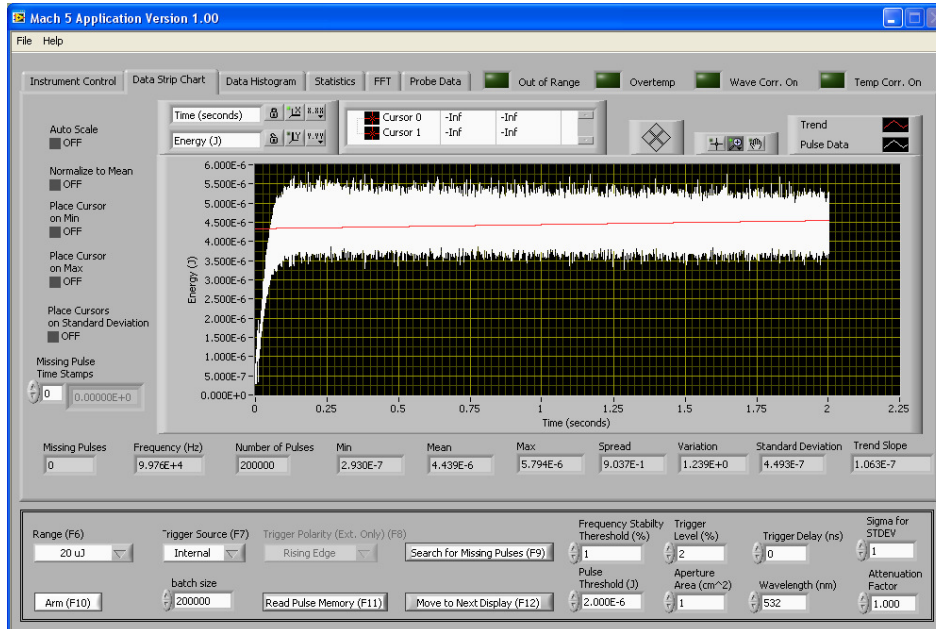


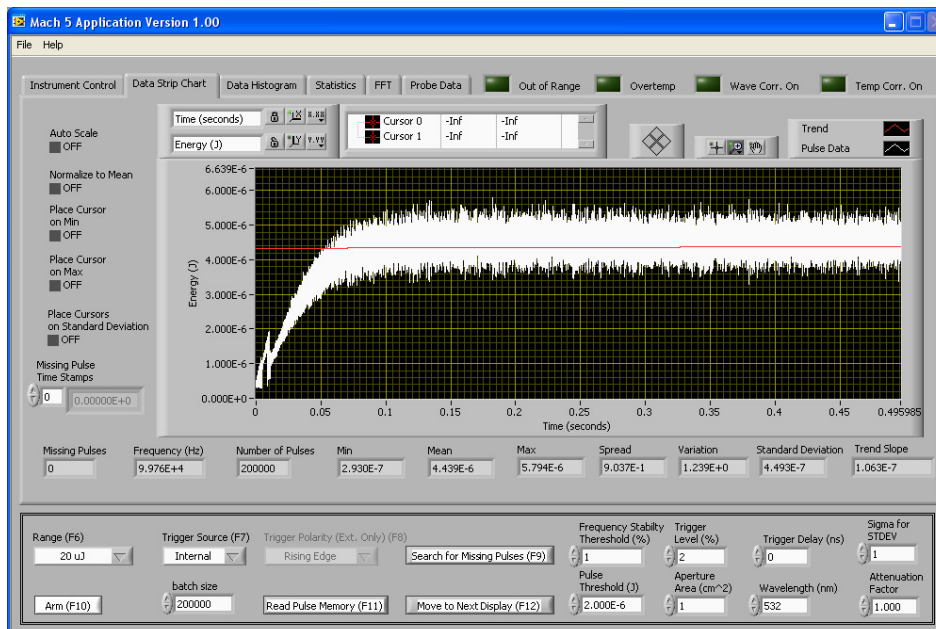
Figure 1: Mach 5, M5-6-Si shown live with analog output to a Digital Oscilloscope and USB output to Laptop PC with Mach 5 Applications Software running.

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Example 1. Lets measure pulse energy as our laser comes out of the standby mode.



We set the instrument up for a data set of 200,000 pulses and set the laser to run at 100 kHz. We ARM the instrument and push the “standby” button on the laser. Bingo, within seconds, we have captured and now are displaying the 200,000 pulse energy set on the Data Strip Chart. And look, we can see the pulse energy ramp over the first 100 msec. Now let’s use the zoom feature in LabView to look closer at the leading edge.

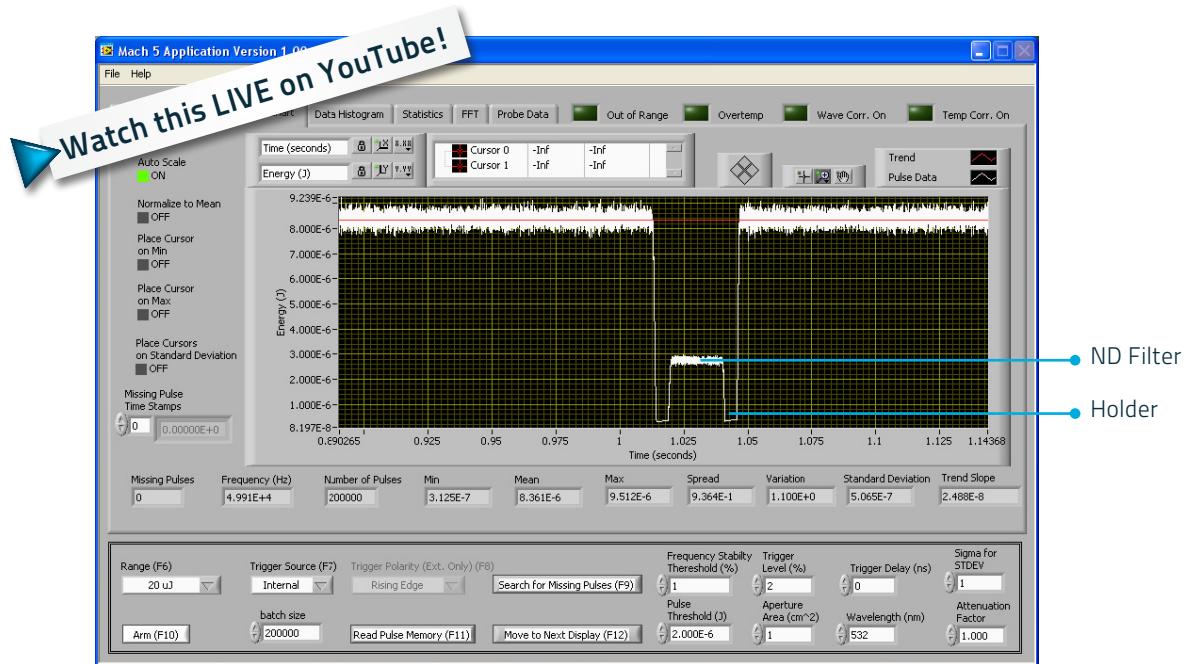


It is not a smooth ramp. There is some funny time-based oscillation at the beginning of the ramp. You wouldn’t have seen this using a Thermal Power Meter or any other Energy Meter.

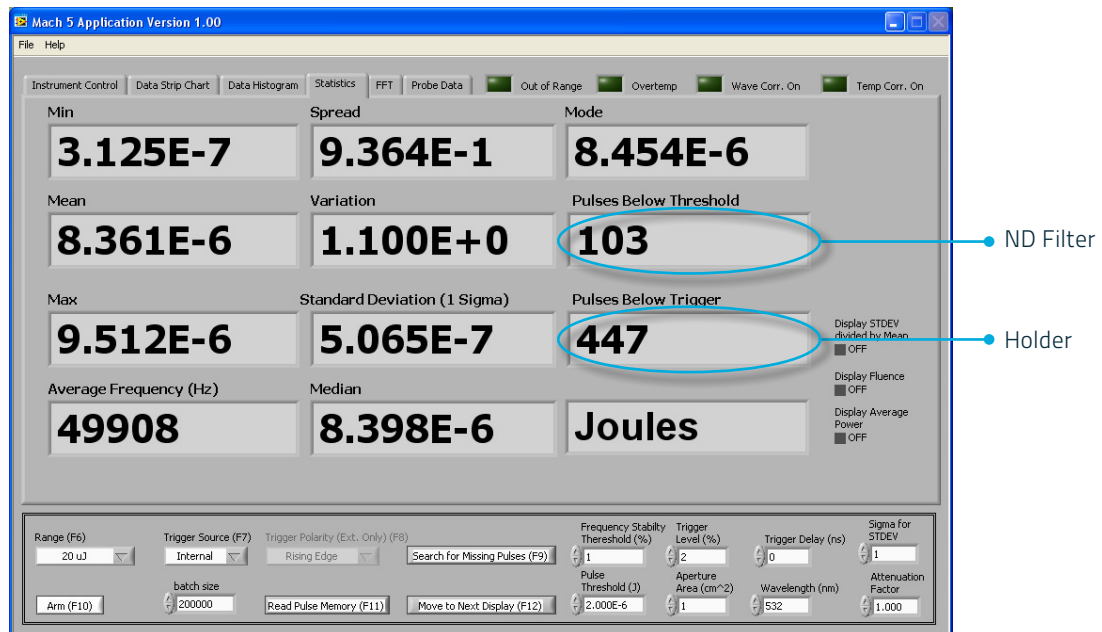
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Example 2. Missing pulses can be critical to a laser process application, the "ND Filter Test"

Let's set up the laser and introduce some missing pulses so that we can show you how Mach 5 handles this.



With the pulsed laser running at 50 kHz and the instrument set up to collect 2 seconds of data (i.e. 100,000 pulses) we dropped an ND 0.2 filter in holder through the beam. In the Data Strip Chart mode you can see where the beam was totally blocked or partially transmitted as the filter dropped through the beam. These data points are equivalent to "missing" pulses and "below threshold" pulses.

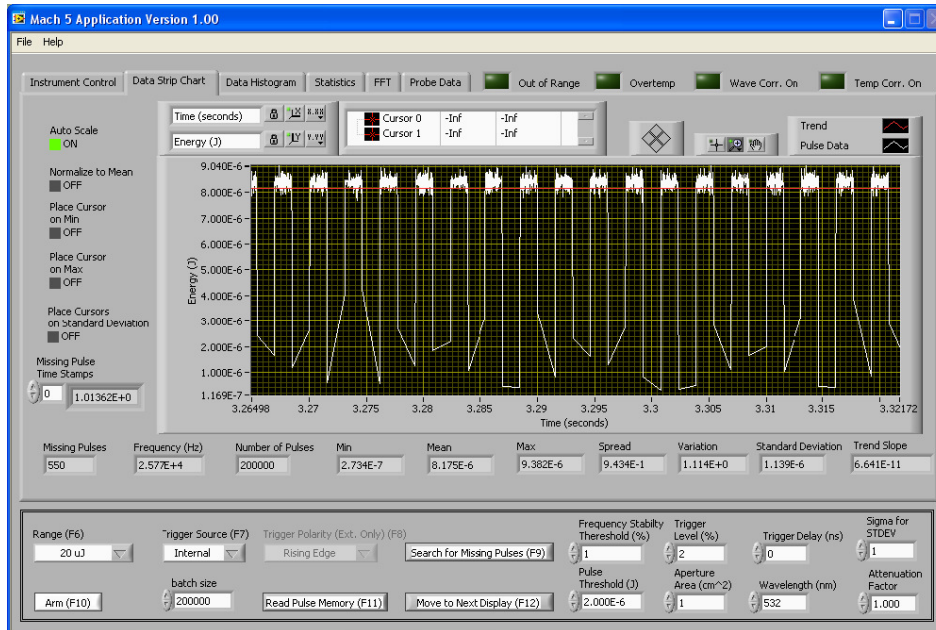


Now, we move to the Statistics screen, click on the Search for Missing Pulses button where we see that there were 447 Pulses Below Trigger and 103 Pulses Below Threshold. We had already set the pulse energy threshold to $2.0 \cdot 10^{-6}$ joules. Note the many other values present on the Statistics screen, i.e. Min, Max, Mean, Spread, and much more.

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Example 3. FFT screen reveals hidden periodic fluctuations in pulse energy.

If you were concerned about the performance of your pulsed laser over time as it relates to the power supply (i.e. 60 Hz ripple), or the Q-Switch electronics modulation, you'll be pleased to know that our Mach 5 includes an FFT (Fast Fourier Transform) mode. The laser is running at 50 kHz and we're set to take 2 seconds of pulse data. We introduced an optical chopper running at 327 Hz to give us period modified pulse energy.



In the STRIP CHART mode (zoomed) you can see the effect of the optical chopper. Pulses are blocked or passed as the blade closes and opens.

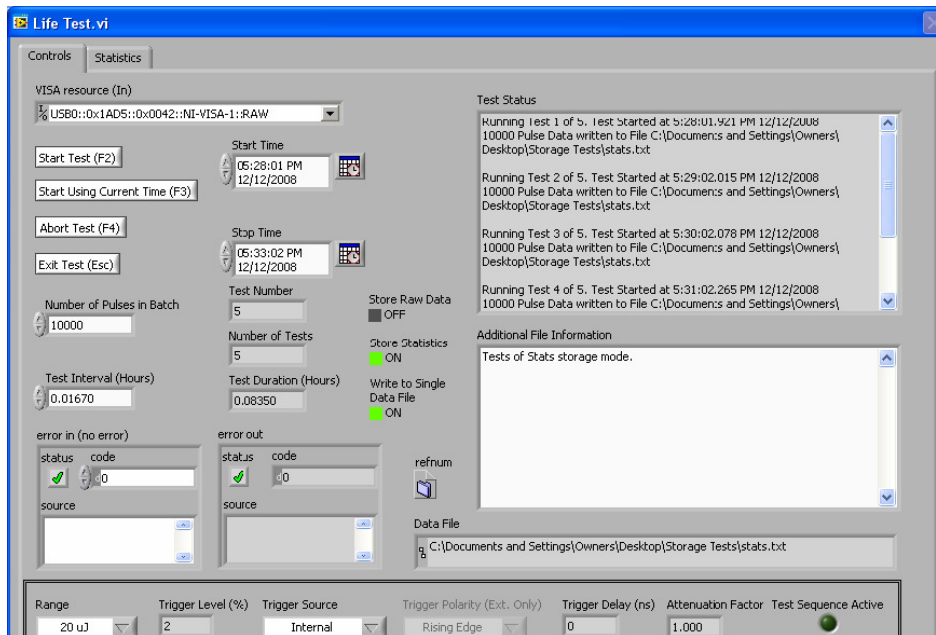


What we see in the FFT amplitude window above is the Fourier Transform of a Square Wave with a fundamental frequency of 327 Hz. This can be an incredible diagnostic tool when your laser performance isn't what's expected.

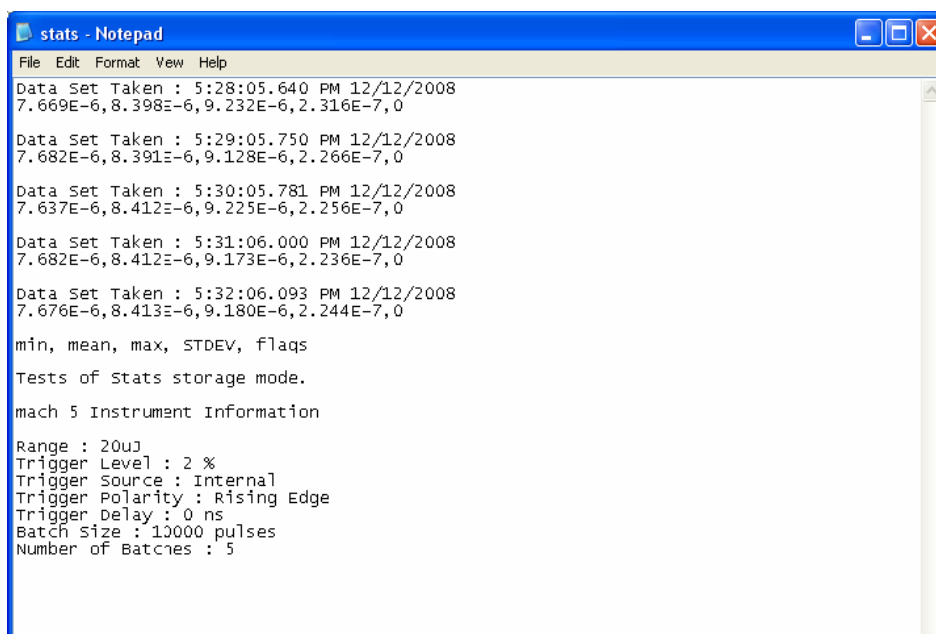
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Example 4. Life Test mode provides an incredibly useful function.

The fourth example should be of special interest to Manufacturing Test Engineers who are tasked with the responsibility of final test. You will find the Life Test mode tremendously useful and convenient. You won't need a bench full of equipment, you'll just need our Mach 5 Meter and an M5 Probe.



In the Mach 5 screen above you can see that set up of a laser life test is easy! Enter the Number of pulses in Batch (i.e. 10,000 pulses), pick the Test Interval (i.e. 0.0167 hrs) and press Start Test (F2). Or set a Start Time and Stop Time, then walk away and come back later with the Life Test complete and the raw data or selected Statistics filed on your test PC like we've shown below.

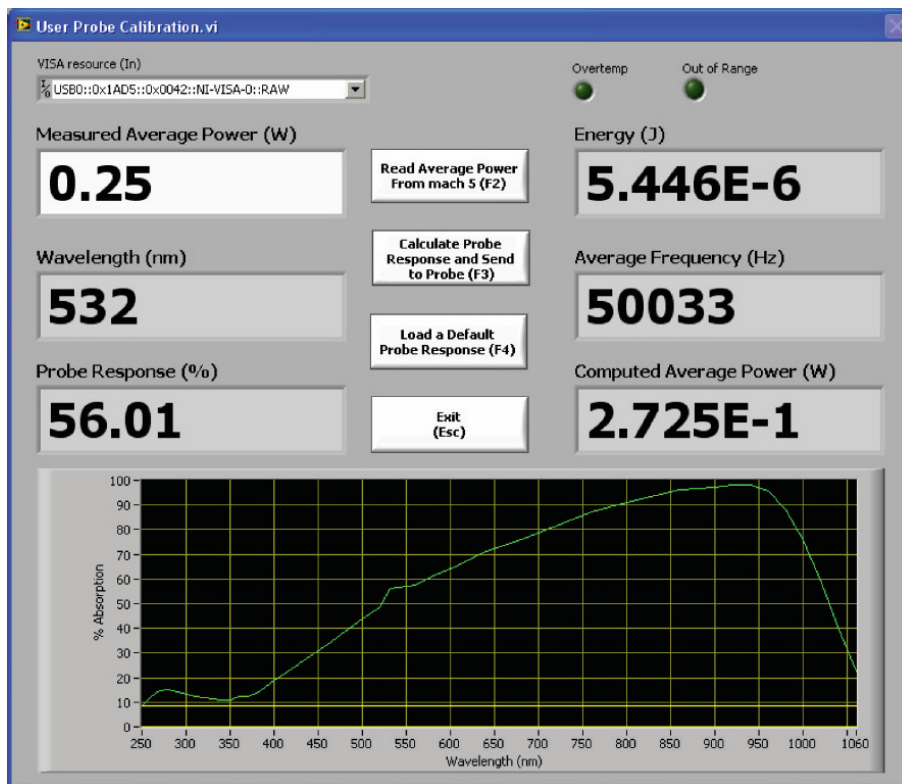


The Life Test data file shown includes user selected statistics (min, mean, max, STDEV) for each of 5 tests taken over a 4 minute period. It also lists complete Mach 5 set up conditions and any additional file description that the user has added. Whether your test lasts minutes, hours or days, you'll find Mach 5 Life Test incredibly valuable to your product development or production test efforts.

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Example 5. User Probe Calibration: a feature you'll find very handy?

The next example explains how to use our latest software feature "User Probe Calibration". This mode allows you to calibrate our Mach 5 probe at a particular wavelength against your in house standard Thermal Power Meter or Energy Meter. You can access this feature when the Mach 5 is "triggered", by selecting the "Probe Data" tab and then selecting the "User Probe Cal" button. The screen shown below will pop up.



Here's a brief explanation of how this works. Measure the average power of your laser with your power meter. Enter the measurement value in the "Measured Average Power" window (like 0.25 W), then select the "Read Average Power (F2)" button, which ARMS Mach 5 to take a power measurement (i.e. pulse energy times average frequency). Now push the "Calculate Probe Response (F3)" button and Mach 5 will calculate the new spectral response factor and then write it to the Mach 5 probe memory. Notice the "% Absorption" curve above and the small "blip" at 532 nm. This is how the new absorption and correction factor shows up. After the probe EPROM is written, the Mach 5 rearms and takes a new data set, to confirm the new correction data is read from the probe.

Should you want to abort this operation simply press "Exit". At any time in the future you can also access this screen and push the "Load a Default Probe Response (F4)" to get back to the factory settings.

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Example 6. Pulse energy, time stamp, probe temperature and error flag.

When you save a data set to a file, what is stored for every pulse is the following: pulse energy, a time stamp, probe temperature ($^{\circ}\text{C}$) and an error flag (if required). When you retrieve the test data file (when the Mach 5 software is not running) you will see it displayed as shown below, in a Windows "Notepad" format. In addition to the pulse data, you'll also see a full description of the Mach 5 set up, batch size and date and time taken.

```
1.612E-4,1.998730406E+1,15.000,0
1.611E-4,1.998732399E+1,15.000,0
1.614E-4,1.998734397E+1,15.000,0
1.613E-4,1.998736395E+1,15.000,0
pulse energy, time stamp, probe temperature, flags

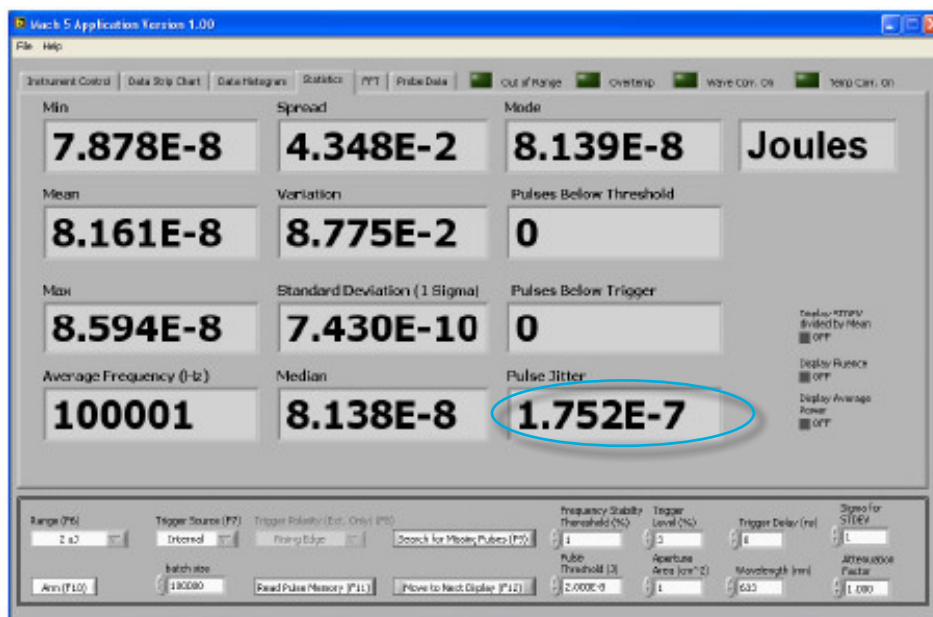
Test 1 of 1. Test Started at 10:26:33.421 AM 8/31/2009

mach 5 Instrument Information

Range : 200uJ
Trigger Level : 5 %
Trigger Source : Internal
Trigger Polarity : Rising Edge
Trigger Delay : 0 ns
Batch size : 1000000 pulses
Number of Batches : 1
```

Example 7. NEW! Measure pulse jitter with nanosecond resolution.

The Mach 5 Applications Software has been modified recently to take advantage of the high resolution (10 nsec) time stamp that is captured with every pulse. It now makes a calculation of the average Pulse Jitter for the data set you've taken and displays it on the "Statistics" screen in a "Pulse Jitter" window, seen in the example below as $1.752\text{E-}7$ seconds, or 175.2 nanoseconds.



In conclusion, the Mach 5 kHz 130 kHz Energy Meter is an indispensable pulsed laser diagnostic tool that is sure to enhance your ability to fully characterize your high repetition rate DPSS or Fiber Laser. Whether you're designing, producing, integrating or just plain testing a high repetition rate laser, you will want to have a Mach 5 system on your laser test bench.