AO 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.

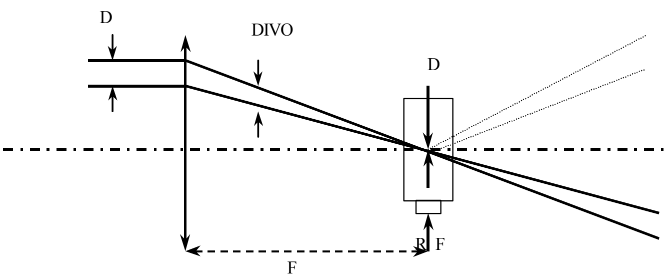
Rise time:
The rise time (T_R) of the modulator is proportional to the acoustic traveling time through the laser beam. The rise time of a fast modulator must be very short:

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

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.

$$T_R = 0.66 \frac{\phi}{V}$$ (TEM00, 1/e² dia)

D: beam diameter before the lens
F: focal length of the lens
DIVO: incident laser beam divergence
$D \approx \alpha * F * \lambda / \phi$: 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.

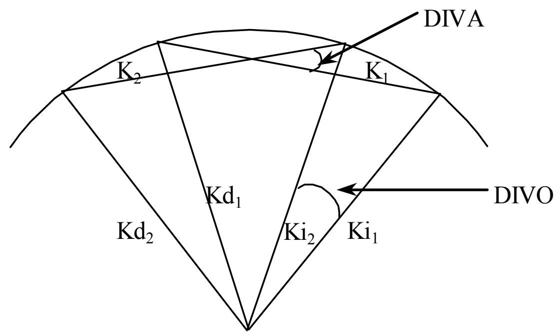
The light beam has a divergence which cannot be neglected. To preserve the efficiency of the interaction on all the bandwidth ΔF, it is necessary to reach the Bragg conditions for all the "angles" of the light beam.

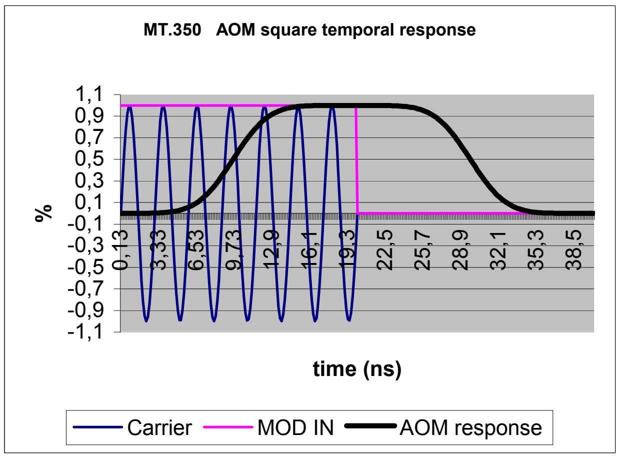
For this purpose, the acoustic divergence (DIVA) ($=\Lambda/L$ where Λ is the acoustic wavelength and L the dimension of the ultrasonic source) must compensate for light divergence DIVO.

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.





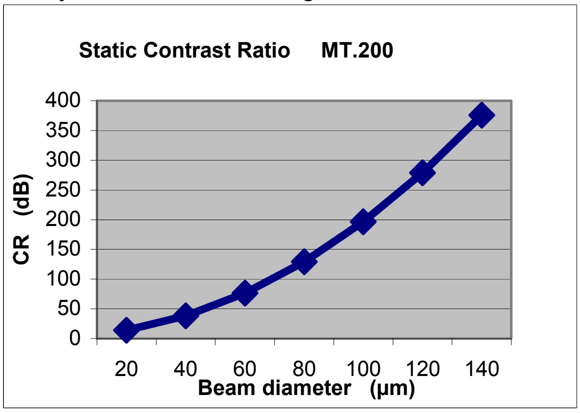
Contrast ratio (static and dynamic)
The incident laser beam properties have a significant impact upon modulator performances (temporal response and extinction ratio). The static contrast ratio measures the ability of the modulator to separate the different diffraction orders (especially 0 and 1st orders).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

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

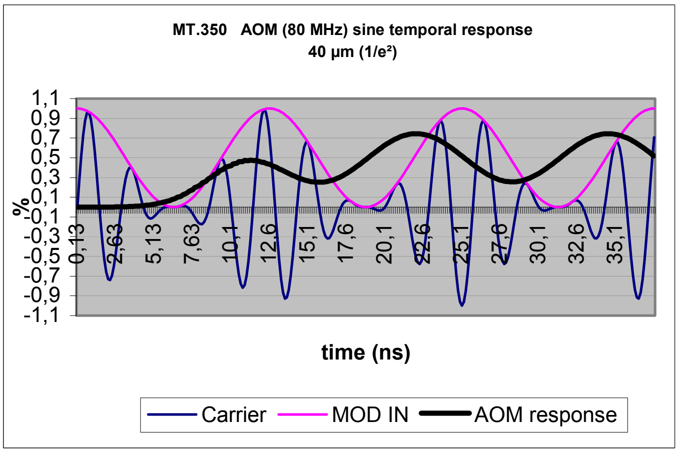
V: acoustic velocity, Φ : beam diameter (1/e²)
Fc : frequency to the 1/e² response rolloff

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 :

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

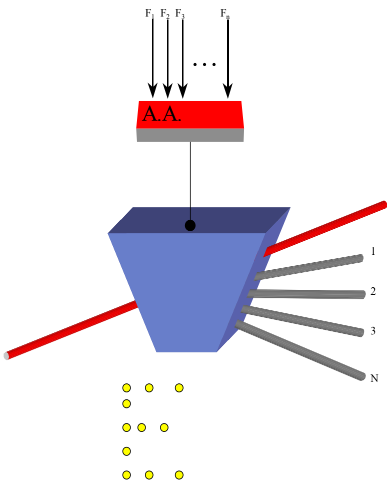


Best performances
rise time: 4-8 ns
efficiency : 70-85 %

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

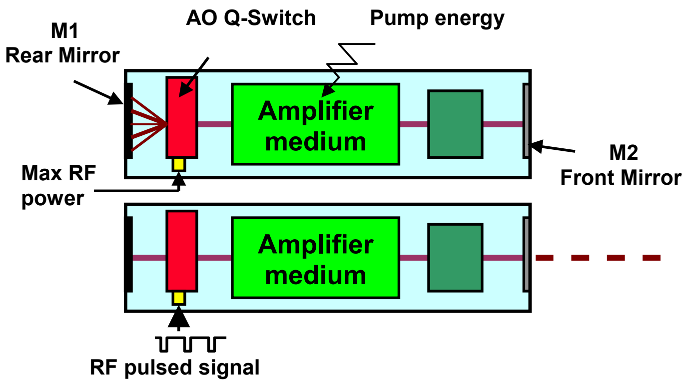
Specific application
Multi-beam modulators. Several discrete frequencies (F_1,F_2,…,F_n) belonging to the bandwidth of the modulator are sent in the modulator. The diffracted beams are ordered separately, in different directions.

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.

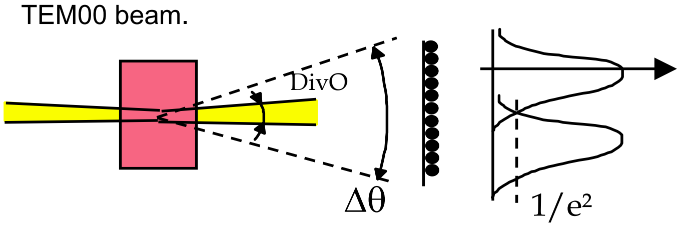


Deflectors

This component is used to deflect the lig
In most applications, a high resolution ed.
For this purpose, one uses large-sized to
30 mm or more) in order to work wit am
diameters, decrease optical divergence se
resolution.

Resolution

Static resolution N
The resolution previously defined can b as
static resolution. It is defined as the nur ıct
directions that can have the diffracte he
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

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

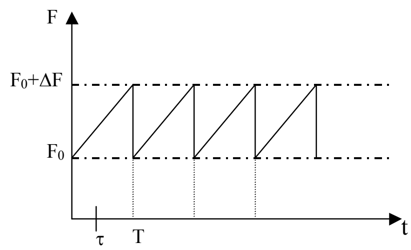
Ta is called access time of the deflector. It corresponds to the necessary time for the acoustic wave to travel through the laser beam and thus to the necessary time for the deflector to commutate from one position to another one.
A deflector is often characterized with the time x bandwidth product Ta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

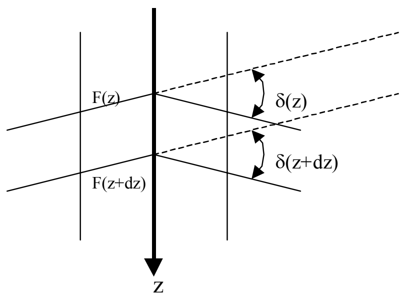
Dynamic resolution N_d
When the field of the frequencies does not consist any more of discrete values but of a continuous sweeping, it is necessary to define the dynamic resolution, which takes account of the " gradient " of frequencies.

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).

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

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

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:

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

-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

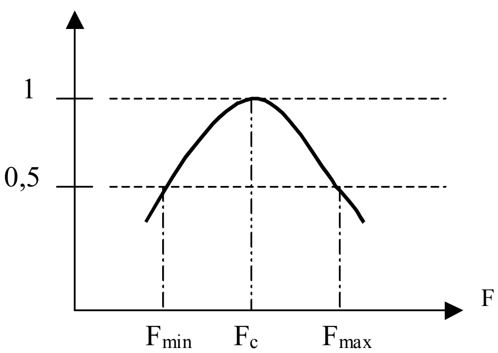
Examples:

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.

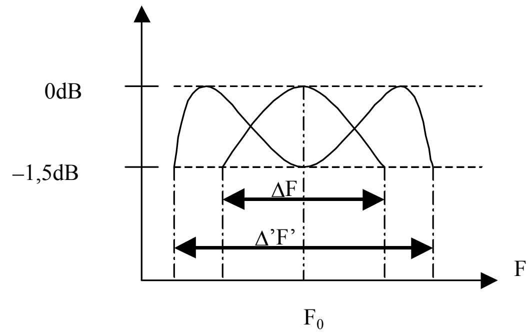
The efficiency curve versus frequency has the following shape for:

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.

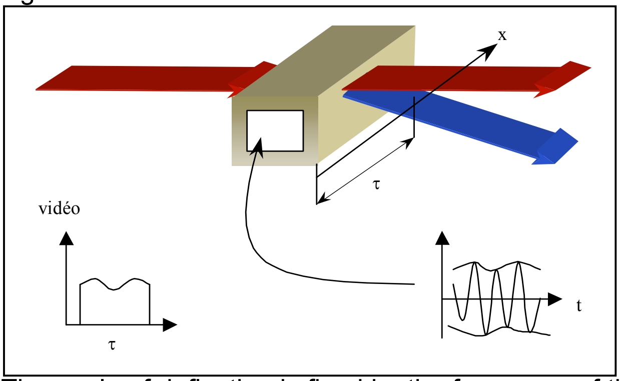
The diffracted light beam from the deflector is focused on a CCD camera using a Fourier lens. The diffracted signal is converted and can be integrated.

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.

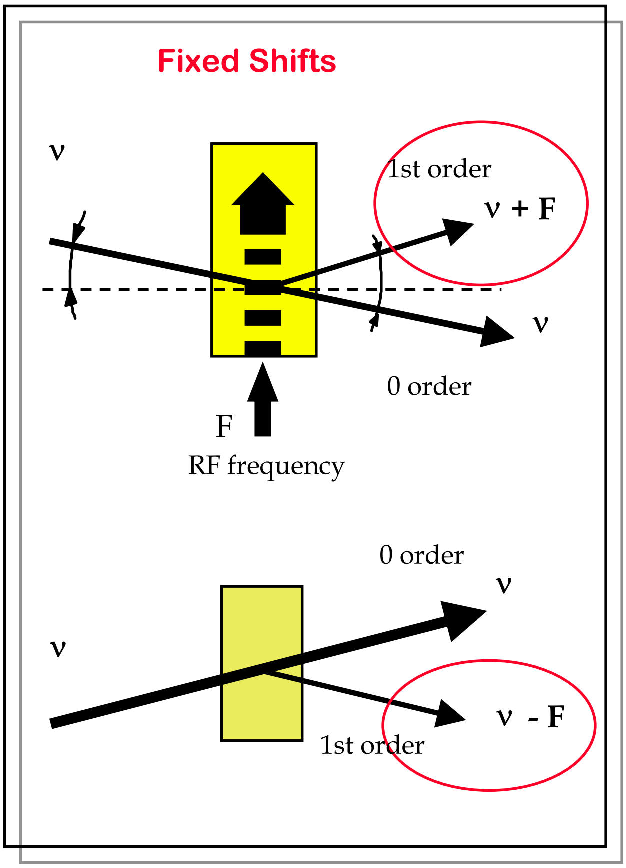


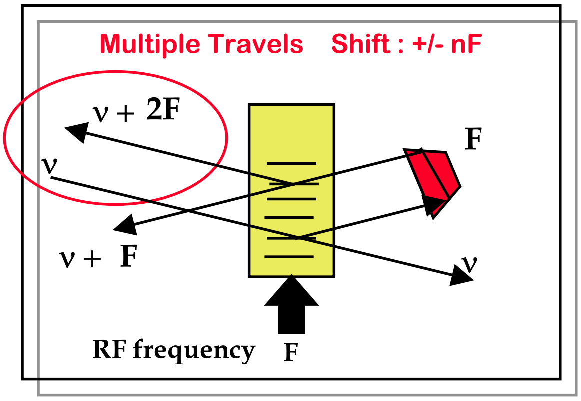
The angle of deflection is fixed by the frequency of the carrier frequency.
The efficiency of the deflector is a function of the distance from the transducer. (x)

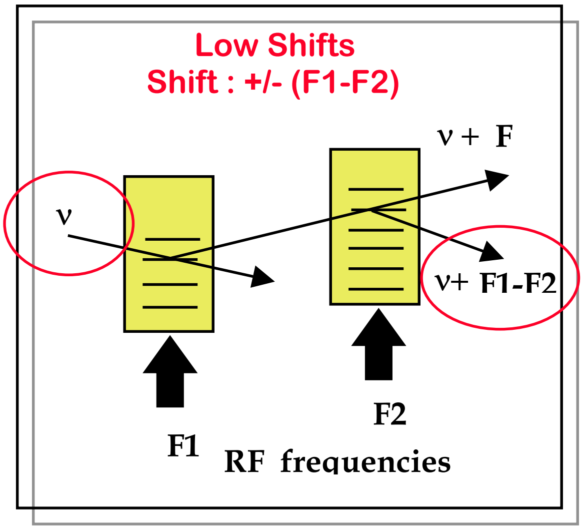
When the deflector contains the video signal corresponding to the access time (Ta), a laser flash gives a deflected light signal, which is the exact spatial representation of the temporal video signal.

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.







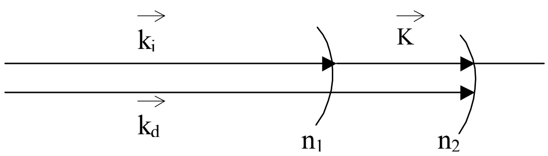
Tunable filters (AOTF)

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:

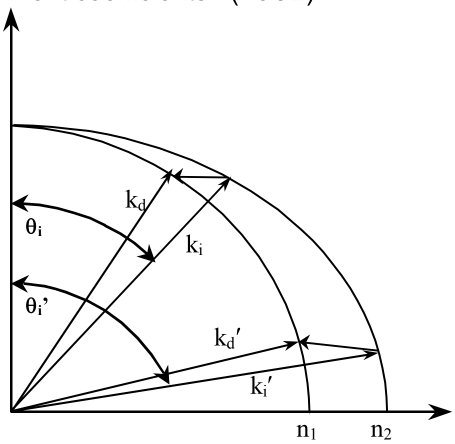
$$\Delta\lambda_0 = \frac{\lambda_0 V}{D}\frac{1}{F}$$

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:



$$\eta \approx \eta_0 \sin c^2 (\frac{\Delta k L}{2\pi})$$ (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. (TeO_2)

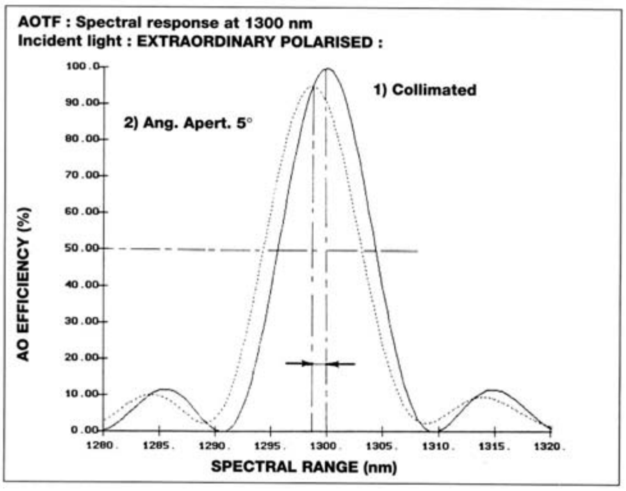


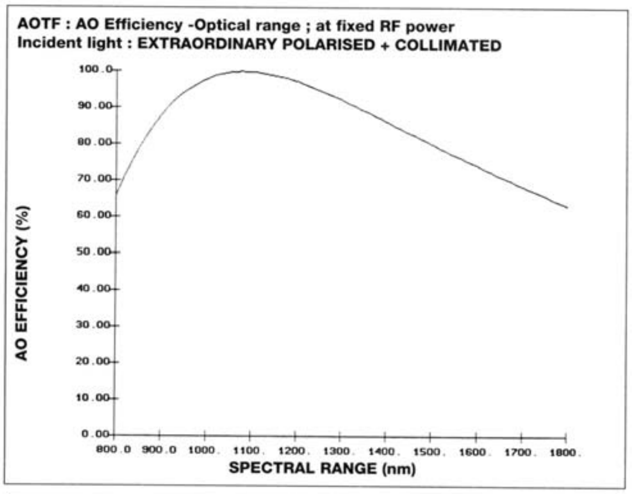
One can show that a large angular aperture is possible as long as the tangents at the point of incidence and synchronism are parallel (the light rays are then parallel in the crystal)

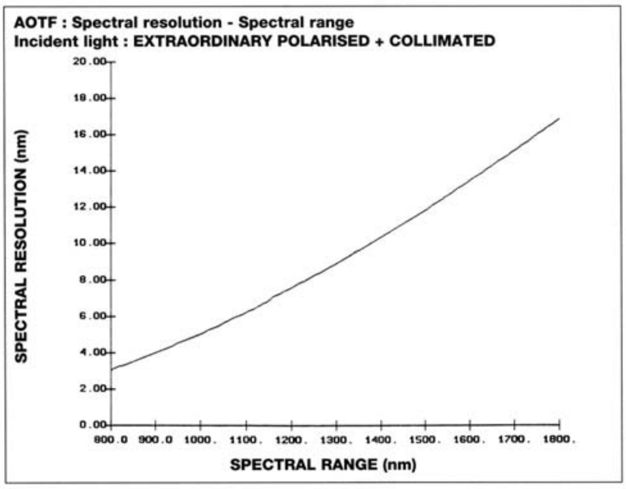
A wide length of interaction (L) and an adequate configuration of the wave vectors (synchronism on a small range of K) guarantee obtaining a low bandwidth and thus a low spectral width ($\Delta\lambda$).

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

Δn: birefringence($=|n_2 - n_1|$)
a and b are parameters which depends of θ_i and θ_a
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 µs
- 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