

# APPLICATION NOTE

## Variable Attenuator for Lasers

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This application note details a simple and cost effective solution for the continuous attenuation of laser output power. The attenuator kit described is based on a half wave-plate and polarizer. It is suitable for attenuation of a linearly polarized laser beam with a wavelength in the 690 nm -1040 nm range and average power up to 100 watts (please refer to Table 1 at the end of this Application Note). The schematic of the device is shown in Fig.1.

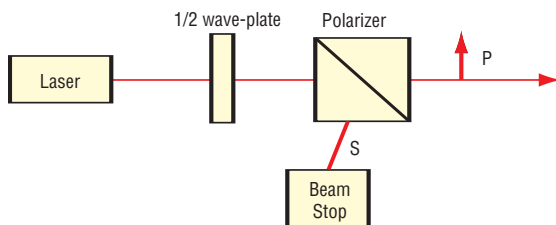


Figure 1. Schematic of variable attenuator for lasers.

## Principle of Operation

The principle of operation is based on Malus' Law. The intensity  $I$  of the polarized light that passes through the polarizer is given by

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

where  $I_o$  is the input intensity, and  $\theta$  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 to a rotational stage allows continuous rotation of the beam's polarization direction. When combined with a polarizer, it provides variable attenuation according to (1).

Wave-plates are usually made of birefringent crystal cut parallel to the optical axis. The electric field  $\vec{E}$  of a linearly polarized light impinging on a wave-plate can be decomposed into two components parallel and perpendicular to the optical axis (Fig. 2). The component that is parallel to the optical axis is called an extraordinary beam, and the component perpendicular to the optical axis is called an ordinary beam. If the index of refraction of the ordinary beam is higher than it is for the extraordinary beam, then the directions along, and perpendicular to, the optical axis are also called a fast and slow axis. The thickness of a 1/2 wave-plate is chosen such that the difference between the phases of two components of light after passing through the wave-plate (retardation) is equal to multiples of  $180^\circ$  or 1/2 wave. A zero-order 1/2 wave-plate is made of two crystals resulting in exactly  $180^\circ$  retardation or one 1/2 wave. The advantage of a zero order wave-plate is that 1/2 wave retardation is maintained over a much broader range of wavelengths.

Rotation of the 1/2 wave-plate by  $\phi$  degrees leads to  $2\phi$  degrees of polarization rotation. Intensity at the output of the attenuator is then given by

$$I = I_o \cos^2(2\phi) \quad (2)$$

where  $\phi$  is the azimuth of the 1/2 wave-plate. Full range of attenuations from minimum to maximum is achieved by 1/2 wave-plate rotation from  $0^\circ$  to  $45^\circ$ .

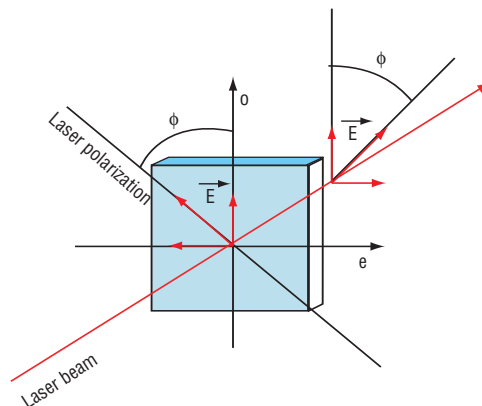


Figure 2. Zero order 1/2 wave-plate. The electric field  $\vec{E}$  of a laser beam decomposes into two orthogonal components. Rotation of the wave-plate by angle  $\phi$  results in a polarization rotation of  $2\phi$ .

## Which Components do I Use?

The choice of optical components is defined by the bandwidth and the power of the laser to be controlled.

For a 1/2 wave-plate we recommend the Newport model 10RP52-2. This achromatic zero-order wave-plate consists of two different birefringent crystals: crystalline quartz and magnesium fluoride ( $\text{MgF}_2$ ), in an air-spaced design for high power. Compared to zero-order quartz wave-plates, achromatic quartz  $\text{MgF}_2$  wave-plates offer excellent retardation accuracy over broad wavelength ranges as shown in Figure 3. Achromatic quartz  $\text{MgF}_2$  wave-plates are less expensive than achromatic polymer film wave-plates and also feature higher damage thresholds. Fig. 4 shows the 10RP52-2 half wave-plate mounted in a 25.4 mm housing to allow easy mounting in any of our manual rotation stages, such as the RM-25 or the RSP-1T

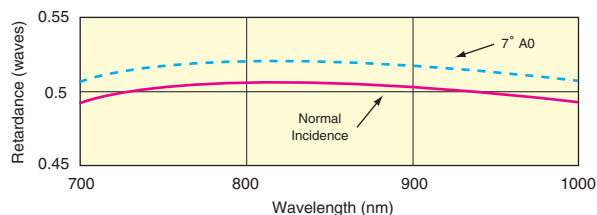


Figure 3. Retardation vs. Wavelength of the Newport 1/2 Wave-plate, model 10RP52-2

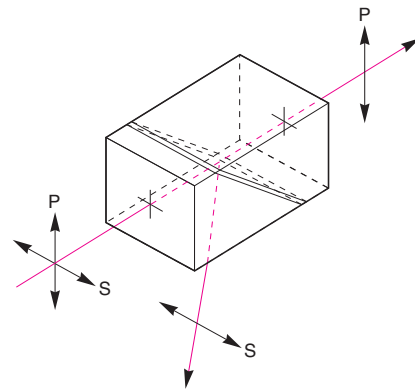


Figure 4. Newport 1/2 Wave-plate, model 10RP52-2 The line on the mount defines the azimuth of the wave-plate. If aligned at 45° relative to the input polarization direction, the output beam polarization is rotated by 90°.

For a polarizer, we recommend the Newport model 10GL08AR.16 Glan-Laser Calcite Polarizer. It consists of two calcite cubes with the optical axis oriented parallel to each other (Fig. 5a). The electric field of the laser beam at normal incidence to the polarizer can be decomposed into orthogonal S and P components oscillating along the fast and slow axes of the crystal. Indices of refraction of calcite are different for S and P components. The cubes are aligned and then cut at an angle such that the S component undergoes total internal reflection and gets rejected through the side window. The P component passes through with minimal loss (see Fig. 5b). Note, the rejected light is not polarized.

The model 10GL08AR.16 Glan-Laser Calcite Polarizer is designed for demanding applications requiring extreme polarization purity and high resistance to laser damage. The polarizers are air-spaced, select-grade calcite prism pairs with the prism interface angles optimized for minimum insertion loss. The housing mounts into standard 25.4 mm holders, and polarizers are offered with broadband AR coatings for the visible and NIR regions (see Fig.5c).

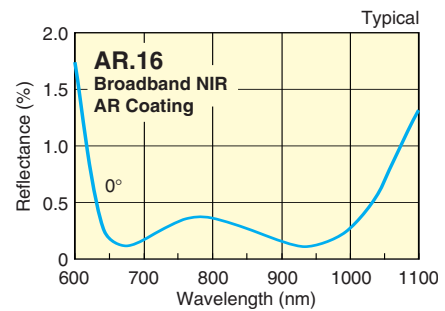
We recommend holding the 10GL08AR.16 in the RM25 mount in order to easily align the polarization either parallel or perpendicular to the table top surface.



(5A)



(5B)



(5C)

Figure 5. Newport Glan-Laser Calcite Polarizer, model 10GL08AR.16 The line on the mount corresponds to the direction of P polarization and defines the azimuth. The rejected S polarized light exits the polarizer through the opening on the side of the housing. A broadband AR coating provides less than 1% reflection from the input and output surface in the 690nm -1040nm spectral region.

## Setup and Alignment

The experimental setup for output power control of a Spectra-Physics Mai Tai® Ultrafast Oscillator is shown in Figure 6. The two steering mirrors at the output of the laser are recommended in order to make the alignment as easy as possible and get the laser output to desired beam height. If more than a 10-20 mm of beam height adjustment is needed, the Newport BSD-2A beam steering kit is easily utilized in addition to these two turning mirrors.

The attenuator can be set up as follows:

1. Install the polarizer on the table and position it in a way that the laser beam passes through the center. Make sure that the back reflected beam is not traveling into the oscillator. Slightly tilt the polarizer in the horizontal plane. If the polarizer or any other optical element needs to be aligned perfectly perpendicular to the laser axis, creating an opportunity for back reflections into the oscillator, a faraday isolator such as the ISO-05-800-BB-G is recommended.
2. Rotate the polarizer and align the azimuth at  $0^\circ$  relative to the horizontal plane.
3. Install a power meter after the polarizer and maximize the power by fine rotation of the rotation stage.
4. Install the 1/2 wave-plate in the beam path before the polarizer at normal incidence angle, and ensure that no back reflection gets into the oscillator. To achieve maximum attenuation, the azimuth of the 1/2 wave-plate should be at  $45^\circ$  relative to the horizontal plane.
5. Install a beam dump in front of the side window of the polarizer housing to capture the rejected beam.

For constant monitoring of the power, the beam dump can be replaced with a power meter. Newport can provide power meters and detectors optimized for your applications. For ultrafast oscillators we recommend 841-PE powermeter and 818 P-020-12 detector. If the output power of the laser is known, as is the case with the Mai Tai Laser, then the attenuated power is equal to the difference between the laser power and the measured power. Total insertion loss of the attenuator, on average, is about 7%.

Calculated and experimentally measured attenuation curves for the Mai Tai Laser, at different wavelengths, are shown in Fig. 7.

Within the measurements error there is good agreement between calculated and measured values. Note that the attenuation sensitivity to the 1/2 wave-plate azimuth depends on the position on the attenuation curve; it is highest at 50% attenuation.

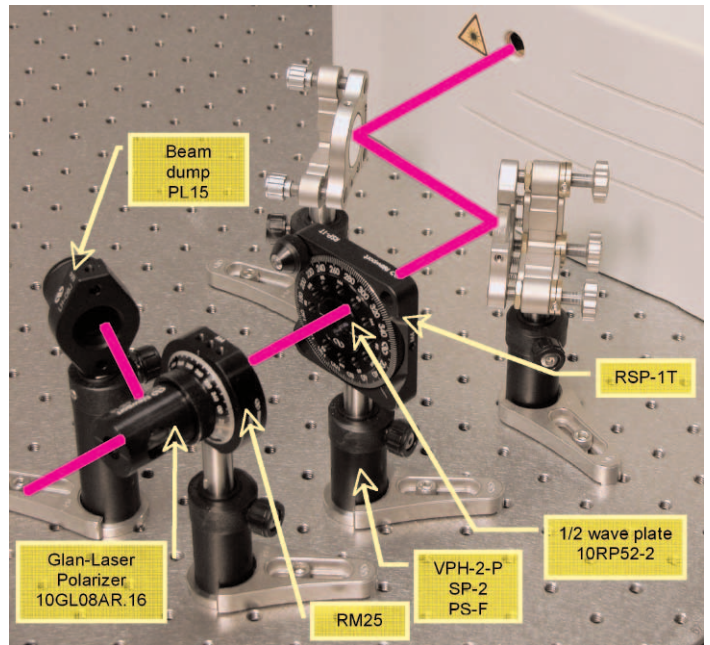


Figure 6. Setup for controlling the output of the Spectra-Physics Mai Tai Ultrafast Oscillator

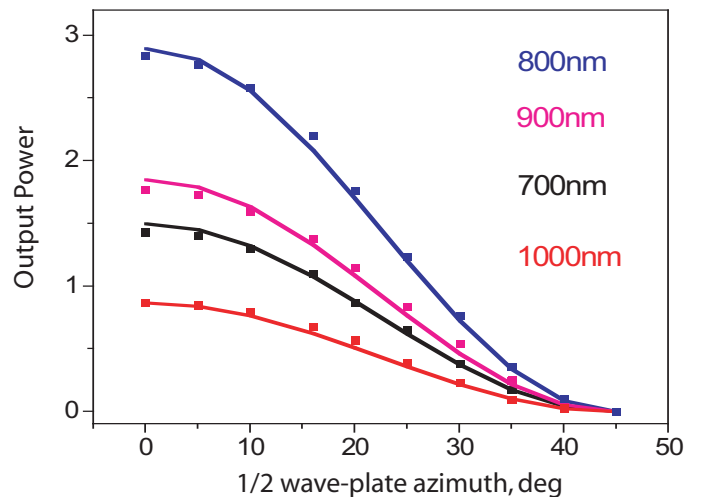


Figure 7. Calculated (solid lines) and measured attenuation curves of the Spectra-Physics Mai Tai Ultrafast Oscillator at different wavelengths

## Power Considerations

The maximum beam diameter that the attenuator can accept is defined by the 10 mm clear aperture of the polarizer. In order to avoid beam clipping, we recommend a maximum beam diameter of 5 mm. Both the polarizer and the 1/2 wave-plate are rated for 500 W/cm<sup>2</sup> damage threshold. The table below defines the maximum allowed power for different beam diameters.

Table 1 Maximum allowed laser power vs. beam diameter

Beam Diameter (mm)	5	4	3	2	1
Laser Power (W)	100	64	36	16	4

For example, if the beam diameter is 1 mm, the maximum laser power at the attenuator should not exceed 4 W. In the case of the Mai Tai Femtosecond Oscillator, the beam diameter is 1.2 mm. The damage threshold will be reached at 5.6 W, which is well above the specified power of 2.4 W at 800 nm.

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