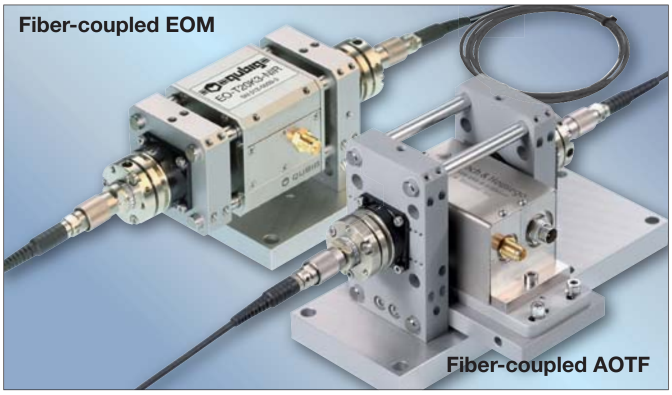
Fundamentals: Optical Modulators

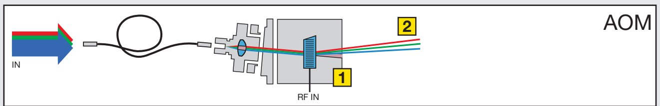
Some applications require modulated pulses instead of continuous radiation or optical switches. This can be provided by an AOM/AOTF (**a**cousto-**o**ptic **m**odulator/**a**cousto-**o**ptic **t**unable **f**ilter) or an EOM (**e**lectro-**o**ptic **m**odulator). Both are highly suitable for the switching of laser beams because of their relatively low response and rise times. Fiber-coupled optic modulators enhance laser safety by confining the beam within optical fibers and they increase stability and reproducibility, especially in comparison with free beam setups.



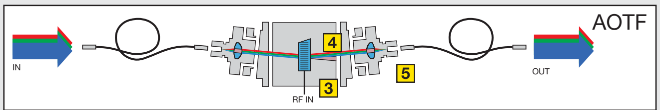
Parameter	EOM	AOM	AOTF
Amplitude Modulation	x	x	x
Phase Modulation	x	-	-
Efficiency	varying	>85 %	> 85%
Modulation bandwidth	static: 500kHz–1MHz, modulation: up to 100 MHz	50–100 MHz	50–100 MHz
Rise/Fall Times	limited by electronics ca. 5 ns	limited by beam diameter, acoustic velocity. ≈ 110–1600 ns/mm	limited by beam diameter, acoustic velocity. ≈ 110–1600 ns/mm
Spectral Filtering	-	-	x
Radiation	monochrome	monochrome	broadband
Wavelength Range (total)	200 nm – 5 µm	250 nm – 15 µm	250 nm – 15 µm
Application	sideband generation, fast switching	fast switching	simultaneous modulation of multiple wavelengths

Acousto-Optic Modulators: AOM and AOTF

AOMs (**a**cousto-**o**ptic **m**odulator) and AOTFs (**a**cousto-**o**ptic **t**unable **f**ilter) function using the same basic modulation principle. The laser radiation is coupled into the AOM/AOTF and is diffracted by an acoustic wave. The amplitude of the acoustic wave determines the intensity of the diffracted beam, while the acoustic frequency determines the angle of the output (Bragg Law). The frequency shift arises from the intractable conservation of energy and momentum. The maximum modulation frequency is determined by the time that the acoustic wave needs to propagate through the complete cross-section of the input beam. In both AOM and AOTF, the first-order diffracted beam is generally used and the zero-order beam is blocked using a trap.



Optical scheme of a fiber-coupled AOM:
The beam modulated by the AOM 1 has a diffraction angle determined by the incident wavelength 2. For broadband radiation, the first-order beam is dispersive and coupling into a fiber is not possible.



Optical scheme of a fiber-coupled AOTF:
The beam modulated by the AOTF 3 has a diffraction angle independent of the wavelength 4 and all wavelengths can be coupled into a single singlemode fiber 5 simultaneously.

Since the modulated beam (first order) in standard **AOMs** is dispersive, the diffraction angle is wavelength-dependent and common **AOMs** cannot be used for the modulation of broadband sources.

Standard **AOMs** are designed for use with monochromatic radiation and only one wavelength can be coupled into a singlemode fiber at a time.

In contrast, an **AOTF** is designed to modulate multiple superimposed wavelengths simultaneously. By applying different acoustic frequencies of different amplitudes to the anisotropic crystal simultaneously, the various appropriate optical wavelengths are switched or modulated precisely.

The first-order beam becomes non-dispersive and the diffraction angle is equal for all input wavelengths. The modulated broadband input radiation can then be coupled into a single singlemode fiber. AOTFs can also be used to switch quickly between several input wavelengths. Schäfter+Kirchhoff now offers RGBV laser beam combiners with an adjacent AOTF, for details see page 53.

Electro-Optic Modulator: EOM

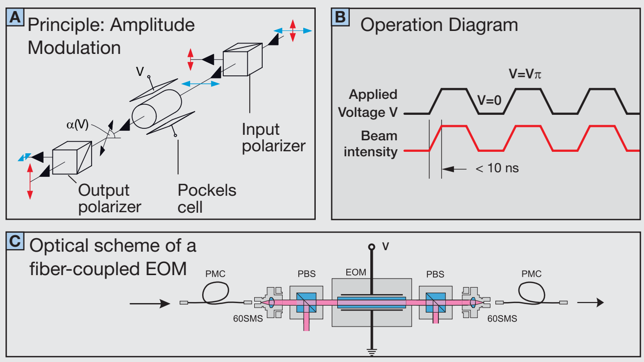
EOMs use the Pockels effect, which describes the linear change in refractive index with applied electric field. When considering a birefringent crystal, the change in refractive index is different for the ordinary and the extraordinary beam. If the input polarization is not parallel with the optical axis of the crystal, the EOM will change the state of polarization. An EOM can be used as a voltage-controlled retarder for amplitude modulation of switching tasks or for phase modulation (e.g. generation of sidebands).

Amplitude Modulation:

To modulate the intensity of a laser beam, the EOM is placed between two crossed polarizers, with the EOM retardation axis orientated at 45° to the first polarizer, as depicted in A, C.

At the specific voltage, $V\pi$, the EOM corresponds to a half-wave plate so that the polarization after the crystal is rotated by 90°, see B.
At V = 0, the EOM does not influence the laser beam polarization and the beam is blocked. At $V = V\pi$, the EOM rotates the polarization of the beam by 90° and the beam is transmitted.

An application example can be found on page 55.



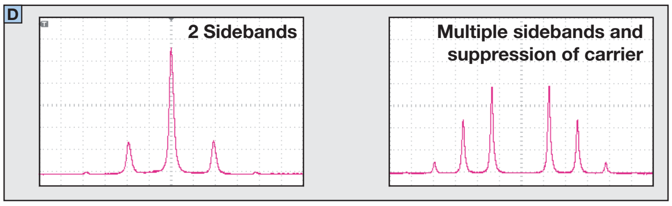
Phase Modulation:

If the input polarization is parallel to the optical axis, the optical phase can be modulated by applying different electrical fields to the crystal. By applying an AC voltage, a time-dependent phase is produced, causing a frequency shift in the output signal.

Sidebands D appear next to the carrier frequency f_c where

$$f = f_c \pm n \cdot f_M \quad (f_M = \text{frequency of the electric field, } n \in N).$$

The amplitude of the sidebands with respect to the carrier can be influenced by the amplitude of the applied voltage in accordance with the Bessel functions. Many applications in quantum optics, such as Pound-Drever-Hall setups or laser frequency stabilization, rely upon well-defined frequency triplets for their implementation.



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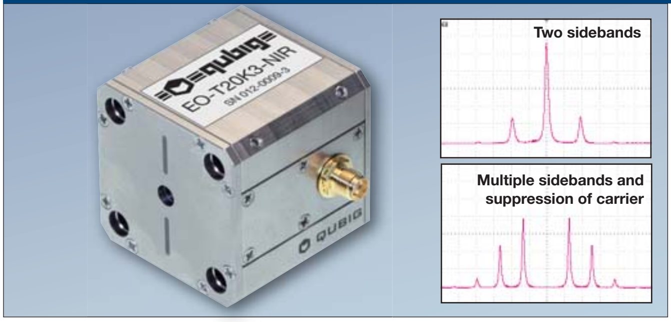
EOM Electro-Optical Phase Modulators with Fiber Optics

using Schäfter+Kirchhoff fiber-optic components



EOMs are capable of modulation and switching tasks (amplitude and phase modulation, generation of sidebands).The EOM described here was specifically designed for high quality phase modulation (for details, see page 56). Schäfter+Kirchhoff offers polarization-maintaining fiber-optic components that are ideally suited for the implementation of an EOM in a measurement setup. Upgrading to fiber optics enhances laser safety by confining the beam to optical fibers and increases the stability and reproducibility of measurement setups, especially when compared with free-beam breadboard constructions.

The EOMs described here are manufactured by QUBIG and are designed for the modulation of the optical phase.

Please visit www.qubig.com for more details of the main product features, which include:

- Electro-optical phase modulator
- High Q resonance
- Fixed and tunable resonance frequencies 0.1 MHz – 3 GHz
- Wavelength range: 200 nm – 5 µm
- Crystal apertures: 3x3, 5x5 mm; large aperture for easy alignment
- Outstanding modulation efficiency
- Standard AR coatings: broadband, single line
- High threshold optical damage crystals
- Low residual amplitude modulation (RAM)
- Low rf drive power
- For *s* and *p*-polarization

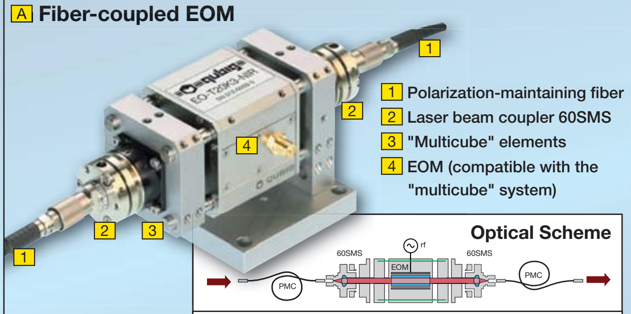
Applications:

- Optical sideband generation
- Laser frequency stabilization
- Cavity-laser lock
- Frequency shifting
- Spectral broadening

Application Fiber-coupled EOM for the generation of sidebands

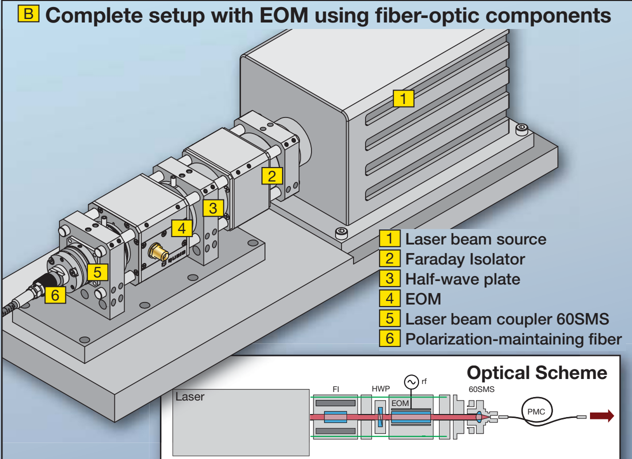
The multicube system and the fiber-optic components offered by Schäfter+Kirchhoff enable a variety of ways to implement EOMs

A Fiber-coupled EOM



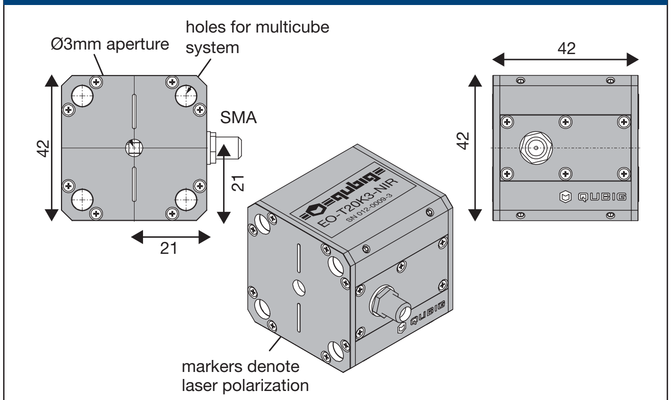
Extremely stable, rugged, compact and enclosed setups for increased safety and reproducibility

B Complete setup with EOM using fiber-optic components



Extremely stable, rugged, compact and enclosed setups for increased safety and reproducibility

Dimensions: EOM

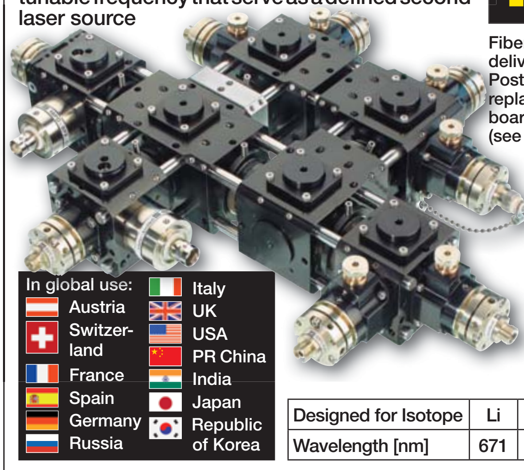


Accessory: DDS Radio-frequency EOM driver

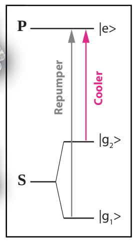
For further details, visit www.qubig.com

Application: EOM with Fiber Port Cluster for

The integrated EOM produces sidebands of a tunable frequency that serve as a defined second laser source

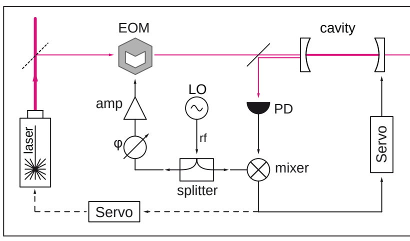


Fiber-coupled beam delivery systems. Postcard-size format replaces 1 m² bread-board construction (see also page 66).



Designed for Isotope	Li	Na	K	Rb
Wavelength [nm]	671	589	767	780

Pound-Drever-Hall Lock



Frequency Stabilization of Laser Beam Sources

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Electromagnetic Shutter EMS-3-30 + SK97120

Figure 1:
1 **EMS-3-30** Electromagnetic Shutter with
2 **SK97120** Shutter Controller

- **Bistable shutter**
- **No power consumption in OFF position**
- **Internal, external, automatic or manual trigger mode**
- **USB 2.0 and RS232 interface**
- **System mount Ø 19.5 mm, compatible with "multicube" system**

Shutter Specifications

Solenoid type	Bistable
Shutter rise/fall time t_{rise} / t_{fall}	11 ms / 22 ms (24 V pulse)
Holding voltage	0 V
Maximum pulse rate	Up to 10 Hz (steady),
Aperture	3 mm
Weight	100 g

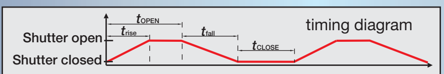
Controller Specifications

- Shutter status indicator
- Voltage 24 V DC +/- 5%
- Power startup peak 1 A / 250 mA
- 19"-rack housing, 3HE / 10 TE, 300 g

Please note: This shutter is bistable and so does NOT conform with the laser safety rules IEC 60825-1.

Timing

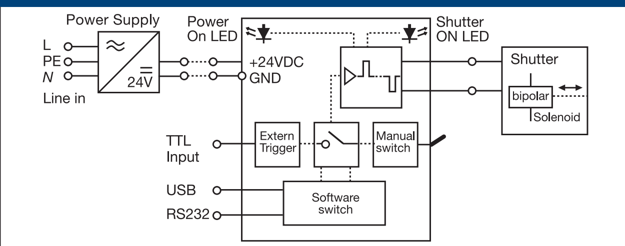
Timing resolution	1 ms
Shutter OPEN time t_{OPEN}	20–60 000 ms
Shutter CLOSE time t_{CLOSE}	0–60 000 ms (pre-trigger)
(Shutter open/close time programmable in software mode only)	
Trigger IN	TTL (BNC connected)



Operating Modes:

- Manual . . . User-controlled open/close
- Software . . PC-controlled operation via USB2 or RS232
- Single . . . Open/close cycles using microcontroller
- Auto . . . Multiple open/close cycles using microcontroller
- Extern. . . . External TTL-triggered open/close

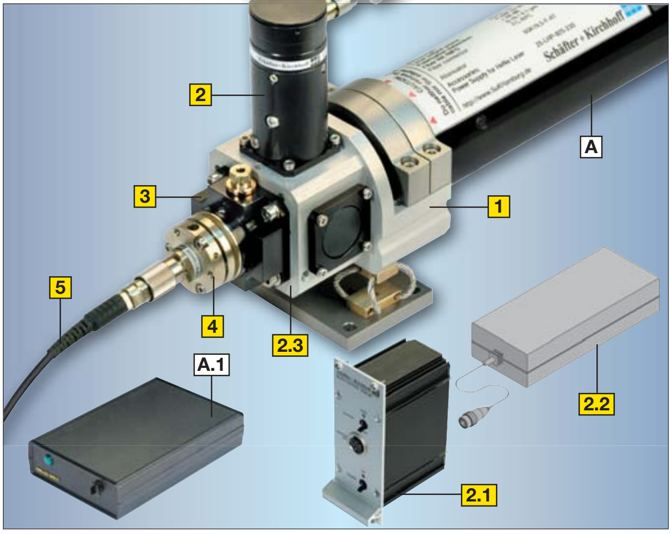
Electrical scheme



Order options

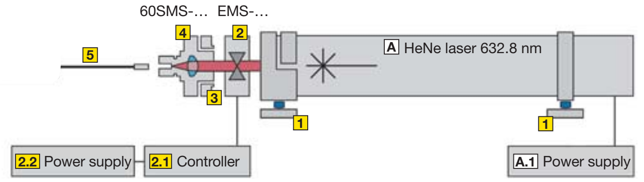
Order Code	
EMS-3-30	Shutter head
SK97120	Controller with power supply, driver and control software
48MC-SM-19.5-SM	"multicube" with shock absorbers

Application HeNe Lasers with fiber optics and electrical shutter



Components

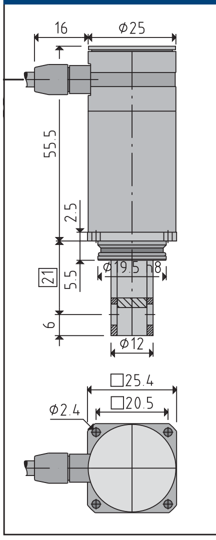
- A HeNe laser
- A.1 Laser power supply
- 1 Mounting bracket **MC-MG-C-44.5-F-R**
- 2 Electrical shutter **EMS-3-30**
- 2.1 Shutter controller **SK97120**
- 2.2 Shutter power supply
- 2.3 "multicube" with shock absorbers **48MC-SM-19.5-SM**
- 3 Attenuator **60A19.5-F-AT**
- 4 Laser beam coupler **60SMS-...**
- 5 Fiber cable **SMC-630-.../ PMC-630-....**

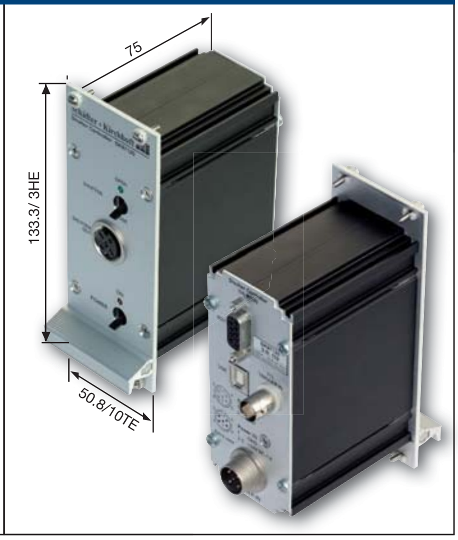


Upon activation, HeNe Lasers require several minutes to reach a stable state of radiation. To circumvent this latency, it is advantageous to use a shutter to block the beam, rather than subjecting the laser to a series of on-off cycles. In the present application, a shutter is mounted in a "multicube" immediately in front of the laser, with shock absorbers preventing any vibration caused by the shutter operation.

The power of the laser radiation can be reproducibly modulated with the attenuator 60A19.5-F-AT. Subsequently, the beam is coupled using a highly efficient beam coupler into a singlemode SMC-... or a polarization-maintaining singlemode PMC-... fiber. The coupling axes can be either coaxial FC or inclined APC to prevent back-reflections into the laser source.

Dimensions





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