

APPLICATION NOTE

Computer Controlled Variable Attenuator for Lasers

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Technology and Applications Center
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Computer Controlled Variable Attenuator for Lasers

This application note describes a closed loop computer controlled variable attenuator (figure 1) for the control of output power of a laser. It is based on the combination of a 1/2 wave-plate and polarizer. The algorithm used to control power operates in a closed loop with Proportional Integral Derivative (PID) feedback, compensating for slow changes in output.

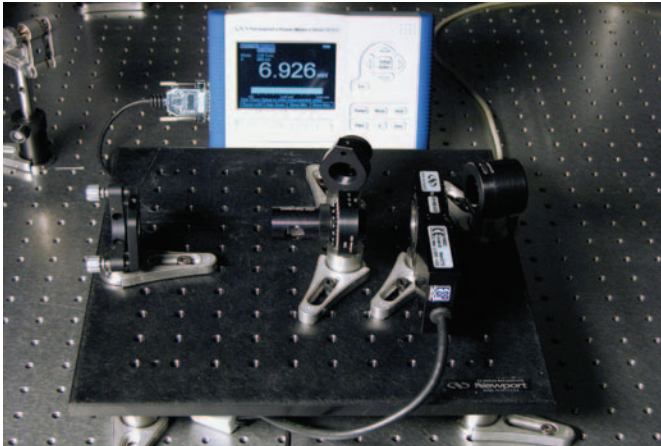


Figure 1. The computer controlled variable attenuator. The setup consists of a detector, a single-channel power meter, a Glan-laser polarizer, a 1/2 wave-plate mounted in a motorized rotation stage, a beam sampler and a PC.

Principle of Operation

The theory of operation for the computer controlled variable attenuator is identical to that presented in Application Note 26 - Variable Attenuator for Lasers (www.newport.com/AppsNote26) and Application Note 30 - Computer Controlled Variable Attenuator for Tunable Lasers (www.newport.com/AppsNote30). The principle of operation is based on Malus' law. The intensity, I , of linearly polarized light that passes through the polarizer is given by

$$I = I_0 \cos^2 \theta \quad (1)$$

where I_0 is the input intensity and θ is the angle between the beam's initial direction of polarization and the axis of the polarizer. Rotation of a 1/2 wave-plate mounted in a rotational stage allows for the continuous rotation of the polarization direction of linearly polarized light. Thus, combined with a polarizer, it provides variable attenuation according to (1). Rotation of the wave-plate by an angle of φ results in a polarization rotation by a factor of 2φ , thus the intensity at the output of the attenuator is given by,

$$I = I_0 \cos^2 2\varphi \quad (2)$$

where φ is the azimuth of the 1/2 wave-plate. The full range of attenuation is realized over 45° of rotation.

The diagram for the attenuator is illustrated in Figure 2.

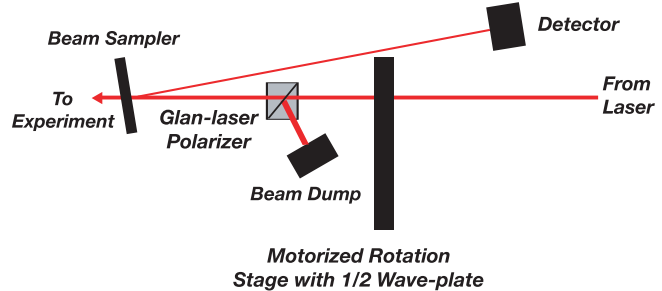


Figure 2. Diagram of the computer controlled variable attenuator.

For the manual variable attenuator, the power is measured directly at the output of the attenuator for each wavelength and set accordingly by rotating the 1/2 wave-plate. In contrast, the closed loop computer controlled attenuator sets and maintains the output power by positioning the 1/2 wave-plate based on a feedback signal from a photodetector. The photodetector can exhibit a strong dependence on wavelength. (www.newport.com/818Series) In Application Note 30 we described an attenuator that monitors the wavelength of the laser and provides the feedback signal accordingly. Here we are presenting a less expensive computer controlled attenuator without wavelength detection. It is useful for applications where the wavelength of the laser is known or can be measured by other means, and continuous wavelength tuning is not required. The value of the wavelength is an input parameter for the control software and must be entered manually.

Depending on the choice of components, the attenuator is suitable for CW or quasi CW lasers with wavelengths ranging from 400 nm to 1100 nm, and average powers from 1nW up to 20 Watts (500 Watts/cm² damage threshold). Additional filters may be required for pulsed lasers, and customers are encouraged to contact customer support to discuss the application. This device is capable of attenuating light by a factor of 1000 while still maintaining an error of less than 10%. The algorithm used to control power operates in a closed loop with PID feedback, compensating for slow changes in output power within the bandwidth of the device (> 500 ms).

The beam travels through the 1/2 wave-plate and Glan-laser polarizer providing the attenuation. The attenuated output from the polarizer passes through the beam sampler where a fraction of the beam is directed towards the detector at an angle of 10 degrees relative to the main beam. The rejected S-plane portion of the beam is directed out the side of the Glan-laser polarizer to a beam dump. The overall losses of the attenuator depend strongly on the degree of polarization as well as the polarization state. However, if the incoming beam is fairly well polarized, the overall losses are below 10%.

Figure 3 illustrates the flow of information within the computer controlled variable attenuator. The red arrows depict the route of the laser through the various optical components as described above. The CPU acts as the “brain” of the system and plays the following role:

1. Determines the angle/phase of the 1/2 wave-plate relative to the polarizer.
2. Monitors the power of the beam out of the attenuator via the power meter.
3. Determines the error between the output power and the requested power.
4. Minimizes this error using a PID algorithm, and updates the rotation stage to a new position, ϕ .

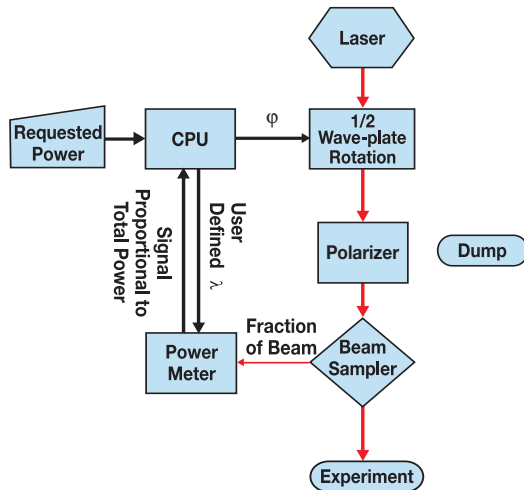


Figure 3. Block diagram describing operation of the computer controlled variable attenuator.

WARNING!! - Visible and invisible radiation emitted by laser devices can be dangerous to the eyes and appropriate precautions must be taken when lasers are in use. Only individuals who are adequately trained in proper laser use and safety procedures should operate the laser devices described herein.



The Glan-laser Polarizer used in this application has a side port where the rejected portion of the laser beam exits. As the polarizer is rotated about the primary beam axis, the exit angle of this beam will change accordingly. Always maintain proper safeguards to block this beam and prevent potential injury.

The instructions provided in this note are intended for use with the Spectra-Physics Mai Tai® laser. For use with other lasers, the height of the device needs to be adjusted to correspond to the height of the beam.

1. Assemble all optical components as shown in Appendix 1.
2. Attach the three, 2-inch pedestals as well as the SMC100CC controller to the underside of the base-plate.
3. Turn the base-plate right side up and position it underneath the beam path. Verify that the center of the beam is approximately 46 mm above the top of the base-plate.
4. Move the base-plate into the final position and secure it to the table using the clamps provided.
5. Temporarily arrange the wave-plate, polarizer, beam dump, beam sampler, and detector as shown in figure 4. Ensure that the angle formed between the primary beam path and the reflected beam path from the beam sampler to the detector is approximately 10°.
6. Secure the detector assembly to the base-plate and remove all other optics. The attenuator on the detector should be set to the On position.

7. Turn on the laser and insert beam sampler into the beam path (see figure 4). Use the tip/tilt adjustments to direct the reflection of the uncoated surface onto the center of the detector. Ensure that the second reflection from the coated surface is not incident on the active area of the detector.
8. Insert the wave-plate and polarizer assemblies into the beam path. Position beam dump to capture rejected beam.
9. Adjust the position of the wave-plate and polarizer assemblies, such that the beam passes through the center of both. Secure the wave-plate. Temporarily clamp the polarizer.
10. Rotate the polarizer in its rotary mount, such that the transmitted light is minimized. Next, loosen the clamping fork and fine tune the angle of the polarizer relative to the beam path to further minimize transmission. Secure the polarizer. Rotate the polarizer such that the tick marks lie in the horizontal plane (P-polarization relative to beam sampler).
11. Adjust beam dump if necessary and secure to base-plate.

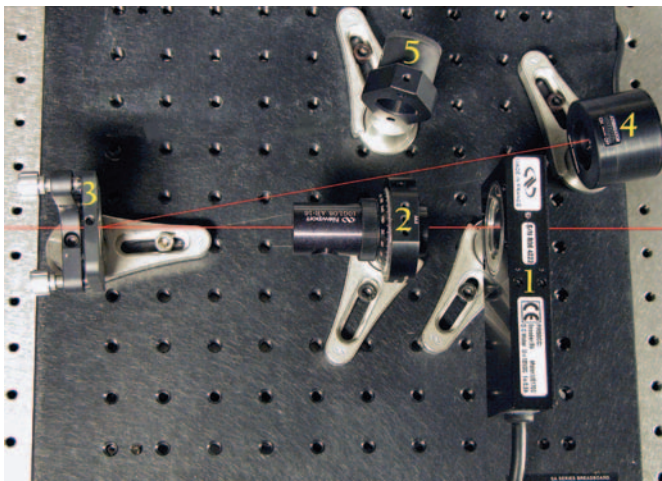


Figure 4. Computer controlled variable attenuator. The red line illustrates the beam path. (Rejected beam from Glan-laser polarizer not shown.) The numbered assemblies correspond to: 1- 1/2 wave-plate and rotation stage, 2- Glan-laser polarizer, 3- beam sampler, 4- 918D-UV-OD3 photodetector, 5- beam dump.

It should be noted that there are many possible attenuator configurations. The configuration described above was chosen because it offers several advantages:

1. The output polarization can be either S or P, depending on the orientation of the polarizer.
(Warning!! – Remember that the angle of the rejected exit beam will correspond to the plane of polarization. Laser safety measures should be taken to ensure this beam is properly blocked at all times to prevent injury.)
2. The power on target is directly sampled rather than calculated.
3. The control algorithm makes no assumptions about the relationship between the wave-plate position and the power on target.

Computer Configuration

The following requirements are necessary to operate the Newport Power Control NS software provided with the Computer Controlled Variable Attenuator Kit. The processor should be at least a Pentium 4 (or equivalent) with 512 MB of RAM. The hard drive should have at least 50 MB of storage space. Windows XP Professional Edition was the operating system tested with this device.

Once the variable attenuator is aligned, unplug any device on any of the USB ports of the computer where the Newport Power Control NS software will be installed. Install the software per the instructions provided on the Newport Power Control NS disk. Once all software and associated drivers are properly installed, you can connect the SMC100CC controller to the computer using the RS232 cable provided. Connect the USB port located on the side of the power meter to a USB port on the computer. Turn the power on for the controller and power meter.

Check the installation and communication of the peripheral devices. Run the SMC100 program from the Start Menu. Reference the SMC100CC User's Manual to walk through the configuration of the SMC100CC controller. Make sure the stage is properly configured and sent to the home position. Note the address settings in the Configuration Panel. Close the SMC100CC program. After successful completion of this step, a green LED should be illuminated on the SMC100CC controller. If it is not, the SMC100CC controller is not properly configured and the device will not function. If this is the case, consult the SMC100CC User's Manual.

In the Windows Control Panel, open up the System window. Under the Hardware tab, select the Device Manager. Under the Ports tab, determine which ports are being used by the power meter and the SMC100CC. Make note of this.

Running the Software for the First Time

Open the Newport Power Control NS software provided with the Computer Controlled Variable Attenuator kit. The Select Communications Port window is displayed (figure 5). If necessary, make adjustments to the Communications Port settings, otherwise press the Continue button and the Data window (figure 8) becomes active.

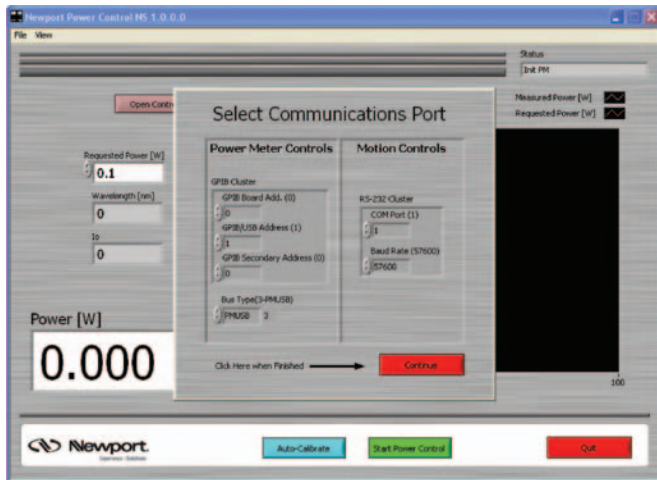


Figure 5. Select Communications Port Window displayed at startup of Newport Power Control NS software

Select the Parameters window (figure 6). The user must enter the laser wavelength (nm). PID control settings are also adjusted in this window, but initially leave them at their default values. The Re-Initialize Communications button will bring up the Select Communications Port window at any time. The communications port settings were set up during initialization and should not require adjustment. If changes are made to the supporting computer later, (e.g. additional devices added to ports), communications settings updates can be made through this screen. Define the settings to match those in the Device Manager.

Additional user-defined Parameters window features (Safety Threshold, Scaling Factor, Wavelength, and PID Cluster) are explained in later sections.

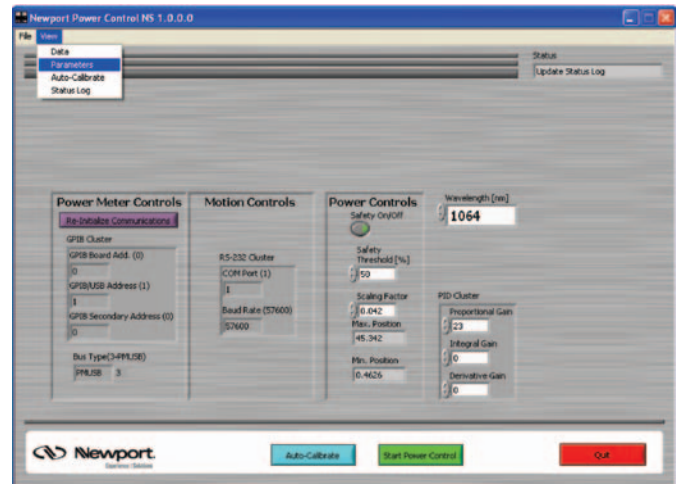


Figure 6. Newport Power Control NS Parameters window

Calibrating the Wave-plate

The heart of the variable attenuator is the 1/2 wave-plate. It is responsible for rotating the polarization of the light. It is not required that the wave-plate be mounted in the rotation stage in any specific way; instead, the program will recognize the angle/phase of the device through the auto-calibrate function. First, select the Auto-Calibrate window (figure 7). Enter the number of points to be used in the calibration. Twenty points is a good starting value; however, more points can be added depending on the required accuracy. Press the Auto-Calibrate button. The stage will rotate the 1/2 wave-plate through 90 degrees, progressively plotting power vs. rotation angle for each point.

Upon successful calibration, a solid line will be displayed on the graph derived from the best fit of the data points to equation 2. This calibration curve is used to set the high and low position limits for the rotation stage as well as determine the parameters used to calculate the intensity of the laser prior to attenuation.

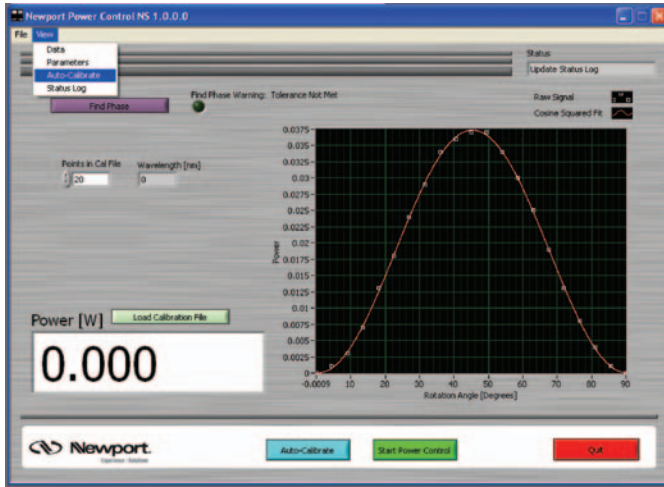


Figure 7. Newport Power Control NS Auto-Calibrate window.

Controlling the Power

After the wave-plate is calibrated, the power control is ready to run. Select the Data window (figure 8). Enter the desired power in the Requested Power control box and select the Start Power Control button. The Loop Closed indicator turns green, the Stop Power Control button is displayed, and the graph displays live updates of requested power (red) and actual power (white). After automated adjustment to the requested power, the white line typically tracks the red line within a few steps. If this is not the case or you would like to improve the transition curve, the PID controls can be adjusted in the Parameters window (figure 6). A reference for PID tuning can be found at <http://www.controleng.com/article/CA307745.html>.

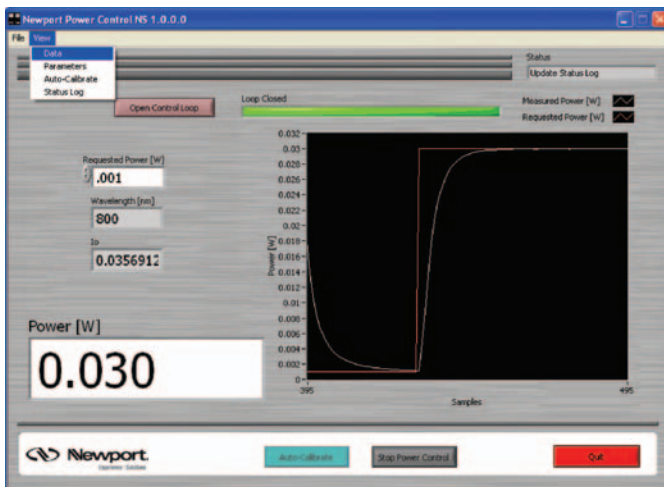


Figure 8. Newport Power Control NS Data window.

As mentioned earlier, the software runs in closed loop. This means that the 1/2 wave-plate is continuously dithering which may adversely affect some experiments. If this is the case, the user has the option to open the loop

by selecting the Open Control Loop button. When open loop is selected, all PID gains are set to zero thus disabling any wheel movement. Deselecting the Open Control Loop button returns all of the gains to their previous values.

The Newport Power Control NS software will also attempt to correct slow fluctuations in laser output. Because of this, if the laser is blocked, the 1/2 wave-plate will try to compensate by rotating to a position corresponding to maximum transmission. Unblocking the beam will then temporarily deliver full power on target until the wave-plate has time to respond, which could result in optical damage to components or a sample positioned after the attenuator. To prevent this, a safety feature is built into the PID loop. If the laser power fluctuates by more than a user specified percentage, the software automatically opens the loop. This event is sent to the Status Log (figure 10) and the user can reset the loop by deselecting the Open Control Loop button. The default Safety Threshold setting is 50%, but this value can be modified in the Parameters window (figure 6). When operating at attenuation levels higher than 100 times, care must be taken to block scattered light from the detectors. In that case it is also recommended to turn the safety feature off (figure 6).

Finally, it is possible for the user to request power values outside of the available range. If this happens, the 1/2 wave-plate will move to its maximum or minimum limit and stop. The power indicator will flash red (figure 9) and an out-of-range error will be sent to the Status Log. It is not necessary to reset this error. Simply command the attenuator back into the appropriate range through the Requested Power control box and the indicator will return to the normal color.

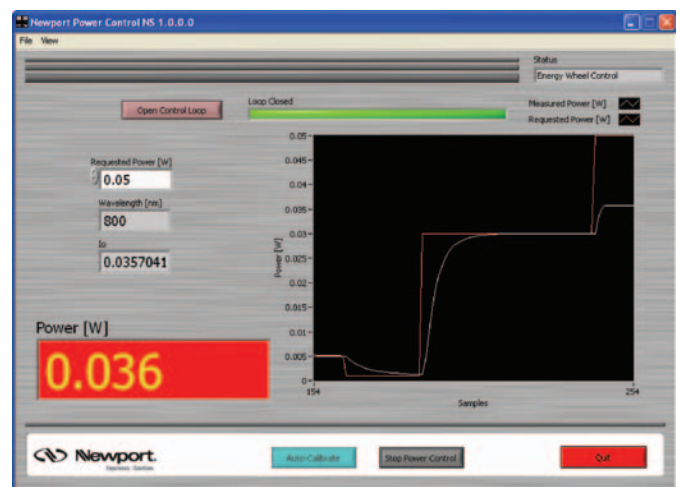


Figure 9. Power display window flashes red when Requested Power is out of range.

Polarization Control

As mentioned earlier, one of the advantages to this specific configuration of the variable attenuator is that the output polarization can be either horizontal or vertical depending on the orientation of the polarizer. Changing the polarization or the angle of the beam sampler after the polarizer will result in a slight systematic error in the output power. To compensate for this, the scaling factor in the Parameters window (figure 6) can be altered. The default setting is 0.042 corresponding to a Fresnel reflection at 10° from a BK7 substrate at 800 nm, P-polarization. At this angle, the Fresnel reflection has minimal wavelength dependence, thus allowing the source to be wavelength tunable without a significant impact to the attenuator's performance. However, if the angle or polarization state is significantly modified, the scaling factor must be altered to compensate for these modifications.

In general the output polarization can be set in any direction by setting up the azimuth of the polarizer. **(Warning!! – Maintain laser safety controls when rotating the polarizer as the rejected portion of the beam will change exit angle.)** The scaling factor should be adjusted accordingly. Table 1 lists the scaling factor as a function of wavelength and angle for both S-(top) and P-(bottom) polarization.

S/P	5°	7°	9°	11°	13°	15°
700 nm	0.044 0.043	0.045 0.043	0.045 0.042	0.046 0.042	0.047 0.041	0.048 0.040
750 nm	0.044 0.043	0.045 0.043	0.045 0.042	0.046 0.042	0.047 0.041	0.048 0.040
800 nm	0.044 0.043	0.045 0.043	0.045 0.042	0.046 0.041	0.047 0.041	0.048 0.039
850 nm	0.044 0.043	0.044 0.043	0.045 0.042	0.046 0.041	0.047 0.040	0.048 0.039
900 nm	0.044 0.043	0.044 0.042	0.045 0.042	0.046 0.041	0.047 0.040	0.048 0.039
950 nm	0.044 0.043	0.044 0.042	0.045 0.042	0.046 0.041	0.046 0.040	0.048 0.039
1000 nm	0.044 0.043	0.044 0.042	0.045 0.042	0.045 0.041	0.046 0.040	0.047 0.039

Table 1: Scaling factors at various wavelengths and angles.

Dynamic Range

The dynamic range of the attenuator can be thought of as the difference between the maximum and minimum achievable powers. The stated dynamic range is 10³; however, dynamic ranges as high as 10⁵ have been demonstrated in our Technology and Applications Center. In order to achieve a dynamic range this high, two important factors must be taken into consideration: stray light incident on the reference detector must be minimized and the incoming light must be highly polarized. If a higher dynamic range is required, it is necessary to include a second polarizer just before the attenuator. To shield the reference detector from stray light, place an iris attached to a tube directly in front of the detector.

Status Log

The Newport Power Control NS software logs all generated events and errors, time stamps them, and records them in the Status Log (figure 10). The Status Log allows the user to monitor any generated errors while the program is operating.

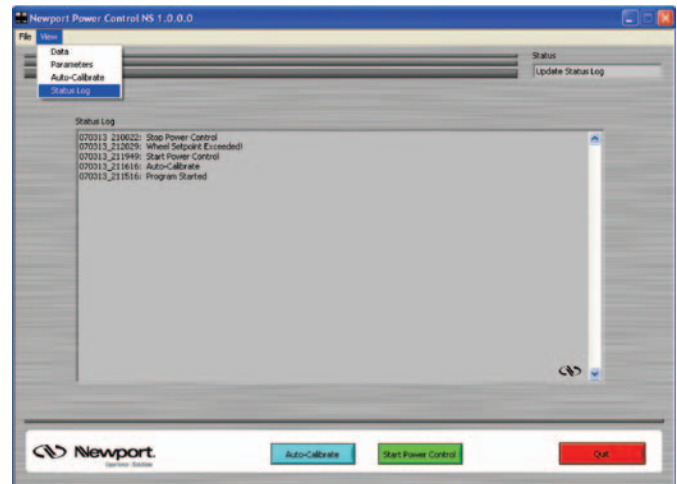
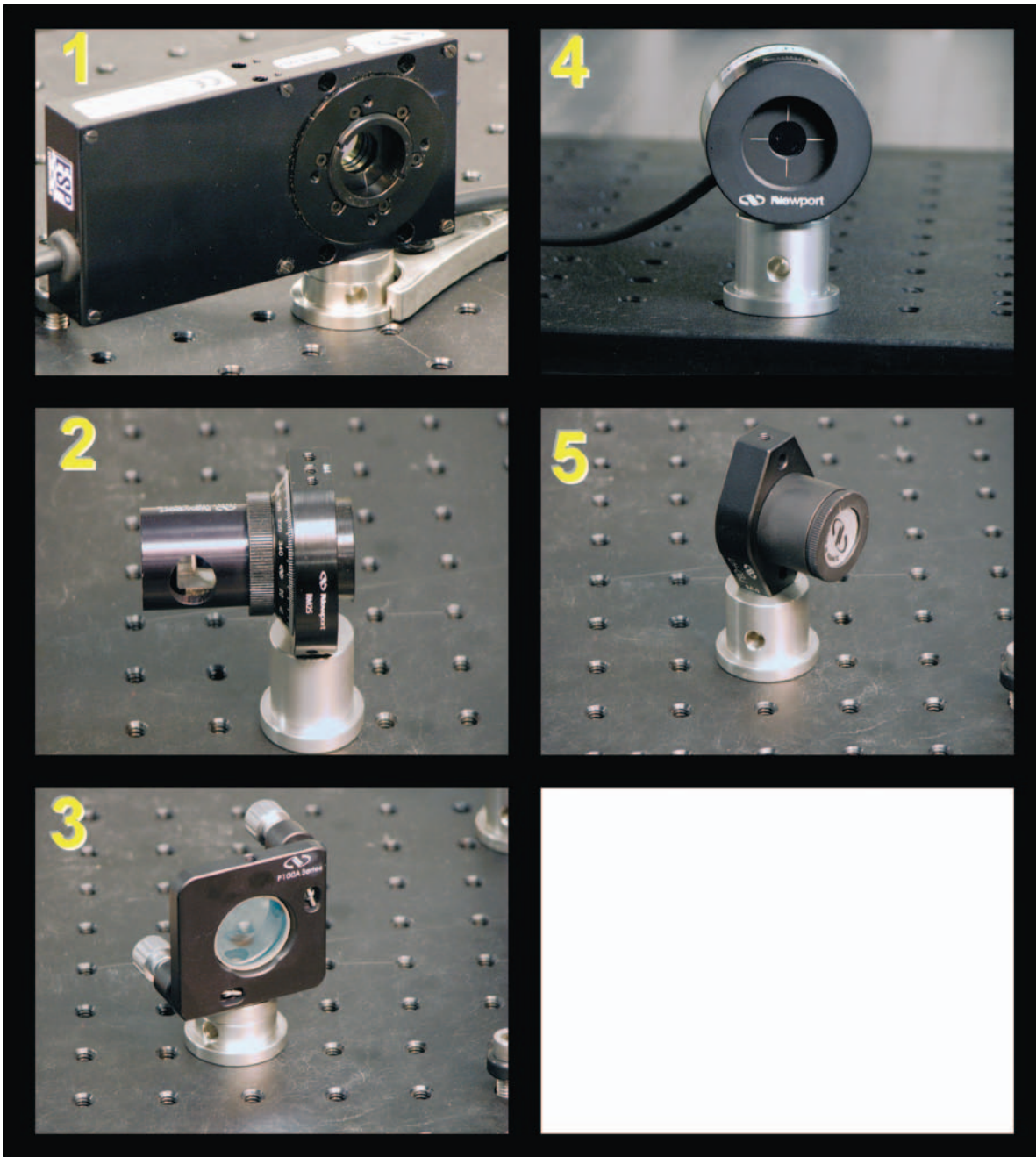


Figure 10. Newport Power Control NS Status Log window.

Exiting the Program

To exit the program, simply hold down the Quit button until the program closes. It is preferable to use the quit button since all of the devices are properly closed when exiting the program this way. Repeatedly closing the program by other means may result in computer instability.

Appendix1: Pictures of Mounted Optics



1. Rotation Stage and 1/2 Wave-plate
2. Polarizer
3. Beam Sampler
4. Photo-detector
5. Beam Dump

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MM# 90000091
DS-03075