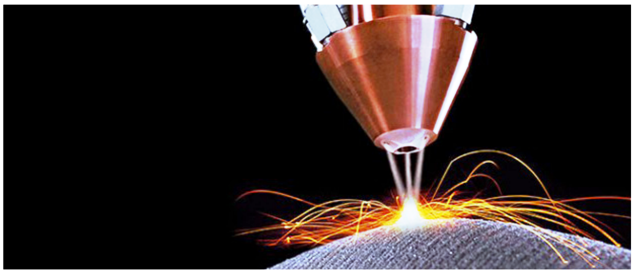
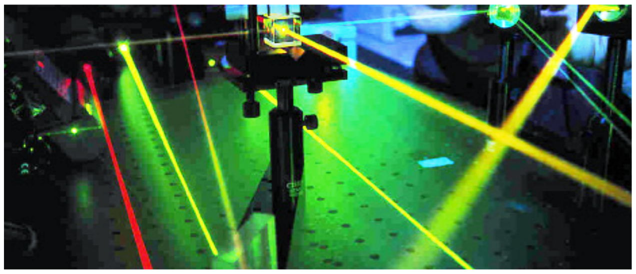
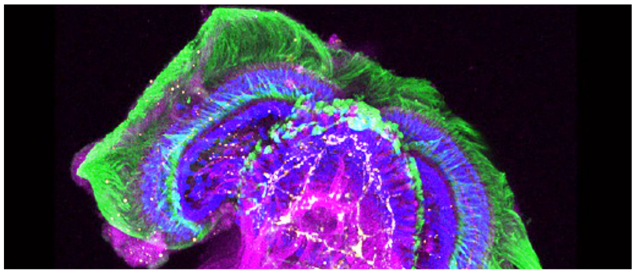
AA OPTO-ELECTRONIC

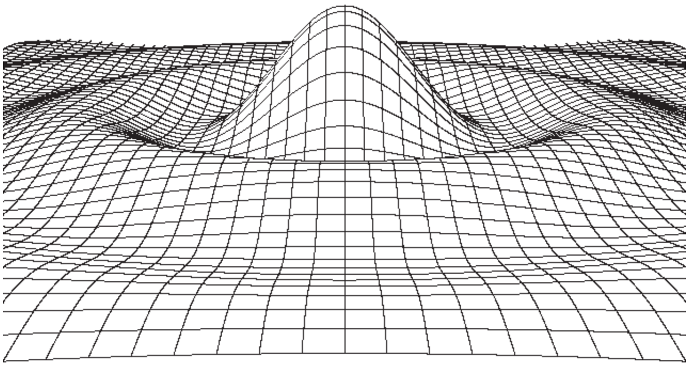
Acousto-Optic RF drivers New Products



Acousto-optic Theory

Application Notes



- 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

Acousto-Optic Theory

1- 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.

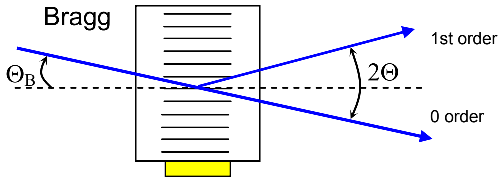
Raman and Nath (1937) have designed a general ideal model of interaction taking into account several orders. This model was developed by **Phariseau** (1956) for diffraction including only one diffraction order.

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.

2- 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 (ΘB):
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 (ΔΘ):
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 (ΔFmod):
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 (ER):
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 piezo-electric transducer. This will be lower than the RF power as the electro-mechanical conversion ratio is lower than 1.

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

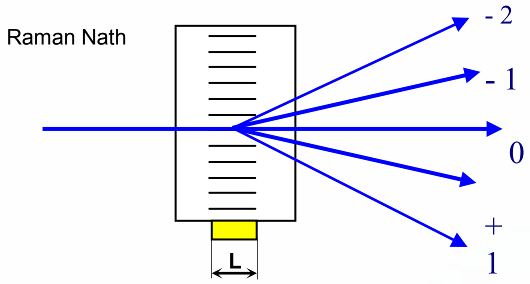
A parameter called the “quality factor, Q”, determines the interaction regime. Q is given by:

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

where 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 Θ_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 = 2pni/l_o – wave vector of the incident beam.
Kd = 2pni/l_d – wave vector of the diffracted beam.
K = 2pF/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 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.

3-3 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, ΘB:

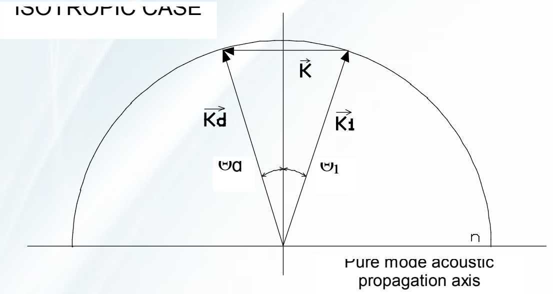
$$\theta_B = \frac{\lambda F}{2v}$$

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

Acousto-Optic Theory

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 I1 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 I0 is the incident light intensity, M2 is the acousto-optic figure of merit for the crystal and H and L are the height and length of the acoustic beam. I_0 is the wavelength of the incident beam.

Diffraction efficiency (relative) is the ratio I_1/I_0:

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

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, K0.

A complicated analysis leads to the result:

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

where ΔΦ = ΔK.L and is called the "phase asynchronism".

In the isotropic case :

$$\Delta\phi = \frac{\pi\lambda}{v}\,\frac{\Delta F}{2}\,\frac{L}{\Lambda_0}$$

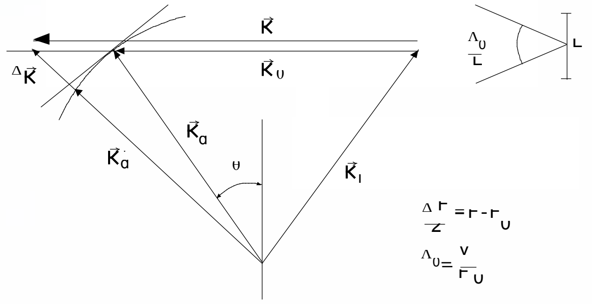
At the correct Bragg frequency, ΔF =0 (F=Fo) and efficiency is maximum

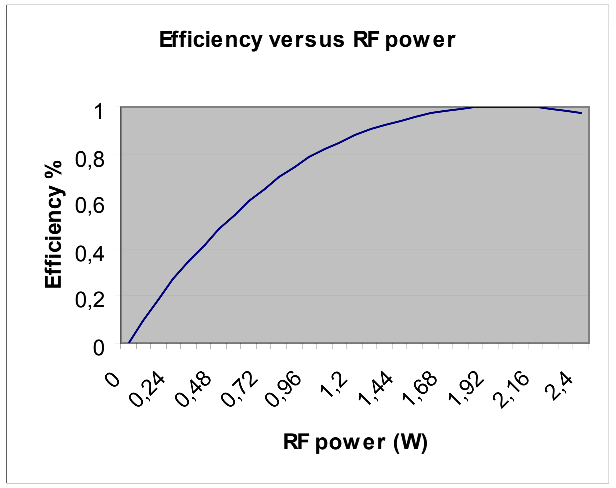
When ΔF increases, diffraction efficiency decreases and will continue to decrease down to zero.

If there is a lower limit on the acceptable diffraction efficiency, then this puts a limit on ΔF. 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.

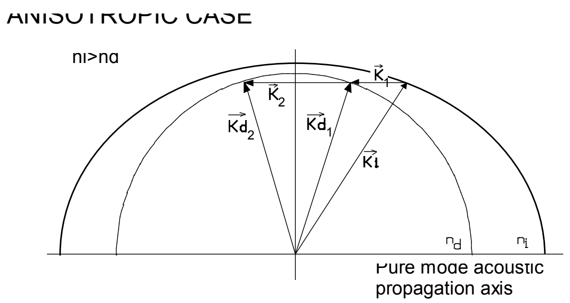




Anisotropic interaction

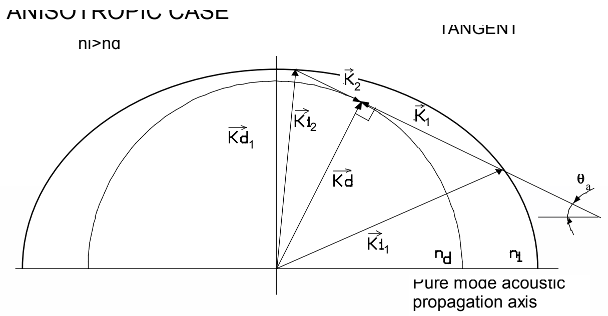
In an anisotropic interaction, on the other hand, the refractive indexes of the incident and diffracted beams will be different due to a change in polarization associated with the interaction. This can be seen in the figure below where the acoustic wave vector K1 connects the index curves of the incident and diffracted waves. (K2 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.



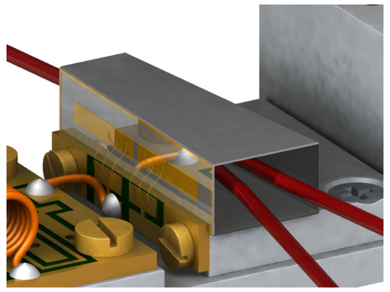
This means that the length of the acoustic wave-vector can vary quite grossly while only producing small changes in the length of the diffracted beam's wave-vector. So, in this situation, DK (and, hence, DF) is quite insensitive to changes in RF frequency.

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.

5- 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.



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.

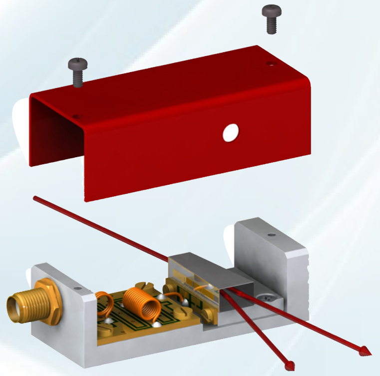
The shape of the electrode can be varied for impedance matching or to "shape" the acoustic wave.

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.



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:

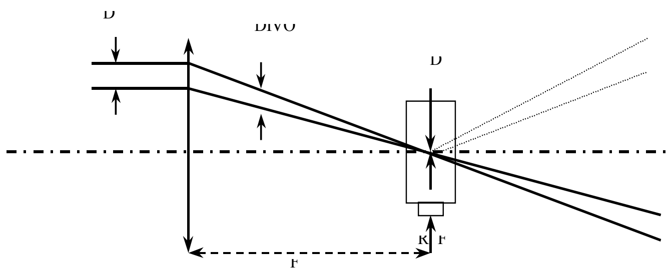
$$T_R = \beta \frac{\phi}{V}$$

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.

$$T_R = 0.66\frac{\phi}{V}$$

(Valid for a TEM00 laser beam, 1/e² dia)



Limitations

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

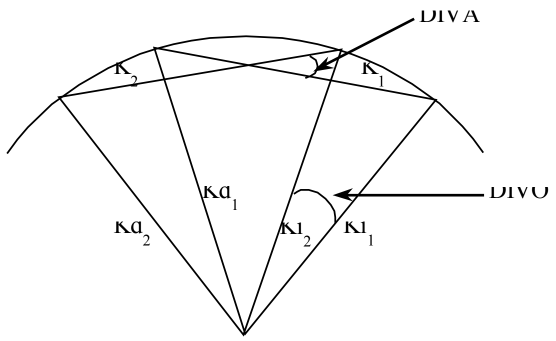
The light beam has a divergence which cannot be neglected. To preserve the efficiency of the interaction on all the bandwidth ΔF, it is necessary to reach the Bragg conditions for all the "angles" of the light beam.

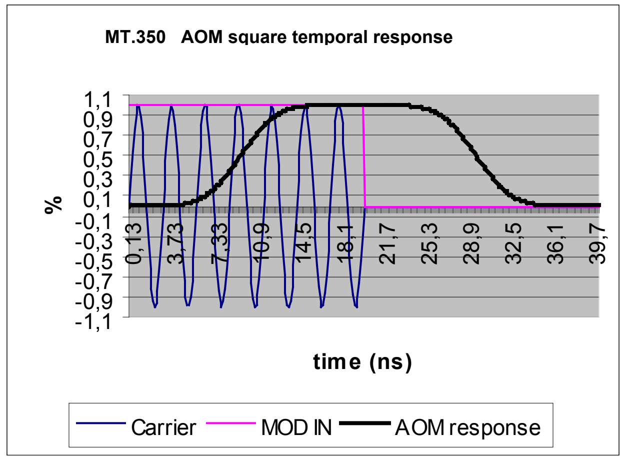
For this purpose, the acoustic divergence (DIVA) (=Λ/L) where Λ is the acoustic wavelength and L the dimension of the ultrasonic source) must compensate for light divergence DIVO.

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)

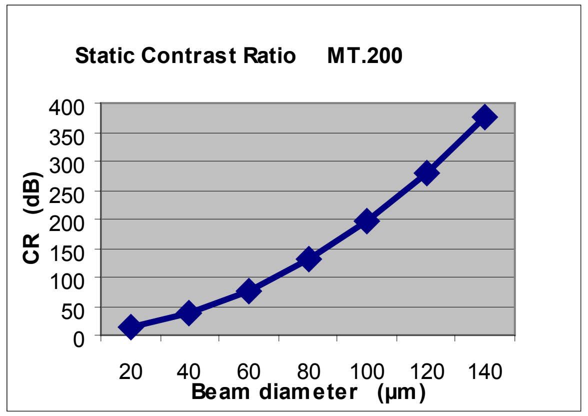
The incident laser beam properties have a significant impact upon modulator performances (temporal response and extinction ratio). The static contrast ratio measures the ability of the modulator to separate the different diffraction orders (especially 0 and 1st orders).

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 :

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

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:

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

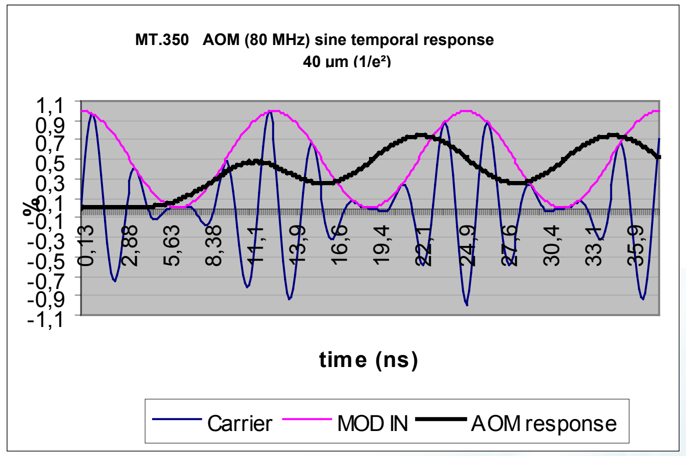
V: acoustic velocity, ϕ: beam diameter (1/e²)
Fc : frequency to the 1/e² response rolloff

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
- Mode-locker

Specific application:

Multi-beam modulators. Several discrete frequencies (F1,F2,…,Fn) belonging to the bandwidth of the modulator are sent in the modulator. The diffracted beams are ordered separately, in different directions.

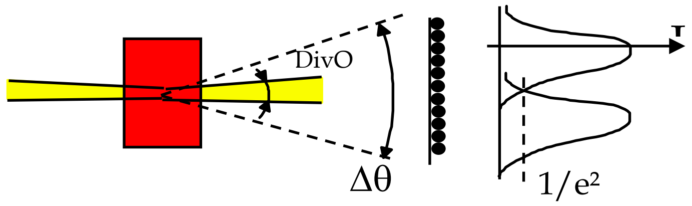
A scanning system (for example deflecting) in the perpendicular direction allows, amongst other thing application, to form characters (printer).

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
Static Resolution of an AOD 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/e²) in the case of a TEM00 beam.



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

ΔΘ: 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/e²)
V: acoustic velocity

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

T_a 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 T_a x ΔF.

Dynamic resolution Nd

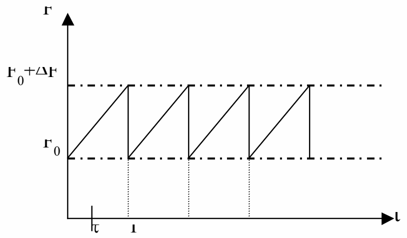
When the field of the frequencies does not consist any more of discrete values but of a continuous sweeping, it is necessary to define the dynamic resolution, which takes account of the " gradient " of frequencies.

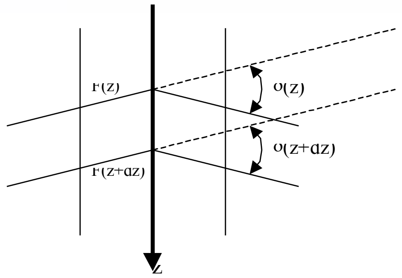
In the case of a linear frequency sweeping:
In Z=O (at the crystal's entry), the frequency F is equal to:

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

In Z, the frequency is equal to

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





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

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

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

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:

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

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

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

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

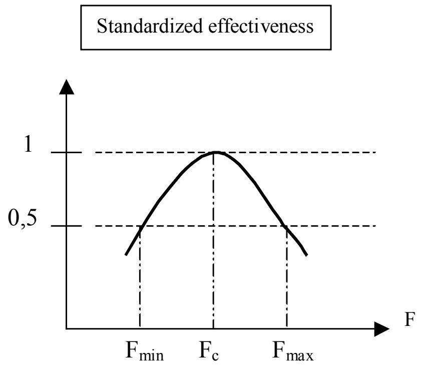
Examples:

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

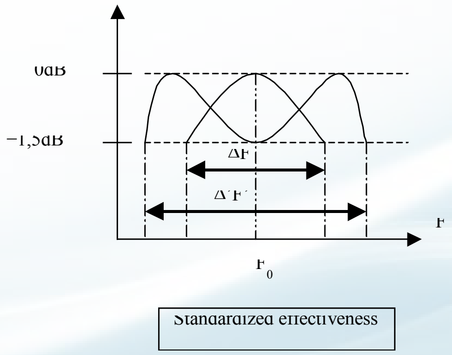
Efficiency and bandwidth

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 isotropic interaction:



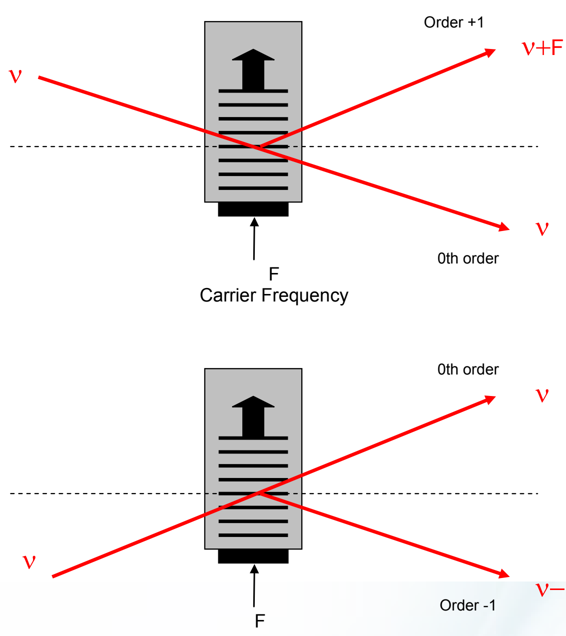
Some applications require a quasi-constant efficiency on all the bandwidth. This can be obtained by decreasing width (L) of the ultrasonic beam, but with the detriment of the maximum efficiency.
Particular case of anisotropic interaction: the bandwidth of the anisotropic interaction can be increased 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.



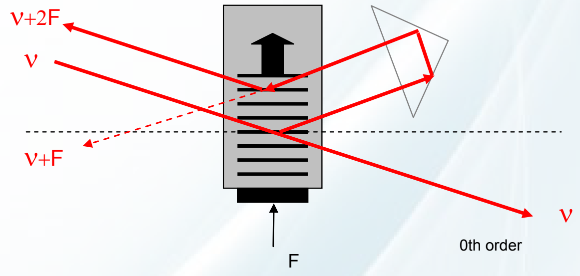
Frequency Shifters

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.

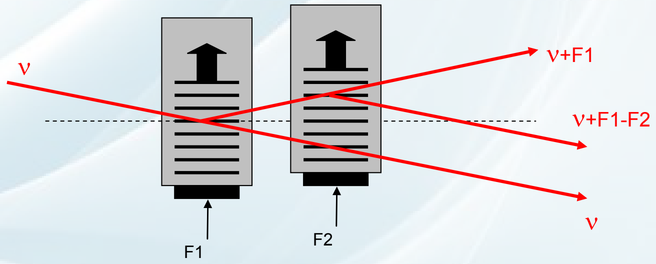
Fixed Frequency Shifts

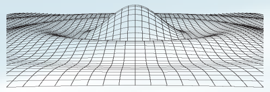


Multiple Travels Frequency Shifts (+/-)



Case of Low frequency Shifts

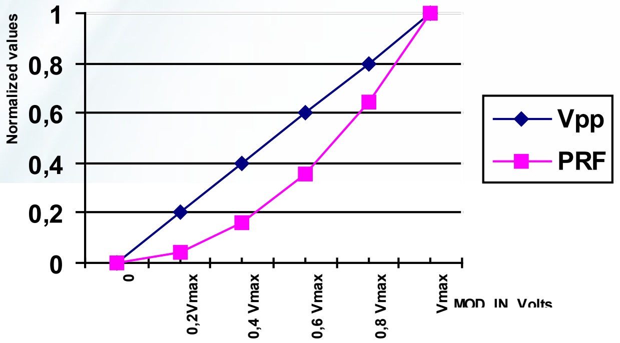




Output RF power

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

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



VSWR (voltage stationary wave ratio)

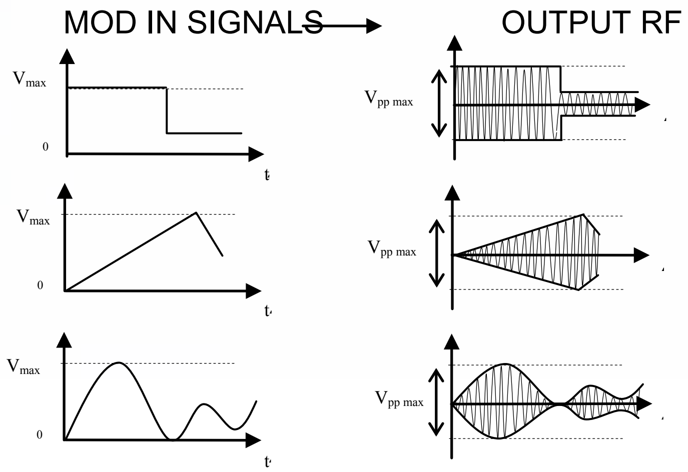
This parameter gives an information on the reflected and transmitted RF power to a system.
In order to have the best matching between an acousto-optic device and a radio frequency source/amplifier, one will have to optimize both impedance matching on the source and the driver. Generally, input impedance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

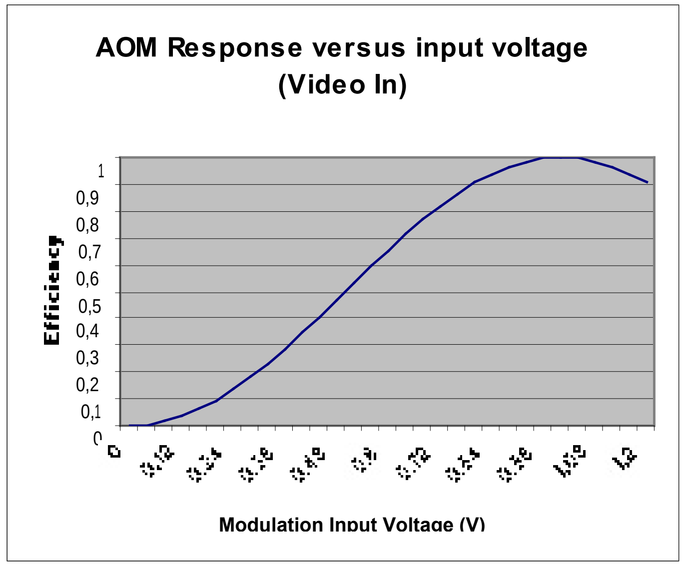
VSWR	Reflected POWER
1.002 / 1	0.0001 %
1.068 / 1	0.1 %
1.15 / 1	0.5 %
1.22 / 1	1 %
1.5 / 1	4 %
2 / 1	11 %
2.5 / 1	18 %
3 / 1	25 %

Amplitude Modulation

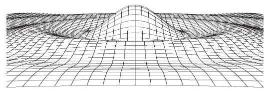
ANALOG MODULATION (0-Vmax)
The analog modulation input of your driver controls linearly and continuously the output RF amplitude of the signal from 0 to maximum level.
When applying 0 V on "MOD IN", no output signal
When applying Vmax on "MOD IN", maximum output signal level

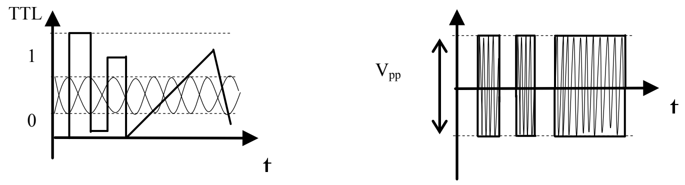
The output RF waveform is a double-sideband amplitude modulation carrier.
Vmax can be adjusted at factory from 1 V to 10 V.



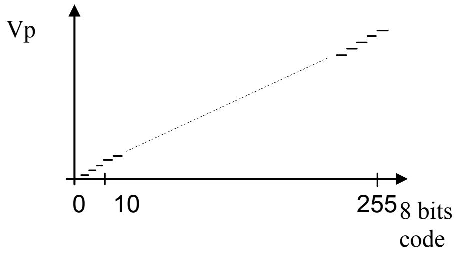


TTL MODULATION (ON/OFF)
The TTL modulation input of your driver is compatible with standard TTL signals. It allows the driver to be driven ON and OFF.
- When applying a "0" level (< 0.8 V) on "MOD IN", no output signal.
- When applying "1" level (> 2.4 V) on "MOD IN", maximum output signal level.
It will be noted that a TTL modulation input can be piloted with an analog input signal.



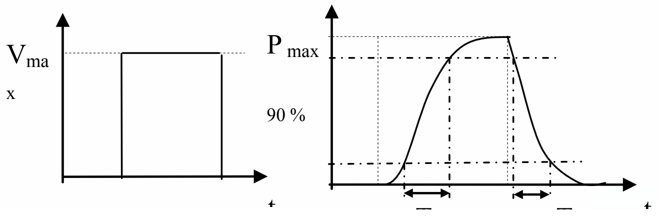


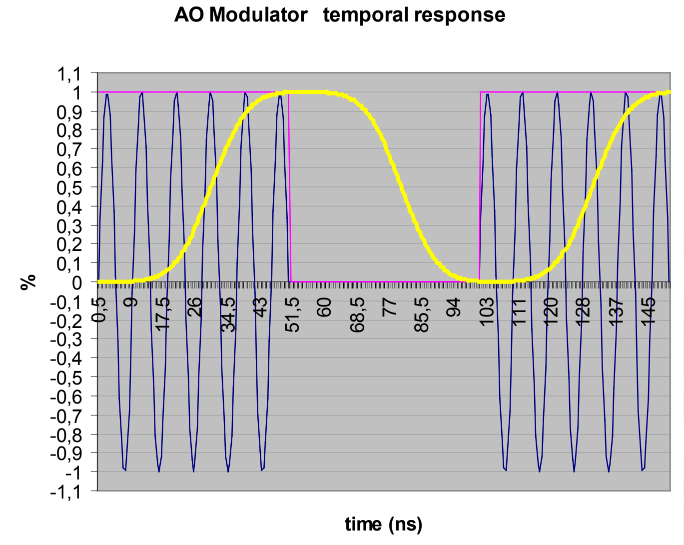
Digital 8 bit AMPLITUDE MODULATION
A byte (8 bit //) controls the amplitude of the output RF signal. A D/A converter converts the 8 bits command (N) on an analog signal which controls linearly the output amplitude.
256 levels are available
- When N=00000000, no output RF signal
- When N=11111111, maximum output level



Rise and 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.





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.

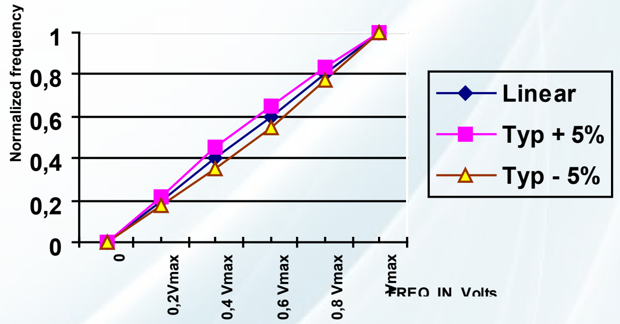
$$Extinction\ ratio = 10\log\left(\frac{P_{\max}}{P_{\min}}\right) = 20\log\left(\frac{V_{pp\max}}{V_{pp\min}}\right) \quad (dB)$$

FREQUENCY CONTROLS

ANALOG CONTROL (0-Vmax)
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 "OFF-SET" 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 / 1KW).



8 BITS FREQUENCY CONTROL (15, 23, 31b)
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

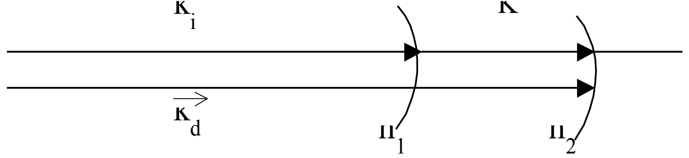
Acousto-Optic AOTF - Tunable Filters

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:

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

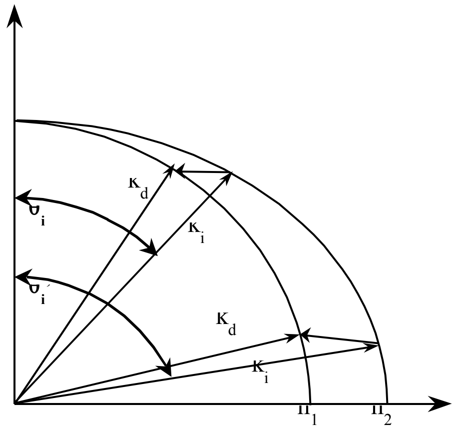
A good resolution (λ0/Δλ0 high) imposes a large dimension (D) of the light beam. The numerical aperture of such systems is thus obligatorily very low and thus their utilization is very limited. The collinear anisotropic interaction makes it possible to tune the filter by simple variation of the acoustic frequency, under significant numerical aperture:



$$\eta \approx \eta_0 \sin c^2\left(\frac{\Delta k L}{2\pi}\right)$$

(collinear AOTF efficiency)

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

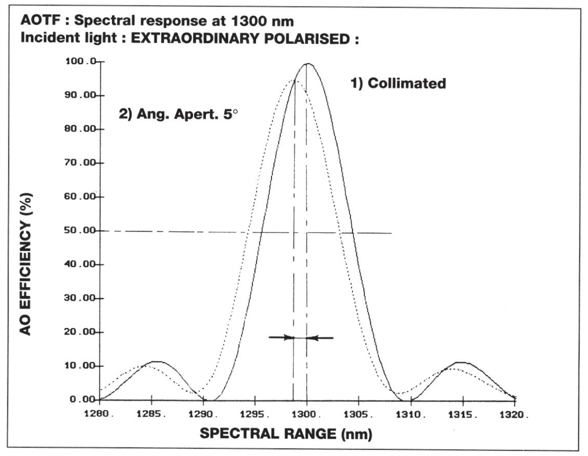


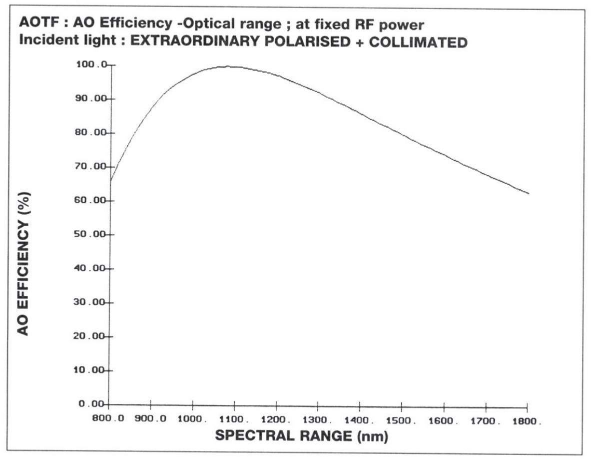
One can show that a large angular aperture is possible as long as the tangents at the point of incidence and synchronism are parallel (the light rays are then parallel in the crystal)

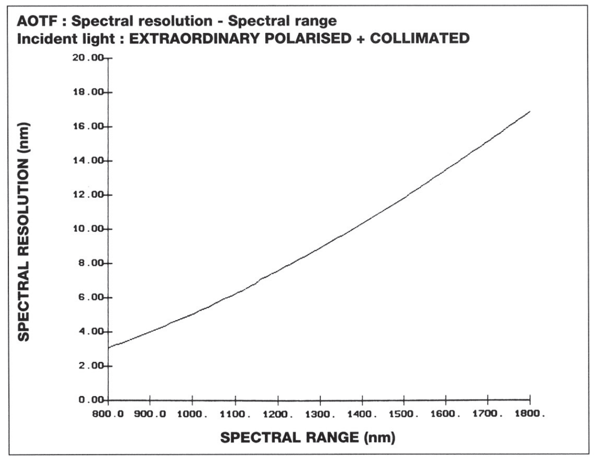
A wide length of interaction (L) and an adequate configuration of the wave vectors (synchronism on a small range of K) guarantee obtaining a low bandwidth and thus a low spectral width (Dl).

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

Dn: birefringence(=|n2-n1|)
a and b are parameters which depends of Θi and Θa
Examples:

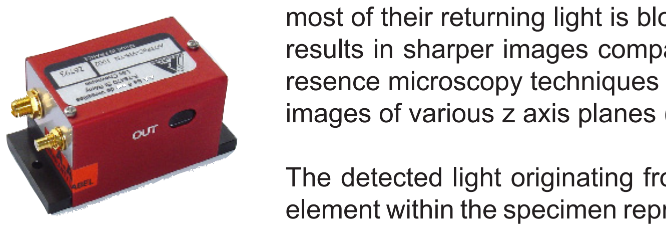






➪ Application example

Confocal Microscopy



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.

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.

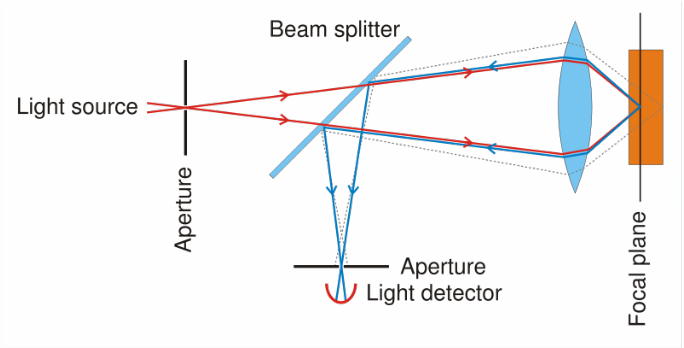


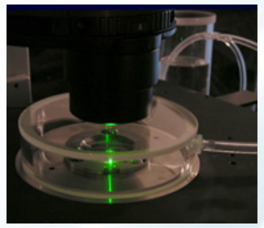
IMAGE FORMATION

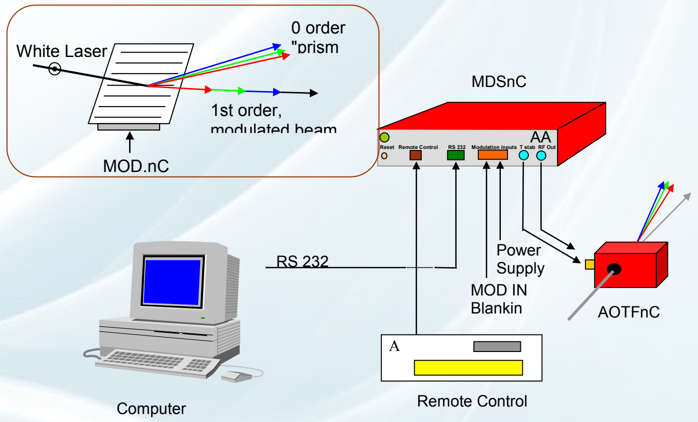
In a laser scanning confocal microscope a laser beam passes a light source aperture and then is focused by an objective lens into a small (ideally diffraction-limited) focal volume within a fluorescent specimen. A mixture of emitted fluorescent light as well as reflected laser light from the illuminated 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).





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.

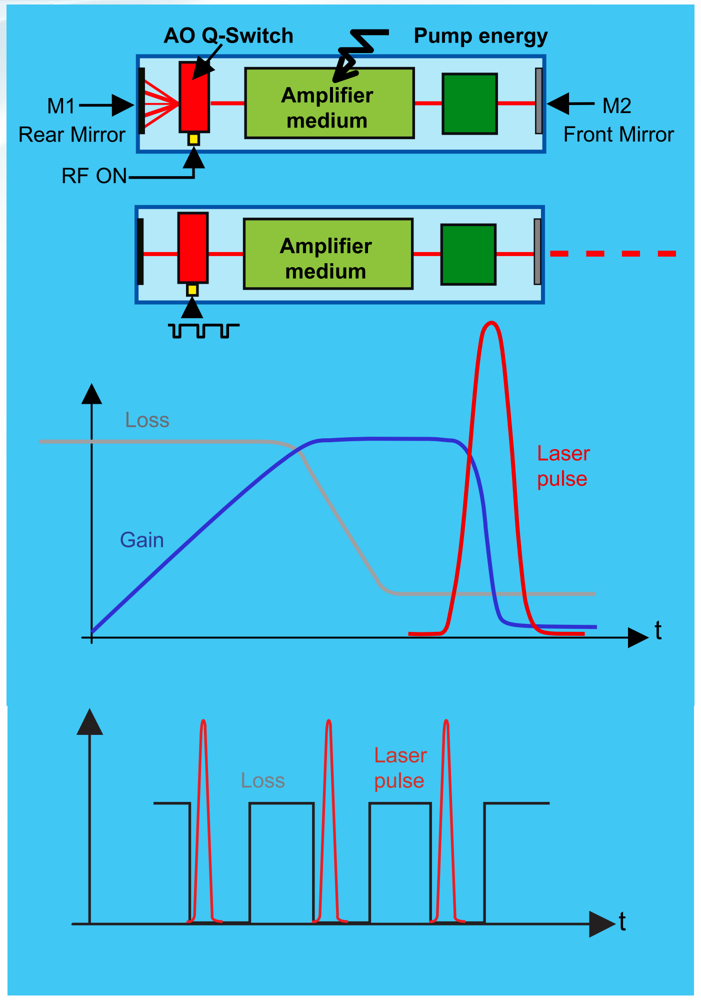
Q-Switching

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:

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

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.

The associated RF driver in combination with the convenient Q-switch is a key component for an efficient Q-switching application. This one must be a class A driver with the fastest fall time in order to get an optimum falling slope of the cavity losses and to get the shortest and highest energy in each pulse.

A synchrone driver can be essential for some applications where synchronism pulse to pulse is critical. Phase locked drivers are also available in case of use of multi Q-switches in the same cavity.

The triggered signals or control signals of the driver may be chosen to have the opportunity to shape the Q-switch losses in time and perform the Q-switching effect safely and efficiently. The thermal security interlock is essential to protect the Q-switch from overheating and to improve its lifetime. Other securities such as VSWR control or disconnection protection can facilitate the task of the user and make the use of the system more safe.

Depending on space and available resources, the choice of the driver will oriented towards an air, conduction through baseplate or water cooling driver, an OEM compact version or a 110/230 VAC version.

Giant Pulses

It is very common in high repetition rate Q-switched lasers, to observe a "giant first pulse" after a certain time of non operation. This giant pulse with excess of energy can create irreversible damages on the intra cavity optics. Moreover, this undesirable increase of energy for the first pulses will lead to a non uniform peak power which may affect badly the application (different marking intensity for instance).

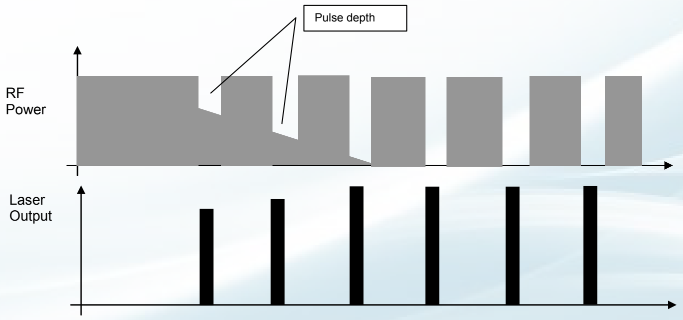
For this reason, user may have to dissipate or suppress the excess of energy of the first pulses. This can be achieved in controlling with a special sequence the Q-switch thanks to the provided RF driver.

General methods to suppress Giant First Pulse

FPS: First Pulse Suppression

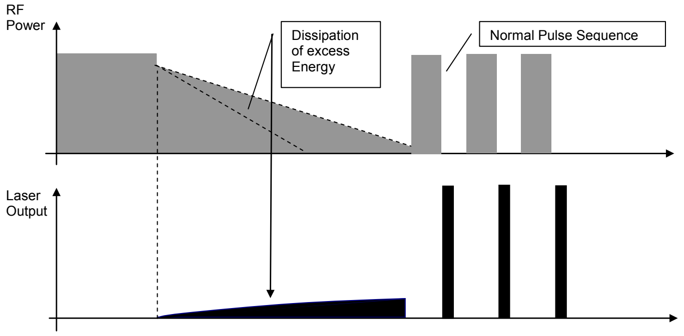
With this method, the pulse depth of the Q-Switch is controlled and limited so as to not open completely the cavity, and thus allow limited Energy to get out of the cavity.

The amount of Losses is decreased progressively so as to obtain the permanent Q-switch regime. It needs typically few pulses to get constant pulses.



PPK: PRE PULSE KILLING

With this method, the excess of energy inside the cavity is dissipated before starting the pulse sequence. As the excess of energy is eliminated prior starting pulse sequence, then the pulse sequence can start normally.



AA Drivers : Methods of control

Basic Pulse control (DPC Input)

For all AA drivers, the Laser pulses are triggered by a TTL signal (Digital Pulse Control).

This input allows to control the Q-swicth with two states :

- No losses (TTL=0)= No RF power applied on Q-switch = Laser pulse can evolved
- Full Losses (TTL=1)= Full RF Power applied on Q-switch = Laser Cavity Blocked

Analog Power control (FAC input)

AA provides a supplementary analog input in order to control the RF power level. This input is pulled down (Typ 0-5Volts) –it means, that if it is not connected, then signal is ramped to 0, then output power is disabled. The analog FAC signal controls linearly the RF amplitude of the output signal.

Note that the analog power control is combined with TTL pulse control (DPC) as follows:

Output RF power ~ TTL (DPC) X Analog (FAC)

- If TTL (DPC) = 0 ⇨ Output RF Power = 0 whatever is FAC input (0 or 5 V)
- If TTL (DPC) = 1 ⇨ Output RF Power = 0 if FAC = 0V
  Maximum if FAC = 5V, Xx versus FAC input

Pulse Analog Control (PAC / RF OFF Analog Control)

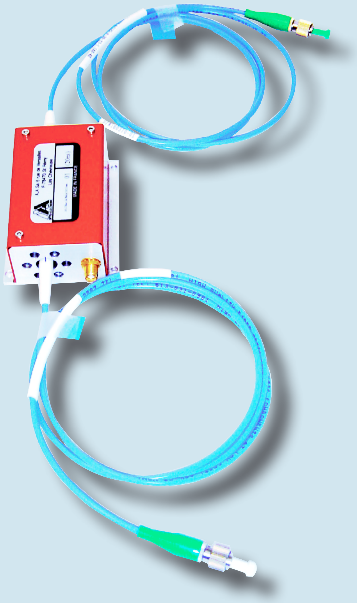
The PAC input is an alternative analog input, which controls the RF OFF level of the driver.

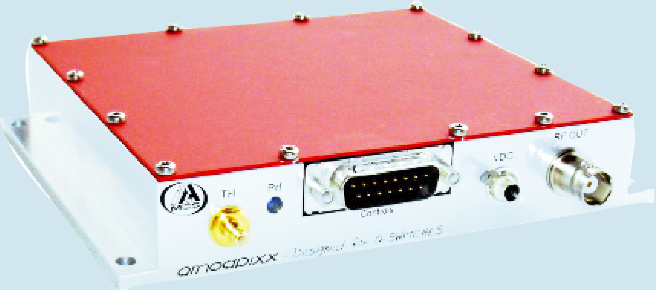
This input (analog 0-5V typ) is pulled up. It means that when it is not connected, the signal ramped up to 5 Volts, and the driver can operate normally.

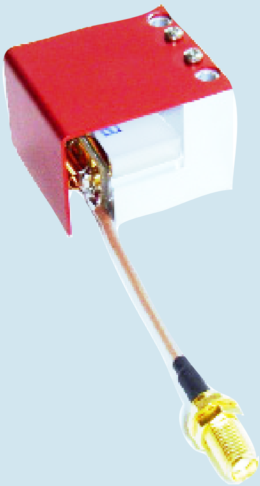
The analog PAC signal controls linearly the RF OFF amplitude of the output signal. It controls the threshold of leakage. Note that the PAC Amplitude control is combined with TTL pulse control (DPC) as follows:

RF POWER OUTPUT ~ TTL (DPC) + Analog (PAC)

- If TTL (DPC) = 0 ⇨ Output RF Power = 0 if PAC=0V
  Maximum if PAC = 5V, Xx versus PAC input
- If TTL (DPC) = 1 ⇨ Output RF Power = Max whatever is PAC input (0 or 5 V)







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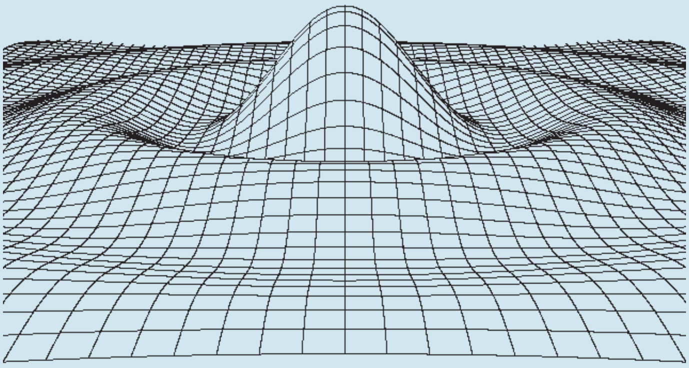

AA OPTO-ELECTRONIC
18, rue Nicolas Appert
91898 Orsay cedex
France
Tel. : +33 (0)1 76 91 50 12
Fax : +33 (0)1 76 91 50 31
sales@a-a.fr
www.aaoptoelectronic.com