Acousto-Optic RF drivers Custom solutions

AA OPTO-ELECTRONIC proposes the most complete range of Acousto-Optic devices covering wavelengths from 180 nm up to 11 µm including all associated Radio Frequency drivers and power amplifiers.

- Modulators - Pulses pickers
- Polychromatic modulators
- Fixed & variable frequency shifters
- Deflectors - AOTF
- Q-Switches - Cavity Dumpers
- Fiber pigtailed devices
- Power Amplifiers
- Fixed and variable frequency sources
- Custom developments

AA OPTO-ELECTRONIC
Components and Innovations for demanding applications...

AA was founded in 1979, under the name «Automates et Automatismes». It became a limited company in 1988 under the new name of AA Sa, specialising in acousto-optic components and their associated RF drivers. AA is a world leader in the manufacturing of quality Acousto-optic and radio frequency devices. Close collaboration with universities and research institutes, provided invaluable knowledge and experience in the design and manufacturing processes of Acousto-optic devices and radio-frequency sources. Continuous R&D keeps pace with advances in laser and electronic technology to ensure AA continues to offer state-of-the-arts products. AA offers its customers solutions from prototype design to large volume manufacturing thanks to its internal resources and In-house capabilities. Our Headquarter is located in ORSAY, near Paris. This is also our optical manufacturing center. All RF drivers are manufactured in our St Avertin plant, located 200 kms south of Paris.

Diffraction Efficiency

$$\frac{I_1}{I_0} = \sin^2\left(\frac{\pi}{2}\sqrt{\frac{P}{P_0}}\right) \qquad with\ P_0 = \frac{\lambda_c^2}{2M_2}\frac{H}{L}$$

Rise time

$$T_r = \frac{\Phi}{V} \times 0\ 66$$

AM Bandwidth (Analog -3dB)

$$F_{-3dB} \approx \frac{0.48}{T_r}$$

Scan Angle

$$\Delta\Theta = \frac{\lambda \Delta F}{V}$$

Static Resolution

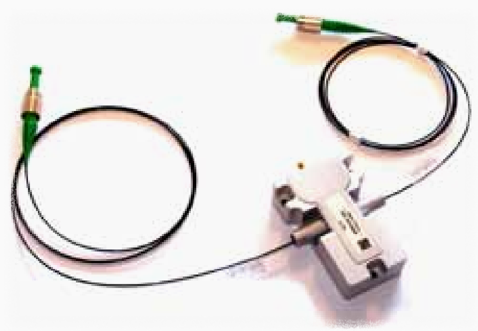
$$N = \frac{\pi}{4}\Delta F \frac{\phi}{V}$$

Dynamic Resolution

$$N_d = N\left(1 - \frac{T_a}{T}\right) + 1$$

1. I_1: Laser Intensity in 1st order
2. I_0: Laser Intensity in 0th order
3. P: RF power
4. P_0: RF power at max efficiency
5. λ: wavelength
6. M_2: Figure of Merite
7. H: Active Aperture Height
8. L: Interaction Length
9. Φ: Beam diameter ($1/e^2$)
10. ΔF: RF Frequency range
11. Δθ: Scan angle
12. V: Acoustic Velocity
13. Ta: Access Time
14. T: Sweeping time

Acousto-Optic Pulse Pickers



A **pulse picker** is an electrically controlled optical switch used to extract single pulses from a fast pulse train.
Short and Ultrashort pulses are in most cases generated by a mode-locked laser in the form of a pulse train with a pulse repetition rate of the order of 10 MHz – few GHz.
For various reasons, it is often necessary to pick certain pulses from such a pulse train, i.e., to transmit only certain pulses and block all the others. This can be done with a pulse picker, which is essentially an electrically controlled optical gate.

FIBER PIGTAILED

Fiber Pigtailed Pulse Pickers

Model	Wavelength (nm)	Fibre Type	Carrier Frequency (MHz)	Rise Time (ns)	Max Repetition rate with Duty cycle (MHz)	Max Laser Power (W)	Losses nom (dB)
MT250-IR6-FIO	1000-1100	PM, SM	250	6	80	0.5	4
MT200-IR10-FIO	1000-1100	PM, SM	200	10	48	1	3.5
MT160-IIR10-FIO	1300-1600	PM, SM	160	10	48	1	4
MT80-FIR40-FIO	1900-2100	PM, SM	80	40	12	5	4
MT200--NIR10-FIO	780-820	PM, SM	200	10	48	1	3.5

FREE SPACE



TeO2 General purpose Pulse Pickers

Model	Wavelength nm	Aperture mmxmm	Polarisation	Beam diameter mm	Rise Time ns	Max Repetition rate with Duty cycle < 1/10 MHz	Separation angle (0-1) mrd	Efficiency %
MT200-A0.5-800	700-950	0.5 x 1	Linear	0.06 - 0.3	10 - 48	3.3 - 0.69	38 @800nm	75 - 85
MT200-A0.5-1064	980-1100	0.4 x 1	Linear	0.09 - 0.3	15 - 48	2.2 - 0.69	50.6 @1064nm	75 - 85
MT250-A0.12-800	700-950	0.12 x 1	Linear	0.04 - 0.1	6 - 16	5.5 - 2	47.6 @800nm	70 - 85
MT250-A0.12-1064	980-1100	0.12 x 1	Linear	0.05 - 0.1	8 - 16	4.1 - 2	63.3 @1064nm	70 - 85

High Damage Threshold Pulse Pickers

Model	Wavelength nm	Aperture mmxmm	Polarisation	Beam diameter mm	Rise Time ns	Max Repetition rate with Duty cycle < 1/100 KHz	Separation angle (0-1)	Efficiency %
MCQ80-A2-1064	1000-1100	2 x 2	Linear	0.5-1.5	55-165			75 - 85
MQ80-A0.7-1064	1000-1100	0.7 x 1	Linear	0.3 - 0.5	33 - 55	100 - 60	14.3 @1064nm	75 - 85
MQ80-A0.3-1064	1000-1100	0.3 x 1	Linear	0.08 - 0.2	15 - 22	370 - 150	26.8 @1064nm	50 - 70

Pulse Pickers Associated RF drivers

These drivers based on quartz oscillators, produce a fixed RF frequency signal. Pulse is controlled thanks to a TTL signal while amplitude is controlled with an analog signal.
Standard MODA driver can also be used in combination with pulse pickers.

Model	Carrier Frequency	Max RF Power	Rise Time	Controls	Exctinction Ratio	Power Supply	Class
MODAXX-2W PPK	160, 200, 250 MHz	2 W /50 Ω	3 ns	0-5 V / 1KΩ for AM +TTL/1 K 1KΩ for pulse	45 dB 60 dB on request	24 VDC or 110/230 VAC	AB

PPK: Synchro driver for fast pulse pickers

These drivers have been designed in order to offer the highest possible performance in high speed Pulse Picking applications.
They include a programmable built-in signal generator synchronized on the laser repetition rate.
These systems are perfectly adapted to fibre pigtailed pulse pickers, but is equally suitable for use with AA's range of free space devices.

Features

- High stability system with Pulse to Pulse Stability contribution <0.5% (PPKAc)
- Dedicated to 80 MHz repetition rate lasers (PPKA) and lower (PPKS)
- Input reference clock from Laser
- With Built-in High accuracy signal generator
- Including Digital delay and window gate adjustments
- Consecutive pulse extinction ratio (CPER) optimisation
- Bluetooth Remote control, USB, RS32 communication for set up
- RoHS compliant

Model	Laser Repetition Rate	Carrier Frequency	Delay range/ step	Pulse Width range	AO Models / Fiber Pigtailed
PPKAc250-B-xx-20*	75-85 MHz	Adapted to RR	20ns (0.1ns)	20ns (0.1ns)	MT250-IR6-Fio-PM-Ic
PPKA250-B-xx-20	40-75 MHz	250 MHz	25ns (0.1ns)	15ns (0.1ns)	MT250-IR6-Fio-PM-Ic
PPKS250-B-xx-128	5-60 MHz	250 MHz	200ns (1ns)	56ns (1ns)	MT250-IR6-Fio-PM-Ic
PPKS200-B-xx-128	5-55 MHz	200 MHz	200ns (1ns)	56ns (1ns)	MT200-IR10-Fio-PM-Ic
PPKS200-B-xx-640	1-30 MHz	200 MHz	1224ns (5ns)	56ns (5ns)	MT200-IR10-Fio-PM-Ic
PPKS80-B-xx-640	1-20 MHz	80 MHz	1080ns (5ns)	200ns (5ns)	MT80-IIR30-Fio-PM-Ic2

Model	Laser Repetition rate	Carrier frequency	Delay Range*	Pulse width range	AO Models Free space
PPKAc250-B-xx-20*	75-85 MHz	Adapted to RR	20ns (0.1ns)	20ns (0.1ns)	MT250-A0.12-1064
PPKA250-B-xx-20	40-75 MHz	250 MHz	20ns (0.1ns)	20ns (0.1ns)	MT250-A0.12-1064
PPKS250-B-xx-128	0,01-60 MHz	250 MHz	128ns (1ns)	128ns (1ns)	MT250-A0.12-1064
PPKS200-B-xx-128	0,01-55 MHz	200 MHz	128ns (1ns)	128ns (1ns)	MT200-A0.4-1064
PPKS80-B-34-640	0,01-20 MHz	80 MHz	640ns (5ns)	640ns (5ns)	MT80-A1-1064 MT80-A0.4-2000

xx=30: 1 watt version, xx=34: 2.5 watts version, xx=36: 4 watts version, xx=42: 15 watts version
* With Synchronized carrier frequency (High Stability). Other carrier frequencies on request.
**Main delay range obtained by laser beam translation inside pulse picker

Acousto-Optic Modulators

and Fixed Frequency Shifters

Acousto-optic **modulators** are used to vary and control laser beam intensity in first order. The rise time of the modulator is simply deduced by the necessary time for the acoustic wave to travel through the laser beam. For highest speeds the laser beam will be focused down, forming a beam waist as it passes through the modulator.

The first order beam of a modulator is frequency shifted by the amount of the RF carrier frequency : it acts like as fixed frequency shifter.

Model	Material	Wavelength nm	Aperture mm^2	Freq (Shift) MHz	Polar	Rise Time* ns	Modul BW MHz (AM)	Efficiency %
MQ200-A1,5-244.266-B	Fused silica	244-266	1,5 x 2	200	Linear	60	8	85
MQ200-A1,5-266.300	Fused silica	266-300	1,5 x 2	200	Linear	60	8	85
MQ180-A0,2-266.300	Fused silica	266-300	0,2 x 1	180	Linear	10	48	85
MQ180-A0,2-UV	Fused silica	325-442	0,2 x 1	180	Linear	10	48	80
MQ110-A3-UV	Fused silica	325-442	3 x 3	110	Linear	50	10	90
MQ240-A0,2-UV	Fused silica	325-442	0,2 x 1	240	Linear	6	80	70
MTS130-A3-400.442	TeO2	400-442	3 x 3	130	Linear	1000	0,4	85
MQ180-A0,25-VIS	Fused silica	440-650	0,25 x 1	180	Linear	10	48	70
MCQ110-A2-VIS	Quartz	488-633	2 x 2	110	Linear	50	8	85
MT350-A0,12-VIS	TeO2	450-700	0,12 x 1	350	Linear	5	96	80
MT250-A0,5-VIS	TeO2	450-700	0,5 x 2	250	Linear	6	80	85
MT200-A0,5-VIS	TeO2	450-700	0,5 x 2	200	Linear	8	60	85
MT110-A1-VIS	TeO2	450-700	1 x 2	110	Linear	15	32	85
MT110-A1,5-VIS	TeO2	450-700	1,5 x 2	110	Linear	50	9	85
MT80-A1-VIS	TeO2	450-700	1 x 2	80	Linear	23	21	85
MT80-A1,5-VIS	TeO2	450-700	1,5 x 2	80	Linear	50	9	85
MTS110-A3-VIS	TeO2	458-633	3 x 3	110	Linear	1000	0,4	85
MTS40-A2-VIS	TeO2	532-700	2 x 2	40	Linear	1000	0,4	85
MTS40-A3-IR	TeO2	750-850	3 x 3	40	Linear	1000	0,4	85
MT110-A1,5-IR-Hk (Ti:sa)	TeO2	690-1064	1,5 x 2	110	Linear	50	9	80
MT350-A0,2-800	TeO2	700-950 (1100)	0,2 x 1	350	Linear	5	96	80
MT250-A0,5-800	TeO2	700-950 (1100)	0,2 x 2	250	Linear	6	80	80
MT200-A0,5-800	TeO2	700-950 (1100)	0,5 x 2	200	Linear	8	60	85
MT110-A1-IR	TeO2	700-950 (1100)	1 x 2	110	Linear	15	32	85
MT110-A1,5-IR	TeO2	700-950 (1100)	1,5 x 2	110	Linear	50	9	85
MT80-A1-IR	TeO2	700-950 (1100)	1 x 2	80	Linear	23	21	85
MT80-A1,5-IR	TeO2	700-950 (1100)	1,5 x 2	80	Linear	50	9	85
MT200-A0,5-1064	TeO2	980-1100	0,5 x 2	200	Linear	8	60	80
MT200-A0,2-1064	TeO2	980-1100	0,2 x 1	200	Linear	8	60	80

*Rise time is beam dimeter dependent

Model	Material	Wavelength nm	Aperture mm^2	Freq (Shift) MHz	Polar	Rise Time ns	Modul BW MHz (AM)	Efficiency %
MT110-A1-1064	TeO2	980-1100	1 x 2	110	Linear	15	32	85
MT80-A1-1064	TeO2	980-1100	1 x 2	80	Linear	23	21	85
MT80-A1,5-1064	TeO2	1000-1100	1,5 x 2	80	Linear	50	9	85
MTS80-A3-1064Ac	TeO2	1030-1080	3 x 3	80	Linear	500	1	85
MQ80-A0.7-L1030.1080	SiO2	1030-1080	0.7 x 1	80	Linear	120	14	85
MCQ40-A1.5-L1064	Quartz	1030-1080	1.5 x 1.5	40	Linear	50	9	85
MQ40-A3-L1064-W	SiO2	1030-1080	3 x 3	40	Linear	120	4	85
MCQ40-A2.5-1064	Quartz	1030-1080	2.5 x 2.5	40	Linear	180	2,5	85
MT80-A0.7-1300.1600	TeO2	1300-1600	0.7 x 1	80	Linear	50	9	80
MTS40-A3-1550	TeO2	1500-1600	3 x 3	40	Linear	500	1	85
MGAS40-A1	Doped Glass	1300-1600	1 x 2	40	Random	50	10	85
MGAS80-A1	Doped Glass	1300-1600	1 x 2	80	Random	50	10	85
MGAS110-A1	Doped Glass	1300-1600	1 x 2	110	Random	25	20	85
MT80-A0.4-2000	TeO2	1900-2100	0.4 x 1	80	Linear	25	20	65
MG40-A6-9300	germanium	9300	6 x 10	40	Linear	120	4	75
MG40-A8-9300	germanium	9300	8 x 10	40	Linear	120	4	75
MG40-A6-10600	germanium	10600	6 x 10	40	Linear	120	4	75
MG40-A8-10600	germanium	10600	8 x 10	40	Linear	120	4	75

Fixed Frequency drivers

These drivers based on quartz oscillators, produce a fixed RF frequency signal. Drivers can be provided at any frequency from 10 MHz to 3 GHz. All models use crystal controlled oscillators.
The RF output can be externally modulated. The rise time varies from 2 ns to 50 ns depending on the fixed frequency and RF power. Usually the driver is coupled internally to a power amplifier; if the output power required is very high then the amplifier will be provided separately, offering RF powers up to 500 W CW.

MODAXX	MODAGXX
Fixed Frequencies Adapted at factory to AO device Standard: 35, 40, 68, 80, 110, 160, 180, 200, 250, 350 MHz (Other on request)	Fixed Frequencies Any frequency in [10-400]MHz Accuracy 1KHz
Modulation Input (AM) Analog 0-1V / 50 Ohms or 0-5 V / 50 Ohms or Digital TTL Dual AM controls Analog + Digital	Modulation Input Analog 0-1V / 50 Ohms or 0-5 V / 50 Ohms or Digital TTL Dual AM controls Analog + Digital
Extinction ratio Standard 45dB - High Extinction ratio on request	Extinction ratio Standard 45dB - High Extinction ratio on request
Power Supply 24VDC or Laboratory 110-230 VAC	Power Supply 24VDC or Laboratory 110-230 VAC
Output RF Power 1, 2, 4, 10, 20, 50, 70, 100 Watts	Output RF Power 1, 2, 4, 10, 20, 50, 70, 100 Watts

Acousto-Optic Fiber Pigtailed

Modulators, Shifters, Pulse Pickers, Q-switches

These **fiber pigtailed** devices can be used depending on the models as modulators, fixed frequency shifters or Q-switches.Our standard versions are proposed with a single mode fiber with polarization maintaining, However on request, we can offer different types of fibers or connectors.These devices are dedicated for telecommunication applications, as well as for printing, microscopy, Q-switching or any other application.

VSF, Versatile Scientific Fibre range of devices

Any wavelength from 400 up to 2100 nm
Any frequency from 35 up to 425 MHz
Any type of fibre PM, SM, LMA...
Any type of jacket
Any fibre connectors

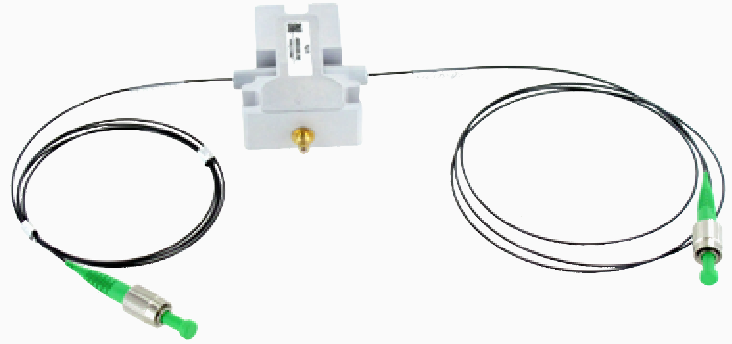
Model	Wavelength nm	Fibre Type	Configuration	Freq (Shift) MHz	Rise Time ns	Max Laser Power W	Losses nom dB
MT180-G430-Fio-MM	532	Multimode	2 ports*	180	430	0.5	3
MT200-BG(9-18)-Fio	488-532	SM, PM	2 ports*	200	9, 18	0.05	3
MT80-G60-Fio	488-532	SM,PM	2 ports*	80	60	0.5	3
MT200-R(9-18)-Fio	630-700	SM, PM	2 ports*	200	9, 18	0.1	3
MQ180-G9-Fio	488-532	PM	2 ports*	180	9	0.1	3
MT80-NIR60-Fio	780-870	SM, PM	2 ports*	80	60	0.5, 5	2
MT110-NIR20-FIO	780-870	SM, PM	2 ports*	110	20	0.5, 5	2.5
MT200-NIR10-Fio	780-870	SM, PM	2 ports*	200	10	0.5	3.5
MT80-IR60-Fio	1000-1100	SM, PM	2 ports*	80	60	0.5, 5	2
MT110-IR20-Fio	1000-1100	SM, PM	2 ports*	110	20	0.5, 5	2.5
MT200-IR10-Fio	1000-1100	SM, PM	2 ports*	200	10	1	3
MT250-IR6-Fio	1000-1100	SM, PM	2 ports*	250	6	0.5	3.5
MT80-IIR30-Fio	1300, 1550	SM, PM	2 ports*	80	30	0.5, 5	2.5
MT110-IIR20-Fio	1300, 1550	SM, PM	2 ports*	110	20	0.5, 5	3.5
MT160-IIR10-Fio	1300, 1550	SM, PM	2 ports*	160	10	1	4
MA40-IIR120-Fio	1300, 1550	SM, PM	2 ports*	40	120	0.5	2
MT80-FIR40-2000-Fio	1900-2100	SM, PM	2 ports	80	40	0.5	6

Associated RF drivers: MODAxx or DRFAxx (VCO based) / DDSPAxx + Power Amplifier

ICF Compact AOM, Pulse Pickers for Industrial applications

Industrial Compact design

- Pulses pickers 1064 nm, 6 ns, 250 MHz
- Pulse pickers 1064 nm, 10ns, 200 MHz
- Fast AO Modulators
- Frequency Shifters 1064nm
- Q-Switches 1064 nm
- AO Modulator 1550 nm, 30 ns
- Frequency shifter, 80 MHz



Model	Wavelength (nm)	Fibre Type	Carrier Frequency (MHz)	Rise Time (ns)	Max Repetition rate with Duty cycle (MHz)	Max Laser Power (W)	Losses nom (dB)
MT250-IR6-FIO	1000-1100	PM, SM	250	6	80	0.5	4
MT200-IR10-FIO	1000-1100	PM, SM	200	10	48	1	3.5
MT160-IIR10-FIO	1300-1600	PM, SM	160	10	48	1	4
MT200--NIR10-FIO	780-820	PM, SM	200	10	48	1	3.5

3 Fio: 3 ports fiber versions

Any wavelength from 400 up to 2100 nm
Any frequency from 35 up to 425 MHz
Any type of fibre PM, SM, LMA...
Any type of jacket
Any fibre connectors

Model	Wavelength (nm)	Fibre Type	Carrier Frequency (MHz)	Rise Time (ns)	Max Repetition rate with Duty cycle (MHz)	Max Laser Power (W)	Losses nom (dB)
MT110-IR25-3Fio	1000-1100	SM, PM	3 ports*	110	25	0.5, 5	2.5
MT110-IIR25-3FIO	1300-1550	SM, PM	3 ports*	110	25	0.5, 5	3
MT80-IIR40-3FIO	1300-1550	SM, PM	3 ports*	80	40	10	3

Acousto-Optic Deflectors

and Variable Frequency Shifters

A Bragg configuration gives a single first order output beam, whose intensity is directly linked to the power of RF control signal, and whose angle is directly linked to the RF frequency. By varying the frequency, the output laser beam angle is modified. A deflector is used to scan a laser beam over a range of angles, or to control with accuracy the output angle of the laser beam.
By varying the frequency, the first order beam is also frequency shifted by the amount of the RF carrier frequency : it acts like a variable frequency shifter.
The main parameters to qualify a deflector are
1.Deflection angle range and
2.Resolution. The deflection angle range is the maximum angle variation of the laser beam : it is linked to the frequency range of the device.
The resolution of a deflection is the number of distinct directions which can be addressed by the deflector : it is linked to the deflection angle range and laser divergence.
Two deflectors can be used in series and at right angles to give full two-dimensional scanning.

High Resolution	Material	Wavelength nm	Aperture mmxmm	Freq (Shift) MHz	Polarisation	Resolution T.DF	Deflexion angle range	Efficiency %
DTSX-250	TeO2	405-1600*	4,5 x 4,5	f(λ)	Linear	300@633nm	48@633nm	> 70
DTSX-400	TeO2	405-1600*	7,5 x 7,5	f(λ)	Linear	500@633nm	48@633nm	> 70
DTSXY-250	2 Axis TeO2	405-1600*	4,5 x 4,5	f(λ)	Linear	300x300@633nm	41 x 41@532nm	> 50
DTSXY-400	2 Axis TeO2	405-1600*	7,5 x 7,5	f(λ)	Linear	500x500@633nm	41 x 41@532nm	> 50
DT230-B120A0,5-UV	TeO2	400-450	0,5 x 17,5	230+/-60	Linear	500	11,4@400nm	> 50
DT230-B120A0,5-VIS	TeO2	450-670	0,5 x 17,5	230+/-60	Linear	500	15@532nm	> 50

Low resolution	Material	Wavelength nm	Aperture mmxmm	Freq (Shift) MHz	Polarisation	Resolution TΔF	Deflexion angle	Efficiency %
MQ110-B30A1-UV	Fused Silica	325-425	1 x 2	110+/-15	Linear	10	1.8@355nm	> 60
MT200-B50A0,5-400.442	TeO2	400-442	0,5 x 2	200+/-25	Linear/random	23	5,4 @458nm	> 80
MT200-B100A0,5-VIS	TeO2	450-700	0,5 x 2	200+/-50	Linear/random	47	12,6@532nm	> 70@633nm
MT110-B50A1,5-VIS	TeO2	450-700	1,5 x 2	110+/-25	Linear/random	23	6,3@532nm	> 65@633nm
MT80-B30A1,5-VIS	TeO2	450-700	1,5 x 2	80+/-15	Linear/random	14	3,8@532nm	> 65
MT200-B100A0,5-800	TeO2	750-950	0,5 x 2	200+/-50	Linear/random	47	18,6 @785nm	> 60
MT200-B40A1-800	TeO2	750-950	1 x 2	200+/-20	Linear/random	19	7,4 @800nm	> 70@785nm
MT250-B100A0,5-800	TeO2	750-950	0,5 x 2	250+/-50	Linear/random	47	19@800nm	> 60
MT200-B100A0,5-800	TeO2	750-950	0,5 x 2	200+/-50	Linear/random	47	19@800nm	> 60@785nm
MT110-B50A1,5-IR	TeO2	700-1100	1,5 x 2	110+/-25	Linear/random	23	9,5@800nm	> 60@785nm
MT80-B30A1,5-IR	TeO2	700-1100	1,5 x 2	80+/-15	Linear/random	14	5,7@800nm	> 70@765nm
MT200-B100A0,5-1064	TeO2	980-1100	0,4 x 2	200+/-50	Linear/random	47	25,3@1064nm	> 35
MT110-B30A1,5-1064	TeO2	960-1100	1,5 x 2	110+/-15	Linear/random	14	7,6@1064nm	> 60
MT80-B30A1,5-1064	TeO2	980-1100	1,5 x 2	80+/-15	Linear/random	14	7,6@1064nm	> 60
MT80-B30A0.7-1300.1600	TeO2	1300-1600	0.7 x 1	80+/-15	Linear/random	14	9.3@1300nm	>65

Variable Frequency RF drivers

VCO drivers

(Voltage Controlled Oscillator)

These drivers are suitable for general purpose applications (raster scan, or random access...). The VCO can be modulated (amplitude) from an external signal.

The frequency is externally controlled by an analog signal. An external medium power amplifier will be required to generate the RF power levels required by the AO device.

DRFA10Y-XX
Frequency range Adapted at factory to AO device Max 50-110, 60-150, 90-210, 150-300, 200-350 MHz (Other on request)
Frequency control 0-10 V/ 10 Kohms
Modulation Input 0-5 V / 50 Ohms
Sweeping Time ≤1 µs
Power Supply 24VDC or 110-230 VAC
Output RF Power Nominal 0 dBm (to be matched with AA power amplifier)
--> On request DRFA1.5Y 85-135 MHz, sweeping time 150 ns

DDSPA-XX
Frequency range Max 10-350 MHz (400 MHz on request)
Frequency control 15, 23 or 31 bits (1 bit E/D)
Frequency Step 15 KHz, 59 Hz, 0.23 Hz
Modulation Input 0-5 V / 50 Ohms (8 bits on request)
Access Time 40, 64, 80 ns
Power Supply 24VDC or 110-230 VAC
Output RF Power Nominal 0 dBm (to be matched with AA power amplifier)
--> On request USB Controller for PC, designed to drive 1 or 2 DDSPA through USB port (Windows XP/NT)

DDS drivers

(Direct Digital Synthesizer)

To get a high resolution driver with fast switching time, AA has designed direct digital synthesizers based on monolithic IC circuits. 3 models have already been released, and different units can be designed to specific requirements.
These models offer high frequency accuracy and stability and extremely fast switching times, generally of a few tens of nanoseconds. The DAC circuits have been designed with utmost care to obtain clean RF signals, with minimum spurious noise.

RF Power amplifiers

AA's acousto-optic **amplifiers** are linear with large bandwidth and medium power. The models below cover a variety of bandwidths from 1MHz to 3 GHz.
Output powers up to 80 W are available. Each amplifier is supplied with its heat sink and all are stable and reliable under all conditions.For High power amplifiers, AA proposes models up to 500 W CW.

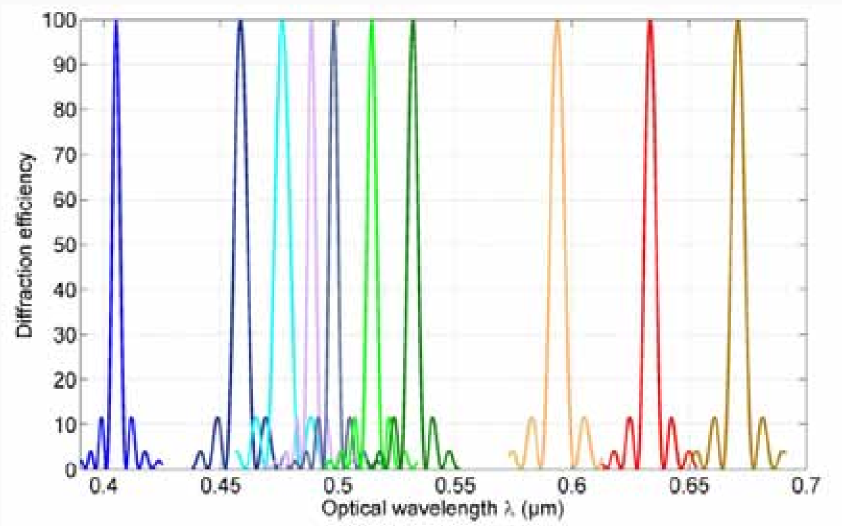
Model	Frequency Range	Gain nom	Output Power	Flatness	Power Supply
AMPA-B-30	20-450 MHz	34 dB	1 watt	+/- 0,5 dB	24 VDC
AMPA-B-34	20-450 MHz	36 dB	2.5 watts	+/- 0,75 dB	24 VDC
AMPA-B-36	20-210 MHz	40 dB	4 watts	+/- 1 dB	24 VDC
AMPA-B-40	50-150 MHz	41 dB	10 watts	+/- 1 dB	24 VDC
AMPA-B-43	60-105, 110-150 150-210 MHz	44 dB	20 watts	+/- 0.75 dB	24 VDC
AMPA-B-47	35-45 MHz	48 dB	50 watts	+/-0.75 dB	24 VDC

Acousto-Optic Polychromatic Modulators

The **AOTFnC** is a special acousto-optic tunable filter which uses the anisotropic interaction inside a tellurium dioxide crystal to control independently or simultaneously different lines from an incoming UV or VISIBLE laser light (White laser, Ar+, Kr+, HeNe, DPSS, Dye...).
Up to 8 distinct lines can be mixed and separately modulated in order to generate different colorimetric patterns.
The specific crystal cut of the AOTF.nC produces good diffraction efficiency (> 90%), narrow resolution (1-2 nm), a low cross-talk between lines, and high extinction ratio.

The large separation angle between 0 and 1st orders, as well as the excellent output chromatic colinearity (<0.2 to <0.3 mrd) make this AOTF a powerful tool for free space or fiber pigtailed applications.
Its associated thermal stabilisation maintains stable diffraction efficiency and reduces dramatically beam drift with single mode fiber pigtailing. This is a major advantage for high sensitivity applications.

AOTFnC*	VIS	VIS Low Res	Low -VIS	IR
Number of channels / Lines	8	4	8	4
Optical wavelength range	450-700 nm	450-700 nm	400-650 nm	700-1100 nm
Transmission	> 95 %	> 95 %	> 90 %	> 95%
Input Light polarization	Linear orthogonal	Linear orthogonal	Linear orthogonal	Linear parallel
Output Light polarization	Linear parallel	Linear parallel	Linear parallel	Linear orthogonal
Active aperture	3 x 3 mm^2	3 x 3 mm^2	3 x 3 mm^2	2.5 x 2.5 mm^2
Spectral resolution (FWHM)	nom 1-2 nm	nom 4-9 nm	nom 1-4 nm	nom 3.5-9 nm
Separation angle (orders 0-1)	> 4,6 degrees	> 4,6 degrees	> 4 degrees	> 4 degrees
Chromatic colinearity (order 1)	< 0,2 mrd	< 0,2 mrd	< 0,3 mrd	< 0.1 mrd
Temperature stabilization	TN	TN	TN	TN
AO Efficiency	>= 90 % /line	>= 90 % /line	>= 90 % /line	>= 85% /line
Rise time	1010 ns / mm	1010 ns / mm	1000 ns /mm	1010 ns/mm
Max accepted RF power	< 1 W all lines	< 1 W all lines	nom 1 W all lines	nom 1 W all lines



Associated RF drivers

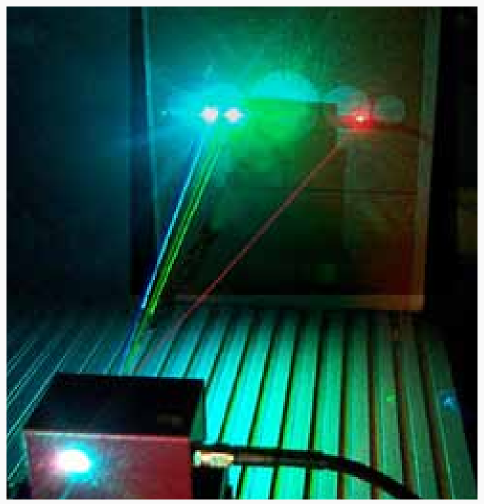
MPDSnC - MULTI PURPOSES DIGITAL SYNTHESIZERS

Product Overview
These drivers based on Direct Digital Synthesizers (DDS), produce multiple fixed stable and accurate RF frequency signals for polychromatic modulators or modulators. Their design with "on the edge" technology offers unique performance in term of accuracy, speed and stability (single/multi-line), thanks to their internal temperature correction and high linearity design.
The built in amplifier delivers the necessary RF power to drive the acousto-optic devices, with reduced power consumption (AA "COLD DESIGN"). In case of Powers higher than 4 Watts, the association with an external power amplifier will be necessary.
The RF power per output can be individually modulated (MOD IN signals) or simultaneously modulated (BLANKING signal). AA focussed on a ultra low crosstalk version with superior fast and fall time.
The adjustments of the driver (Frequency & Power) can be done with a remote control, USB or through RS 232 communication to allow user flexibility in power control or frequency scanning.

MPDSnCXX	
Number of channels	1 to 8
Frequency range	in [20-200] MHz adapted to AO device at factory
External Modulation Input per channel	Analog 0-10 V / 10 KOhms or 0-5 V / 10 KOhms
External Blanking	Analog 0-10 V / 10 KOhms or 0-5 V / 10 KOhms
Extinction ratio	nom 120 dB
Communication	USB, RS232, RC03
Power Supply	24VDC or 110-230 VAC Rack 19 inch - Current <1A
Output RF Power	Total 1, 2, 4 Watts

Features
- Based on DDS (Direct Digital Synthesizer)
- 1 to 8 channels
- Full USB/RS232 control – Analog/Digital external controls
- Low Noise
- Bluetooth Remote control
- Embedded automatic Controls
- Compact size - Low heat dissipation / High reliability
- RoHS Compliant – CE Compliant

Applications
- Suitable to control simultaneously multi-line lasers
- Suitable to drive simultaneously multi-channel devices
- Biomedical, marking, material processing, printing…



Acousto-Optic AOTF

Tunable Filters

An **AOTF** is a solid-state, electronically tunable bandpass filter, which uses the acousto-optic interaction inside an anisotropic medium. These filters can be used with multi-lines sources (mixed gas lasers, Laser diodes...) or with broad-band light sources (Xenon, Halogen lamps...). They allow to select and transmit a single wavelength from the incoming light.

AA proposes a whole range of AOTFs based on TeO2 with shear acoustic mode. The filters are designed so as to get the best performances in each wavelength range and to satisfy most of the applications: resolution down to 1 nm, Field of view up to 20 degrees, apertures up to 10 mm...
In most cases, the filtered output from the tunable filter is made collinear to make easier the use of these devices, and to satisfy fiber pigtailing conditions. A random input polarization will be separated into two orthogonal polarizations (order -1 and +1).

Model	Source	Wavelength nm	Aperture mmxmm	Field of View degrees	Tuning Time µs	Polarization	Resolution nm -3dB	Efficiency %
AOTFnC-UV	Laser	350-430	2 x 2	1	<2	Linear	1-2	85
AOTFnC-400.650	Laser	400-650	3 x 3	1	<4	Linear	1-4	85
AOTFnC-VIS	Laser	450-700	3 x 3	1	<4	Linear	1-2	85
AOTF3-LR	Laser/Lamp	400-700	6 x 6	4	<9	Linear/Random	5-25	85
AOTF3-MR	Lamp	400-700	4 x 4	4	<6	Linear/Random	3,5-17	85
AOTF3-HR	Lamp	400-700	3,5 x 3,5	3	<5	Linear/Random	2,5-12	85
AOTF-A2-500.850	laser/Lamp	500-850	3 x 3	4	<4	Linear	5-15	85
AOTFnC-IR	Laser/Lamp	700-1100	2.5 x 2.5	4	<3	Linear	3-9	85
AOTF10	Lamp	1250-2500	3 x 3	20	<4,5	Linear/Random	2-10	70-30

Associated RF drivers: DRFAxx (VCO based) or DDSPAxx + Power Amplifier / MPDSnC

Acousto-Optic Q-Switches &Associated RF drivers

Air cooled and Water cooled

AA propose a complete line of Acousto-optic **Q-switches** and associated RF drivers, for a wide range of applications. They are manufactured from the highest quality materials, with optimized hard coatings for high damage threshold and long term operation. All AA Q-switches are designed so as to optimize heat dissipation and beam stability with a unique glueing and mechanical technology which reduces stress during operation.

Air-cooled Q-Qwitches: Compact solutions for short cavities, or low gain cavities

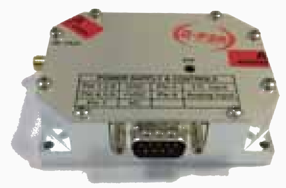
Model	Material	Polarization	Carrier Freq. MHz	Aperture mm x mm	Losses %	Optional Length mm
QCQ40-A1.5-L1064*	QUARTZ	Linear	40.68	1.5 x 2	> 80	32
QCQ80-A1.2-L1064*	QUARTZ	Linear	80	1.2 x 1.22	> 80	32
QCQ80-A2-L1064*	QUARTZ	Linear	80	2 x 2	> 80	32

*Products available only on special request

Q-Switches RF drivers

Reliable and Stable drivers for Industry...

QMODP0xx [10-20 Watts]	
Frequency	24, 27.12, 40.68, 68, 80, 110 MHz
Power Supply	15 VDC or 24 VDC, Class A
Modulation Input Control	TTL + Analog 0-5 V
Rise/Fall Time	< 20 ns
Max RF power	20 Watts
Extinction Ratio	45 dB nom
Heat Exchange	Conduction through baseplate + Fan + Heatsink

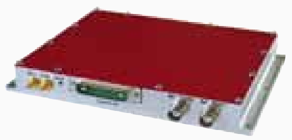


QMODP2Axx [10-20 Watts] Compact	
Frequency	24, 27.12, 40.68, 68, 80, 110 MHz
Power Supply	15 VDC or 24 VDC, Class A
Modulation Input Control	TTL + Analog 0-5 V
Rise/Fall Time	< 20 ns
Max RF power	20 Watts
Extinction Ratio	45 dB nom
Heat Exchange	Conduction through baseplate

QMODP1xx [20-70 Watts]	
Frequency	24, 27.12, 40.68, 68, 80, 110 MHz
Power Supply	15 VDC or 24 VDC, Class A
Modulation Input Control	TTL + Analog 0-5 V
Rise/Fall Time	< 20 ns
Max RF power	20, 35, 50, 70 Watts
Extinction Ratio	45 dB nom
Security Signals	Thermal QST + driver security Output power/Return power signal
Heat Exchange	Conduction through baseplate

QMODP3xx [120 Watts]	
120 Watts for	24, 27.12, 40.68 MHz Water cooled QST

QMODP4xx [2 x 30 and 2 x 60 Watts]	
Dual Outputs driver	for dual Q-switches 2x30 and 2x60 Watts



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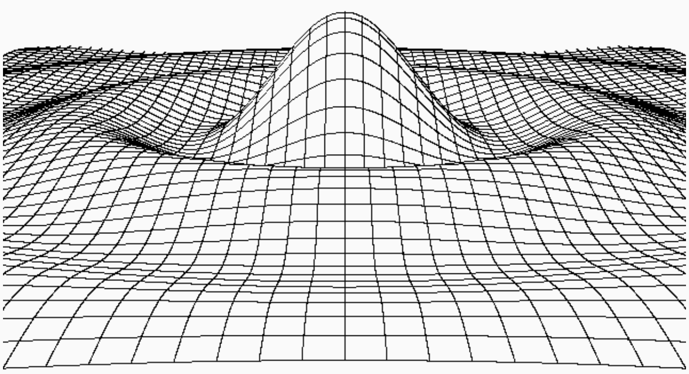
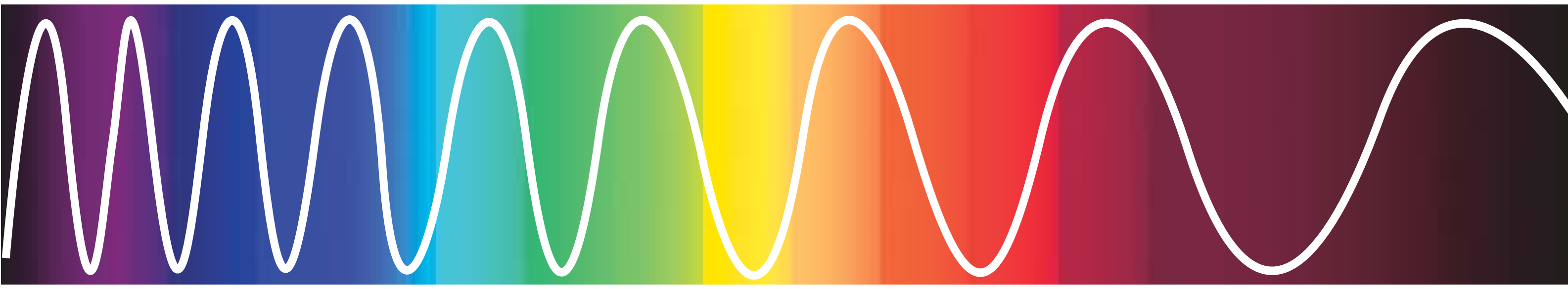
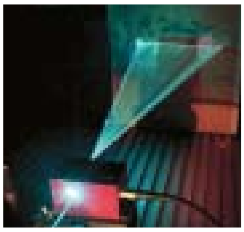
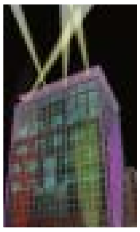
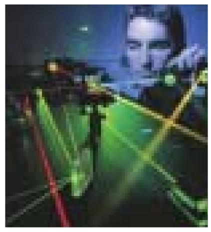


Distributor

Do you know Acousto-optics ?





A.A : Innovative Solutions for Industry

Application Notes

A.A Sa

Acousto-Optics - Radio Frequency - Microwaves

OPTO-ELECTRONIC

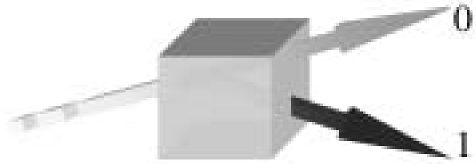
AO HISTORY

Brillouin predicted the light diffraction by an acoustic wave, being propagated in a medium of interaction, in 1922.
In 1932, Debye and Sears, Lucas and Biquard carried out the first experimentations to check the phenomena.
The particular case of diffraction on the first order, under a certain angle of incidence, (also predicted by Brillouin), has been observed by Rytow in 1935.
Raman and Nath (1937) have designed a general ideal model of interaction taking into account several orders. This model was developed by Phariseau (1956) for diffraction including only one diffraction order.
At this date, the acousto-optic interaction was only a pleasant laboratory experimentation. The only application was the measurement of constants and acoustic coefficients.
The laser invention has led the development of acousto-optics and its applications, mainly for deflection , modulation and signal processing. Technical progresses in both crystal growth and high frequency piezoelectric transducers have brought valuable benefits to acousto-optic components ‘ improvements.

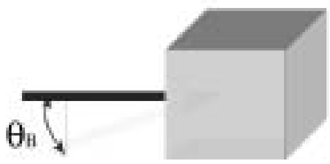
GLOSSARY

Bragg cell:
A device using a bulk acousto-optic interaction (eg. deflectors, modulators, etc...).

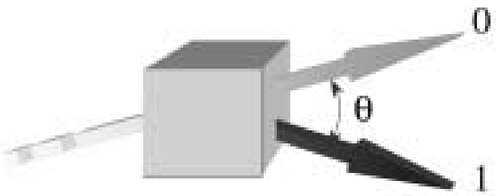
“Zero” order,”1st” order:
The zero order is the beam directly transmitted through the cell. The first order is the diffracted beam generated when the laser beam interacts with the acoustic wave.



Bragg angle (θ_B)**:**
The particular angle of incidence (between the incident beam and the acoustic wave) which gives efficient diffraction into a single diffracted order. This angle will depend on the wavelength and the RF frequency.

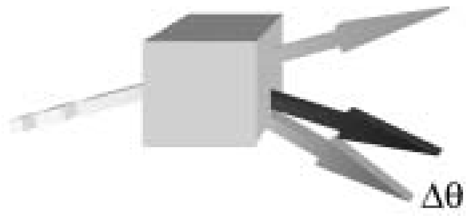


Separation angle (Θ)**:**
The angle between the zero order and the first order.



RF Bandwidth (ΔF)**:**
For a given orientation and optical wavelength there is a particular RF frequency which matches the Bragg criteria. However, there will be a range of frequencies for which the situation is still close enough to optimum for diffraction still to be efficient. This RF bandwidth determines, for instance, the scan angle of a deflector or the tuning range of an AOTF.

Maximum deflection angle ($\Delta\theta$)**:**
The angle through which the first order beam will scan when the RF frequency is varied across the full RF bandwidth.



Rise time (T_R):
Proportional to the time the acoustic wave takes to cross the laser beam and, therefore, the time it takes the beam to respond to a change in the RF signal. The rise time can be reduced by reducing the beam’s width.

Modulation bandwidth (ΔF_{mod}):
The maximum frequency at which the light beam can be amplitude modulated. It is related to the rise time - and can be increased by reducing the diameter of the laser beam.

Efficiency (η):
The fraction of the zero order beam which can be diffracted into the “1st” order beam.

Extinction ratio:
The ratio between maximum and minimum light intensity in the “1st” order beam, when the acoustic wave is “on” and “off” respectively.

Frequency shift (F):
The difference in frequency between the diffracted and incident light beams. This shift is equal to the acoustic frequency and can be a shift up or down depending on orientation.

Resolution (N):
The number of resolvable points, which a deflector can generate - corresponding to the maximum number of separate positions of the diffracted light beam - as defined by the Rayleigh criterion.

RF Power (P_{RF}):
The electrical power delivered by the driver.

Acoustic power (P_a):
The acoustic power generated in the crystal by the piezoelectric transducer. This will be lower than the RF power as the electro-mechanical conversion ratio is lower than 1.

PHYSICAL PRINCIPLES
MAIN EQUATIONS

An RF signal applied to a piezo-electric transducer, bonded to a suitable crystal, will generate an acoustic wave. This acts like a "phase grating", traveling through the crystal at the acoustic velocity of the material and with an acoustic wavelength dependent on the frequency of the RF signal. Any incident laser beam will be diffracted by this grating, generally giving a number of diffracted beams.

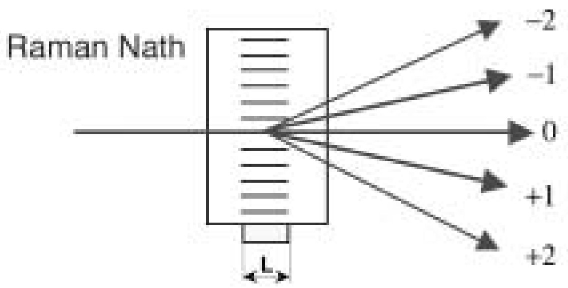
Interaction conditions

A parameter called the "quality factor, Q", determines the interaction regime. Q is given by:

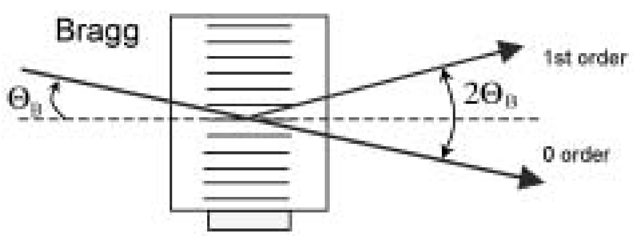
$$Q = \frac{2\pi\lambda_0 L}{n\Lambda^2}$$

where l_0 is the wavelength of the laser beam, n is the refractive index of the crystal, L is the distance the laser beam travels through the acoustic wave and L is the acoustic wavelength.

Q<<1 : This is the Raman-Nath regime. The laser beam is incident roughly normal to the acoustic beam and there are several diffraction orders (...-2 -1 0 1 2 3...) with intensities given by Bessel functions.



Q>>1 : This is the **Bragg regime**. At one particular incidence angle B, only one diffraction order is produced - the others are annihilated by destructive interference.



In the intermediate situation, an analytical treatment isn't possible and a numerical analysis would need to be performed by computer.

Most acousto-optic devices operate in the Bragg regime, the common exception being acousto-optic mode lockers and Q-switches.

Wave vectors constructions

An acousto-optic interaction can be described using wave vectors. Momentum conservation gives us :

$$\vec{K}_d = \vec{K}_i + / - \vec{K}$$

$K_i = \dfrac{2\pi n_i}{\lambda_0}$ – wave vector of the incident beam.

$K_d = \dfrac{2\pi n_d}{\lambda_0}$ – wave vector of the diffracted beam.

$K = \dfrac{2\pi F}{V}$ – wave vector of the acoustic wave.

Here F is the frequency of the acoustic wave traveling at velocity v. ni and nd are the refractive indexes experienced by the incident and diffracted beams (these are not *necessarily* the same).

Energy conservation leads to : $F_d = F_i +/- F$

So, the optical frequency of the diffracted beam is by an amount equal to the frequency of the acoustic wave. This "Doppler shift" can generally be neglected since $F << F_d$ or F_i, but can be of great interest in heterodyning applications.

Acousto-optic components use a range of different materials in a variety of configurations. These can be heard described by terms such as *longitudinal*- and *shear-mode, isotropic* and *anisotropic*. While these all share the basic principles of momentum and energy conservation, these different modes of operation have very different performances - as shall be seen.

Characteristics of the diffracted light

Isotropic Interactions

An **isotropic** interaction is also referred to as a **longitudinal-mode** interaction. In such a situation, the acoustic wave travels longitudinally in the crystal and the incident and diffracted laser beams see the same refractive index. This is a situation of great symmetry and the angle of incidence is found to match the angle of diffraction. There is no change in polarization associated with the interaction.
These interactions usually occur in homogenous crystals, or in birefringent crystals cut appropriately.

In the isotropic situation, the angle of incidence of the light must be equal to the Bragg angle, θ_B:

$$\theta_B = \frac{\lambda F}{2v}$$

where $\lambda = \lambda_0/n$ is the wavelength inside the crystal, v is the acoustic velocity and F is the RF frequency.

The separation angle θ between the first order and zero order beams is twice the angle of incidence and, therefore, twice the Bragg angle.

$$\theta = \frac{\lambda F}{v}$$

The diffracted light intensity I_1 is directly controlled by the acoustic power P :

$$I_1 = I_0 \sin^2\sqrt{\eta} \qquad \text{with} \qquad \eta = \frac{\pi^2}{2\lambda_0^2} M_2 \frac{L}{H} P$$

Here I_0 is the incident light intensity, M_2 is the acousto-optic figure of merit for the crystal and H and L are the height and length of the acoustic beam. λ_0 is the wavelength of the incident beam.

$$\frac{I_1}{I_0} = \sin^2 \frac{\pi}{2}\sqrt{\frac{P}{P_0}} \qquad \text{with} \qquad P_0 = \frac{\lambda_0^2}{2M_2}\frac{H}{L}$$

Diffraction efficiency (relative) is the ratio I_1/I_0:
For a given orientation, if the RF frequency is slightly different from that required to match the Bragg criterion, diffraction will still occur. However, the diffraction efficiency will drop. The situation is shown in the figure below, where the acoustic wave-vector, K, is longer than the ideal "Bragg" wave-vector, K_0.

A complicated analysis leads to the result:

$$\frac{I_0}{I_1} = \eta \,\mathrm{sinc}^2 \sqrt{\eta + \frac{\Delta\phi^2}{4}}$$

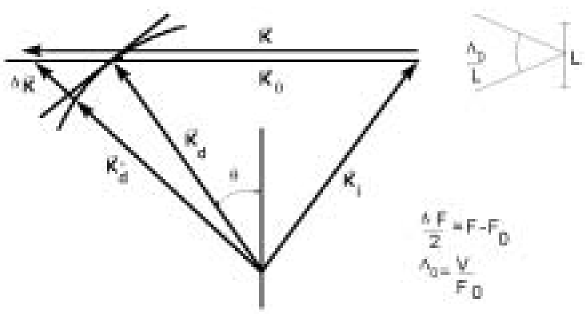
where $\Delta\phi = \Delta K.L$ and is called the "phase asynchronism".

In the isotropic case : $$\Delta\phi = \frac{\pi\lambda}{v}\frac{\Delta F}{2}\frac{L}{\Lambda_0}$$

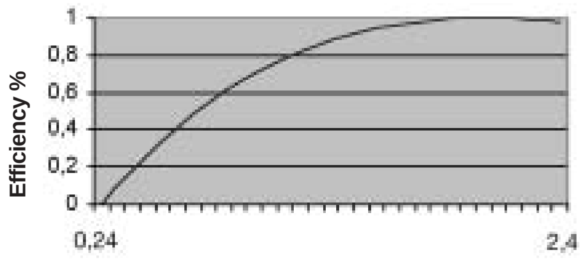
At the correct Bragg frequency, $\Delta\phi = 0$ (F=Fo) and efficiency is maximum.

When $\Delta\phi$ increases, diffraction efficiency decreases and will continue to decrease down to zero.
If there is a lower limit on the acceptable diffraction efficiency, then this puts a limit on $\Delta\phi$. This, in turn, implies a maximum ΔF - and defines the RF bandwidth for the device.

To increase this RF bandwidth, the ratio Λ_0/L (the acoustic divergence) can be increased.
As the RF frequency varies, the diffracted beam's direction changes. This is the basis behind acousto-optic deflectors.



Efficiency versus RF power

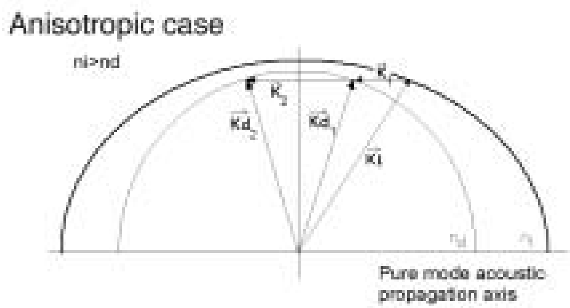


RF power (W)

Anisotropic interaction

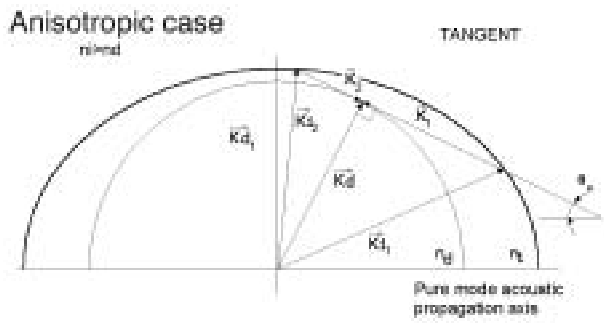
In an **anisotropic** interaction, on the other hand, the refractive indexes of the incident and diffracted beams will be **different** due to a change in polarization associated with the interaction. This can be seen in the figure below where the acoustic wave vector K_1 connects the index curves of the incident and diffracted waves. (K_2 simply represents a similar interaction at a very different RF frequency).

The same asymmetry which causes the difference in refractive indexes also causes the acoustic wave to travel in a **"shear-mode"** and, in the particular example of tellurium dioxide, this results in a drastic reduction in the acoustic velocity.



Anisotropic interactions generally offer an increase in efficiency and in both acoustic and optical bandwidth. They are used almost universally in large aperture devices. The reduction in the acoustic velocity, seen in shear-mode tellurium dioxide, lends this material to be used in high resolution deflectors.

The increased bandwidth available from shear-mode devices can be seen most immediately in the figure below where the interaction configuration is chosen so that the acoustic wave-vector lies tangential to the diffracted beam's index ellipse.



This means that the length of the acoustic wave-vector can vary quite grossly while only producing small changes in the length of the diffracted beam's wave-vector. So, in this situation, ΔK (and, hence, $\Delta\phi$) is quite insensitive to changes in RF frequency.

Shear-mode interactions are very much more complex to analyze, requiring detailed information on crystal cut, refractive indexes, orientation. However, these interactions have a lot of advantages and most deflectors and all AOTFs will use shear-mode interactions. The reduced acoustic velocity makes these devices very much slower than longitudinal-mode units and this can be seen as a disadvantage in some circumstances.

ACOUSTO-OPTIC EFFECTS ON THE LIGHT BEAM

In summary, the Bragg interaction has four basic properties which are highly used in the devices. Some of the properties are coexisting in all devices: for instance, a modulator is also a fixed frequency shifter, a deflector can also be used as a variable shifter or modulator.
The main difference between each device is due to the design strategy which is different and most often antagonist to match the application 's purposes. At this step, it is very important for the component designer to work closely with the applications engineers.

1. Deflection
The angular deviation of the diffracted beam is proportional to the acoustic frequency. Deflectors are based on this principle.

2. Amplitude modulation (Intensity)
The diffracted beam intensity is a function of the acoustic power. Modulators (q-switches) use this property.

3. Frequency shifting
A frequency shift is introduced by the acoustic interaction (+/- equal to the acoustic frequency). So, any acousto-optic device can be used as a fixed or variable frequency shifter.

4. Tunable Wavelength Filtering
Wavelength selection can be carried out with large spectral band sources since only one wavelength will match the Bragg condition. This property is used in acousto-optical tunable filters.

CONSTITUTION OF A BRAGG CELL

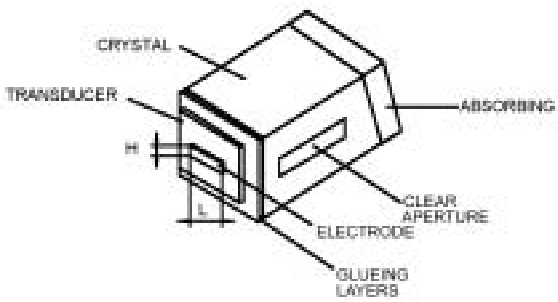
Although acoustic interactions can be observed in liquids, practical devices use crystals or glasses as the interaction medium, with RF frequencies in the MHz to GHz range.
A piezo-electric transducer generates the acoustic wave when driven by an RF signal (figure 6).

The transducer is placed between 2 electrodes. The top electrode determines the active limits of the transducer. The ground electrode is bonded to the crystal.

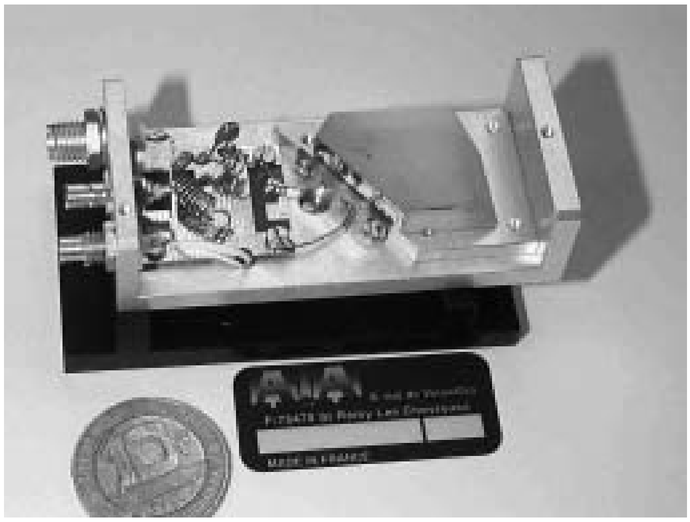
The transducer thickness is chosen to match the acoustic frequency to be generated. The height of the electrode H depends on the type of application, and must exceed the laser beam diameter. For a deflector, it is selected in order to collimate the acoustic beam inside the crystal during propagation.
The electrode length L is chosen to give the required bandwidth and efficiency.
The shape of the electrode can be varied for impedance matching or to "shape" the acoustic wave.
An "apodization" of the acoustic signal can be obtained by optimizing the shape of the electrode.

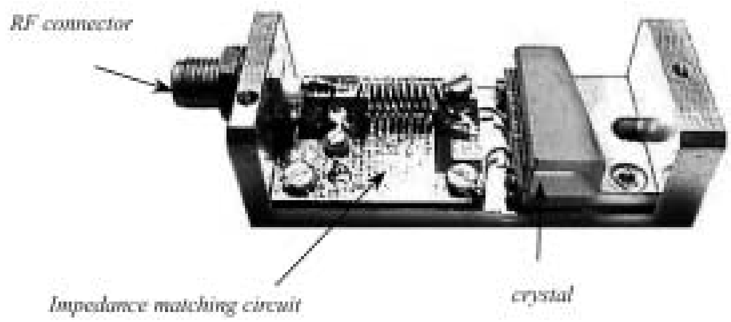
An impedance matching circuit is added to couple the transducer to the driver. Indeed, this circuit is necessary to adapt the Bragg cell to the impedance of the RF source (in general 50 Ohms), to avoid power returned losses. The RF power return loss is characterized with the VSWR of the AO device.

The crystal will generally be AR coated to reduce reflections from the optical surfaces. Alternatively, the faces can be cut to Brewster's angle for a specific wavelength.
A variety of different materials can be used. All have their own advantages and disadvantages.



Length of the crystal : typically 3 to 50 mm
Transducer thickness : typically 1 to 100 µm
Electrode thickness : typically 0.1 to 10 µm





ACOUSTO OPTIC MATERIALS

A.A. Opto-Electronic produces standard, general purpose acousto-optic components for use from 180 nm tu 11 µm, as well as custom products for specific applications.
A variety of different materials are used depending on the wavelength, laser power and precise application. A.A. also develops devices for use with specific lasers : Dye, YAG, Ti:Saph…

†he following gives an overview of the main characteristics of the most used materials for acousto-optic devices.

Material	Type	Optimum optical range for AO application (nm)	Incident optical polarization (*)	Refractive index	@ λ (nm)	Max CW laser power density (W/mm^2)	Acoutic velocity (m/s)	M_2 AO figure of merite ($10^{-15} S^3/kg$)	@ λ (nm)
Ge	Crystal	2500 - 11000	Linear//	4	10600	5	5500	180	10600
Doped Glass	Glass	500 - 650	Unpolarized	2.09	633	1	3400	24	633
$Ge_{33}AS_{12}Se_{55}$	Glass	1100 - 1700	Unpolarized	2.59	1064	1	2520	248	1064
As_2S_3	Glass	700-900	Unpolarized	2.46	1150	1	2600	433	633
$PbMoO_4$	Crystal	450 - 1100	Unpolarized	2.26/2.38	633	0.5	3630	36	633
TeO_2	Crystal	450 - 1100	Linear ⊥	2.26	633	5	4200	34	633
TeO_2	Crystal	350 - 4500	Linear-Circular	2.26	633	5	620	1200	633
SiO_2 (fused silica)	Glass	200 - 200	Linear ⊥	1.46	633	> 100	5960	1.5	633
SiO_2 (fused silica)	Glass	200 - 200	Unpolarized	1.46	633	> 100	3760	0.5	633

(*) : // and ⊥ means parallel and perpendicular to the acoustic wave direction for optimum AO coupling

APPLICATION NOTES

Modulators

Such a device allows the modulation of the light intensity. The Bragg interaction regime with only one diffracted order is used for these devices.

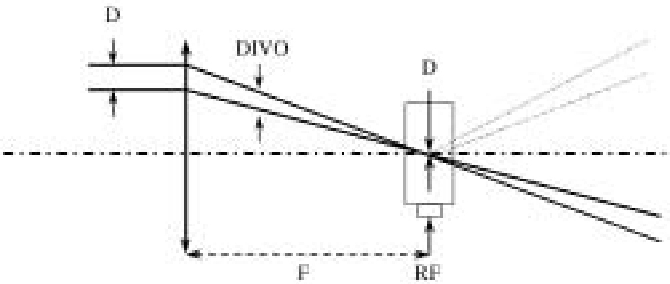
Rise time:
The rise time (T_R) of the modulator is proportional to the acoustic traveling time through the laser beam. The rise time of a fast modulator must be very short:

$$T_R = \beta \frac{\phi}{V}$$

β: constant depending on laser beam profile
ϕ: beam diameter
V: acoustic velocity
ϕ is the only parameter to minimize T_R. Consequently, one focuses the incident light beam on the acoustic beam in order to reduce the beam diameter and reduce rise time.
β is equal to 0.66 in the case of a TEM00 beam.

$$T_R = 0.66 \frac{\phi}{V} \quad \text{(TEM00, 1/e}^2\text{ dia)}$$

D: beam diameter before the lens
F: focal length of the lens
DIVO: incident laser beam divergence
D = $\alpha * F * \lambda / \phi$: diameter of the light beam in the crystal.
α: constant depending on beam profile (=$4/\pi$ for TEM00 beams)



Limitations
To allow the interaction, (L) must remain sufficiently large compared with the acoustic wavelength.

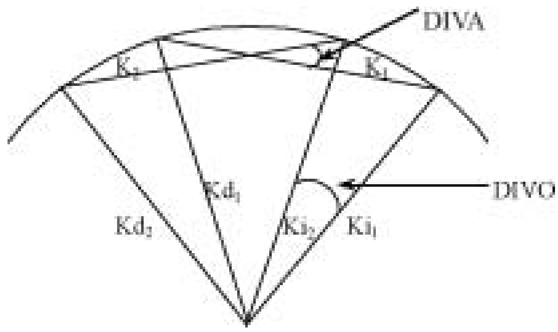
The light beam has a divergence which cannot be neglected. To preserve the efficiency of the interaction on all the bandwidth ΔF, it is necessary to reach the Bragg conditions for all the "angles" of the light beam.

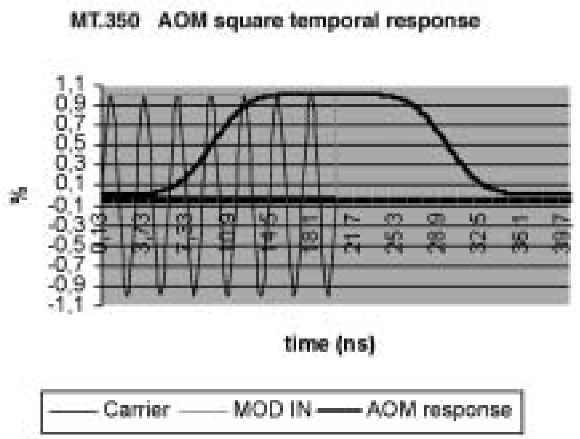
For this purpose, the acoustic divergence (DIVA) (=Λ/L where Λ is the acoustic wavelength and L the dimension of the ultrasonic source) must compensate for light divergence DIVO.

If DIVO>>DIVA : the "asynchronism" is very large for the directions of incidence far away from the Bragg angle, and then the interaction will not occur correctly. The section of the diffracted light beam is then elliptic.

If DIVO<<DIVA : the bandwidth is reduced. An acoustic divergence slightly higher than the light divergence makes it possible to neglect the ellipticity all while maintaining the bandwidth.

Lastly, let us remind that the efficiency of the modulator is related to $\sqrt{P/Po}$ and that Po is inversely proportional to L. For a maximum acceptable value of Po by the crystal (which takes account the maximum power that can withstand the crystal), one reaches a limit of the efficiency.

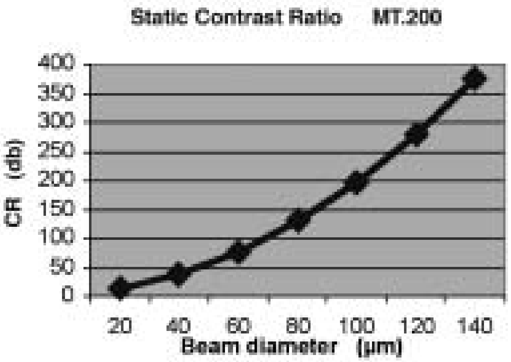




Contrast ratio (static and dynamic)
The incident laser beam properties have a significant impact upon modulator performances (temporal response and extinction ratio). The static contrast ratio measures the ability of the modulator to separate the different diffraction orders

(especially 0 and 1st orders). As a consequence, the lower carrier frequencies and highly focused beams will be a physical limitation of the static extinction ratio. The Gaussian profile (TEM00) gives the best performances and will be considered in the following part. The far field 1st order beam (propagating at angle $+\theta B$) is typically separated from the 0 order ($-\theta B$) with a beam block which is placed such that angles up to 0 are stopped (angles higher than $+2\ \theta B$ can also be stopped to suppress higher orders scattering light).
TEM00 static contrast ratio can be written as :

$$CR = \int_0^{2\theta_B} I(\theta)d\theta \ \ / \ \ \int_{-\infty}^{+\infty} I(\theta)d\theta$$



The static CR is physically limited by imperfection of the crystal and scattered light.
The dynamic contrast ratio is the reduction of the CR due to the finite response time of the AOM.
This leads to a reduction of the contrast ratio of ON light intensity to OFF light intensity in dynamic operation. The dynamic contrast ratio is directly related to the modulation bandwidth of the modulator.

Analog Modulation bandwidth
The rise time is a convenient and easy tool to characterize a modulator' s temporal response. However, a more complete characterization can be useful for accurate results. The AOM temporal response is a linear convolution integral which can be analyzed with Fourier transforms to get the Modulation Transfer Function (MTF) of the AOM.
Without giving detailed calculations, the MTF of an acousto-optic modulator in response to a Gaussian input light profile is:

$$MTF(f) = \exp\left(\frac{-f^2}{f_c^2}\right) \qquad fc = \frac{\sqrt{8}V}{\pi\phi}$$

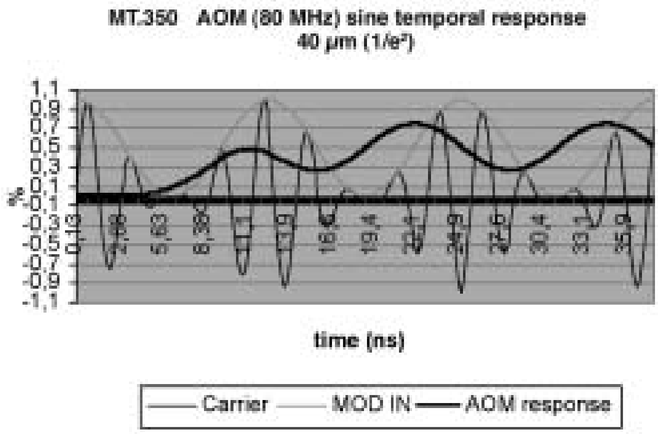
V: acoustic velocity, Φ : beam diameter ($1/e^2$)
Fc : frequency to the $1/e^2$ response rolloff

An other common measure of frequency response rolloff is the analog modulation bandwidth at –3dB (50% reduction point) which is related to fc by

$$F_{-3dB} = \sqrt{\log_e 2}\, f_c$$

From which we can deduce the relationship between f_{-3dB} and rise time :

$$F_{-3dB} \approx \frac{0.48}{T_r}$$

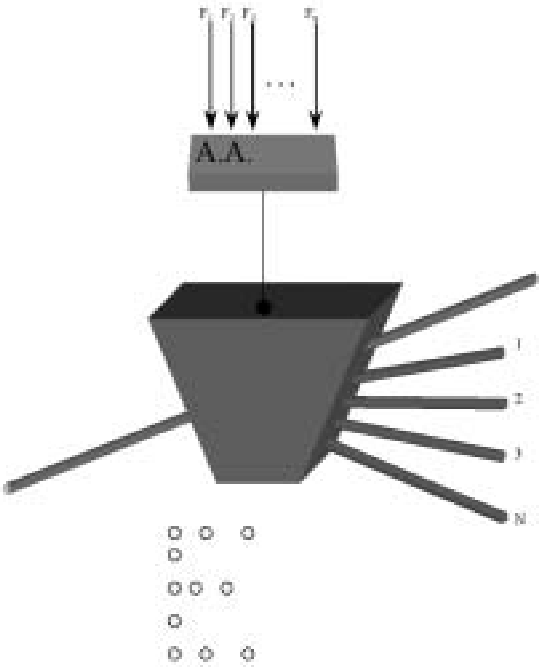


Best performances
rise time: 4-8 ns
efficiency : 70-85 %

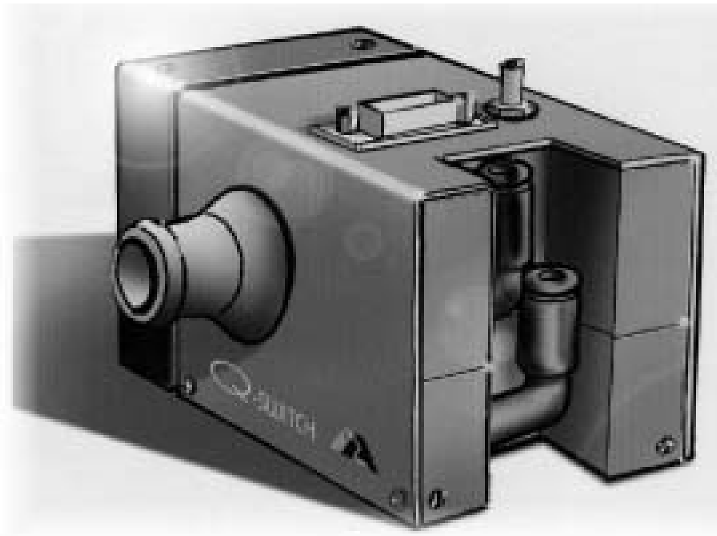
Applications
- Laser Printing
- Transmission of a video signal
- Noise eater
- Locker-mode

Specific application
Multi-beam modulators. Several discrete frequencies ($F_1, F_2, \ldots, F_n$) belonging to the bandwidth of the modulator are sent in the modulator. The diffracted beams are ordered separately, in different directions.

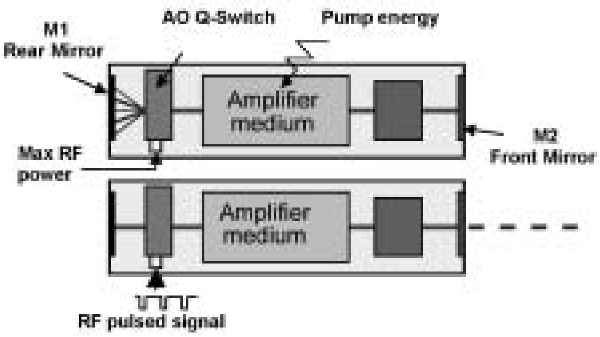
A scanning system (for example deflecting) in the perpendicular direction allows, amongst other thing application, to form characters (printer).



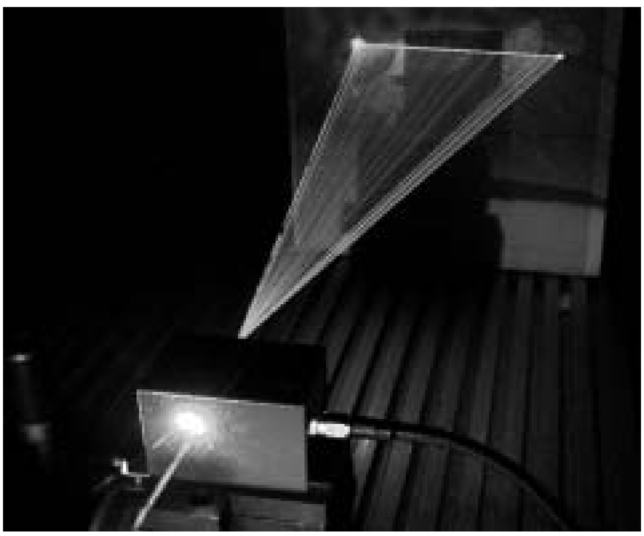
Q-Switches



Q-Switches are special modulators designed for use inside laser cavities. They are designed for minimum insertion loss and to be able to withstand very high laser powers. In normal use an RF signal is applied to diffract a portion of the laser cavity flux out from the cavity (Raman Nath or Bragg regime). This increases the cavity losses and prevents oscillation. When the RF signal is switched off, the cavity losses decrease rapidly and an intense laser pulse evolves.



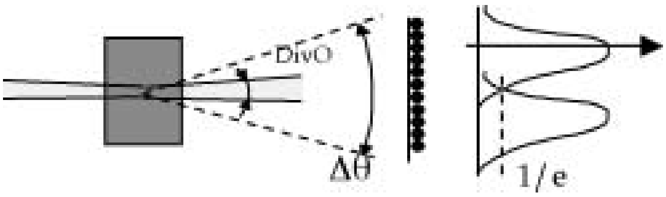
Deflectors



This component is used to deflect the light beam.
In most applications, a high resolution is requested. For this purpose, one uses large-sized crystals (up to 30 mm or more) in order to work with large beam diameters, decrease optical divergence and increase resolution.

Resolution

Static resolution N
The resolution previously defined can be described as static resolution. It is defined as the number of distinct directions that can have the diffracted beam. The center of two consecutive points will be separated by the laser beam diameter (at $1/e^2$) in the case of a TEM00 beam.



$$N = \frac{\Delta\theta}{DIVO}$$

$\Delta\theta$: deflection angle range
DIVO: laser beam divergence

$$N = \frac{\pi}{4}\Delta F \frac{\phi}{V}$$ for a TEM00 laser beam

ΔF: AO frequency range
ϕ: beam diameter ($1/e^2$)
V: acoustic velocity

$$T_a = \frac{\phi}{V}$$ Access time

Ta is called access time of the deflector. It corresponds to the necessary time for the acoustic wave to travel through the laser beam and thus to the necessary time for the deflector to commutate from one position to another one.
A deflector is often characterized with the time x bandwidth product Ta x ΔF.

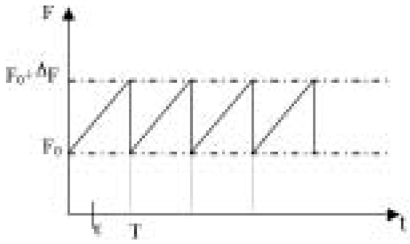
Dynamic resolution N_d
When the field of the frequencies does not consist any more of discrete values but of a continuous sweeping, it is necessary to define the dynamic resolution, which takes account of the " gradient " of frequencies.

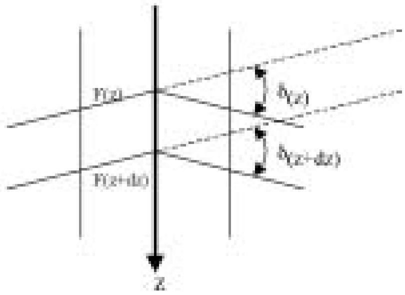
In the case of a linear frequency sweeping:
In Z=O (at the crystal's entry), the frequency F is equal to:

$$F = F_0 + \frac{\Delta F}{T} t$$

In Z, the frequency is equal to

$$F = F_0 + \frac{\Delta F}{T} t - \frac{\Delta F}{T}\frac{Z}{V}$$





The angle of deviation (δ) is now a function of the distance (z) and of time (t).

$$\delta = \delta(Z,t) = \frac{\lambda F}{V} = \frac{\lambda}{V}\left(F_0 + \frac{\Delta F}{T}\left(t - \frac{Z}{V}\right)\right)$$

$$d\delta = \frac{\lambda}{V}\left(\frac{\partial F}{\partial t}dt + \frac{\partial F}{\partial Z}dZ\right)$$

In z and z+dz, the angle of deviation is not the same one. There is focusing, in only one plan, of the diffracted beam. It is significant to notice this effect of cylinder lens, intervening during sequential sweeping (television with raster scan, printing…).
Equivalent cylindrical focal length:

$$F_{Cyl} = \alpha^2 \frac{V}{\lambda \frac{dF}{dt}}$$

-dF/dt: frequency modulation slope
-V: acoustic velocity
-α: parameter depending on beam profile
(=1 for rectangular shape, ≈1.34 for TEM00)

The dynamic resolution translates a consecutive reduction in the number of points resolved for this purpose.
It can be written versus static resolution as:

$$N_d = N\left(1 - \frac{T_a}{T}\right) + 1$$

- Nd: dynamic resolution
- N : static resolution
- Ta : access time
- T : sweeping time from Fmin to Fmax

Examples:

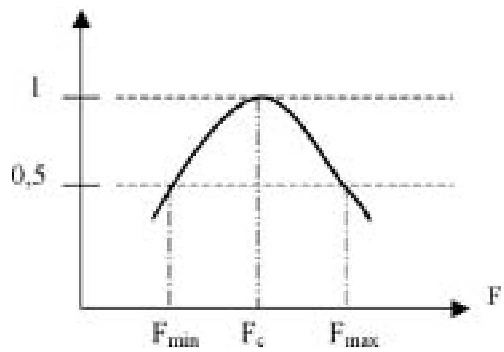
N	Ta (µs)	T (µs)	Nd
1000	10	50	800
2500	50	50	1

Efficiency and bandwidth

The bandwidth is limited to an octave to avoid the overlap of orders 1 and 2.

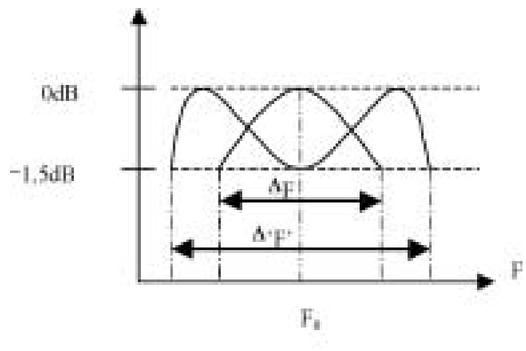
The efficiency curve versus frequency has the following shape for:

Standardized effectiveness



Some applications require a quasi-constant efficiency on all the bandwidth. This can be obtained by decreasing width (l) of the ultrasonic beam, but with the detriment of the maximum efficiency.

Particular case of anisotropic interaction: the bandwidth of the anisotropic interaction can be increased compared with isotropic interaction.
With specific interaction angles, there can be two synchronism frequencies to match the Bragg conditions, so that the deflection angle range can be broaden with good efficiency.



Standardized effectiveness

Applications

• Generation of images, (printing, photolithography…)
• Compensation of the angular errors of the polygonal mirrors,
• Cavity dumper (the acousto-optical component is placed in the laser cavity and makes it possible to obtain pulsed laser of great energy),

▲ particular application 1:
radio frequency spectrum analyzer
An RF signal to be analyzed is transformed into an acoustic signal of same frequency. The incident laser beam is deflected

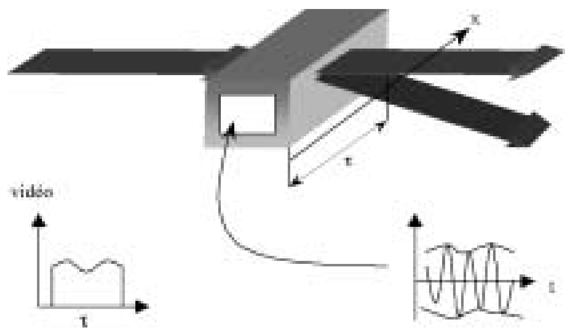
with an angle proportional to the frequency present in the crystal with intensity proportional to RF power (true only with the low powers) .

It is then possible to carry out the spectral analysis in real time of the RF signal limited simply by the access time of the deflector.
The incident laser beam is collimated and increased to illuminate all the aperture of the crystal and to thus allow obtaining a great number of points of resolution.

The diffracted light beam from the deflector is focused on a CCD camera using a Fourier lens. The diffracted signal is converted and can be integrated.

It is possible to carry out particularly compact systems of analysis with low power consumption.

▲ **Particular application 2**
" Scophony "
A carrier wave frequency F_0 is modulated by a video signal.

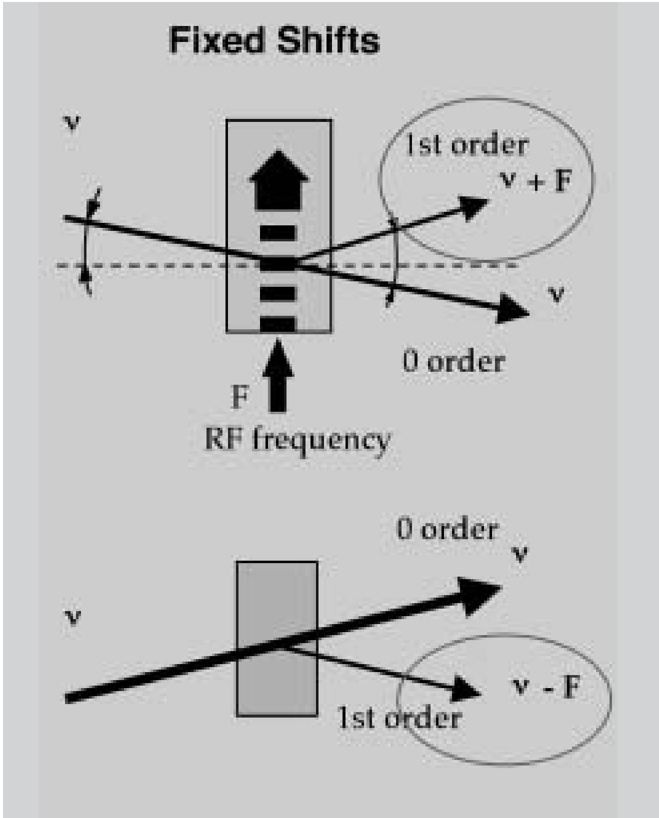


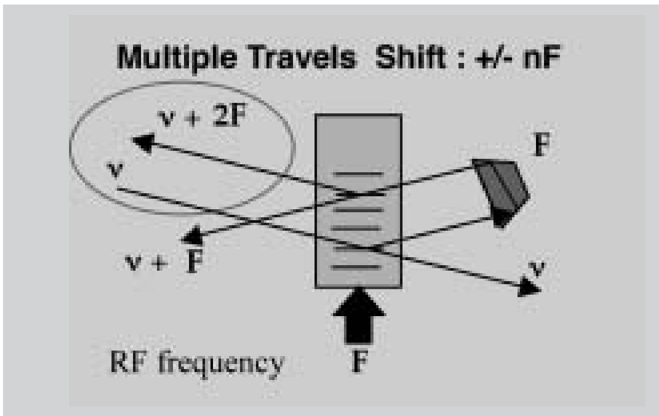
The angle of deflection is fixed by the frequency of the carrier frequency.
The efficiency of the deflector is a function of the distance from the transducer. (x)

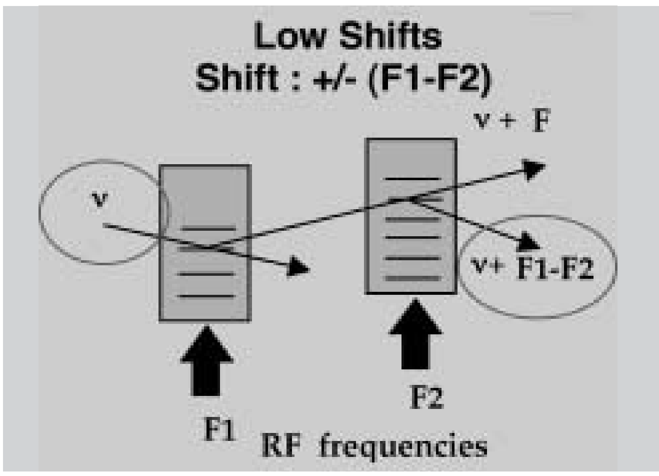
When the deflector contains the video signal corresponding to the access time (Ta), a laser flash gives a deflected light signal, which is the exact spatial representation of the temporal video signal.

Frequency Shifters

These components use the modification of frequency of the diffracted light. (Fd=Fi±F) All the applications using optical heterodyning or Doppler effect are using this property.
Note : the frequency shifter is also a modulator as well as a deflector.





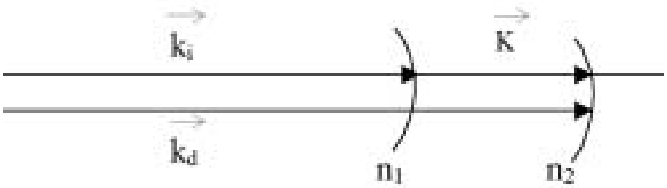


Tunable filters (AOTF)

The extraction of a spectral component of an incoming light source can be carried out by the acousto-optic interaction.
The angle of deflection of an acousto-optic deflector is proportional to the optical wavelength. It is thus possible to extract a particular wavelength. The spectral resolution is then limited by diffraction due to finished dimension (D) of the light beam. The limit of the spectral width can be deduced as:

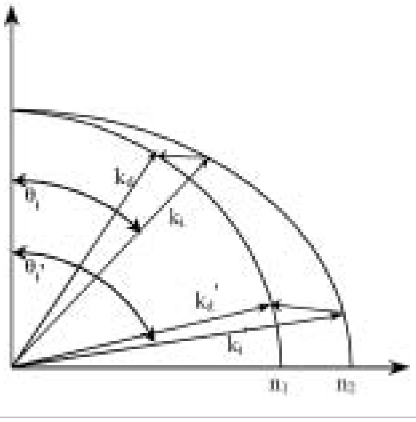
$$\Delta\lambda_0 = \frac{\lambda_0 V}{D}\frac{1}{F}$$

A good resolution ($\lambda 0/\Delta\lambda 0$ high) imposes a large dimension (D) of the light beam. The numerical aperture of such systems is thus obligatorily very low and thus their utilization is very limited. The collinear anisotropic interaction makes it possible to tune the filter by simple variation of the acoustic frequency, under significant numerical aperture:



$$\eta = \eta_0 \operatorname{sinc}^2\left(\frac{\Delta k L}{2\pi}\right)$$ (collinear AOTF efficiency)

The non collinear anisotropic interaction, is also usable under a high angle of incidence ($\theta_i \geq 10°$). This last configuration allows the use of materials with high figure of merit coefficients. (TeO2)



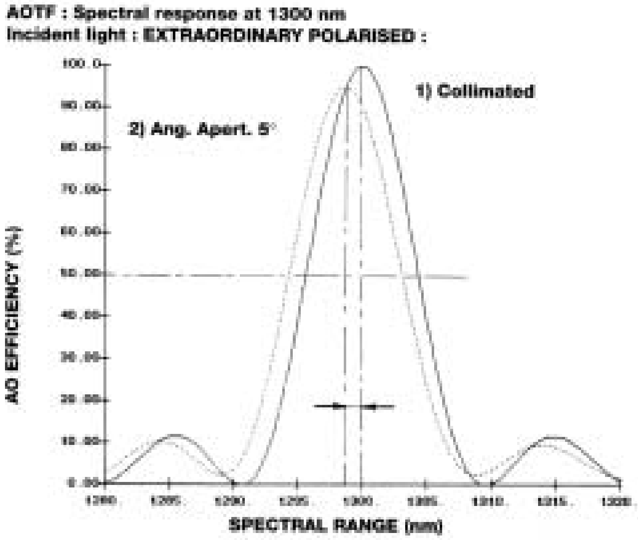
One can show that a large angular aperture is possible as long as the tangents at the point of incidence and synchronism are parallel (the light rays are then parallel in the crystal)

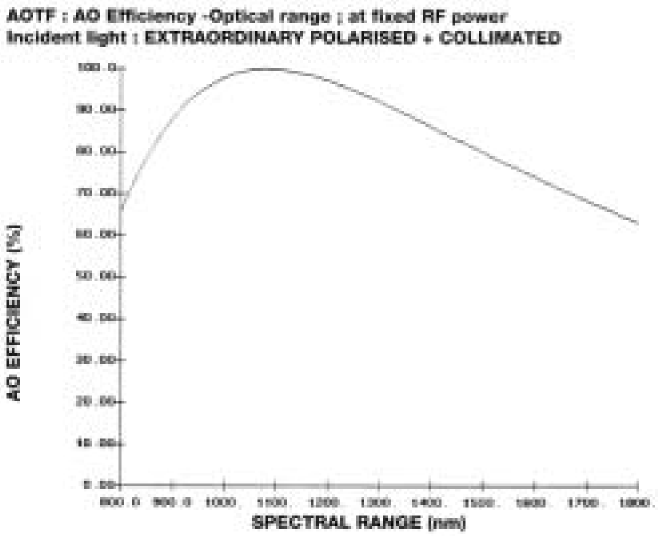
A wide length of interaction (L) and an adequate configuration of the wave vectors (synchronism on a small range of K) guarantee obtaining a low bandwidth and thus a low spectral width ($\Delta\lambda$).

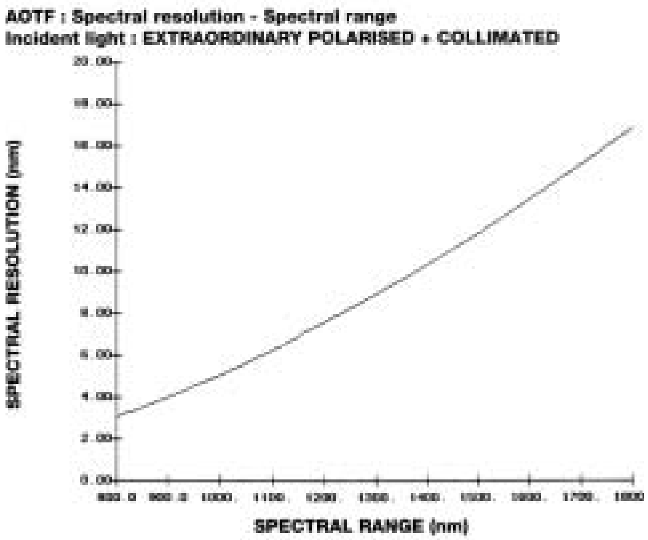
$$\lambda = a\frac{\Delta n(\lambda)}{F} \qquad \Delta\lambda = b\frac{\lambda^2}{L}$$

Δn: birefringence($=|n_2-n_1|$)
a and b are parameters which depends of θi and θa

Examples:







Characteristics of AOTFs

- The transmitted beam and the diffracted beam can be separated spatially or using polarizers.
- Can work in polarized light, or random polarization (lasers or lamps)
- Access time to a wavelength: several ms
- Temporal sweeping of the spectrum: µs to ms
- Possible auto calibration between each measurement
- Temporal modulation and synchronous detection
- Random or sequential access to any wavelength

Applications

The development of these devices is not so old, and many applications are still to come. The speed of measurements and the absence of any mechanical movement are the remarkable specifications of the acousto-optic filters.

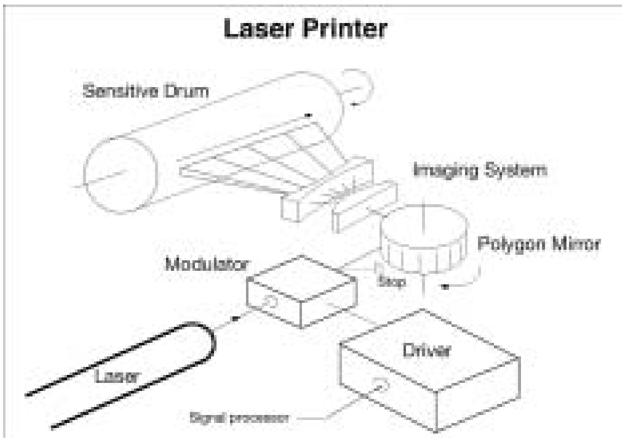
- Multi-spectral imagery (the AOTF is inserted in the imagery system)
- Spectral analysis
- Absorption, fluorescence analysis
- Polarimetric analysis

General

LASER PRINTING
One typical application for acousto-optic modulators is their use in laser printers :

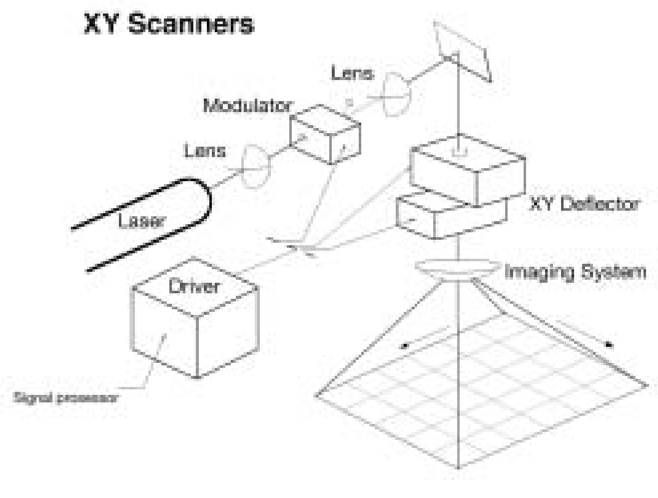
A rotating polygonal mirror scans a laser beam to form a complete line on the surface of a photosensitive drum (usually made from selenium). The laser beam is turned on and off with an acousto-optic modulator so that the scanned line is broken up into individual pixels. In this way, every time a polygon mirror facet goes past, a line of information is “written” to the drum. The drum, in turn rotates so that the document is reproduced line by line.

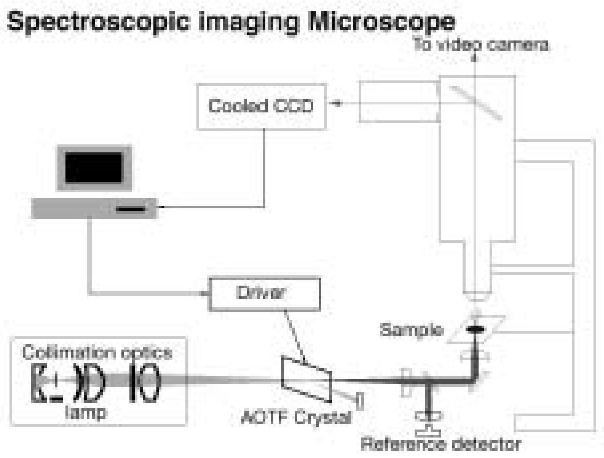
The information stored electrostatically on the drum’s surface is finally transferred to paper using “toner” – carbon particles.



VIDEO DISC RECORDERS
Information is recorded onto a video disc master using a high power laser (usually Ar^{+}). The application requires great accuracy in the direction and the intensity of the marking laser at the disc surface since the “pits” formed are generally only a few µm of diameter. An acousto-optic modulator is suitable for its accuracy, speed and reliability.

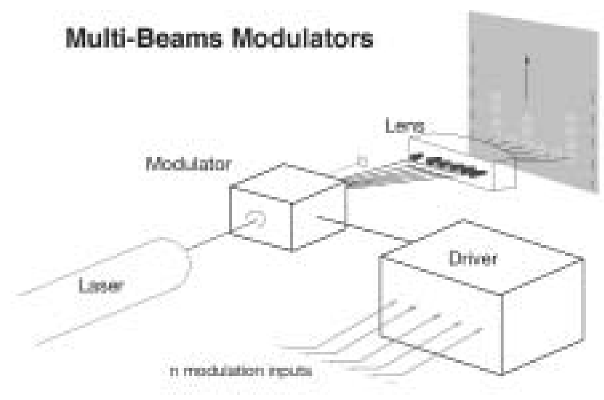
LASER PROJECTION SYSTEMS
Laser projection systems use a combination of modulators and scanners in a wide range of activities such as: displays, metrology, medical measurements…...
A laser beam is scanned, using either raster or random scanning. Different techniques for scanning include:
-One or two-axis acousto-optic deflectors
-Rotating polygon scanners
-Galvanometric scanners
Most systems will use one (or a combination) of these technologies but all these methods require a mechanism for modulating the scanned beam.
In systems using acousto-optic deflectors, the modulation function can often be carried out by the deflector itself. In other systems, a separate modulator is required.
Working with a single wavelength, a simple acousto-optic modulator can be used. In multi-color systems at very high modulation rates one modulator will be required for each color. At most modulation rates, however, a single polychromatic modulator (AOTF.nC) can be used to control the different wavelengths independently.





MULTI-BEAM DEFLECTORS

In certain printing applications, characters can be formed conveniently by writing data with several beams simultaneously.
This kind of device is called a “multi-beam deflector” and uses a single modulator crystal driven at several different RF frequencies. This produces a number of output beams, allowing a line of pixels be printed simultaneously. Characters can rapidly be built up by moving a photosensitive medium across the line of pixels or, alternatively, this technique can be used in combination with polygonal mirrors (or deflectors) to increase the printing speed rate.
Multi-beam modulators are generally used in custom applications, such as the coding of photographic film.



SPECTROSCOPIC IMAGING MICROSCOPE

In a spectroscopic imaging microscope, an AOTF is used as a programmable filter for a broad-band lamp. The sample is illuminated with near infrared radiation to stimulate the vibrational levels of various molecules, which absorb light at specific wavelengths and proportionally to the molecular concentration. So, a CCD image of the transmitted light is a map of molecular concentration. By varying the pass band of the AOTF, different molecules can be studied and the speed of operation of the AOTF matches the high data acquisition rate of the CCD.
This technique can be very useful in research laboratories for medical diagnostics.

MICROFILMER/MICROFICHER

A microfilm system uses the same principles as a laser printer. However, the polygonal mirror is replaced by an acousto-optic deflector. This device modulates and deflects the laser beam at the same time and can be used since the dimensions of the microfilm are small. Other useful applications for these devices are bdurategraphy and the fabrication of masks for circuit board production.

MONOCHROMATOR

A tunable acousto-optic filter can be used with an incoherent, broad-band source (such as a xenon lamp…). The light is collected and then collimated to match the filter’s aperture and acceptance angle.
The filter is driven with a RF signal whose frequency controls the transmitted wavelength.

At the filter’s output, the transmitted component (typical resolution – several nm) is available for use as a tunable light source.
This method has three main advantages :
-speed : a complete spectrum can be swept in a few milliseconds.
-wavelength and intensity can be controlled. Modulation up to many tens of KHz is possible – for fluorescence studies, perhaps.
-Ease of use, repeatability, and lack of mechanical parts.
The range of applications is vast : molecular absorption spectroscopy, fluorescence spectroscopy, microscopy…
AOTF spectrometers and spectrophotometers are being developed very widely in the pharmaceutical, chemical, food and plastics industries for rapid composition analysis.

CONTACTLESS MEASUREMENTS

Acousto-optic deflectors can be used for 2- and 3-dimensional surface mapping, even with complex shapes. Measurements are made by triangulation. The shape being mapped is scanned with a laser beam (HeNe, laser diode…), controlled accurately by an XY acousto-optic deflector and microprocessor. One or more CCD cameras, looking obliquely, record the positions of the laser spot and, by combining the data used to control the deflector and the measurements from the CCD cameras, a computer can generate a 3-dimensional position for each laser spot, and draw a map of an object.

COLOR MIXER

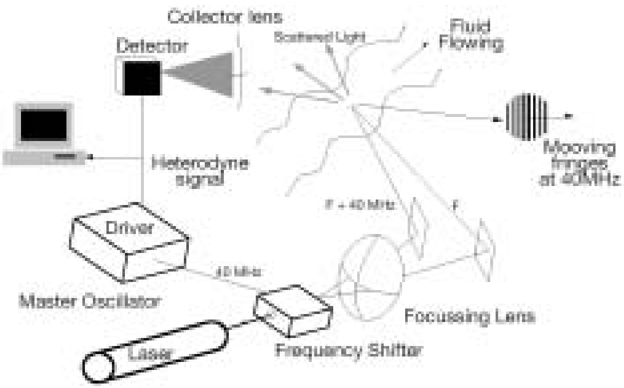
The AOTF.nC is a special filter which allows different lines of a high power laser beam (Ar+, Kr+, mixed gas…) to be controlled independently. Up to 12 lines can be mixed and separately modulated in order to compose different colors. While the main application is laser show field, further applications are being developed in, for instance, colorimetry.

LASER DOPPLER VELOCIMETER

Acousto-optic frequency shifters can be used to generate two optical beams with a fixed (or variable) RF frequency shift between them. This has many applications in diverse fields such as high resolution spectroscopy, telecommunications or metrology.

In the laser Doppler velocimeter, an acousto-optic shifter to generate a 1st order beam shifted by typically 40MHz from the 0th order. The 2 laser beams are then made to cross in a region of interest in a fluid or gas and will produce fringes. When this light is scattered from a particle it is found to be modulated at the 40MHz shift frequency – but slightly Doppler shifted according to the velocity of the particle. So, by sampling the scattered light the speed and direction of the particle's motion can be analyzed.

Laser Doppler veloci meter



MOLECULAR TRAPPING

Molecules can be "trapped" simply with a stationary laser beam, being attracted to the center of the beam by "pressure" of radiation. If the laser beam is focused down hard to create a definite beam waist then the molecule can be trapped in three dimensions.

With the addition of a 2-axis deflector, the laser beam can be moved and molecules can actually be manipulated and moved around.

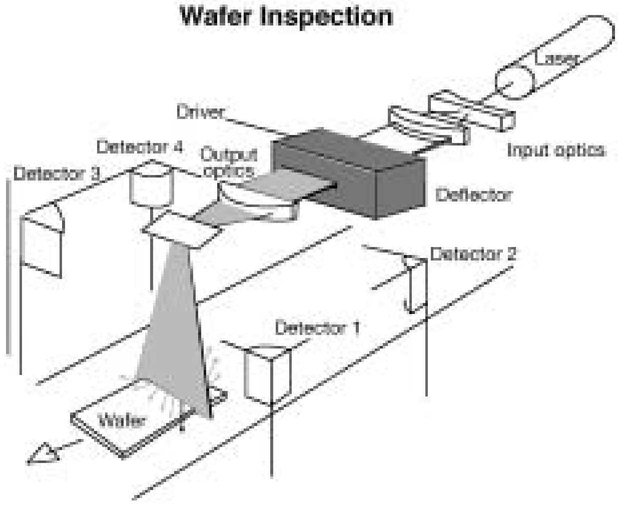
YAG lasers operating at 1064nm are generally used and deflectors are used to scan the laser beam through about one degree. Movements comparable with the pointing stability of the laser beam are used – generally only about 1% of the laser beam's divergence. To get this degree of resolution, and to be able to vary the frequency at the required rates, DDS drivers are used., with frequency steps of around 2kHz.

WAFER INSPECTION

A high speed acousto-optic deflector is used to scan a laser beam over an inspection line at high speed and with great accuracy. Light scattered from the wafer is continuously recorded by four detectors placed at the 4 corners of the wafer. The signal from the detectors is analyzed and processed. Depending on the light levels at the 4 detectors, the system can determine the number and position of defects, the presence of dust…...

Production can be stopped if the number of defects exceeds acceptable levels.

Wafer Inspection



POLARIMETRIC HYPERSPECTRAL IMAGERY

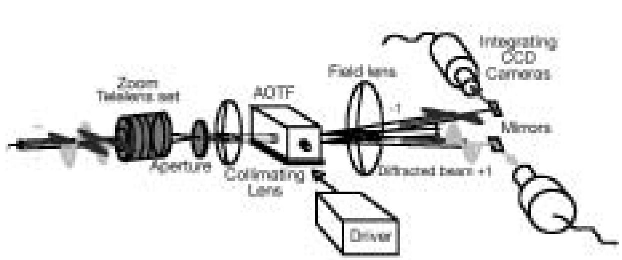
Many laboratories have orientated their researchs using AOTF for polarimetric hyperspectral imagery.

The AOTF technology has opened many potential applications, especially in geoscience, air and space borne remote sensing, target detection, vegetation analysis…

The great advantage using an AOTF is to be capable of measuring spatial, spectral and polarization characteristics of a target, in real time, without moving parts, only with a single instrument.

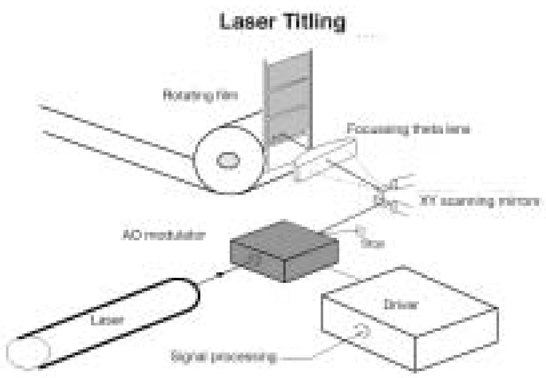
The multiplication of the analysis criterion (multi-spectral images+ H&S polarization images) improve the accuracy of the detection, and let us think to great developments in the near future.

Polarimetric hyperspectral Imagery

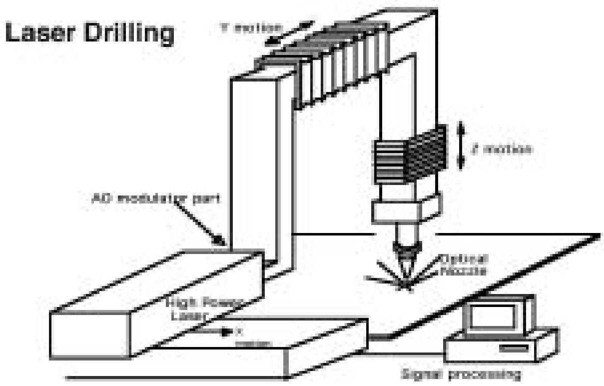


LASER TITTLING

Laser titling is a special application where high visible laser power is involved (generally Ar+). Laser power is focused down to the film where the tittles are written thanks to XY mirrors scanners. The AO modulator is used as a laser switch to obturate laser power between scanner displacement between two characters. It is also used as a laser power regulator in order to optimize the marking power to each kind of film support.



LASER DRILLING / CUTTING
While CO2 (10.6 µm) laser has been a standard for drilling, cutting and welding industry, the market is shared nowadays with other lasers such as Nd:Yag lasers (1.06 µm).
The couple AO modulator+driver is then the best alternative for medium / high laser power fast switch off. It is also used as a power regulator to match the applications / supports requirements in term of laser power level.
This technology can be used in applications ranging from perforating carbonless papers at low powers to welding metal bellows and cutting sunroof openings in auto bodies at higher powers.



RF DRIVERS

To meet the needs of its acousto-optic components over the last 20 years, A.A has developed a comprehensive range of fixed and variable frequency sources with associated RF drivers, operating from 1kHz to 3GHz. A number of techniques are used.

Fixed frequency sources:
Quartz
Fixed PLL

Variable frequency sources:
VCO (Voltage Control Oscillators)
PLL (Phase Locked Loop)
DDS (Direct Digital Synthesizer)

The choice of a driver will be given by the type of AO device and will depend on the application purposes.

Quartz drivers

These drivers have been especially designed to produce RF power levels and frequencies compatible with A.A's modulators. Drivers can be provided at any frequency from 10 to 300 MHz. All models use high stability (<50ppm) crystal controlled oscillators. The RF output can be externally modulated. The settling time varies from 100ns to 3ns depending on the fixed frequency. Usually the driver is coupled internally to a power amplifier; if the output power required is very high then the amplifier will be provided separately, offering RF powers up to 150 W.

PLL drivers (Phase locked Loops)
Phase Locked Loop drivers are VCO based, but stabilize the output frequency against a crystal based reference. The fundamental crystal frequency is divided down and, by changing the division ratio, the output frequency can be altered.
At frequencies over 300MHz, where quartz oscillators may be difficult to build, these sources offer very high performance. Optional amplifiers can be added to increase the output power. These variable frequency drivers will be chosen for their accuracy and stability, but their commutation time is slow : from several µs to ms.
Identical in principle to fixed frequency PLL sources, these units are designed for variable frequency operation. Since the PLL loop needs time to stabilize, these drivers are suitable for high accuracy but lower speed applications.

The typical models cover a wide range from 10 to 3000MHz, with octave or multi-octave frequency ranges. The number of frequency steps can be specified from 100 to > 10000. Frequency control is generally digital, controlled via a parallel or series input.

VCO drivers (Voltage controlled oscillators)

Deflectors or variable frequency shifters require a variable frequency source covering a suitable frequency which might lie anywhere between 10MHz and 2GHz. VCOs are ideal for raster scan or random access. Their stability and linearity will be a limitation for some applications.
For general purpose applications, three types of VCO drivers are available, differing only in their sweep time (Fmin to Fmax.) which can be ≤ 1 µs, ≤ 10 µs or ≤ 100 µs.
The VCO's can be modulated (amplitude) from an external signal. An external medium power amplifier will be required to generate the RF power levels required by the AO device.

DDS drivers (Direct Digital Synthesizers)

To get a high resolution driver with fast switching time, A.A has designed direct digital synthesizers based on monolithic IC circuits. 2 models have already been released, and different units can be designed to specific requirements.
Both models offer high frequency accuracy and stability and extremely fast switching times, generally of a few tens of nanoseconds.
The DAC circuits have been designed with utmost care to obtain clean RF signals, with minimum spurious noise.

Power amplifiers

A.A's acousto-optic amplifiers are linear with large bandwidth

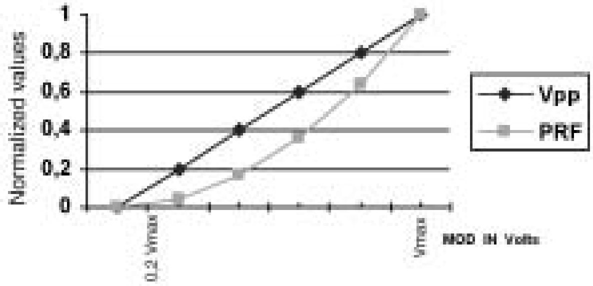
and medium or high power.
They are specially designed for AO devices and adjusted at factory to fit the AO frequency range, impedance and necessary RF power..
Each amplifier is supplied with its heat sink and all are stable and reliable under all conditions.

Glossary

Output RF power

The output RF power PRF through a 50 Ω load (R) is related to the peak to peak signal amplitude Vpp by the relation :

$$P_{RF} = \frac{V_{pp}^2}{8R} = \frac{V_{pp}^2}{400}$$



VSWR (voltage stationary wave ratio)

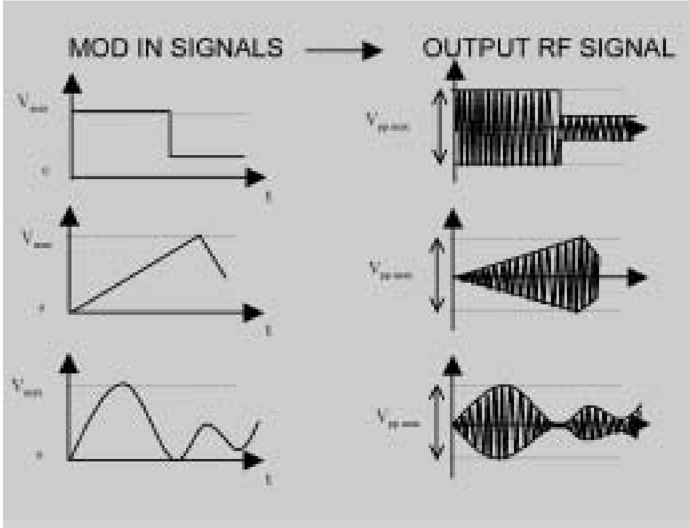
This parameter gives an information on the reflected and transmitted RF power to a system.
In order to have the best matching between an acousto-optic device and a radio frequency source/amplifier, one will have to optimize both impedance matching on the source and the driver. Generally, input impedance of an acousto-optic device is fixed to 50 Ohms as well as the output impedance of the driver/amplifier.

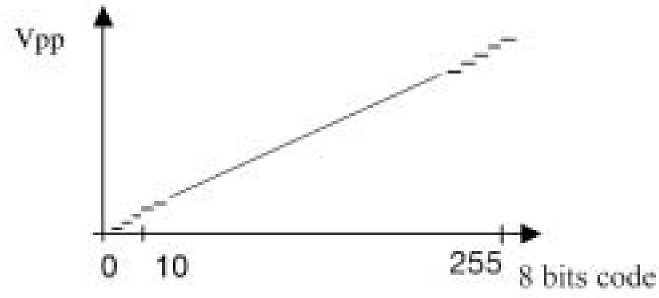
VSWR	POWER reflected %
1.002 / 1	0.0001
1.068 / 1	0.1
1.15 / 1	0.5
1.22 / 1	1
1.5 / 1	4
2 / 1	11
2.5 / 1	18
3 / 1	25

AMPLITUDE MODULATION

ANALOG MODULATION (0-Vmax)

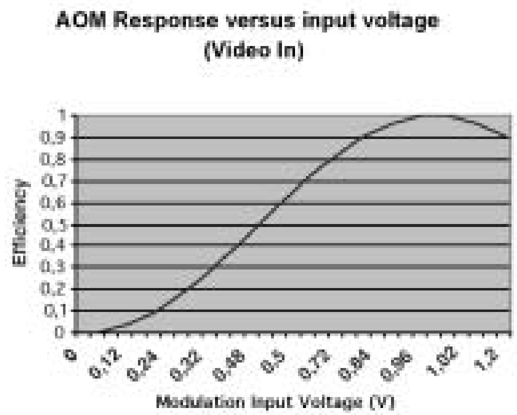
The analog modulation input of your driver controls linearly and continuously the output RF amplitude of the signal from 0 to maximum level.
• When applying 0 V on "MOD IN", no output signal
• When applying Vmax on "MOD IN", maximum output signal level
The output RF waveform is a double-sideband amplitude modulation carrier.
Vmax can be adjusted at factory from 1 V to 10 V.

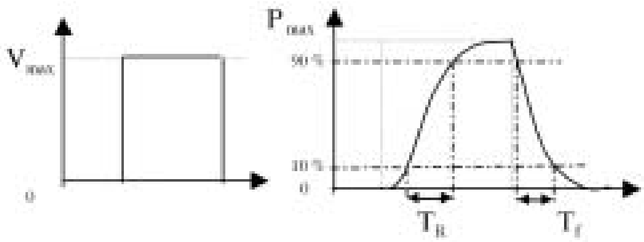




RISE TIME / FALL TIME

The rise time Tr and fall time Tf of your driver specified in your test sheet corresponds to the necessary time for the output RF signal to rise from 10 % to 90 % of the maximum amplitude value, after a leading edge front. This time is linked to carrier frequency and RF technology.
The class A drivers from AA, offer the best rise/fall time performances.





TTL MODULATION (ON/OFF)

The TTL modulation input of your driver is compatible with standard TTL signals. It allows the driver to be driven ON and OFF.

- When applying a “0” level (< 0.8 V) on “MOD IN”, no output signal.
- When applying “1” level (> 2.4 V) on “MOD IN”, maximum output signal level.

It will be noted that a TTL modulation input can be piloted with an analog input signal.

EXTINCTION RATIO

The extinction ratio of your driver specified in the test sheet is the ratio between the maximum output RF level (MOD IN = max value) with the minimum output level (MOD IN = MIN value).

A bad modulation input signal can be responsible for the extinction ratio deterioration.

$$Extinction\ ratio = 10\log\left(\frac{P_{max}}{P_{min}}\right) = 20\log\left(\frac{V_{pp\,max}}{V_{pp\,min}}\right) \quad (dB)$$

Digital 8 bit AMPLITUDE MODULATION

A byte (8 bit //) controls the amplitude of the output RF signal.
A D/A converter converts the 8 bits command (N) on an analog signal which controls linearly the output amplitude.
256 levels are available

- When N=00000000, no output RF signal
- When N=11111111, maximum output level

FREQUENCY CONTROLS

ANALOG CONTROL (0-V$_{max}$)

The analog frequency control input of your driver controls linearly and continuously the output RF frequency of the signal from Fmin (minimum frequency) to Fmax (maximum frequency).
The minimum and maximum frequencies are set at factory, and can be slightly adjusted with potentiometers “OFFSET” and “GAIN”.
The typical linearity of the frequency versus input command for standard VCOs is typically +/- 5%.

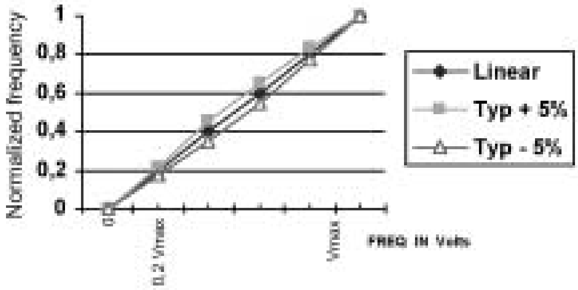
Sweeping time (VCO)

This is the maximum necessary time to sweep frequency from minimum to maximum, or maximum to minimum.
This value will be taken as the maximum random access time, though it depends on the frequency step.

- When applying 0 V on “FREQ IN”, Frequency = F min
- When applying Vmax on “FREQ IN”, Frequency = F max

(Standard frequency control input : 0-10 V / 1KΩ).

Acousto-optics from A.A Sa 6,rue de Versailles F-78470 Saint-Rémy-lès-Chevreuse Tél. : 33(0)1 30 52 87 17 - Fax : 33(0)1 30 52 78 03 - www.a-a.fr



8 BITS FREQUENCY CONTROL

A byte (8 bit //) controls the frequency of the output RF signal. A D/A converter converts the 8 bits command (N) on an analog signal which controls linearly the output frequency.
256 steps are available : refer to your test sheet for pin connexions.

- When N=00000000, RF signal frequency = F minimum
- When N=11111111, RF signal frequency = F maximum

AO ADJUSTMENTS AND PRECAUTIONS

Mechanical Precautionary Measures

To avoid any damage to the crystal or glass, make sure that fixing screws and the rotation axis are not so long as to protrude through the base of the device.

Optical Precautionary Measures - Windows cleaning

Use a Q-tip. Clean first with pure ethanol, then with acetone. Most AO devices use soft materials and need careful cleaning.
"Oily stains" should be removed immediately to avoid irreversible marks.

Laser power density

Check the maximum value specified for the given AO device, especially when focusing the laser to maximize bandwidth. With a high power laser, make sure you do not focus directly onto the optical faces.

Laser polarization

Check the specified optical polarization is correct for optimum AO efficiency (random, circular, perpendicular or parallel to the base - depending on device).

Optical aperture

The holes in the housing of the modulator are usually larger than the actual specified optical aperture. The AO device will need to be adjusted, using slight translations perpendicular to the laser beam, to get the beam traveling through the correct area of the crystal and to maximize efficiency.

Incidence angle

For an isotropic interaction, adjust the incidence angle to achieve the Bragg configuration. For a birefringent interaction, work to the sketch of interaction which will be supplied with the unit.

Electrical Precautionary Measures

Do not operate the RF driver without the specified amount of cooling!
Do not operate the RF driver without a load!
(either a suitable 50 W load or an AO device)
Do not exceed the specified values for the power supply and control voltages.

CONCLUSION

The goal of these application notes is not to give a complete overview of acouto-optics, but to give the user the main useful informations to select an acousto-optic device and to start an acousto-optic application.
For more detailed informations several books are available from literature. It will also be a pleasure for AA's engineers to help the user to set up his application.

CONTENTS

OPTO-ELECTRONIC

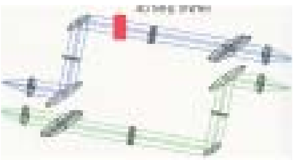
A.A is a world leader in the manufacturing of quality Acousto-optic and radio frequency devices.

Founded in France (1979) as "Automates et Automatismes", for the manufacturing of Pneumatic Automation, A.A evolved in the early 80's, when an Acousto-optic laboratory was created by a spin-off from "Soro", a famous French optical manufacturer, into a design and manufacturing company of optical systems and Acousto-optic devices. In 1988 A.A became a limited company, focused on Acousto-optic and associated radio-frequency drivers.
The telecommunication/microwave division, created in 1994, specializes in providing solutions for the French satellite communication market and microwaves/RF systems for military, spatial and telecom applications.

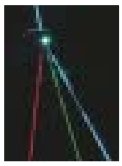
Close collaboration with universities and research institutes, provided invaluable knowledge and experience in the design and manufacturing processes of Acousto-optic devices and radio-frequency sources. Continuous R&D keeps pace with advances in laser and electronic technology to ensure A.A continues to offer state-of-the-arts products.

A.A. offers its customers solutions from prototype design to large volume manufacturing:
1) In-house design capabilities:
AO design software, opto-mechanical design software, RF/microwave simulation software
2) In-house manufacturing capabilities:
X-ray orientation, crystals and glasses cutting and polishing, coating, metallic deposition, molecular bonding under vacuum, soldering wave-machine for large radio-frequency sources production.
3) In-house test and quality control equipment:
Laser interferometers, network analyzers, spectrum analyzers, digital oscilloscopes, a large range of lasers for final tests and controls, and more.

Mastering all critical areas of the AO and RF technology, allows A.A to accompany its customers from the concept design to large volume manufacturing.
A.A thrives to maintain a high-tech up-to-date line of products and excellent service. Dedicated to customer's satisfaction, A.A's worldwide representation ensures quality products, local support with competitive prices.





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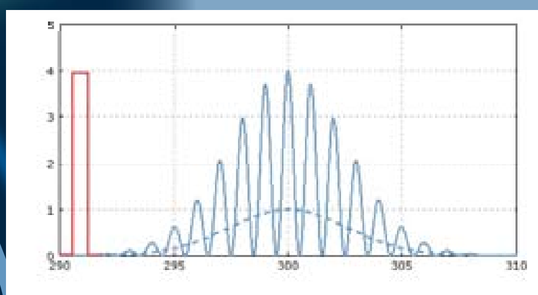
PULSE PICKING

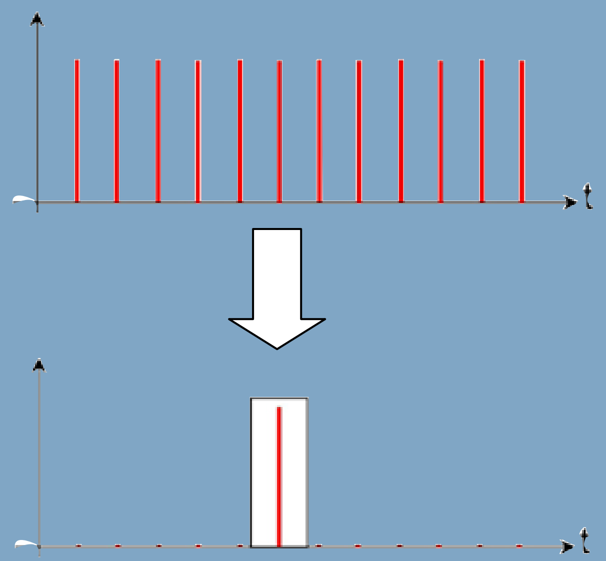
Acousto-optic products



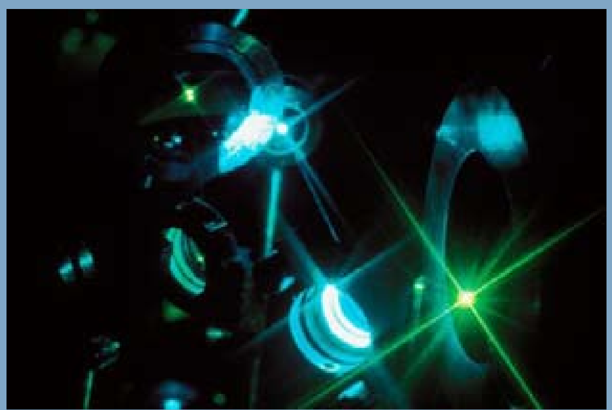
www.aaoptoelectronic.com

Introduction
Pulse Picking

A pulse picker is an electrically controlled optical switche used for extracting single pulses from a fast pulse train.



Short and Ultrashort pulses are in most cases generated by a mode-locked laser in the form of a pulse train with a pulse repetition rate of the order of 10 MHz – few GHz.
For various reasons, it is often necessary to pick certain pulses from such a pulse train, i.e., to transmit only certain pulses and block all the others. This can be done with a pulse picker, which is essentially an electrically controlled optical gate.



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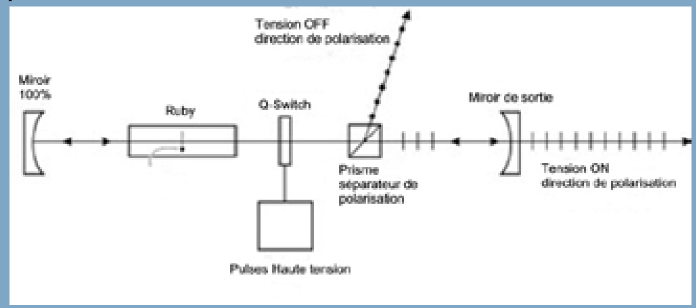
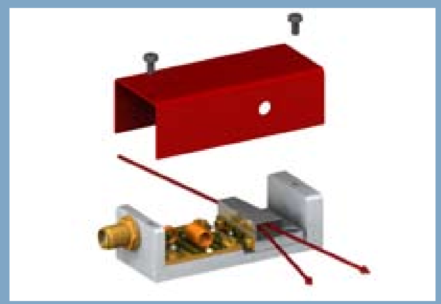
Types of Pulse Pickers

A pulse picker is in most cases either an electro-optic modulator either an acousto-optic modulator, combined with a suitable fast electronic driver.

EOM: In the case of an electro-optic device, a pulse picker consists of a Pockels cell and some polarizing optics, the Pockels cell manipulates the polarization state, and the polarizer then transmits or blocks the pulse depending on its polarization.



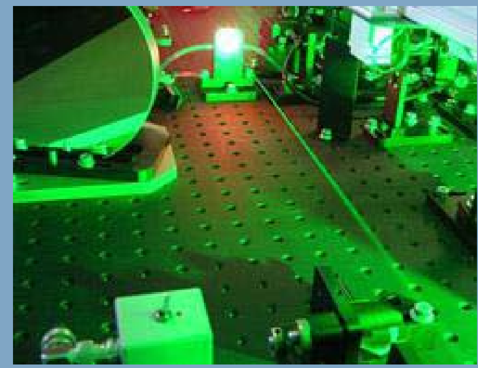
AOM: The principle of an acousto-optic pulse picker is to apply a short RF pulse to the acousto-optic modulator so as to deflect the wanted pulse into a slightly modified direction. The deflected pulses can then pass an aperture, whereas the others are blocked.
In any case, the required speed of the modulator is determined by the temporal distance of pulses in the pulse train (i.e. by the pulse repetition rate of the pulse source), rather than by the pulse duration.



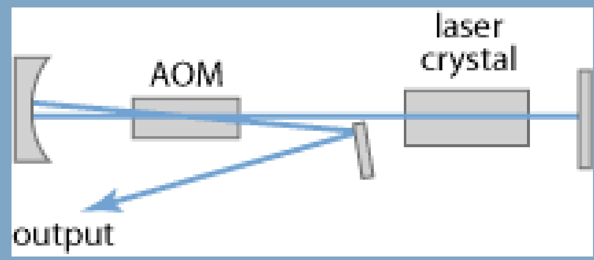
The EOM is a fast solution but generally does not offer high repetition rates due to the high voltage driver which cannot be switchable at high repetition rate. In this case, despite the AOM is slower, it will be preferred offering repetition rates over MHz.

Applications of Pulse Pickers

Some typical applications of a pulse picker are described in the following:

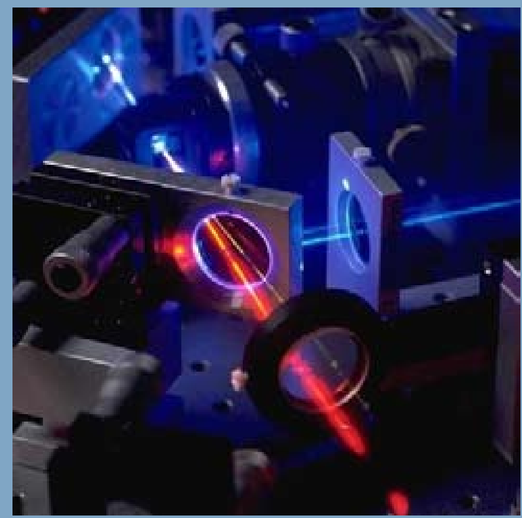


• To obtain high pulse energies in ultrashort pulses, it is frequently necessary to reduce the pulse repetition rate. This can be achieved by placing a pulse picker between the seed laser and the amplifier. The amplifier will then act only on the wanted pulses. The blocked pulses do not necessarily constitute a strong energy loss since the average power of the seed laser may be small compared with the average output power of the amplifier, and the remaining average power can be sufficient for saturating the amplifier.



• In a cavity-dumped laser, a pulse picker (then often called cavity dumper) extracts the circulating pulse from the cavity in only every Nth round trip. During all the other round trips, the pulse experiences low optical losses and can be amplified to a high energy.

• A pulse picker can be used for injection and extraction of pulses in a regenerative amplifier. (See AO fiber pulse picker)



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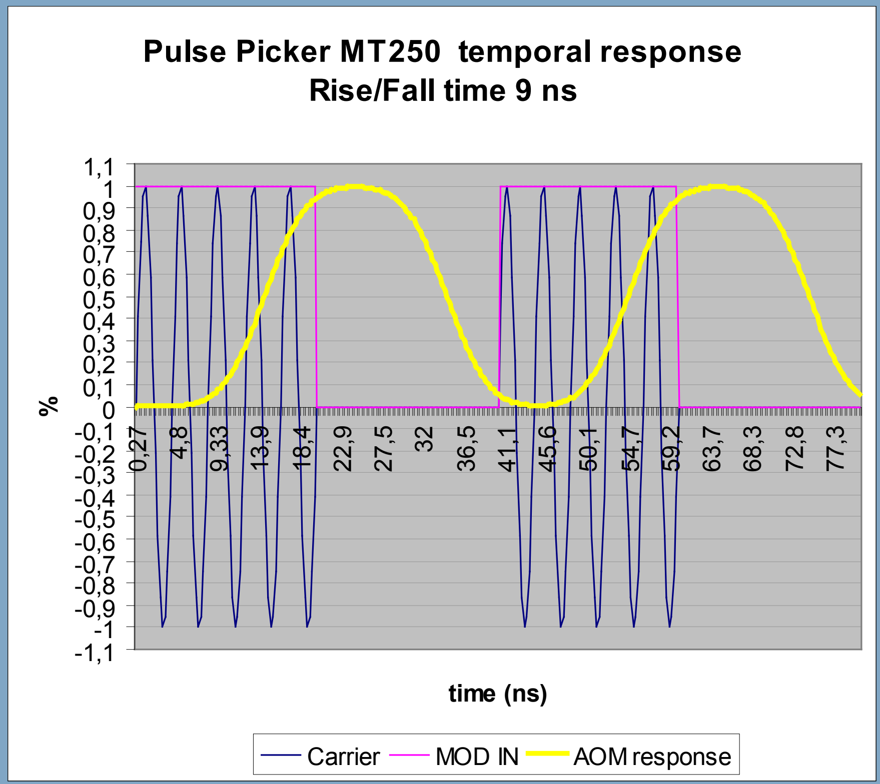
http://www.rp-photonics.com/encyclopedia.html - http://www.rp-photonics.com

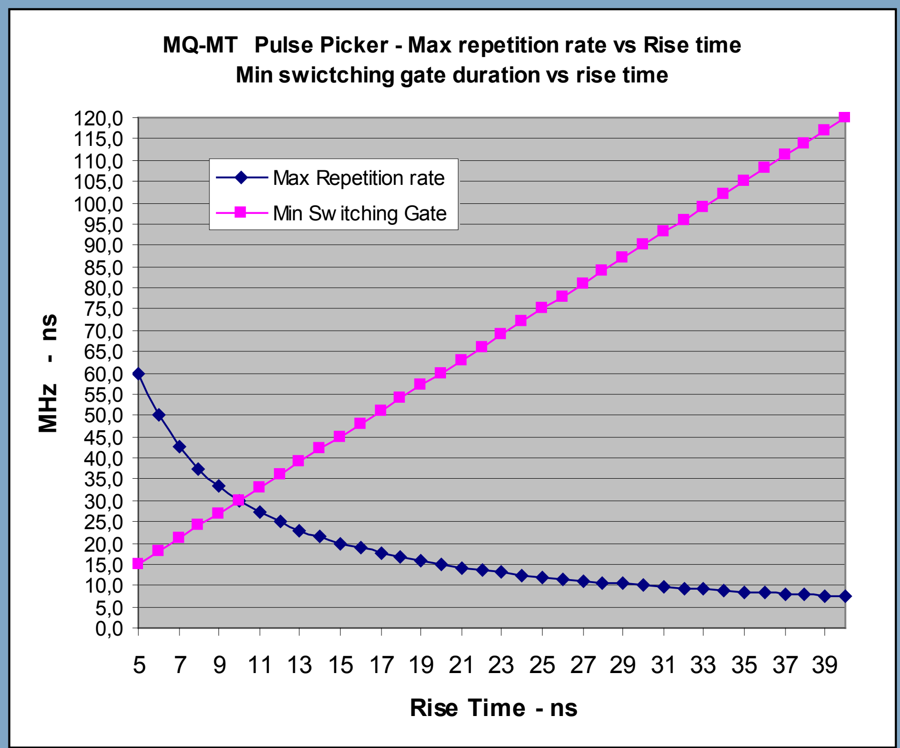
How to choose an AO Pulse Picker?

Depending on the application, different properties of a pulse picker can be critical:



- **The switching time** (particularly for high input pulse repetition rates) or Rise/Fall time

For an AO pulse picker, the rise/fall time is linked to the laser beam diameter inside the AOM.
We define this time for the AO to reach efficiency from 10 to 90% in first order. For fast rise/fall times, the beam will be focussed inside AOM downto few 10s of micrometers.



- **The maximum repetition rate for the switching**

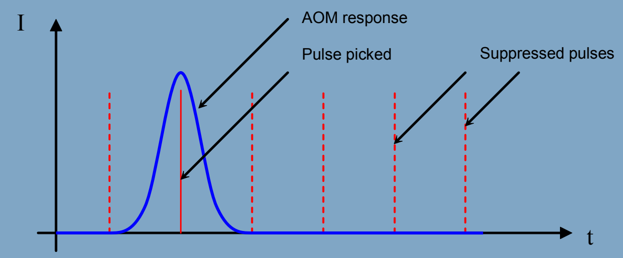
For an AOM, this time is directly linked to rise/fall time of the AOM.
Nevertheless, the average RF power inside AOM will be another limit so as to not get thermal effects, or simply to avoid water cooling.

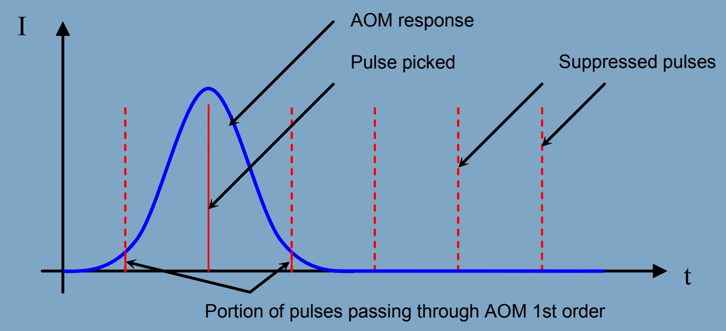
- **The energy loss of transmitted pulses**

It is directly linked to diffraction efficiency of AO device, or what is called losses in case of a fiber coupled device. For most AO pulse pickers, it can reach 75 to 90%.

- **The degree of suppression of unwanted pulses**

It is related to the extinction ratio of the AOM and associated RF driver. Most of the time the main problem is linked to dynamic extinction ratio. For instance, the fall time of the AOM is not fast enough so that a portion of the next (or previous) pulse is also passing through AOM first order.





- **The optical bandwidth (particularly for broadband pulses fs)**

The output first order angle is proportional to the wavelength. In case the linewidth of the incoming beam is brroaden because of an ultra-short pulse then it can lead to a broadening of output first order angle. In an other hand, the transmission of the AOM can be affected because of a mismatch with transmission curve of the AOM AR coating.

- **The chromatic dispersion (particularly for broadband pulses, with durations <<100 fs)**

The optical velocity inside the interaction medium is different for each wavelength. Broader will be the input spectrum, higher will be the chromatic dispertion of the pulse. This effect will be more sensitive in TeO2 (High refractive index) than in fused silica.

- **The size of the active aperture**

This is the area where the acousto-optic effect can occur. The laser beam must be completely inside this area in order to get maximum performances. This aperture will also be linked to requested rise time.

- **The outer dimensions/cooling**

Because generally the duty cycle of the pulse picker is low (<<1% ON), then the average RF power inside AOM is low and consequently we can have a high efficiency, air cooled pulse picker either based on TeO2, either based on Fused Silica. Nevertheless, due to the low figure of Merite of SiO2, the necessary RF peak power will be much higher than with TeO2.

- **The damage threshold**

The TeO2 pulse picker will be selected for its low driving RF power, while the SiO2 pulse picker will be chosen for its higher damage threshold.
TeO2 (Typ 100W/mm², <30 MW/cm² with ns pulses @1µm)
SiO2 (Typ > 1GW/cm² with ns pulses @1µm)

- The capabilities of the corresponding electronic driver, regarding rise/Fall time, extinction ratio, synchronization and control signals.

Selection of AA Standard Pulses Pickers

TeO2 General purpose Pulse Pickers

Model	Material	Wavelength nm	Aperture mmxmm	Polarisation	Beam diameter mm	Rise Time ns	Max Repetition rate with Duty cycle < 1/10 MHz	Separation angle (0-1) mrd	Efficiency %
MT200-A0.4-IR	TeO2	700-900	0.4 x 1	Linear	0.06 - 0.3	10 - 48	3.3 - 0.69	38 @800nm	75 - 85
MT200-A0.4-1064	TeO2	980-1100	0.4 x 1	Linear	0.09 - 0.3	15 - 48	2.2 - 0.69	50.6 @1064nm	75 - 85
MT250-A0.12-IR	TeO2	700-900	0.12 x 1	Linear	0.04 - 0.1	6 - 16	5.5 - 2	47.6 @800nm	70 - 85
MT250-A0.12-1064	TeO2	980-1100	0.12 x 1	Linear	0.05 - 0.1	8 - 16	4.1 - 2	63.3 @1064nm	70 - 85

ASSOCIATED RF DRIVERS

Driver MODAXX
TTL or Analog control

SiO2 High Damage Threshold Pulse Pickers

Model	Material	Wavelength nm	Aperture mmxmm	Polarisation	Beam diameter mm	Min Rise Time ns	Max Repetition rate with Duty cycle < 1/100 KHz	Separation angle (0-1)	Efficiency %
MQ80-A0.7-1064	SiO2	1000-1100	0.7 x 1	Linear	0.3 - 0.5	33 - 55	100 - 60	14.3 @1064nm	75 - 85
MQ150-A0.3-1064	SiO2	1000-1100	0.3 x 1	Linear	0.08 - 0.2	9 - 22	370 - 150	26.8 @1064nm	50 - 70

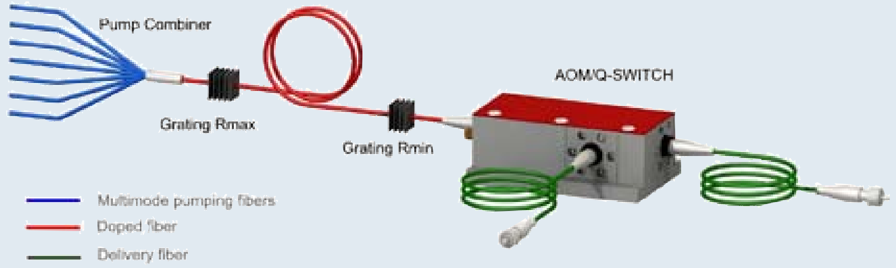
Driver QMODP0XX
TTL and Analog control

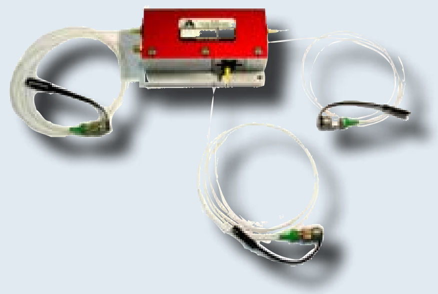
Fiber Pigtailed Pulse Picker

Model	Material	Wavelength nm	Fiber Type	Number of ports	Min Rise Time ns	Max Repetition rate with Duty cycle < 1/10 MHz	Losses dB Nom
MT110-IR20-FIO	TeO2	1000-1100	SM or PM	2	20	1.6	2.5
MT200-IR10-FIO	TeO2	1000-1100	SM or PM	2	10	3.2	5
MT250-IR6-FIO	TeO2	1000-1100	SM or PM	2	6	5.5	5.5
MT110-IR25-3FIO	TeO2	1000-1100	SM or PM	3	25	1.3	2.5

Driver QMODP1XX
TTL and Analog control

Fiber Laser





NOTES on Pulse Picker operation

1] Effect of the driver on pulse picking

The rise and fall time of the driver has a critical influence on average switching time of the pulse picker, especially in the case of fast switching time. The average rise/fall time of the AOM is linked to intrinsic rise time of AOM and driver as follows :

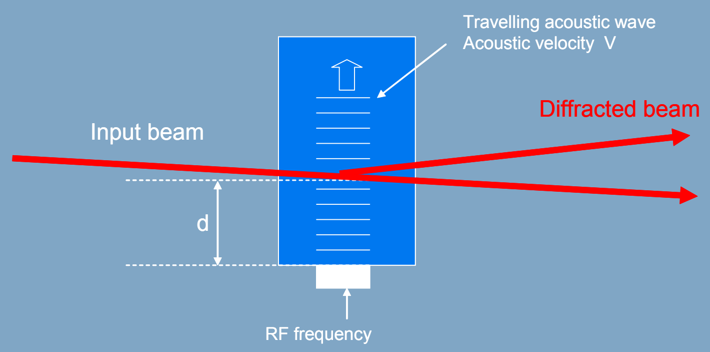
$$T_{r\_avr} = \sqrt{T_{rAO}^2 + T_{rRF}^2}$$

Example:
Tr AO = 8 ns
Tr Driver = 10 ns --> Taverage = 12.8 ns

2] Synchronization of the pulse and Delay time

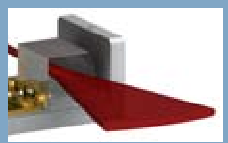
The acousto-optic interaction occurs after a certain time (delay time) after the trig signal. This time called «delay time» corresponds to the acoustic propagation from transducer to laser beam after distance d. This corresponds to 238 ns/mm in TeO2-L and 168 ns/mm in fused silica. The synchronisation of the AO open gate with the laser pulse to be picked can be realized in two ways:

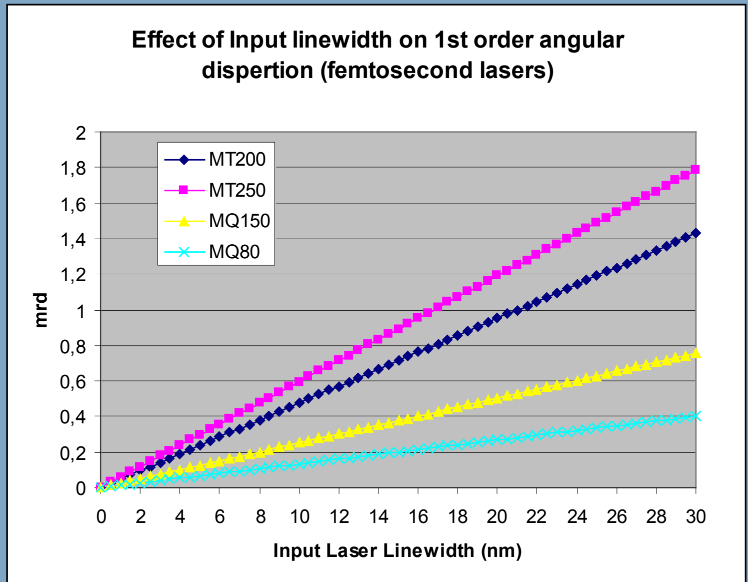
1- Mechanical way: by translating AO cell along acoustic axis, and thus modifying distance d
2- Electronic way: either by introducing delay on RF driver trigg signal, either by introducing delay on output RF signal



3] 1st orderAngle broadening vs input linewidth

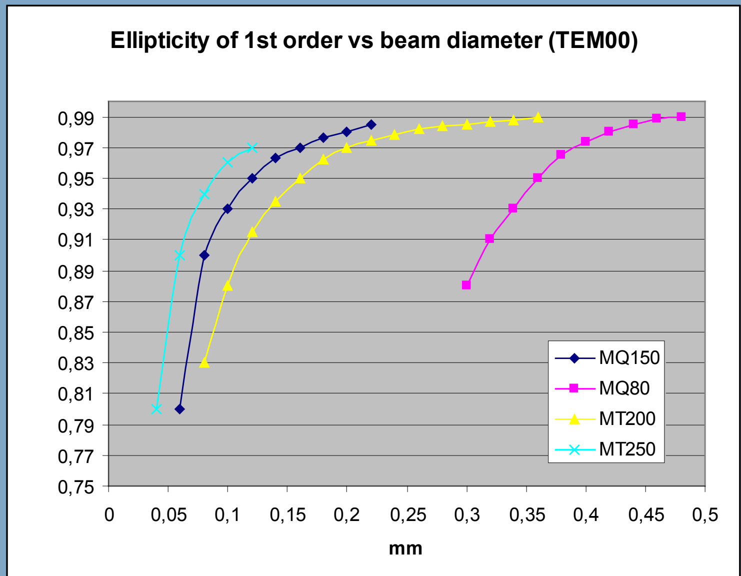
The output first order angle is proportional to the wavelength. In case the linewidth of the incoming beam is brroaden because of an ultra-short pulse then it can lead to a broadening of output first order angle.





4] Effect of highly focussed beams inside AOM

To get correct diffraction efficiency and low ellipticity of first order, there must be a convenient overlap between acoustic divergence and optical input divergence. At the contrary, first order beam becomes highly eliptical and diffraction efficiency drops.

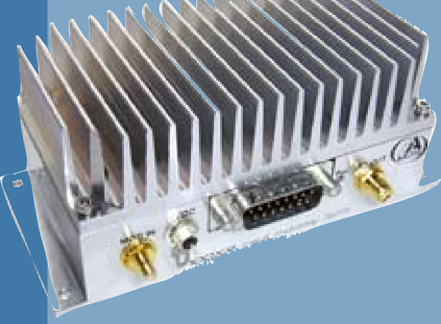


ASSOCIATED RF DRIVERS

MODAxx

1 to 20 Watts

Power supply 24 VDC
80, 110, 200, 250 MHz
AM control TTL or Analog 0-1V / 0-5V
Rise / Fall time typ 2-10 ns (freq dependant)
Heat exchange Heatsink+fan+conduction
Class A



QMODP0

10 to 20 Watts

Power supply 24 VDC
80 MHz, 110 MHz
Pulse control TTL or TTL reversed
Power control Analog 0-5V (PAC or FAC)
Rise / Fall time typ 10-20 ns
Heat exchange Heatsink+fan+conduction
Class AB

QMODP1

10 to 20 Watts version

Power supply 24 VDC
80, 110 MHz
Pulse control TTL reversed
Power control Analog 0-5V (PAC or FAC)
Riise / Fall time typ 20 ns
Heat exchange: conduction through baseplate
Class AB
Thermal security

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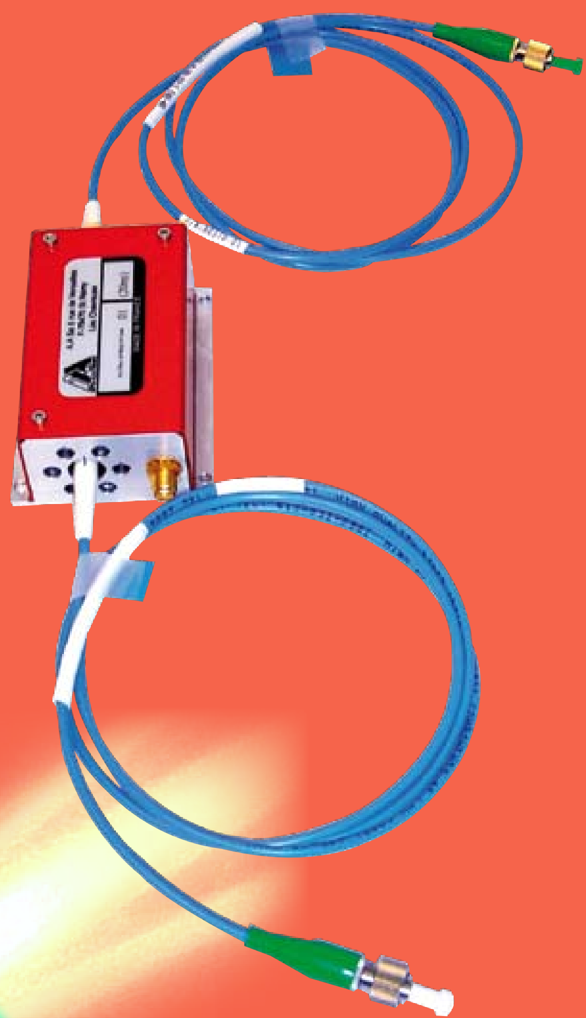
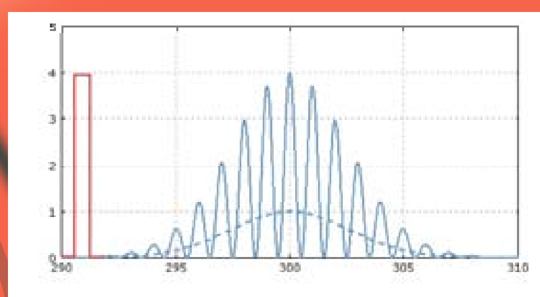
Fiber Pigtailed Variable Frequency Shifters

Acousto-optic products





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Introduction Frequency Shift

3- PHYSICAL PRINCIPLES MAIN EQUATIONS

An RF signal applied to a piezo-electric transducer, bonded to a suitable crystal, will generate an acoustic wave. This acts like a "phase grating", traveling through the crystal at the acoustic velocity of the material and with an acoustic wavelength dependent on the frequency of the RF signal. Any incident laser beam will be diffracted by this grating, generally giving a number of diffracted beams.

3-1 Interaction conditions

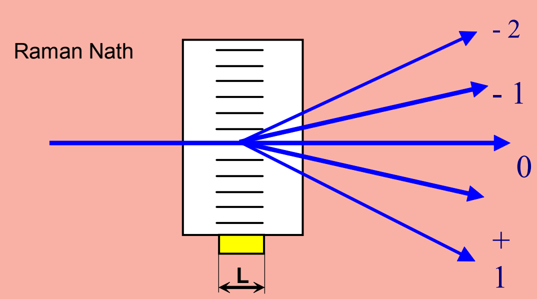
A parameter called the "quality factor, Q", determines the interaction regime. Q is given by:

$$Q = \frac{2\pi\lambda_0 L}{n\Lambda^2}$$

where λ_0 is the wavelength of the laser beam, n is the refractive index of the crystal, L is the distance the laser beam travels through the acoustic wave and Λ is the acoustic wavelength.

Q<<1 :This is the Raman-Nath regime. The laser beam is incident roughly normal to the acoustic beam and there are several diffraction orders (...-2 -1 0 1 2 3...) with intensities given by Bessel functions.

Q>>1 : This is the Bragg regime. At one particular incidence angle *B, only one diffraction order is produced - the others are annihilated by destructive interference.



In the intermediate situation, an analytical treatment isn't possible and a numerical analysis would need to be performed by computer.

Most acousto-optic devices operate in the Bragg regime, the common exception being acousto-optic mode lockers and Q-switches.

3-2 Wave vectors constructions

An acousto-optic interaction can be described using wave vectors. Momentum conservation gives us :

$$\vec{K}_d = \vec{K}_i +/- \vec{K}$$

Ki = $2\pi ni/\lambda_o$ – wave vector of the incident beam.
Kd = $2\pi ni/\lambda_d$ – wave vector of the diffracted beam.
K = $2\pi F/v$ – wave vector of the acoustic wave.

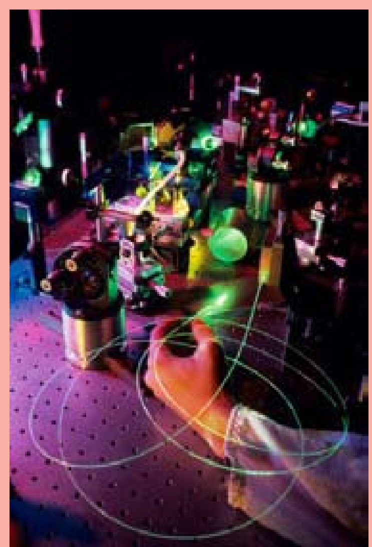
Here F is the frequency of the acoustic wave traveling at velocity v. ni and nd are the refractive indexes experienced by the incident and diffracted beams (these are not necessarily the same).

Energy conservation leads to : Fd = Fi +/- F

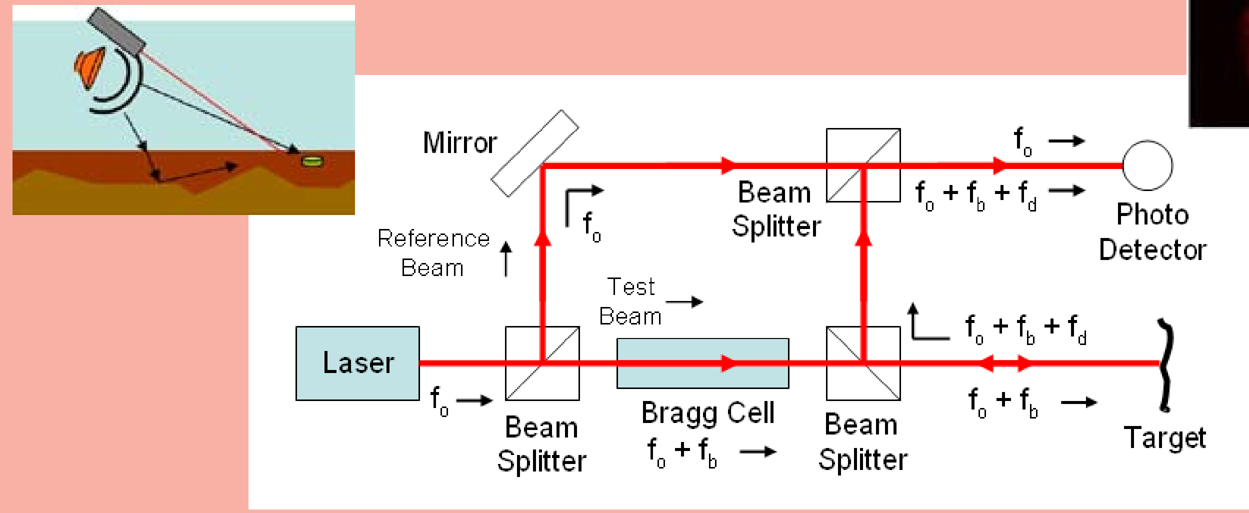
So, the optical frequency of the diffracted beam is by an amount equal to the frequency of the acoustic wave. This "Doppler shift" can generally be neglected since F<<Fd or Fi, but can be of great interest in other applications such as heterodyning, Doppler or OTDR applications.
It is important to notice that the frequency shift can be positive or negative.

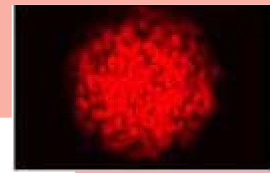
Double pass
The double pass inside the same AOS allows to double the frequency shift linked to the interaction. With this method, we can create high shifts values over 500MHz.

Low frequency shifts
The cascade of two frequency shifters, one with positive shift and the second one with negative shift, allows to create small values of frequency shift as low as 0. this method is commonly used for low frequency shifters below 35 MHz.



LASER DOPPLER VIBROMETER (LDV)





A Laser Doppler Vibrometer (LDV) is a scientific instrument that is used to make non-contact vibration measurements of a surface. The laser beam from the LDV is directed at the surface of interest, and the vibration amplitude and frequency are extracted from the Doppler shift of the laser beam frequency due to the motion of the surface. The output of an LDV is generally a continuous analog voltage that is directly proportional to the target velocity component along the direction of the laser beam.

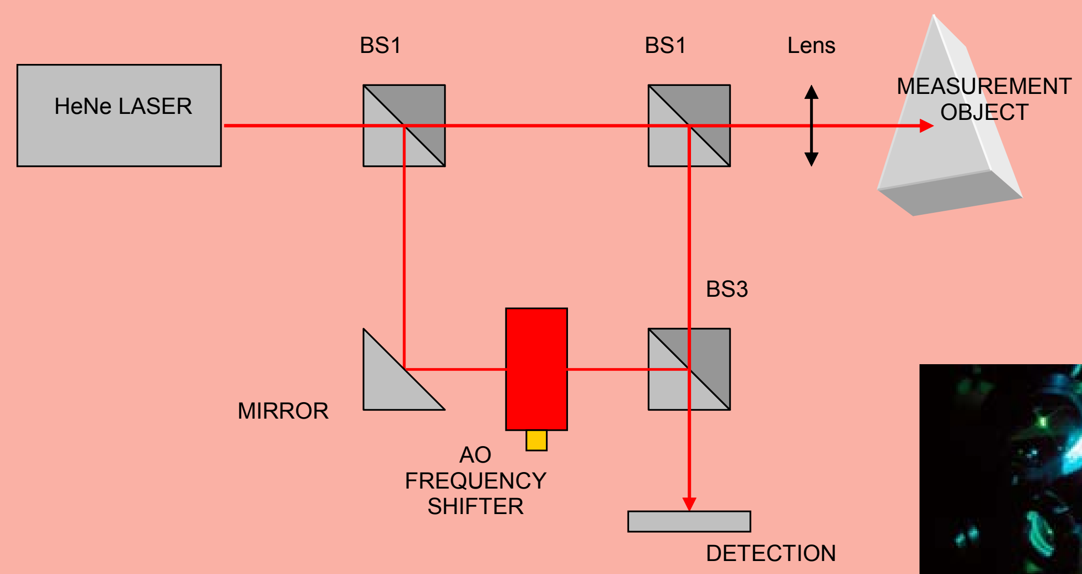
A vibrometer is generally a two beam laser interferometer that measures the frequency (or phase) difference between an internal reference beam and a test beam. The most common type of laser in an LDV is the Helium-Neon laser[1], although laser diodes[2], fiber lasers, and Nd:YAG lasers are also used. The test beam is directed to the target, and scattered light from the target is collected and interfered with the reference beam on a photodetector, typically a photodiode. Most commercial vibrometers work in a heterodyne regime by adding a known frequency shift (typically 30-40 MHz) to one of the beams. This frequency shift is usually generated by a Bragg cell, or acousto-optic modulator.

A schematic of a typical laser vibrometer is shown below. The beam from the laser, which has a frequency fo, is divided into a reference beam and a test beam with a beamsplitter. The test beam then passes through the Bragg cell, which adds a frequency shift fb. This frequency shifted beam then is directed to the target. The motion of the target adds a Doppler shift to the beam given by fd = 2*v(t)*cos(α)/λ, where v(t) is the velocity of the target as a function of time, α is the angle between the laser beam and the velocity vector, and λ is the wavelength of the light.

Light scatters from the target in all directions, but some portion of the light is collected by the LDV and reflected by the beamsplitter to the photodetector. This light has a frequency equal to fo + fb + fd. This scattered light is combined with the reference beam at the photo-detector. The initial frequency of the laser is very high (> 1014 Hz), which is higher than the response of the detector. The detector does respond, however, to the beat frequency between the two beams, which is at fb + fd (typically in the tens of MHz range).

The output of the photodetector is a standard frequency modulated (FM) signal, with the Bragg cell frequency as the carrier frequency, and the Doppler shift as the modulation frequency. This signal can be demodulated to derive the velocity vs. time of the vibrating target.

Optical Heterodyne detection



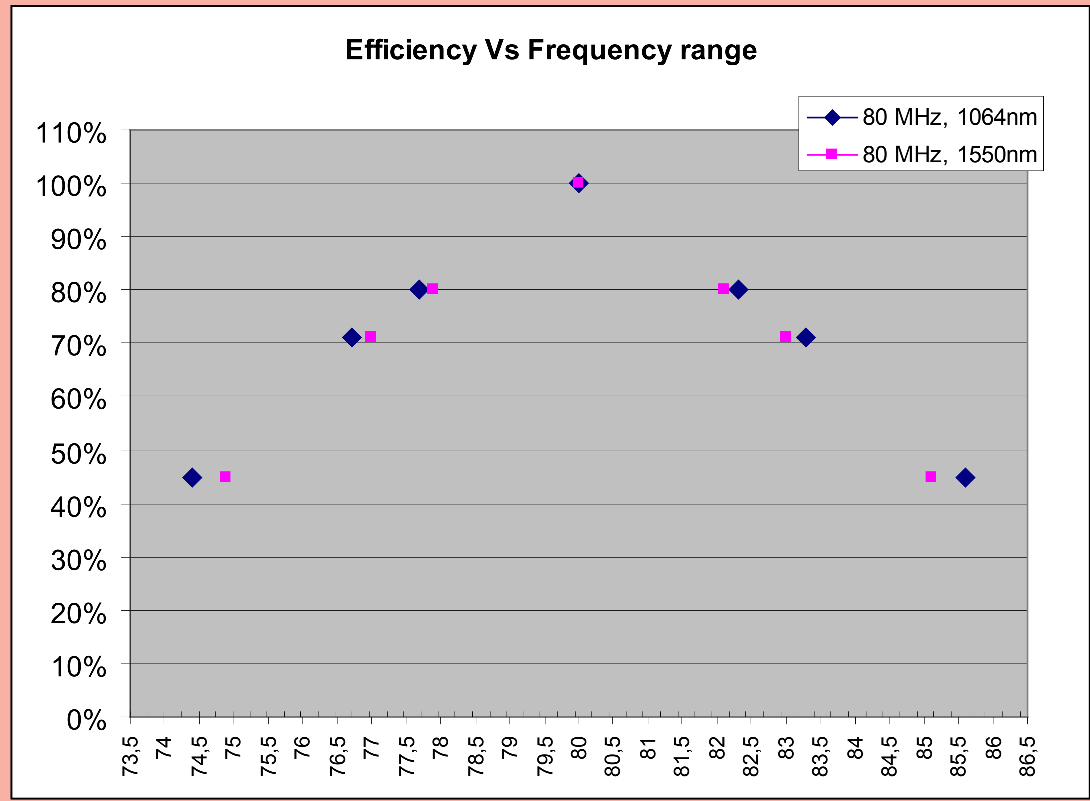
Optical heterodyne detection is special case of heterodyne detection. In heterodyne detection, a signal of interest at some frequency is non-linearly mixed with a reference «local oscillator» (LO) that is set at a close-by frequency. The desired outcome is the difference frequency, which carries the information (amplitude, phase, and frequency modulation) of the original higher frequency signal, but is oscillating at a lower more easily processed carrier frequency.

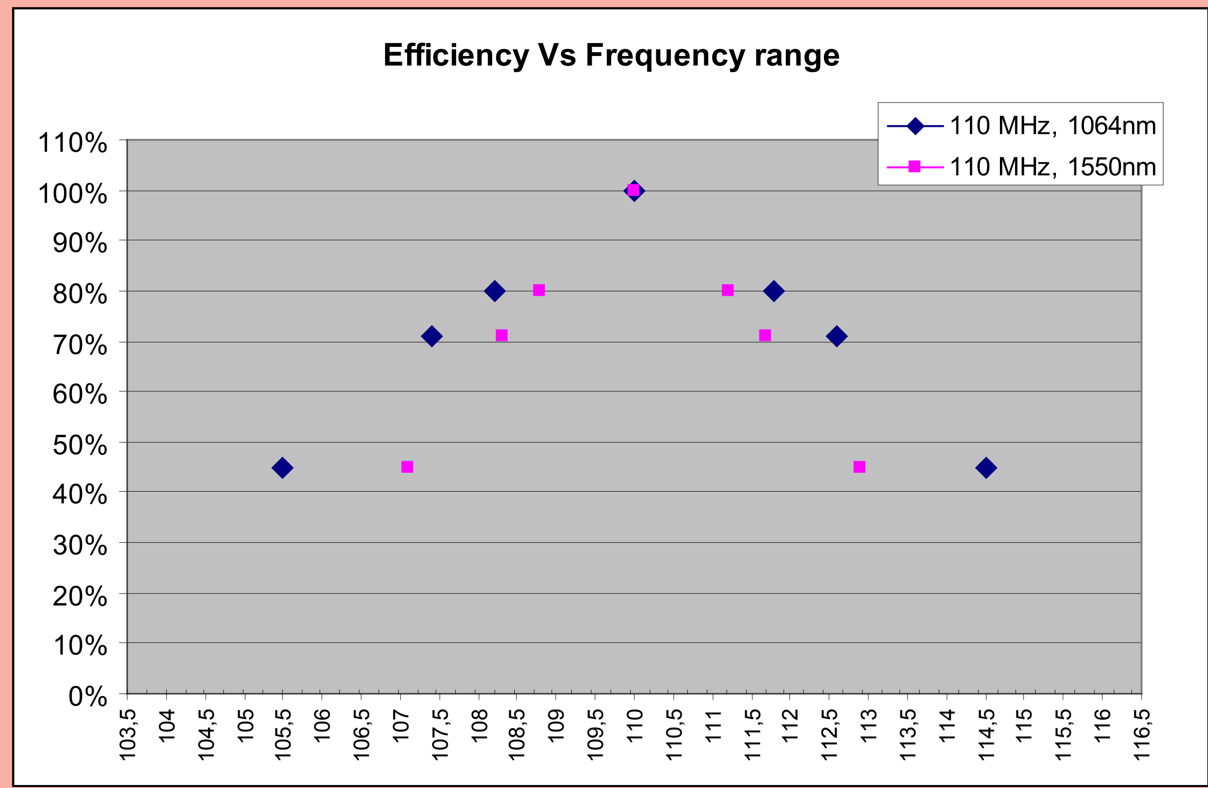
Optical heterodyne detection has special characteristics and special problems that distinguish it from conventional RF heterodyne detection. While an old technique, key limiting issues were solved only as recently as 1994 with the invention of Synthetic array heterodyne detection.

In heterodyne detection, one modulates, usually by a frequency shift, one of two beams prior to detection. A special case of heterodyne detection is optical heterodyne detection, which detects the interference at the beat frequency. The AC signal now oscillates between the minimum and maximum levels every cycle of the beat frequency. Since the modulation is known, the relative phase of the measured beat frequency can be measured very precisely even if the intensity levels of the beams are (slowly) drifting. This phase is identical in value to the phase one measures in the homodyne case. There are many additional benefits of optical heterodyne detection including improved signal to noise ratio when one of the beams is weak.

Selection of AA Standard Fibre Pigtailed Variable Frequency Shifters

During the acousto-optic interaction, the first order beam is shifted by the amount of the RF carrier frequency. This shift can be positive or negative. When the Carrier frequency is varied, the frequency shift can be modified in a certain frequency range. This becomes a variable frequency shifter. However, the variation of frequency is accompanied by a variation of the first order beam angle. In case of fiber pigtailed AOS, this angle variation introduces a fiber mis-coupling which reduces the frequency bandwidth of the fiber AOS.

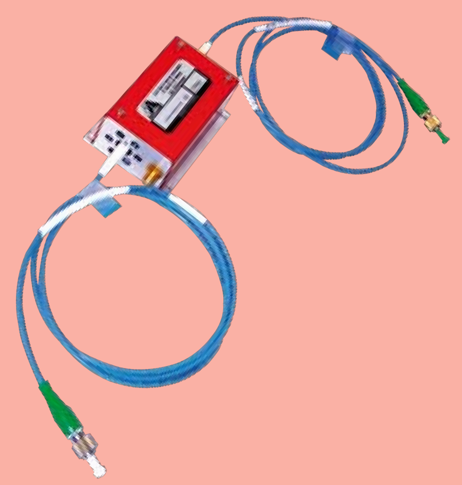




Selection of AA Standard Variable frequency Shifters

Variable Frequency Shifters VISIBLE

Model	Wavelength nm	Min Losses dB	Frequency Shift Band -1.5 dB (nom)	Frequency Shift Band -3dB (nom)	Rise Time ns	Fiber type
MT200-BG18-FIO	478-630	3	200 +/- 7.5 MHz	200 +/- 11 MHz	18	SM, PM
MT200-R18-FIO	630-700	2.5	200 +/- 7.5 MHz	200 +/- 11 MHz	18	SM, PM

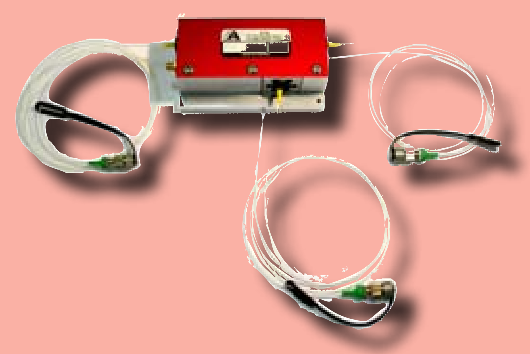


Variable Frequency Shifters 1064 nm

Model	Wavelength nm	Min Losses dB (nom)	Frequency Shift Band -1.5 dB (nom)	Frequency Shift Band -3dB (nom) MHz	Rise Time ns	Fiber type
MT80-IR60-FIO	1000-1100	1.5	80 +/- 2.5 MHz	80 +/- 3.7 MHz	60	SM, PM
MT110-IR20-FIO	1000-1100	2.5	110 +/- 7 MHz	110 +/- 10 MHz	20	SM, PM
MT200-IR10-FIO	1000-1100	4	200 +/- 10 MHz	200 +/- 15MHz	10	SM, PM

Variable Frequency Shifters 1550 nm

Model	Wavelength nm	Min Losses dB (nom)	Frequency Shift Band -1.5 dB (nom)	Frequency Shift Band -3dB (nom)	Rise Time ns	Fiber type
MA40-IIR120	1550	2	40 +/- 1.5 MHz	--	120	SM, PM
MT80-IIR60-FIO	1550	2.5	80 +/- 2.5 MHz	80 +/- 3.7 MHz	60	SM, PM
MT110-IIR20-FIO	1550	3	110 +/- 7 MHz	110 +/- 10 MHz	20	SM, PM



Large Spectrum SLC Fiber pigtailed AOM

Model	Wavelength nm	Min Losses (nom)	Configuration	Carrier Frequency MHz	Rise Time ns	Fiber type
MT80-IIR30-SCL-3Fio-SM	* S band : 1460-1530 nm * C band : 1530-1565 nm * L band : 1565-1625 nm	2 dB @1550nm 5 dB over SCL	3 ports Input + 0 + 1st orders	110	30	SM
MT80-IIR30-SCL-Fio-SM	* S band : 1460-1530 nm * C band : 1530-1565 nm * L band : 1565-1625 nm	2 dB @1550nm 5 dB over SCL	2 ports Input + 1st order	110	30	SM

Others on request

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Variable frequency drivers

VCO and DDS based

VCO drivers

(Voltage Controlled Oscillator)

These drivers are suitable for general purpose applications (raster scan, or random access...). The VCO can be modulated (amplitude) from an external signal.

The frequency is externally controlled by an analog signal. An external medium power amplifier will be required to generate the RF power levels required by the AO device.

Model: DRFA10Y-XX

Frequency range:	Adapted at factory to AO device max 40-100, 60-150, 80-200, 140-300, 190-350 MHz (Other on request)
Frequency control:	0-10 V / 1 Kohms
Modulation Input:	0-5 V / 50 ohms
Sweeping time:	≤1 µs
Power Supply:	24VDC, 110-230 VAC
Output RF power*:	Nominal 0 dBm

--> On request DRFA1.5Y 85-135 MHz, sweeping time 150 ns

* To be used in association with AA power amplifiers

DDS drivers

(Direct Digital Synthesizer)

To get a high resolution driver with fast switching time, AA has designed direct digital synthetisers based on monolithic IC circuits. 3 models have already been released, and different units can be designed to specific requirements.

These models offer high frequency accuracy and stability and extremely fast switching times, generally of a few tens of nanoseconds. The DAC circuits have been designed with utmost care to obtain clean RF signals, with minimum spurious noise.

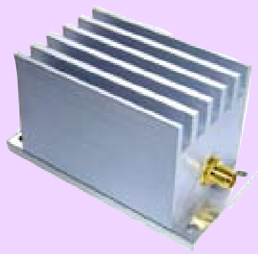
Model: DDSPA-XX

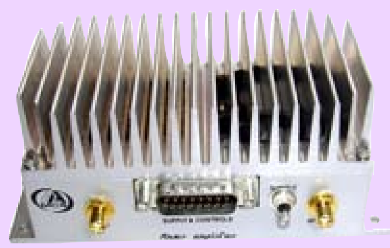
Frequency range:	Adapted at factory to AO device Max 10-350 MHz (400 MHz on request)
Frequency control:	15, 23 or 31 bits
Frequency step:	15 KHz, 1 KHz, 0.25 Hz
Modulation Input:	0-5 V / 50 ohms, Option: 8 bits
Access time:	40, 64, 80 ns
Power Supply:	24VDC, 110-230 VAC
Output RF power*:	Nominal 0 dBm

--> On request USB Controller for PC, designed to drive 1 or 2 DDSPA through USB port (Windows XP/NT)

* To be used in association with AA power amplifiers

RF Power amplifiers





AA's acousto-optic amplifiers are linear with large bandwidth and medium power.he models below cover a variety of bandwidths from 1MHz to 3 GHz.
Output powers up to 80 W are available. Each amplifier is supplied with its heat sink and all are stable and reliable under all conditions.For High power amplifiers, AA proposes models up to 500 W CW.

Model	Frequency Range	Gain nom	Output Power	Flatness	Power Supply
AMPA-B-30	20-450 MHz	34 dB	1 Watt	+/- 0,5 dB	24 VDC
AMPA-B-33	20-600 MHz	40 dB	2 watts	+/- 0,5 dB	24 VDC
AMPA-B-36	20-210 MHz	40 dB	4 watts	+/- 1 dB	24 VDC
AMPA-B-40	20-210 MHz	41 dB	10 watts	+/- 1 dB	24 VDC

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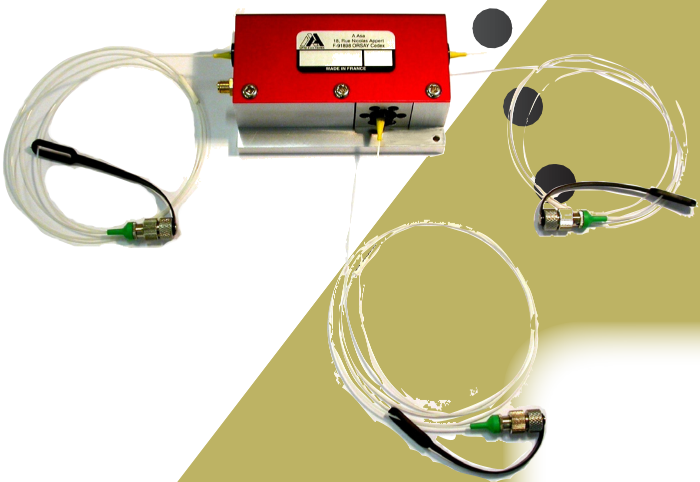
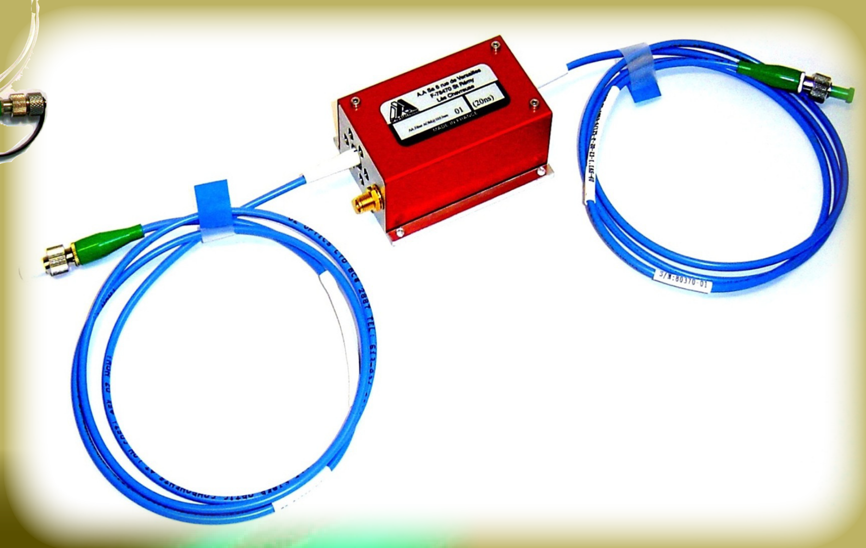
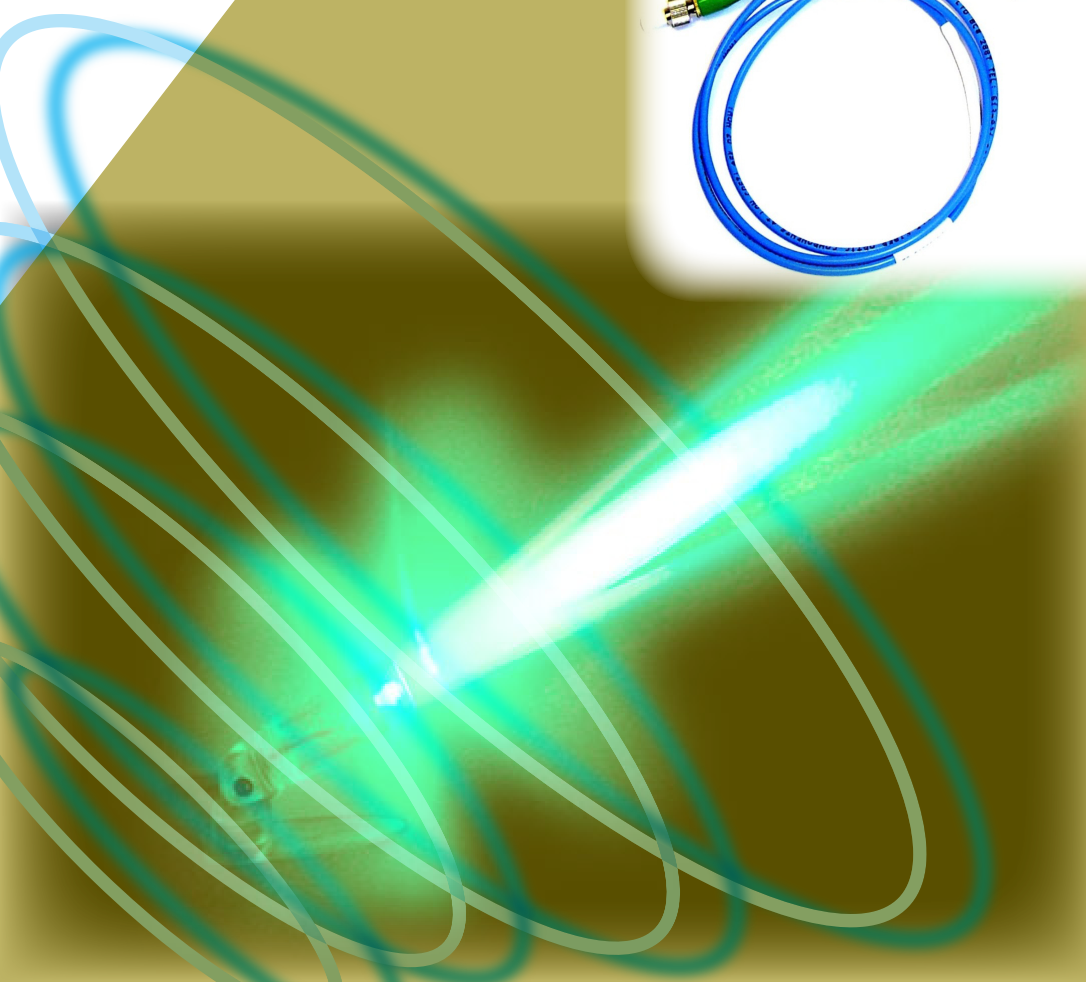
Fiber Lasers

Acousto-optic products







AA OPTO-ELECTRONIC
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Introduction
Fibre Laser

A fiber laser or fibre laser is a laser in which the active gain medium is an optical fiber doped with rare-earth elements such as erbium, ytterbium, neodymium, dysprosium, praseodymium, and thulium. Fiber nonlinearities, such as Stimulated Raman Scattering or Four Wave Mixing can also provide gain and thus serve in effect as gain media. Unlike most other types of lasers, the laser cavity in fiber laser is constructed monolithically by fusion splicing the different types of fibers; most notably fiber Bragg gratings replace here conventional dielectric mirrors to provide optical feedback.

To pump fiber lasers, semiconductor laser diodes or other fiber lasers are used almost exclusively. Fiber lasers can have several kilometer-long active regions and provide very high optical gain. They can support kilowatt level of continous output power because the fiber's high surface area to volume ratio allows efficient cooling. The fiber waveguiding properties reduce or remove completely thermal distortion of the optical path thus resulting in typically diffraction-limited high-quality optical beam. Fiber lasers also feature compact layout compared to rod or gas lasers of comparable power, as the fiber can be bent to small diameters and coiled. Other advantages include high vibrational stability, extended lifetime and maintenance-free turnkey operation.

Many high-power fiber lasers are based on double-clad fiber. The gain medium forms the core of the fiber, which is surrounded by two layers of cladding. The lasing mode propagates in the core, while a multimode pump beam propagates in the inner cladding layer. The outer cladding keeps this pump light confined. This arrangement allows the core to be pumped with a much higher power beam than could otherwise be made to propagate in it, and allows the conversion of pump light with relatively low brightness into a much higher-brightness signal. As a result, fiber lasers and amplifiers are occasionally referred to as «brightness converters.»

Applications include: Material processing,telecommunications,spectroscopy, and medicine.

Fiber-hosted lasers

Solid state lasers also include glass or optical fiber hosted lasers, for example, with erbium or ytterbium ions as the active species. These allow extremely long gain regions and can support very high output powers because the fiber's high surface area to volume ratio allows efficient cooling. In addition, the fiber's waveguiding properties tend to reduce thermal distortion of the beam. Quite often, the fiber is designed as a double-clad glass fiber. This type of fiber consists of a fiber core, an inner cladding and an outer cladding. The index of the three concentric layers is chosen so that the fiber core acts as a single-mode fiber for the laser emission while the outer cladding acts as a highly multimode core for the pump laser. This lets the pump propagate a large amount of power into and through the active inner core region, while still having a high numerical aperture (NA) to have easy launching conditions. Fiber lasers have a fundamental limit in that the intensity of the light in the fiber cannot be so high that optical nonlinearities induced by the local electric field strength can become dominant and prevent laser operation and/or lead to the material destruction of the fiber.

Doped fibre amplifiers

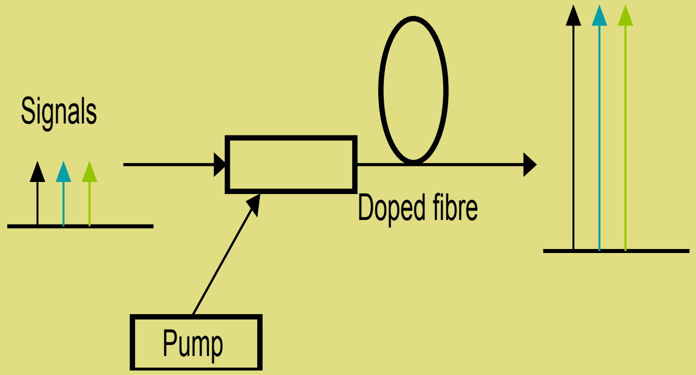
Doped fibre amplifiers (DFAs) are optical amplifiers which use a doped optical fibre as a gain medium to amplify an optical signal. They are related to fibre lasers. The signal to be amplified and a pump laser are multiplexed into the doped fibre, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where core of a silica fiber is doped with trivalent Erbium ions (Er+3), can be efficiently pumped with a laser at 980 nm or at 1,480 nm, and exhibits gain the 1,550 nm region.

Amplification is achieved by stimulated emission of photons from dopant ions in the doped fibre. The pump laser excites ions into a higher energy from where they can decay via stimulated emission of a photon at the signal wavelength back to a lower energy level. The excited ions can also decay spontaneously (spontaneous emission) or even through nonradiative processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification.

The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fibre, and the wavelength and power of the pump laser.

Although the electronic transitions of an isolated ion are very well defined, broadening of the energy levels occurs when the ions are incorporated into the glass of the optical fibre and thus the amplification window is also broadened. This broadening is both homogeneous (all ions exhibit the same broadened spectrum) and inhomogeneous (different ions in different glass loations exhibit different spectra). Homogeneous broadening arises from the interactions with phonons of the glass, while inhomogenous broadening is caused by differences in the glass sites where different ions are hosted.

Different sites expose ions to different local electric fields, which shifts the energy levels via the Stark effect. In addition, the Stark effect also removes the degeneracy of energy states having the same total angular momentum (specified by the quantum number J). Thus, for example, the trivalent Erbium ion (Er+3) has a ground state with $J = 15/2$, and in the presence of an electric field splits into $J + 1/2 = 8$ sublevels with slightly different energies. The first excited state has $J = 13/2$ and therefore a Stark manifold with 7 sublevels. Transitions from the $J = 13/2$ excited state to the $J = 15/2$ ground state are responsible for the gain at 1.5 µm wavelength. The gain spectrum of the EDFA has several peaks that are smeared by the above broadening mechanisms. The net result is a very broad spectrum (30 nm in silica, typically). The broad gain-bandwidth of fibre amplifiers make them particularly useful in wavelength-division multiplexed communications systems as a single amplifier can be utilized to amplify all signals being carried on a fiber and whose wavelengths fall within the gain window.



Acousto-optic Q-switches

Generation of optical pulses

Pulsed lasers have some advantages versus continuous lasers:

In some applications, such as optical communications, pulses convey information

Short pulses are used to achieve very large peak powers. All the emitted energy is compressed into very short pulses, so as to reach very large peak powers

Some applications rely on optical pulses to take snap-shots of very rapidly occurring process, such as fast chemical reactions, or electronic processes in semiconductors. Lasers can produce flashes of light that are many orders of magnitude shorter and brighter than ordinary flashlight

In some circumstances, it is the laser excitation mechanism itself that restricts the laser to pulsed mode operation, to reduce unwanted thermal load on the laser

A simple way to generate pulsed output is to put an optical switch (AO modulator for instance) at the output of a continuous wave laser (CW). By turning on and off, user can get pulses of light. For some applications, this is not efficient and this is preferable to use a switch (Q-Switch) inside the laser cavity. This has at least two advantages:

When the switch is closed, the laser cannot operate. This means the pump energy is not lost but stored in the active material in the form of excited atoms, or in the cavity in the form of light

When the switch is abruptly opened all the stored energy may be regained in a short pulse, generating peak powers that are many times higher than the average (CW) power.

Q-Switching

The Q or Quality factor of a laser cavity describes the ability of the cavity to store light energy in the form of standing waves. The Q factor is the ratio of energy contained in the cavity divided by the energy lost during each round trip in the cavity:

$$Q = 2\,\frac{\text{Energy stored in the cavity}}{\text{Energy lost in a cycle}}$$

This means that a cavity with high losses dissipates a lot of energy per cycle hence it has a low Q value. A high Q cavity means the energy loss per cycle is small in the given cavity.

By inserting a device in the cavity which is capable of controlling the loss of a cavity, we are effectively controlling the Q of the cavity. This device acts as an optical shutter or switch inside the cavity, which, when closed, absorbs or scatters the light, resulting in a lossy, low Q cavity. When the shutter is open, the cavity becomes low loss, high Q. This switch is called a Q-SWITCH.

Acousto-optic Q-Switches

A Q-switch is a special modulator which introduces high repetition rate losses inside a laser cavity (typ 1 to 100 KHz). They are designed for minimum insertion loss and to be able to withstand very high laser powers. In normal use an RF signal is applied to diffract a portion of the laser cavity flux out of the cavity. This increases the cavity losses and prevents from oscillation. When the RF signal is switched off, the cavity losses decrease rapidly and an intense laser pulse evolves.

It is essential in Q-switching to correlate the timing sequence of the optical pumping mechanism with the Q-switching. This means the following :

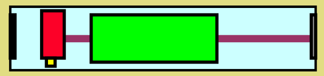
Assume that at the time when the laser pumping is turned on, the Q of the cavity is low. The high loss prevents laser action occurring so the energy from the pumping source is deposited in the upper laser level of the medium

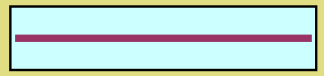
At the instant, when the population inversion is at its highest level, the switch is suddenly open to reduce the cavity loss

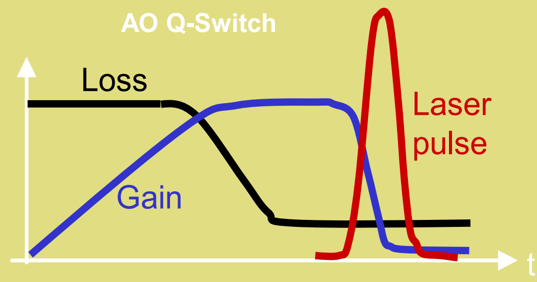
Because of the very large built up population difference, laser oscillations will quickly start and the stored energy is emitted in a single giant pulse

The lasing stops because the pulse quickly depopulates the upper lasing level to such an extent that the gain is reduced to below threshold.

This operation is periodically repeated in order to obtain the operating regime.



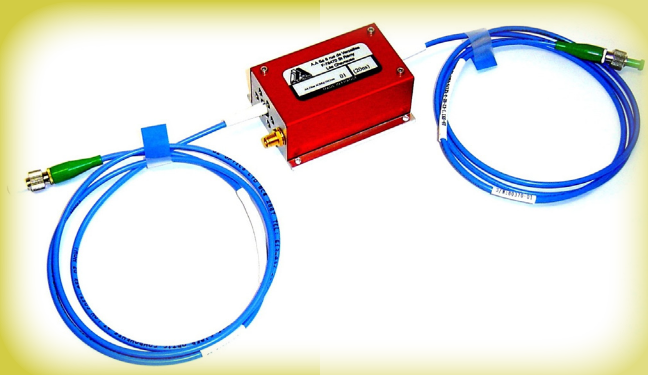




Fibre Modulators and Q-switches

1000 to 1100 nm

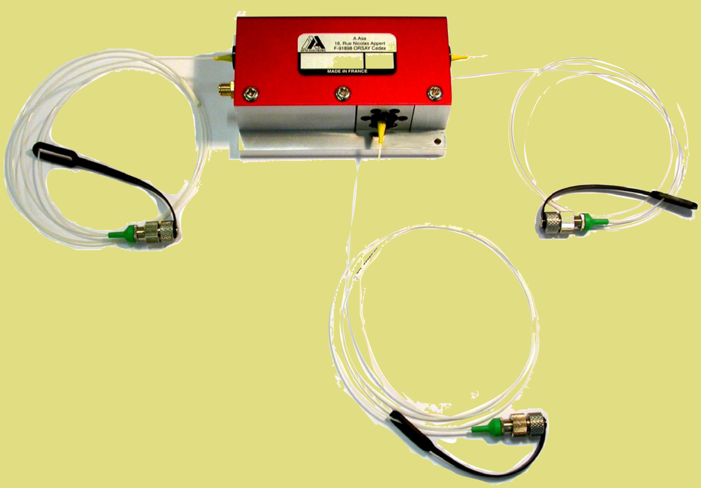
MT110-IR20-FIO 1000-1100
Fiber: SM, PM
Rise/fall time: 20 ns
Carrier frequency: 110
Insertion Losses: Nom 2.5 dB
Laser Power: 5 W



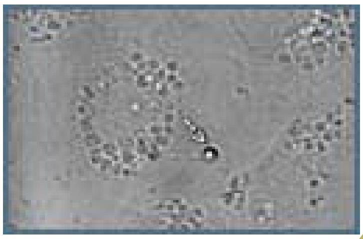
MT80-IR60-FIO 1000-1100
Fiber:: SM, PM
Rise/fall time: 60 ns
Carrier frequency: 80 MHz
Insertion Losses: Nom 1.5 dB
Laser Power: 5 Watts

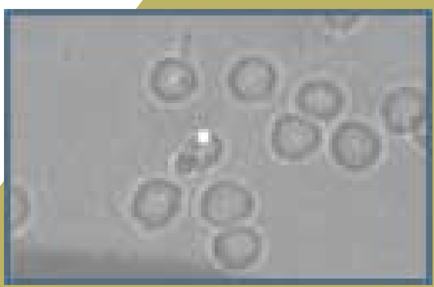
3 Ports Fiber pigtailed Model Wavelength

MT80-IR60-3FIO 1000-1100
Fiber: SM, PM
Rise/fall time: 60 ns
Carrier frequency: 80 MHz
Insertion Losses: Nom 2.5 dB (orders 0+1)
Laser Power: 5 Watts
Pigtailed orders : 0 +1st orders

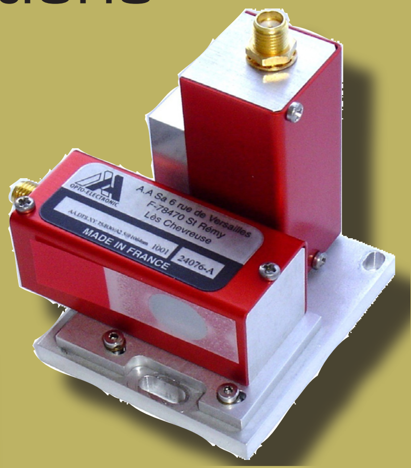


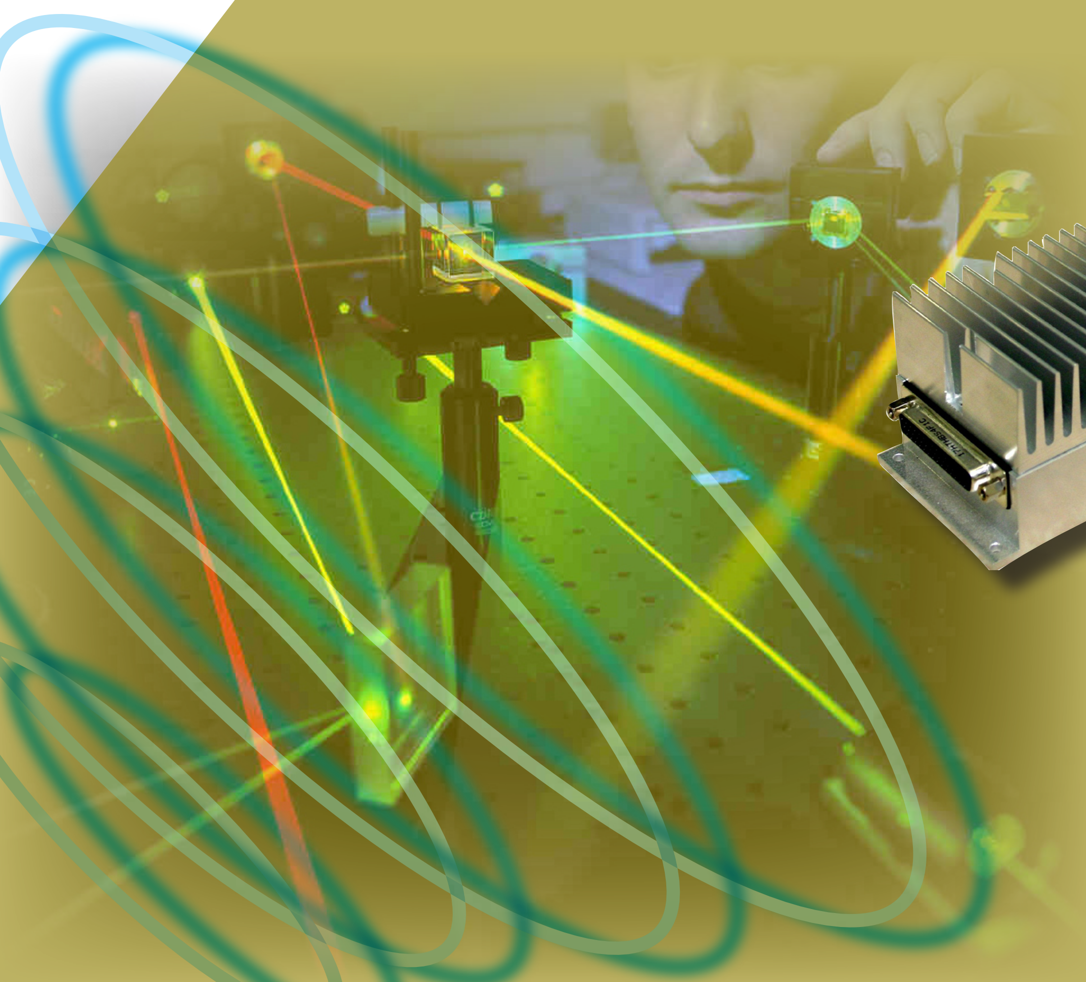
OPTICAL TWEEZERS

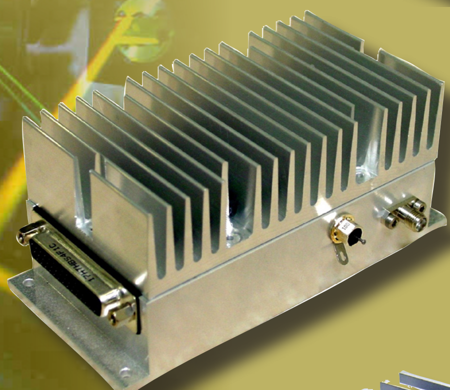


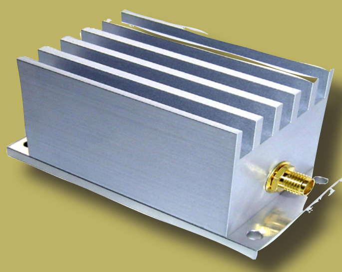


A complete
Acousto-Optic
2 axis deflection set
for optical tweezing
applications





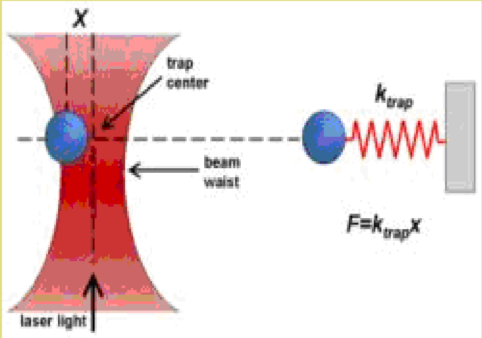




AA OPTO-ELECTRONIC
QUANTA TECH

Optical tweezers

An optical tweezer is a scientific instrument that uses a focused laser beam to provide an attractive or repulsive force, depending on the index mismatch (typically on the order of piconewtons) to physically hold and move microscopic dielectric objects. Optical tweezers have been particularly successful in studying a variety of biological systems in recent years.



Dielectric objects are attracted to the center of the beam, slightly above the beam waist, as described in the text. The force applied on the object depends linearly on its displacement from the trap center just as with a simple spring system.

General Description

Optical tweezers are capable of manipulating nanometer and micrometer-sized dielectric particles by exerting extremely small forces via a highly focused laser beam. The beam is typically focused by sending it through a microscope objective.

The narrowest point of the focused beam, known as the beam waist, contains a very strong electric field gradient. It turns out that dielectric particles are attracted along the gradient to the region of strongest electric field, which is the center of the beam.

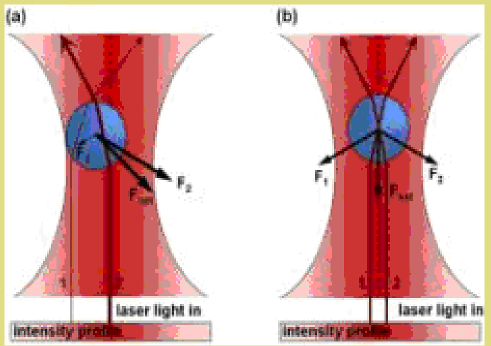
The laser light also tends to apply a force on particles in the beam along the direction of beam propagation. It is easy to understand why if you imagine light to be a group of tiny particles, each impinging on the tiny dielectric particle in its path. This is known as the scattering force and results in the particle being displaced slightly downstream from the exact position of the beam waist, as seen in the figure.

Optical traps are very sensitive instruments and are capable of the manipulation and detection of sub-nanometer displacements for sub-micron dielectric particles.[9]

For this reason, they are often used to manipulate and study single molecules by interacting with a bead that has been attached to that molecule. DNA and the proteins and enzymes that interact with it are commonly studied in this way.

For quantitative scientific measurements, most optical traps are operated in such a way that the dielectric particle rarely moves far from the trap center. The reason for this is that the force applied to the particle is linear with respect to its displacement from the center of the trap as long as the displacement is small. In this way, an optical trap can be compared to a simple spring, which follows Hooke's law.

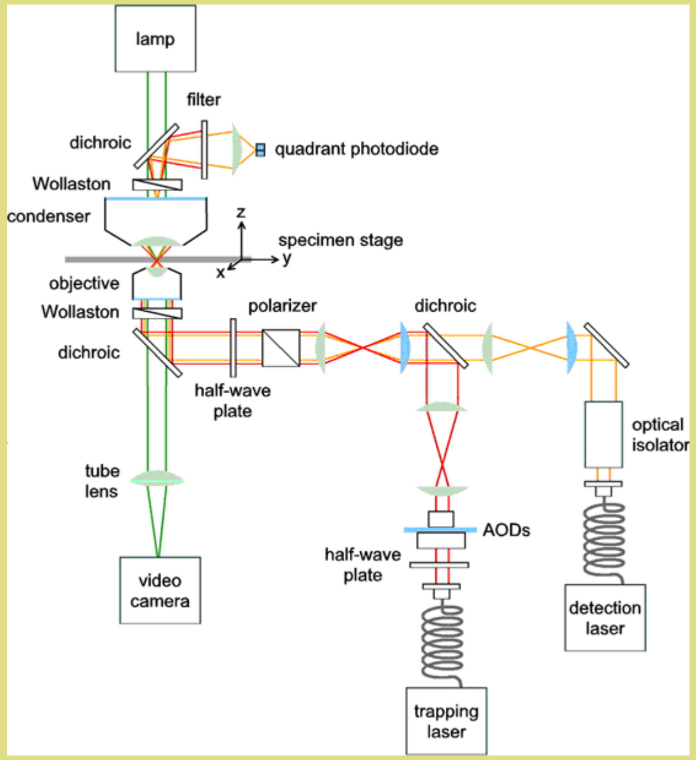
Proper explanation of optical trapping behavior depends upon the size of the trapped particle relative to the wavelength of light used to trap it. In cases where the dimensions of the particle are greater than this wavelength, a simple ray optics treatment is sufficient. On the other hand, if the wavelength of light exceeds the particle dimensions, then the particles must be treated as tiny electric dipoles in an electric field.



Experimental design, Construction and operation

A generic optical tweezer diagram with only the most basic components.
The most basic optical tweezer setup will likely include the following components: a laser (usually Nd:YAG), a beam expander, some optics used to steer the beam location in the sample plane, a microscope objective and condenser to create the trap in the sample plane, a position detector (e.g. quadrant photodiode) to measure beam displacements and a microscope illumination source coupled to a CCD camera.

The Nd:YAG laser (1064 nm wavelength) is the most common laser choice because biological specimens are most transparent to laser wavelengths around 1000 nm. This assures as low an absorption coefficient as possible, minimizing damage to the specimen, sometimes referred to as opticution. Perhaps the most important consideration in optical tweezer design is the choice of the objective. A stable trap requires that the gradient force, which depends upon the numerical aperture (NA) of the objective, be greater than the scattering force. Suitable objectives typically have a NA between 1.2 and 1.4.[11]



Example of an optical tweezer setup

While alternatives are available, perhaps the simplest method for position detection involves imaging the trapping laser exiting the sample chamber onto a quadrant photodiode. Lateral deflections of the beam are measured similarly to how its done using atomic force microscopy (AFM).

Expanding the beam emitted from the laser to fill the aperture of the objective will result in a tigher, diffraction-limited spot.[12] While lateral translation of the trap relative to the sample can be accomplished by translation of the microscope slide, most tweezer setups have additional optics designed to translate the beam to give an extra degree of translational freedom.

This can be done by translating the first of the two lenses labelled as «Beam Steering» in the figure. For example, translation of that lens in the lateral plane will result in a laterally deflected beam from what is drawn in the figure. If the distance between the beam steering lenses and the objective are chosen properly, this will correspond to a similar deflection before entering the objective and a resulting lateral translation in the sample plane. The position of the beam waist, that is the focus of the optical trap, can be adjusted by an axial displacement of the initial lens. Such an axial displacement causes the beam to diverge or converse slightly, the end result of which is an axially displaced position of the beam waist in the sample chamber. A very clear explanation has been presented by Joshua W. Shaevitz a former graduate student in the Block Lab at Stanford University.[13]

Visualization of the sample plane is usually accomplished through illumination via a separate light source coupled into the optical path in the opposite direction using dichroic mirrors. This light is incident on a CCD camera and can be viewed on an external monitor or used for tracking the trapped particle position via video tracking.

Descriptions of various optical tweezer setups

Optical tweezers based on alternate laser beam modes

The majority of optical tweezers make use of conventional TEM00 Gaussian beams. However a number of other beam types have been used to trap particles, including high order laser beams i.e Hermite Gaussian beam (TEMxy), Laguerre-Gaussian (LG) beams (TEMpl) and Bessel beams.

Optical tweezers based on Laguerre Gaussian beam have the unique capability of trapping particles that are optically reflective and absorptive. Laguerre-Gaussian beams also possess a well-defined orbital angular momentum that can rotate particles.[14][15] This is accomplished without external mechanical or electrical steering of the beam.

Both zeroth and higher Bessel Beams also possess a unique tweezing ability. They can trap and rotate multiple particles that are millimeters apart and even around obstacles. [16]

Micromachines can be driven by these unique optical beams due to their intrinsic rotating mechanism due to the spin and orbital angular momentum of light.[citation needed]

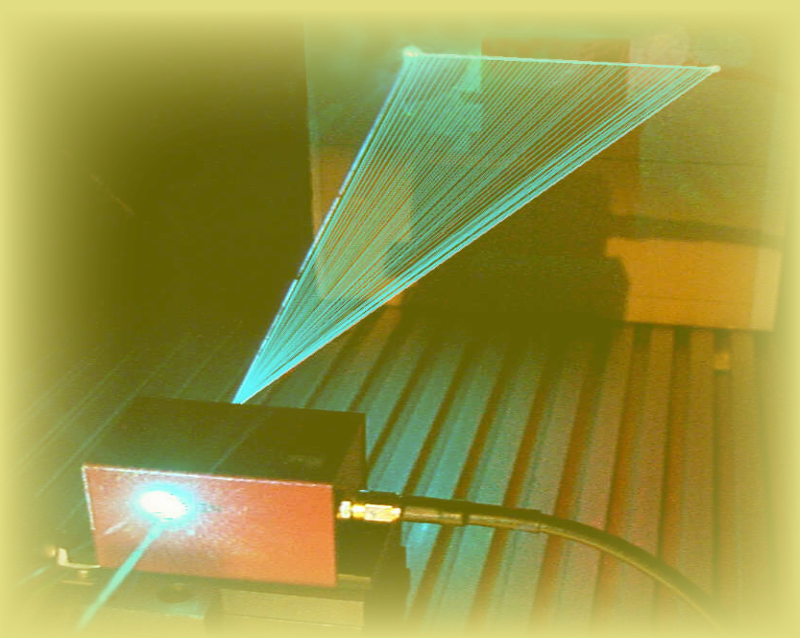
Multiplexed optical tweezers

A typical setup uses one laser to create one or two traps. More complex optical tweezing operations can be achieved either by time-sharing a single laser beam among several optical tweezers or by diffractively splitting the beam into multiple traps. With acousto-optic deflectors or galvanometer-driven mirrors, a single laser beam can be shared among hundreds of optical tweezers in the focal plane, or else spread into an extended one-dimensional trap. Specially designed diffractive optical elements can divide a single input beam into hundreds of continuously illuminated traps in arbitrary three-dimensional configurations. The trap-forming hologram also can specify the mode structure of each trap individually, thereby creating arrays of optical vortices, optical tweezers, and holographic line traps, for example. When implemented with a spatial light modulator, such holographic optical traps also can move objects in three dimensions.

Optical tweezers based on optical fibers

The fiber optical trap relies on the same principle as the optical trapping, but with the laser delivered through an Optical fiber. If one end of the optical fiber tip is moulded into a lens-like facet, that lens tip will act as a focusing (converging) point for the high optical gradient trap to be formed.[17]

On the other hand, if the ends of the fiber are not moulded, the laser exiting the fiber will be diverging and thus a stable optical trap can only be realised by balancing the gradient and the scattering force from two opposing ends of the fiber. The gradient force will trap the particles the transverse direction, while the axial optical force comes from the scattering force of the two counter propagating beams emerging from the two fibers.
The equilibrium z-position of such a trapped bead is where the two scattering forces equal each other. This work was pioneered by A. Constable et al., Opt. Lett. 18,1867 (1993), and followed by J.Guck et al., Phys. Rev. Lett. 84, 5451 (2000), who made use of this technique to stretch microparticles.
By manipulating the input power into the two ends of the fiber, there will be an increase of a «optical stretching» that can be used to measure viscoelastic properties of cells, with sensitivity sufficient to distinguish between different individual cytoskeletal phenotypes. i.e. human erythrocytes and mouse fibroblasts. A recent test has seen great success in differentiating cancerous cells from non-cancerous ones from the two opposed, non-focused laser beams.[citation needed]



Optical tweezers in a 'landscape' (cell sorting)

One of the more common cell sorting systems make use of flow cytometry through fluorescent imaging. In this method, a suspension of biologic cells is sorted into two or more containers, based upon specific fluorescent characteristics of each cell during an assisted flow. By using an electrical charge that the cell is «trapped» in, the cell are then sorted based on the fluorescence intensity measurements. The sorting process is undertaking by an electrostatic deflection system that diverts cell into containers based upon their charge.

In the optically actuated sorting process, the cell are flowed through into an optical landscape i.e 2D or 3D optical lattices. Without any induce electrical charge, the cell would sorting based on their intrinsic refractive index properties and can be re-configurability for dynamic sorting. Mike MacDonald, Gabe Spalding and Kishan Dholakia, Nature 426, 421-424 (2003)[1] made use of diffractive optics and optical elements to create the optical lattice. An automated cell sorter was described at the University of Toronto in 2001, but made use of mechanical parameters as opposed to spatial light modulation [18]

On the other hand, K. Ladavac, K. Kasza and D. G. Grier, Physical Review E 70, 010901(R) (2004)[2] made use of the spatial light modulator to project an intensity pattern to enable the optical sorting process.
The main mechanism for sorting is the arrangement of the optical lattice points. As the cell flow through the optical lattice, there are forces due to the particles drag force that is competing directly with the optical gradient force(See Physics of an Optical Tweezers) from the optical lattice point. By shifting the arrangement of the optical lattice point, there is a preferred optical path where the optical forces are dominate and biased. With the aid of the flow of the cells, there is a resultant forces that is directed along that preferred optical path. Hence, there is a relationship of the flow rate with the optical gradient force. By adjusted the two forces, one will be able to obtain a good optical sorting efficiency.

Competition of the forces in the sorting environment need fine tuning to succeed in high efficient optical sorting. The need is mainly with regards to the balanced of the forces; drag force due to fluid flow and optical gradient force due to arrangement of intensity spot.

Scientists at the University of St. Andrews have received considerable funding from the UK Engineering and Physical Sciences Research Council (EPSRC) for an optical sorting machine. This new technology could rival the conventional fluorescence-activated cell sorting.[19]

Optical tweezers based on evanescent fields

An evanescent field [3] [4] is a residue optical field that «leaks» during total internal reflection. This «leaking» of light fades off at an exponential rate. The evanescent field has found a number of applications in nanometer resolution imaging (microscopy); optical micromanipulation (optical tweezers) are becoming ever more relevant in research.

In optical tweezers, a continuous evanescent field can be created when light is propagating through an optical waveguide (multiple total internal reflection). The resulting evanescent field has a directional sense and will propel microparticles along its propagating path. This work was first pioneered by S. Kawata and T. Sugiura, in 1992 (Opt. Lett. 17 (11), 772 (1992)). Kawata showed that the field can be coupled to the particles in proximity on the order of 100 nanometers.

This direct coupling of the field is treated as a type of photon tunnelling across the gap from prism to microparticles. The result is a directional optical propelling force.

A recent updated version of the evanescent field optical tweezers make use of extended optical landscape patterns to simultaneously guide a large number of particles into a preferred direction without using a waveguide. It is termed as Lensless Optical Trapping ("LOT") [5]. The orderly movement of the particles is aided by the introduction of Ronchi Ruling that creates well-defined optical potential wells (replacing the waveguide). This means that particles are propelled by the evanescent field while being trapped by the linear bright fringes. At the moment, there are scientists working on focused evanescent fields as well.

Optical tweezers: an indirect approach

Ming Wu, a UC Berkeley Professor of electrical engineering and computer sciences invented the new optoelectronic tweezers.
Wu transformed the optical energy from low powered light emitting diodes (LED) into electrical energy via a photoconductive surface. The ideas is to allow the LED to switch on and off the photoconductive material via its fine projection. As the optical pattern can be easily transformable through optical projection, this method allow a high flexibility of switching different optical landscapes.

The manipulation/tweezing process is done by the variations between the electric field actuated by the light pattern. As the particles will be either attracted or repelled from the actuated point due to the its induced electrical dipole. Particles being suspended in a liquid will be susceptible to electrical field gradient, this is known as dielectrophoresis.

One clear advantage is that the electrical conductivity between a different cells. Living cells have a lower conductive medium while the dead ones have minimum or no conductive medium. The system may be able to manipulate roughly 10,000 cells or particles at the same time.
See comments by Professor Kishan Dholakia on this new technique, K. Dholakia, Nature Materials 4, 579-580 (01 Aug 2005) News and Views

Optical binding

When a cluster of microparticles are trapped within a monochromatic laser beam, the organisation of the microparticles within the optical trapping is heavily dependent on the redistributing of the optical trapping forces amongst the microparticles. This redistribution of light forces amongst the cluster microparticles provides a new force equilibrium on the cluster as a whole. As such we can say that the cluster of microparticles are somewhat bounded together by light. One of the first evidence of optical binding was reported by Michael M. Burns, Jean-Marc Fournier, and Jene A. Golovchenko [6].

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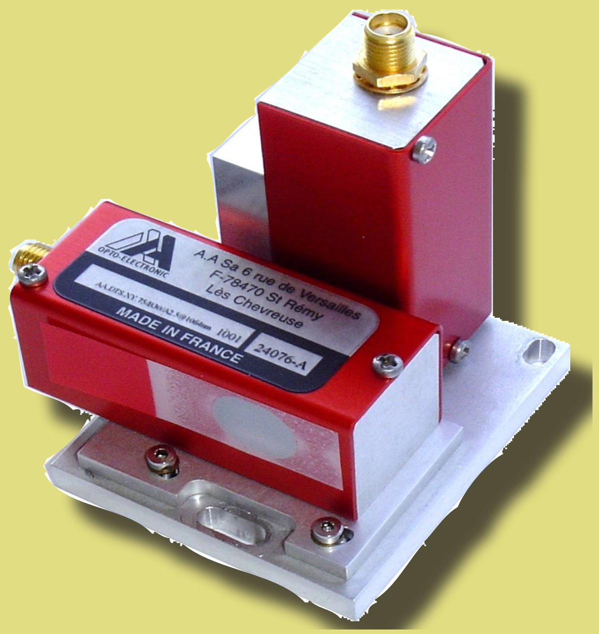
2 Dimensional Acousto-Optic deflector



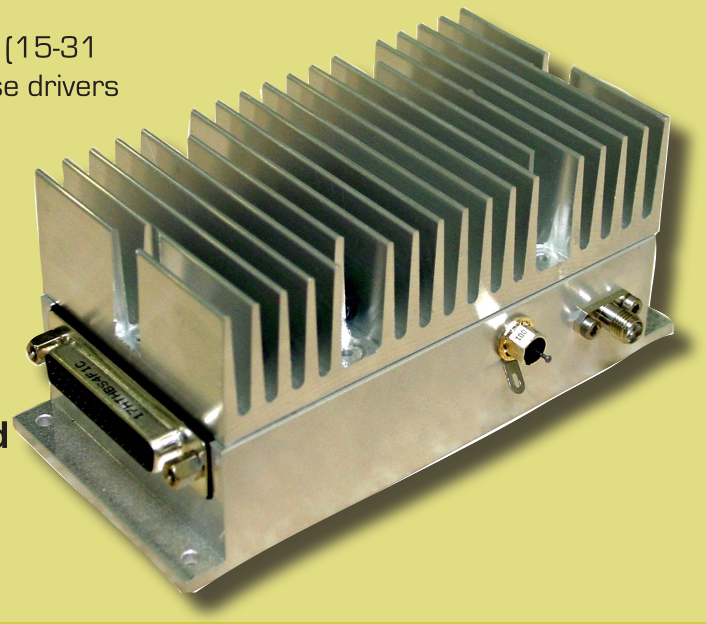
These deflectors offer a typical total resolution of 160 000 dots (2 axis) with a round input laser beam up to 6.7 mm ($1/e^2$). Main advantage is the large scan angle which can reach up to 3 x 3 degrees.
With an adapted frequency driver, this two axis deflector is a very powerfull tool for optical tweezing applications.

	DTSXY-400
Material-Acoustic mode	TeO2 [S]
Acoustic Velocity	Nom V=650 m/s
Optical Wavelength range	1064 nm or single in [350-1600 nm]
Transmission	> 95 % per axis (broadband coating)
Optical Input / Output polarizations	Linear orthogonal
Aperture	7.5 x 7.5 mm² (Beam diameter 6.7 mm)
Carrier frequency / Frequency shift	Wavelength dependent
Frequency range	30 MHz @1064 nm
Scan angle	49 x 49 mrd² @1064 nm
Diffraction efficiency	> 50 % across frequency range (2 axis)
Access time	10.3 µs (beam dia 6.7 mm)
Resolution (N)	240x240 @1064 nm
Static extinction ratio	> 2000/1
Max optical power density	> 10 W / mm² @1064 nm
Input impedance	Nom 50 Ohms
V.S.W.R.	Nom < 2/1
RF Power	< 2 Watts @1064 nm (per axis)
Connectors	SMA
Operating Temperature	10 to 40°C

Note : AA also propose Version DTSXY-250 with an aperture of 4.5 x 4.5 mm²

High Resolution Direct Digital Synthesizers (DDSA)

These Direct Digital Synthesizers are dedicated to high accuracy applications for which high resolution is the key factor.
A PC interface board will be used to control the frequency (15-31 bits) as well as the latch of the frequency (1 bit E/D). These drivers are used in combination with AA amplifiers.

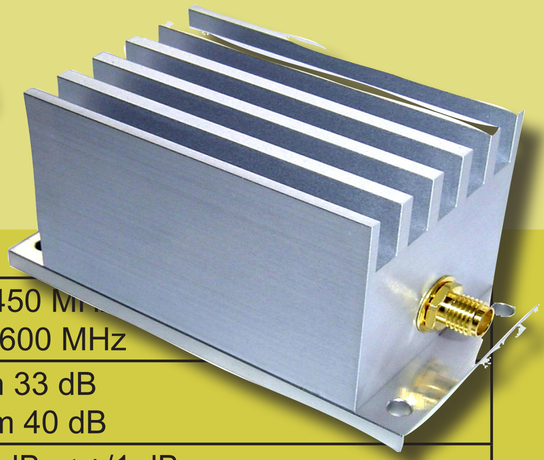


High Stability

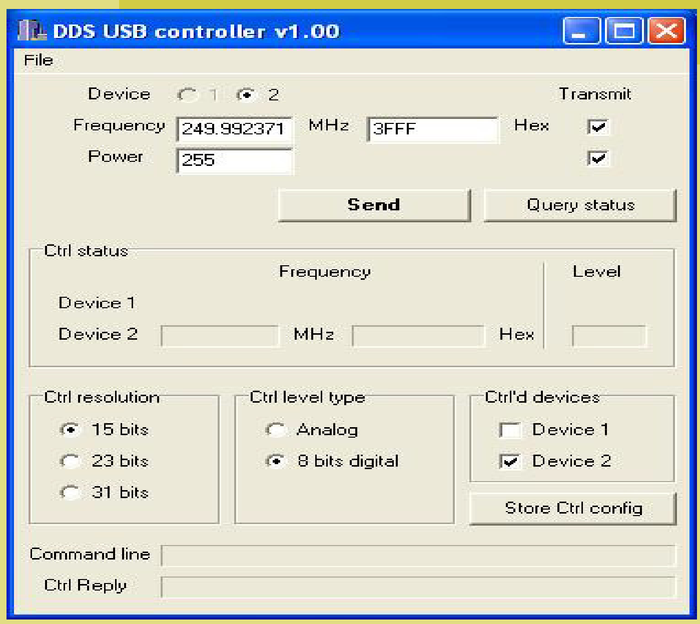
High Accuracy
Positionning accuracy < 0.5 nrad
with DDSA 31 bits

Frequency range	10 to 350 MHz
Frequency stability/accuracy	Nom +/- 1 ppm / °C
Frequency step	Nom 15 KHz (15 bits) Nom 1 KHz (23 bits) Nom 0.25 Hz (31 bits)
Commutation time	< 40 ns (15 bits) < 64 ns (23 bits) < 80 ns (31 bits)
Frequency control	15, 23, 31 bits digital + 1 bit Enable/disable
Rise time / Fall time (10-90 %)	< 10 ns analog (< 100 ns 8 bits)
Modulation input control	Analog 0-5 V / 50 ohms (8 bits on request)
Extinction ratio	> 40 dB for F < 250 MHz
Harmonics	H2 > 30 dBc
Output RF power	Nom 0 dBm (to be associated with AA Amplifier)
Output impedance	50 ohms
V.S.W.R.	< 1.2 : 1
Power supply	OEM version : 15-28 VDC – nom 320 mA @24 VDC Laboratory version 4 : 110-230 VAC – 50-60 Hz
Input / Output connectors	SMA, HD44 / SMA
Size	OEM version : 129 x 61 x 55 mm3 Laboratory version 4 : 310 x 250 x 105 mm3
Cooling	Conduction through baseplate
Maximimun case temperature	50 °C
Operating temperature	10 to 40 °C

Associated RF Power amplifiers (AMPA)

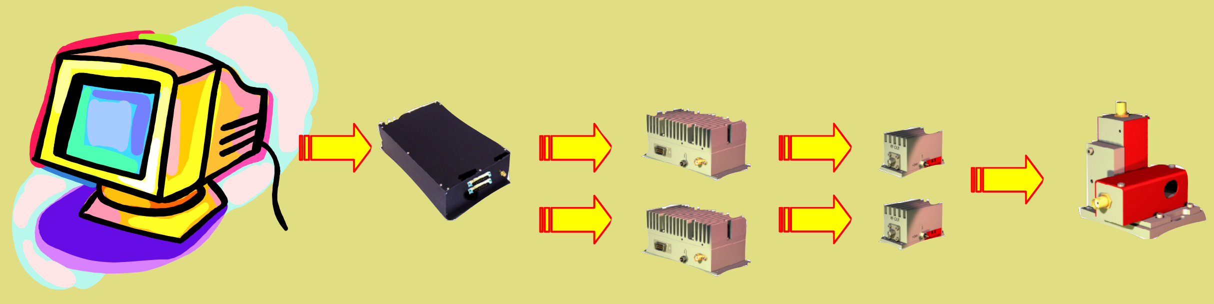


Frequency range	1 Watt : 20-450 MHz 2 watts : 20-600 MHz
Gain	1 Watt : nom 33 dB 2 watts : nom 40 dB
Gain Flatness	Nom +/- 0.5 dB, < +/1 dB
Noise Figure	1 Watt : nom 5 dB 2 watts : nom 7 dB
Output RF Power (1 dB compression)	> 30 dBm (> 29.5 dBm @ <40 MHz), 1 Watt > 33 dBm , 2 Watts
Output Impedance	50 Ohms
CLASS	A
Power supply3	1 Watt : 24 +/- 0.5 VDC - < 340 mA 2 watts : 24 +/- 0.5 VDC - < 500 mA
Input / Output connectors	SMA female
Size	76 x 40 x 42 mm3
Heat exchange	Conduction through baseplate
Operating temperature	-10 to +55 °C



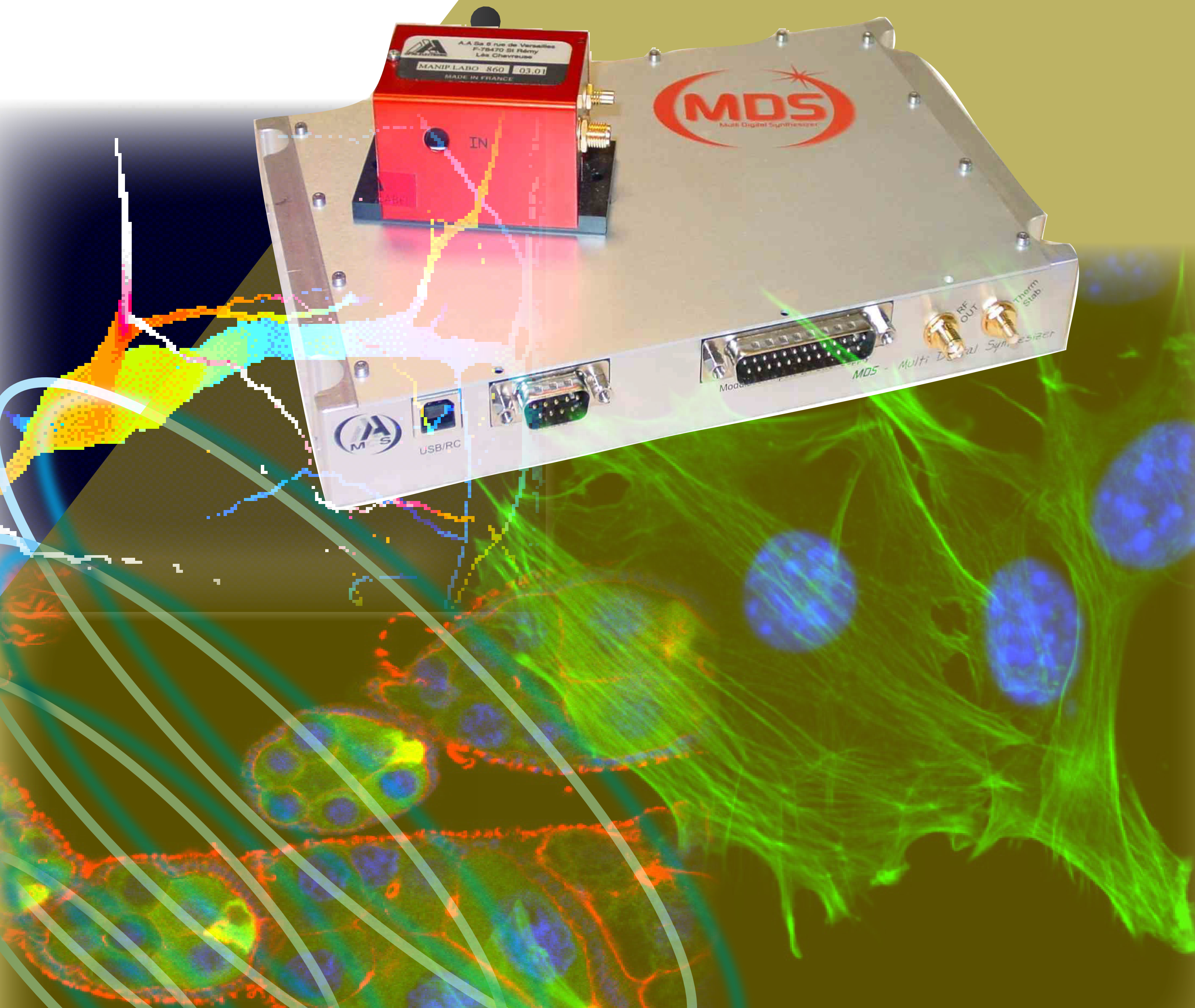
USB Controller (USB-CTRL-DDS)

AA propose an external USB controller suitable to drive high resolution Direct Digital Synthesizers. Its USB 2.0 interface will allow user a fast and easy set up to drive one axis or two axis synthesizers for variable frequency shifters, one axis deflectors or two axis deflectors.
This USB controller is compatible with the 15, 23 and 31 bits DDS drivers.



Confocal Microscopy

Acousto-optic products



AA OPTO-ELECTRONIC
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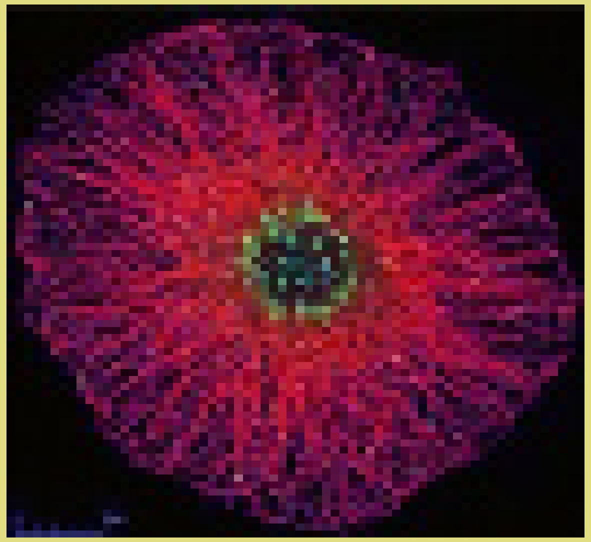
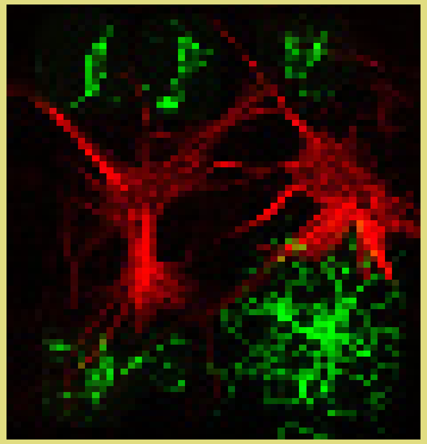
Introduction

Confocal microscopy is an imaging technique used to increase micrograph contrast and/or to reconstruct three-dimensional images by using a spatial pinhole to eliminate out-of-focus light or flare in specimens that are thicker than the focal plane. This technique has been gaining popularity in the scientific and industrial communities. Typical applications include life sciences and semiconductor inspection.



Basic concept

The principle of confocal imaging was patented by Marvin Minsky in 1961. In a conventional (i.e., wide-field) fluorescence microscope, the entire specimen is flooded in light from a light source. Due to the conservation of light intensity transportation, all parts of specimen throughout the optical path will be excited and the fluorescence detected by a photodetector or a camera. In contrast, a confocal microscope uses point illumination and a pinhole in an optically conjugate plane in front of the detector to eliminate out-of-focus information. Only the light within the focal plane can be detected, so the image quality is much better than that of wide-field images. As only one point is illuminated at a time in confocal microscopy, 2D or 3D imaging requires scanning over a regular raster (i.e. a rectangular pattern of parallel scanning lines) in the specimen. The thickness of the focal plane is defined mostly by the square of the numerical aperture of the objective lens, and also by the optical properties of the specimen and the ambient index of refraction.



Different principles

Three types of confocal microscopes are commercially available: Confocal laser scanning microscopes, spinning-disk (Nipkow disk) confocal microscopes and Programmable Array Microscopes (PAM). Generally speaking, confocal laser scanning microscopy yields better image quality but the imaging frame rate is very slow (less than 3 frames/second); spinning-disk confocal microscopes can achieve video rate imaging—desired for dynamic observations.

Confocal Laser scanning Microscopy

Confocal laser scanning microscopy (CLSM or LSCM) is a valuable tool for obtaining high resolution images and 3-D reconstructions. The key feature of confocal microscopy is its ability to produce blur-free images of thick specimens at various depths. Images are taken point-by-point and reconstructed with a computer, rather than projected through an eyepiece. The principle for this special kind of microscopy was developed by Marvin Minsky in 1953, but it took another thirty years and the development of lasers for confocal microscopy to become a standard technique toward the end of the 1980s.

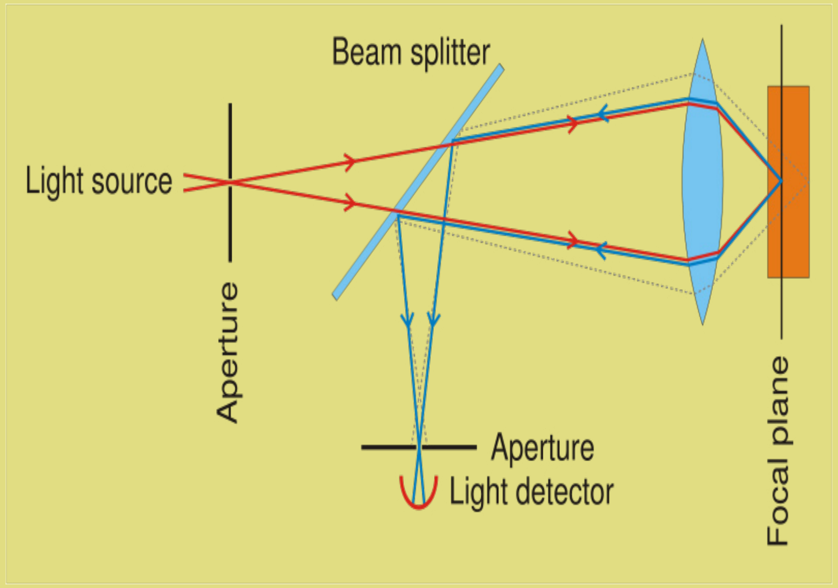


Image formation

In a laser scanning confocal microscope a laser beam passes a light source aperture and then is focused by an objective lens into a small (ideally diffraction-limited) focal volume within a fluorescent specimen. A mixture of emitted fluorescent light as well as reflected laser light from the illuminated spot is then recollected by the objective lens. A beam splitter separates the light mixture by allowing only the laser light to pass through and reflecting the fluorescent light into the detection apparatus. After passing a pinhole the fluorescent light is detected by a photo-detection device (photomultiplier tube (PMT) or avalanche photodiode) transforming the light signal into an electrical one which is recorded by a computer.

The detector aperture obstructs the light that is not coming from the focal point, as shown by the dotted grey line in the image. The out-of-focus points are thus suppressed: most of their returning light is blocked by the pinhole. This results in sharper images compared to conventional fluoresence microscopy techniques and permits one to obtain images of various z axis planes (z-stacks) of the sample.

The detected light originating from an illuminated volume element within the specimen represents one pixel in the resulting image. As the laser scans over the plane of interest a whole image is obtained pixel by pixel and line by line, while the brightness of a resulting image pixel corresponds to the relative intensity of detected fluorescent light. The beam is scanned across the sample in the horizontal plane using one or more (servo-controlled) oscillating mirrors. This scanning method usually has a low reaction latency and the scan speed can be varied. Slower scans provide a better signal to noise ratio resulting in better contrast and higher resolution. Information can be collected from different focal planes by raising or lowering the microscope stage. The computer can generate a three-dimensional picture of a specimen by assembling a stack of these two-dimensional images from successive focal planes.

In addition, confocal microscopy provides a significant improvement in lateral resolution and the capacity for direct, non-invasive serial optical sectioning of intact, thick living specimens with an absolute minimum of sample preparation. As laser scanning confocal microscopy depends on fluorescence, a sample usually needs to be treated with fluorescent dyes to make things visible. However, the actual dye concentration can be very low so that the disturbance of biological systems is kept to a minimum. Some instruments are capable of tracking single fluorescent molecules. Additionally transgenic techniques can create organisms which produce their own fluorescent chimeric molecules. (such as a fusion of GFP, Green fluorescent protein with the protein of interest).

Resolution enhancement by the confocal principle

Laser scanning confocal microscopy (LSCM) is a scanning imaging technique in which the resolution obtained is best explained by comparing it with another scanning technique like Scanning electron microscope (SEM). Not to be confused with phonograph-like imaging—AFM or STM, for example, where the image is obtained by scanning with an atomic tip over a conducting surface.

In LSCM a fluorescent specimen is illuminated by a point laser source, and each volume element is associated with a discrete fluorescence intensity. Here, the size of the scanning volume is determined by the spot size (close to diffraction limit) of the optical system. This is due to the fact that the image of the scanning laser is not an infinitely small point but a three-dimensional diffraction pattern.

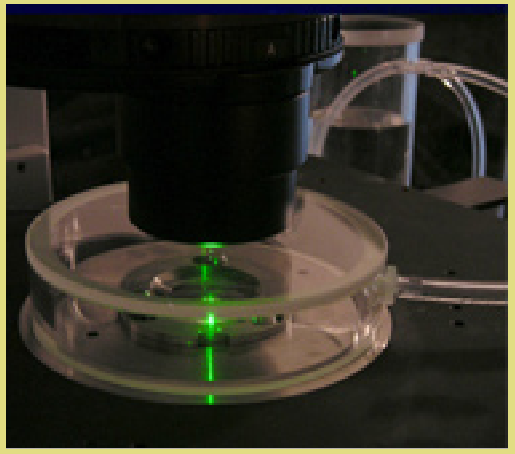
The size of this diffraction pattern and the focal volume it defines is controlled by the numerical aperture of the system's objective lens and the wavelength of the laser used. This can be seen as the classical resolution limit of conventional optical microscopes using wide-field illumination. However, with confocal microscopy it is even possible to overcome this resolution limit of wide-field illuminating techniques as only light generated in a small volume element is detected at a time. Here it is very important to note that the effective volume of light generation is usually smaller than the volume of illumination; that is, the diffraction pattern of detectable light creation is sharper and smaller than the diffraction pattern of illumination.
In other words, the resolution limit in confocal microscopy depends not only on the probability of illumination but also on the probability of creating enough detectable photons, so that the actual addressable volume being associated with a generated light intensity is smaller than the illuminated volume. Depending on the fluorescence properties of the used dyes, there is a more or less subtle improvement in lateral resolution compared to conventional microscopes. However, by using light creation processes with much lower probabilities of occurrence such as second harmonic generation (SHG), the volume of addressing is reduced to a small region of highest laser illumination intensity resulting in a significant improvement in lateral resolution.

Unfortunately, the probability decrease in creation of detectable photons has a bad effect on the signal to noise ratio. This can be compensated by using more sensitive photo-detectors or by increasing the intensity of the illuminating laser point source. Increasing the intensity of illumination latter risks excessive bleaching or other damage to the specimen of interest, especially for experiments in which comparison of fluorescence brightness is required.

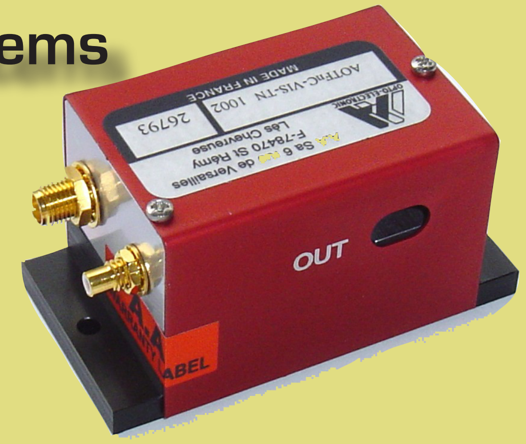
Uses

Confocal microscopy is clinically used in the evaluation of various eye diseases. It is particularly useful for imaging, qualitative analysis and quantitafication of endothelial cells of the cornea. It is used for localising and identifying presence of filamentary fungal elements in the corneal stroma in cases of keratomycosis, enabling rapid diagnosis and thereby early institution of definitive therapy.

Confocal microscopy is also used as the data retrieval mechanism in some 3D optical data storage systems and has helped determine the age of the Magdalen papyrus



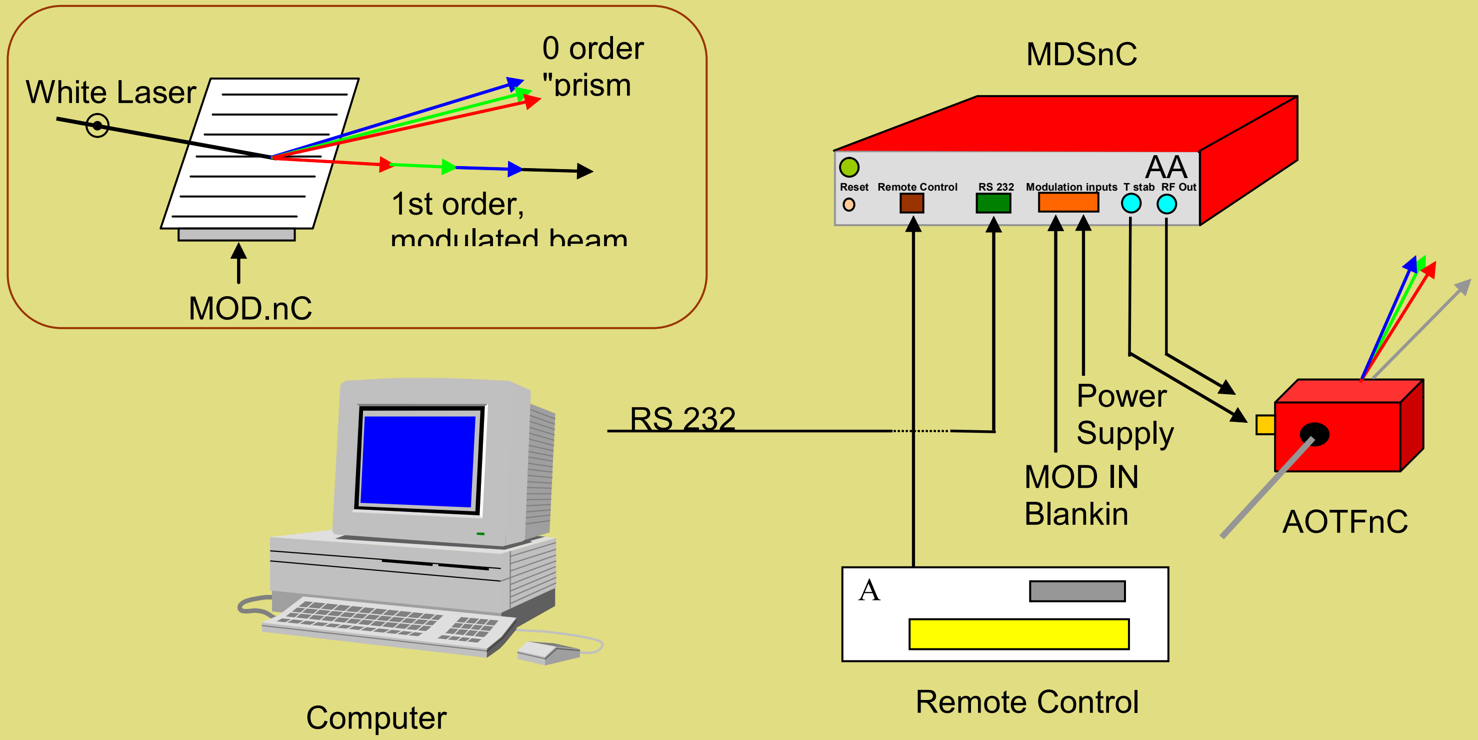
Polychromatic Modulation Systems



The AOTF.nC is a special acousto-optic tunable filter which uses the anisotropic interaction inside a tellurium dioxide crystal to control independently or simultaneously different lines from an incoming laser light (White laser, Ar+, Kr+, HeNe, DPSS, Dye...).
Up to 12 distinct lines can be mixed and separately modulated in order to generate different colorimetric patterns.

The specific crystal cut of the AOTF.nC produces good diffraction efficiency (> 90%), narrow resolution (1-2 nm), a low cross-talk between lines, and high extinction ratio.
The large separation angle between 0 and 1st orders, as well as the excellent output chromatic colinearity (<0.2 mrd over 450-700 nm) make this AOTF a powerful tool for free space or fiber pigtailed applications.
Its associated thermal stabilisation maintains stable diffraction efficiency and reduces dramatically beam drift with single mode fiber pigtailing. This is a major advantage for high sensitivity applications.

The associated driver MOD.nC, based on PLLs (Phase Locked Loop), has been specially designed in order to exploit the best of the AOTF.nC features.
Its compact design with single power supply, low RF emissions and ease of use will satisfy the most demanding of applications, where accuracy and flexibility are key requirements.
Thanks to its complete numerical design and integrated microcontroller setting up is fast, simple and repeatable.
Access to and adjustments of functions is simple with either a bright LCD display (with remote control adjustment) or through a RS232 serial link (with computer control).
All parameters are stored in an EEPROM and are automatically loaded after each switch on.
Each line is externally controlled by a distinct modulation input signal which can be TTL or analog. Additionally, all lines can be simultaneously controlled by a blanking signal which produces smooth effects without modifying the colorimetric balance.
The combination of the modulation input and blanking signals provides the best extinction ratio performance (> 140 dB).

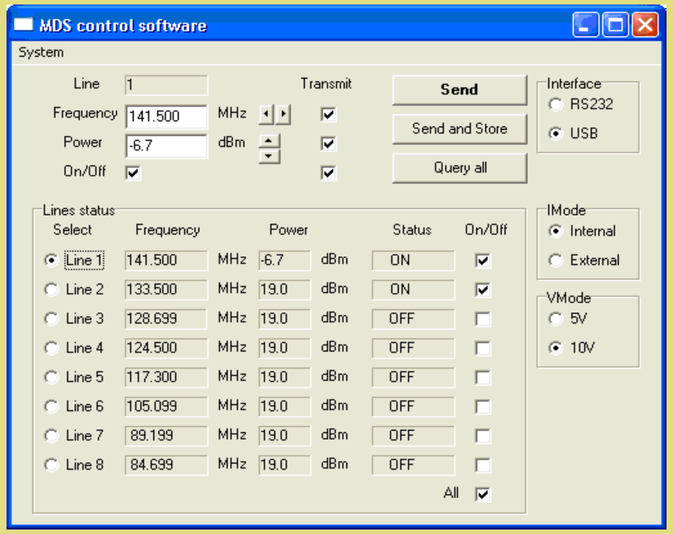


Polychromatic Modulators

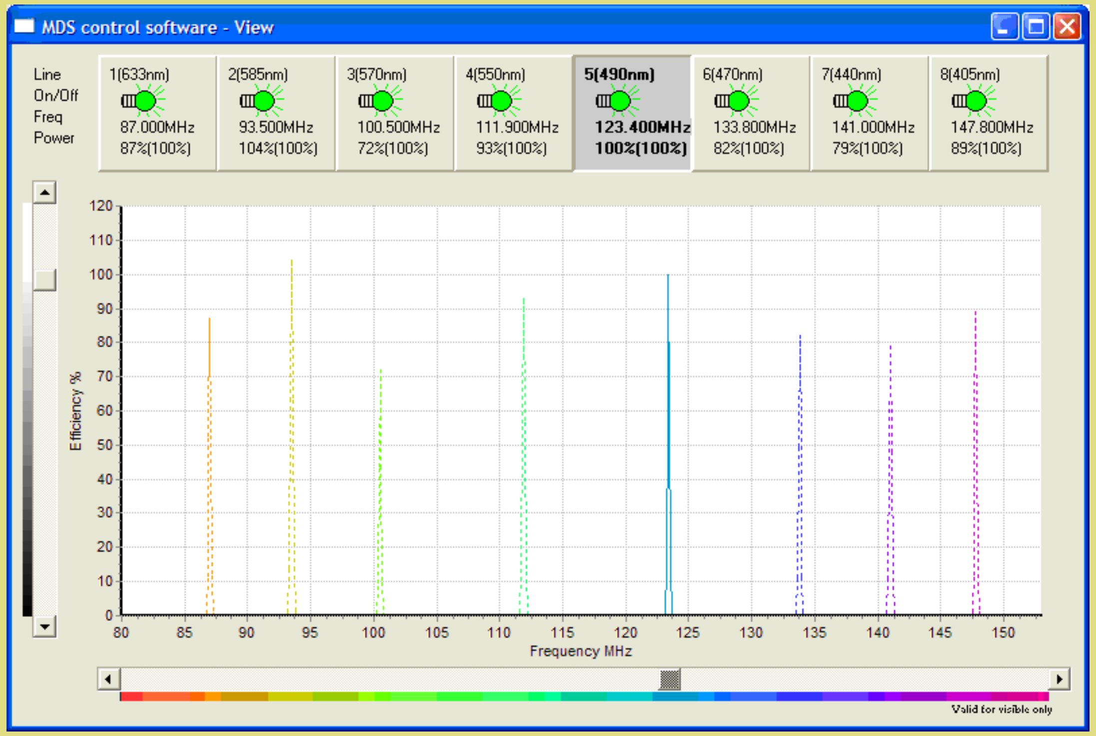
AOTFnC	UV	VIS	VIS
Number of channels / Lines	4	8	8
Acoustic velocity (nom)	675 m/s	650 m/s	660 m/s
Optical wavelength range	350-430 nm	450-700 nm	400-650 nm
Transmission	> 80 % -nom 90%	> 95 %	> 90 %
AO interaction type	Birefringent	Birefringent	Birefringent
Selected order	+1	-1	-1
Input Light polarization	Linear parallel	Linear orthogonal	Linear orthogonal
Output Light polarization	Linear orthogonal	Linear parallel	Linear parallel
Drive frequency range	110-180 MHz	80-153 MHz	74-158 MHz
Active aperture	2 x 2 mm²	3 x 3 mm²	3 x 3 mm²
Spectral resolution (FWHM)		nom 1-2 nm	nom 1-4 nm
Separation angle (orders 0-1)	> 4.2 degrees	> 4.6 degrees	> 4 degrees
Chromatic colinearity (order 1)	< 0.2 mrd @351+363 nm	< 0.2 mrd	< 0.3 mrd
Temperature stabilization	T or TN	T or TN	T or TN
AO Efficiency	>=90%	>= 90 % /line	>= 90 % /line
Rise time	980 ns / mm	1010 ns / mm	1000 ns /mm
Max accepted RF power	< 1 W all lines	< 1 W all lines	nom 1 W all lines
Electrical impedance	50 Ohms	50 ohms	50 ohms
VSWR	< 2/1	< 2/1	< 2/1
Size	70 x 36.6 x 35.8 mm3		
Operating temperature	10 to 40 °C		

Polychromatic Drivers / Digital versions

These drivers based on Direct Digital Synthesizers (DDS), produce multiple fixed stable and accurate RF frequency signals for polychromatic modulators. Their brand new design with "on the edge" technology offers unique performance in term of accuracy, speed and stability (single/multi-line), thanks to their internal temperature correction and high linearity design.
The built in amplifier delivers the necessary RF power to drive the acousto-optic device, with reduced power consumption (AA "COLD DESIGN").
The RF output power per channel can be individually modulated (MOD IN signals) or simultaneously modulated (BLANKING signal). AA focussed on a ultra low crosstalk version with superior fast and fall time.
The adjustments of the driver (Frequency & Power) can be done with a remote control, USB or through RS 232 communication to allow user flexibility in power control or frequency scanning.



USB Software



MDSnC

Number of channels	Up to 8
Frequency range	Octave or above in 20-180MHz – will be adapted to AO
Frequency stability	+/- 2 ppm/°C
Frequency accuracy	Nom 1 KHz
Frequency step	Nom 1 KHz
Frequency control	Remote Control or USB, Option : RS232
Power Supply	OEM version : 24 VDC - nom 0.85A
Laboratory version	110/230 VAC - 50-60 Hz
Rise Time / Fall time (10-90 %)	< 50ns
Modulation Input Control	Analog 0-5 V or 0-10 V / 10 KOhms
Blanking Input Control	Analog 0-5 V or 0-10 V / 10 KOhms
Extinction ratio @ 125 MHz	MOD IN > 80 dB typ 90dB BLK > 70 dB typ 80dB MOD IN + BLK > 90 dB typ 100 dB
Output RF power	22 dBm per channel
Output Impedance	50 Ohms
V.S.W.R.	Nom < 1.5/1
Input / Output connectors	DB25 / SMA (DB9 for RS232)
Size	OEM version : 207 x 127 x 20.2 mm3
Laboratory version	Rack 19", 1U
Weight	OEM version : nom 1 kg
Laboratory version	nom 4 kg
Heat exchange	OEM version : Conduction
Laboratory version	stand alone
Operating temperature	10 to 40 °C
Maximum case temperature	OEM version : 50 °C
Option	Cover with Fan