Choosing a Modulator

New Focus™ offers a broad line of optical modulators and drivers that are versatile, reliable and easy to use. All our optical modulators are based on the electro-optic or Pockels’ effect—the linear dependence of the index of refraction on an applied electric field. Applying a voltage across the electrodes of an electro-optic crystal changes the effective refractive index and thus the phase of light as it passes through the crystal.

Our amplitude and phase modulators span the frequency range from DC to 9.2 GHz and feature low drive voltages, low insertion losses, and high maximum optical powers. They use lithium niobate (LiNbO₃) and magnesium-oxide-doped lithium niobate (MgO:LiNbO₃) crystals which have large electro-optic coefficients minimizing required drive voltages. In addition, the small loss tangents at RF frequencies of LiNbO₃ permit operation of these devices over a broad range of frequencies from DC to 9.2 GHz. LiNbO₃ is also non-hygroscopic, and has high maximum optical-power limits and low optical insertion loss.

When choosing a modulator, keep in mind whether you need phase or amplitude modulation, broadband versus resonant (or single-frequency) operation, and over what wavelength range you are operating. The last will determine the AR coatings on the crystal.

Phase Modulators

Phase modulators are used to vary the phase of an optical beam. When driven sinusoidally, phase modulators can generate frequency sidebands on a cw optical beam. Sinusoidal phase modulation at a frequency \( \Omega \) generates frequency sidebands at multiples of \( \Omega \) about the central optical frequency, \( \omega_0 \).

Given a sinusoidal phase modulation at frequency \( \Omega \) and a peak phase modulation \( m \), the phase variation is \( \phi(t) = m \sin(\Omega t) \).

The electric field of the optical beam after passing through the modulator can be written:

\[
E_{\text{out}} = E_{\text{in}} e^{j[m \sin(\omega_0 t + \phi(t))]
\]

= \( E_{\text{in}} \sum_k \left[ r_k e^{-j2\pi k \Omega} + \sum_{n=1}^{\infty} (-1)^n J_n(r_k e^{-j2\pi k}) e^{i\omega_0 t} \right] \).

The amplitude of the \( k \)-th sideband is proportional to \( J_k(m) \), where \( J_k \) is the Bessel function of order \( k \). The fraction of optical power transferred into each of the first-order sidebands is \( |J_1(m)|^2 \), and the fraction of optical power that remains in the carrier is \( |J_0(m)|^2 \).

For example, imposing a phase modulation with peak phase shift of 1 radian will transfer 19\% of the initial carrier power to each of the first-order sidebands and leave 59\% of the power in the carrier. The maximum power that can be transferred to the first-order sidebands is about 34\%, which requires a peak phase shift of 1.8 radians.

Transmitted intensity spectrum from a scanning Fabry-Perot optical spectrum analyzer. The 1.06-\( \mu \)m laser was phase modulated with a Model 4003 resonant phase modulator. The driving frequency was 7.94 MHz and the peak voltage was 3 V.

Top: When a phase modulator is used, the laser beam should be well collimated and its polarization should be oriented vertically to within 1°. For an unpolarized laser, the polarizer should have an extinction ratio greater than 100:1. We recommend our Glan-Thompson polarizers (page 290) or our low-cost sheet polarizers (page 291).

Bottom: In our amplitude modulators, we mount the crystals at 45°. The input beam should be either vertically or horizontally polarized.

NOTE: Polarizers (pages 290–291) are available separately.
Amplitude Modulators
A bulk electro-optic amplitude modulator consists of a voltage-tunable wave plate followed by a polarizer. Thus, the modulation of the intensity is a sin² function. (See figures at bottom left.) If the input polarization is oriented at 45° to the crystal axes, the applied voltage will produce a variable phase delay between the ordinary and extraordinary field components.

New Focus™ simplifies your optical setup by mounting the crystal at 45°. Thus, the input polarization can be either vertical or horizontal.

In order to suppress birefringence variations due to temperature changes, we use two matched crystals arranged in series with their applied electric fields oriented at 90° relative to each other. Our amplitude modulators exhibit less than 1 mrad/°C of temperature-dependent polarization rotation. We cancel thermal birefringence while doubling the electro-optically induced polarization rotations by reversing the crystal axes such that both polarization components travel equal optical paths in the ordinary and extraordinary orientations.

We do not recommend using a general-purpose phase modulator as an amplitude modulator. This will result in a slowly varying amplitude modulation, due to the temperature-dependent birefringence of the phase-modulator crystal.

Broadband Versus Resonant Modulators
Our modulators are available in both broadband and resonant configurations. Broadband modulators can be driven over a range of frequencies, while resonant modulators operate at a single customer-specified frequency.

The advantage of the broadband devices is that they can be operated from DC to 100 MHz (200 MHz for the Model 4104 amplitude modulator), making them appropriate for applications where modulation over a broad frequency range is required. However, since the input drive voltage is applied directly across the crystal electrodes, these devices require a relatively high drive voltage, making it difficult to achieve large modulation depths.

For applications requiring modulation at a single frequency, resonant modulators are preferred because much higher modulation can be achieved with a given drive voltage.

To compare the advantages of resonant enhancement, we use the half-wave voltage, $V_{\pi}$, which is the voltage required to produce a $\pi$ phase shift. The $V_{\pi}$ of a broadband phase modulator at 1.06 μm is 210 V, corresponding to a modulation depth of 0.015 rad/V. These values scale with wavelength, so at 532 nm, $V_{\pi}$ is 105 V and the modulation depth is 0.03 rad/V. In contrast, the Model 4001 and 4003 resonant phase modulators have much higher modulation depths: $V_{\pi}$ at 1.06 μm is typically 10–31 V, corresponding to a modulation depth of 0.1–0.3 rad/V.

NOTE: For these modulators, the modulation depth is typically 0.3 rad/V in the low-frequency range (0.01–20 MHz) and drops to 0.1 rad/V at high frequencies (120–200 MHz).

Using Your Modulator
New Focus modulators are truly user-friendly: simply point the beam through the mechanical apertures. The apertures coincide with the optical axis so that the beam propagates through a region where the electric field is very uniform. You get minimal beam-shape distortion and low residual amplitude modulation (RAM). (Étalons in the crystal make it impossible to completely eliminate RAM.) With careful adjustment of the beam's alignment and polarization, our modulators exhibit less than ~60 dB of RAM for a 1-radian peak phase shift.

To align the modulator, we suggest using the Model 9071 four-axis tilt aligner (page 242). In order to minimize clipping through the modulator, a good rule of thumb is that the beam diameter should be less than one-third the aperture size. Larger beams can be focused into the modulator and then collimated afterwards using a pair of lenses. If you do this, make sure the intensity inside the modulator doesn’t exceed the damage threshold.

Input-Power Considerations
The electro-optic crystals used in our modulators are susceptible to optical damage through the photorefractive effect. This phenomenon is caused by photoexcited charge carriers migrating from illuminated regions to darker regions. The localized refractive-index variations resulting from this field and the electro-optic effect reduce the modulator's effectiveness and cause beam distortions.

Photorefractive damage is a serious concern for visible wavelengths, high optical powers, and tightly focused beams. Photorefractive damage can occur gradually over days or hours, or, for high optical powers and short wavelengths, this effect can occur in seconds.

If your modulator becomes damaged, it may be possible to at least partially reverse the damage by carefully annealing the crystal and thus mobilizing the charge carriers. Because of the sensitive parts contained inside the modulator housing, this should be done only at New Focus. Please contact us for details.

Driving the Modulators
New Focus can help you find the driver that's right for your specific application. Contact us for help selecting a driver.

For resonant applications, use the Model 3363 driver and source (page 114).

To drive a broadband modulator, use the Model 3211 high-voltage amplifier (page 116) which has a bandwidth up to 600 kHz.

A typical setup for observing phase modulation: a HeNe laser beam is sent through a Model 4001 resonant phase modulator operating at 29 MHz, and the beam is focused into an optical spectrum analyzer. The laser's phase-modulated spectrum, with its characteristic frequency sidebands, is observed on an oscilloscope.