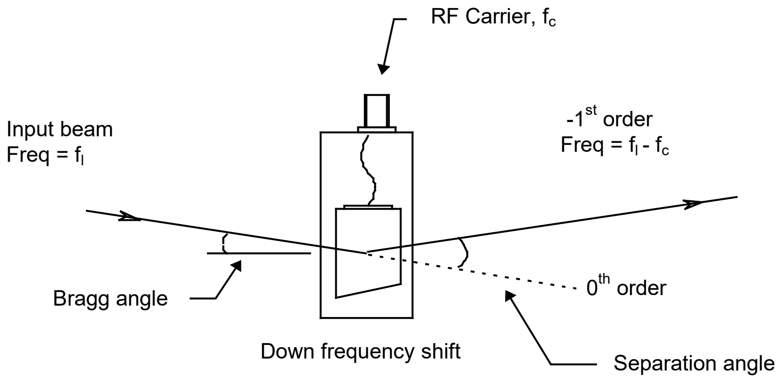
Application Note

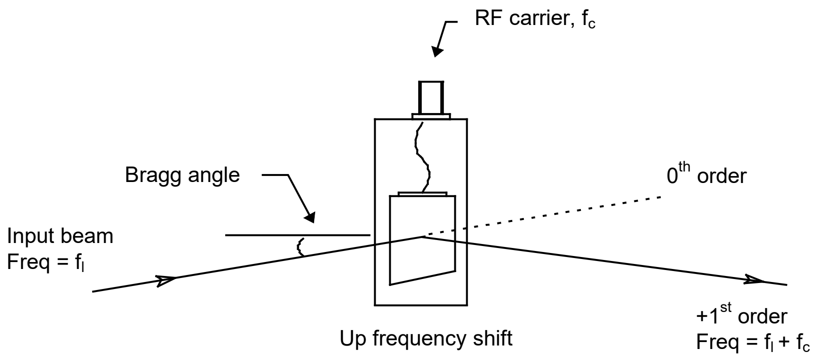
May 2024

AN0724

Acousto-Optic Frequency shifters

AO optic devices frequency shift the output first order diffracted light beam by an amount equal to the RF driver (carrier) frequency. This shift will be positive or negative depending on the Bragg orientation and in relative terms is very small e.g. the frequency of red light is in the order of 500 THz compared to the AO frequency range of ~100MHz range. The AO frequency shift can be varied within the RF bandwidth of the AO device by tuning the input RF carrier frequency.





Maximum diffraction efficiency into the first order is achieved when the input light beam to the AO device is aligned at the Bragg angle and the RF power is adjusted for saturation.

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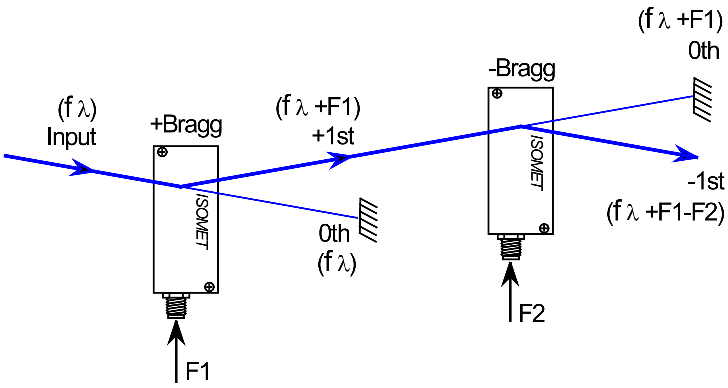
Frequency shift range

Isomet offer a wide range of AO modulators/frequency shifters. Typical centre frequencies range from 30 - 300MHz for devices operating in the visible to NIR and from 30 - 80 MHz for devices operating in the Far IR.   However, frequencies outside these general limits can be achieved using multiple AO devices or multiple passes in one AO device.

Small frequency shifts

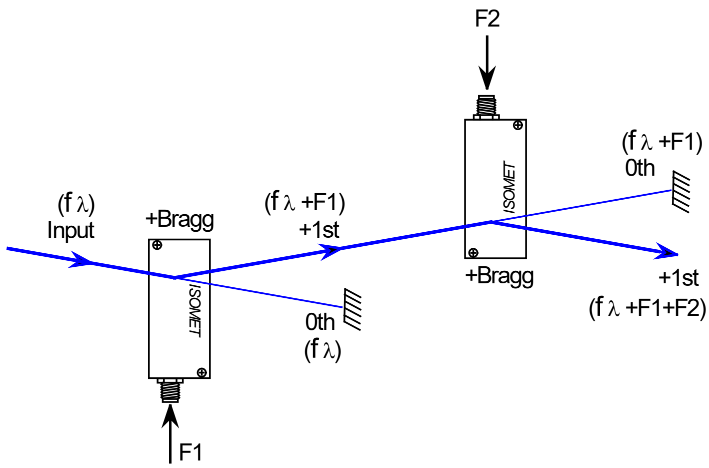
For frequencies much lower than the minimum AO centre frequency two devices can be placed in series, one applying a frequency upshift and one a downshift. The final first order output frequency will be given by the difference of this up and down shift.

The lowest value shift is usually limited by the accuracy and stability of the driver frequency source. Values of less than 10 KHz are possible with care.



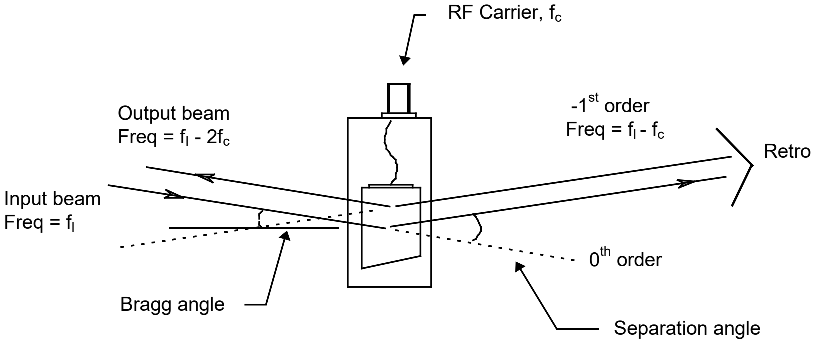
Large frequency shifts

For frequencies much higher than the maximum AO centre frequency then two or more devices can be placed in series, each applying a frequency upshift . The final first order output frequency will be the sum the upshifts.



Alternatively, a multiple pass can be made through a single AO device using (say) a retro reflector. The suitability of this method will depend on the beam size relative to the maximum useable crystal aperture. The diagram below shows a basic double downshift configuration.

In the above cases, the overall efficiency will equate to the combined diffraction efficiencies. e.g. for a 85% maximum per AO modulator, the overall efficiency for a double AO system would be approximately 70%.



Bragg Angle

The input Bragg angle is given by:

$$\theta_{Bragg} = \frac{\lambda . f}{2 . V}$$

where: f = RF frequency
λ = wavelength
V = acoustic velocity,
TeO2: 4.2mm/us
PbMoO4: 3.63mm/us
Quartz: 5.7mm/us
Ge: 5.5mm/us

Variable Frequency Shifts

For dynamic frequency shifting applications with fixed Bragg angle adjustment, the diffraction efficiency of the AO device will vary due to Bragg angle mis-match error. The transducer characteristics of most AO devices are designed to minimise this effect. However in practice the useable bandwidth of a single electrode AO device is limited to approximately 1/3 to 1/2 of the centre frequency.

To circumvent this difficulty and improve efficient bandwidth, the acoustic signal in the AO material can be steered and made to track the optimum Bragg conditions over a wider range of frequencies. This requires an array of electrodes on the transducer, each electrode progressively phase shifted according to tuned RF frequency. This phase shift between the electrodes "steers" the launch angle of the transmitted acoustic beam effectively adjusting the Bragg angle.

RF Drive Power

Diffraction efficiency is a function of the acoustic drive power. The optimum (saturation) power is given by:

$$P_{sat} = \frac{k.\lambda^2.H}{2.L.M_2}$$

This is termed the saturation power level.

where: f = RF frequency
V = acoustic velocity
L = interaction (electrode) length
λ = wavelength
H = electrode height
M_2 = Figure of Merit
k = Transducer Conversion loss (1.12 typ.)

For a given device L, H and M2 are constant and thus the value depends on the operating wavelength.

RF Power Limitations

If the device is operated at a RF power (P) less than Psat, the reduction in efficiency can be determined from the formula:

Relative efficiency (ε) $\varepsilon = \sin^2 \frac{\pi}{2}.\sqrt{P_{in}/P_{sat}}$

This may be the case when operating at NIR wavelengths with devices that have a limitation on the maximum input RF power.

If wideband tuneable systems, it is common for the RF drive power to be dynamically adjusted to flatten the amplitude of the deflected output with changing frequency.

RF Drivers

Isomet offer a comprehensive range of RF drivers. Most feature amplitude control for modulation or switching of the first order beam. The crystal controlled drivers offer the best frequency stability for fixed frequency applications, typically ± 25ppm.

For applications requiring stable frequency tuning and/or low frequency differential applications we recommend our synthesizer based drivers. These can be configured for differential control between two AOM's operated in series and allow precise generation of frequency shifts below 10Hz.