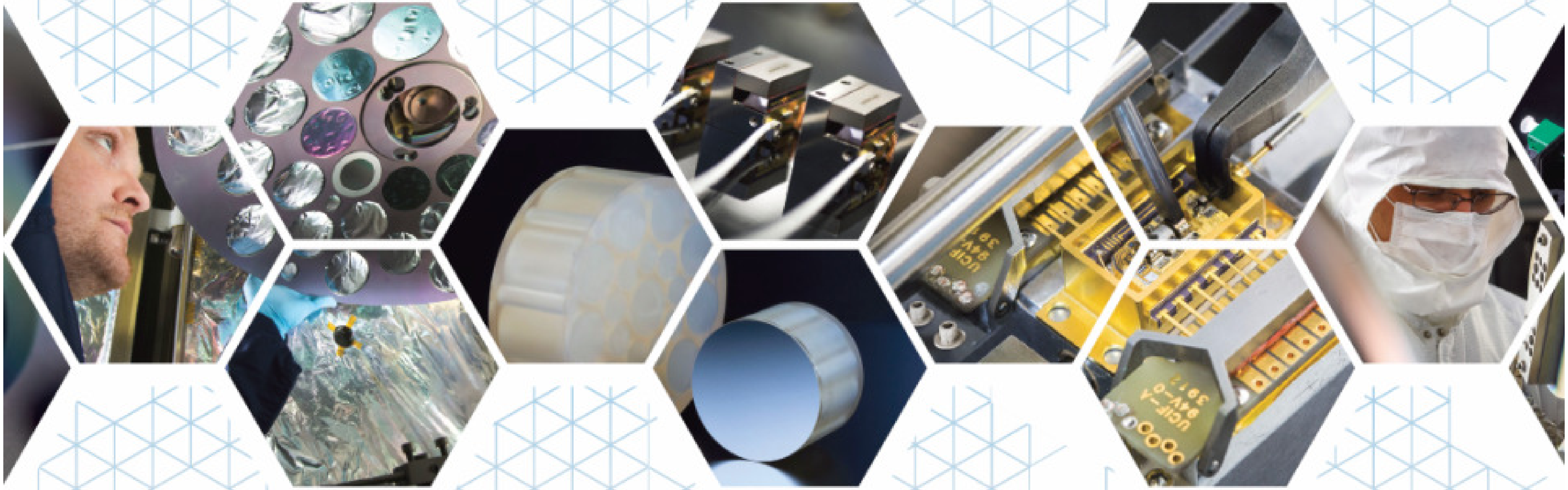

GOOCH & HOUSEGO NOVEL OPTICAL COMPONENTS FOR THE IR

June 2017

SEVENTH FRAMEWORK PROGRAMME

Gooch & Housego
ENABLING PHOTONIC TECHNOLOGIES

Gooch & Housego
NOVEL Optical components for the IR

Acousto-Optic components for:-

$2\mu m < \lambda < 4\mu m$

ACOUSTO OPTICS

- Acousto-Optics: the interaction between sound waves and light waves, especially the diffraction of laser light by ultrasound (*Wikipedia*)

- Ultrasound generates a regular refractive index variation (photoelastic-effect) in a suitable medium that acts as a (travelling) diffraction-grating.

- Strong diffraction occurs when certain matching conditions are satisfied
  - optical wavelength & direction
  - acoustic frequency & direction
  - acoustic power

- Main types of AO device
  - Modulators, Pulse-Pickers & Cavity Dumpers
  - Deflectors
  - Frequency-Shifters
  - Mode Lockers
  - Q Switches
  - Tunable Filters

AO Basics

The Diffraction Efficiency (η) is defined as

$$\frac{I_D}{I_0} = \eta \approx \sin^2 \sqrt{\frac{\pi^2 L_{Int} M_2 P_a}{2H\lambda^2}}$$

Where; I_D - Intensity in diffracted order
I_0 - Intensity in 0 order (no diffraction)
L_{int} - Interaction Length
H - Active Aperture
P_a - Acoustic Power
M_2 - AO Figure of Merit (material dependent)

$$M_2 = \frac{n_o^3 n_e^3 p_{eff}^{\;2}}{\rho v^3}$$

$$P_0 = \frac{H\lambda^2}{2L_{int}M_2}$$

Peak Diffraction Efficiency when $P_a = P_0$

NOTE λ^2 DEPENDENCE!

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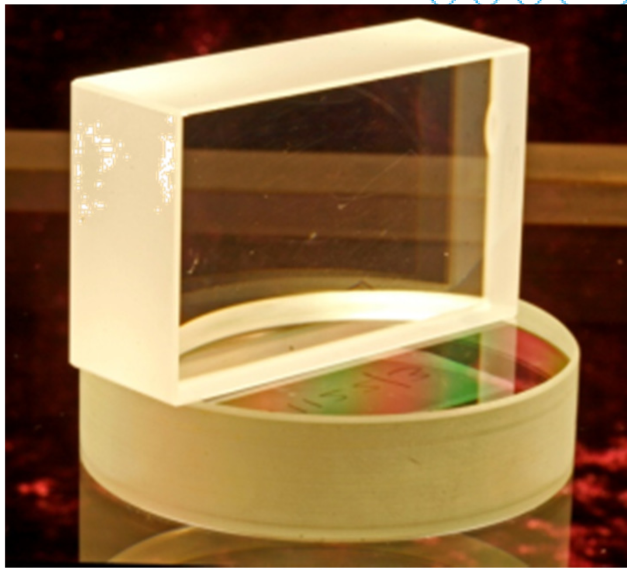
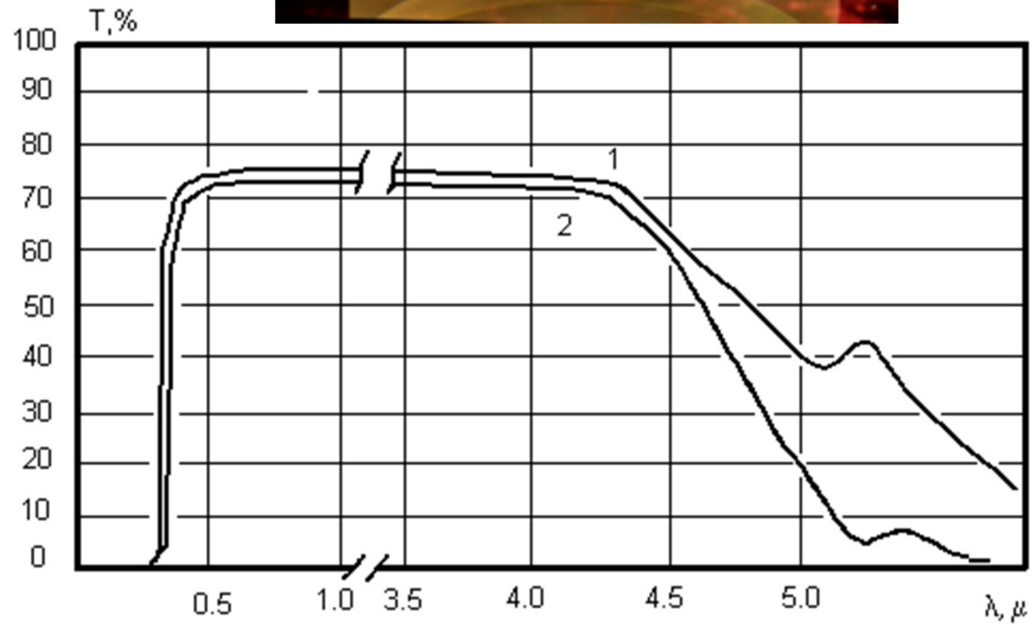
Choice of Material

- The optical medium should be transparent over the required operational range
  - Optical damage threshold must be adequate

- The material should have good Acousto-Optic properties
  - Efficient AO interaction
  - Reasonable acoustic attenuation
  - Compatible with manufacturing process

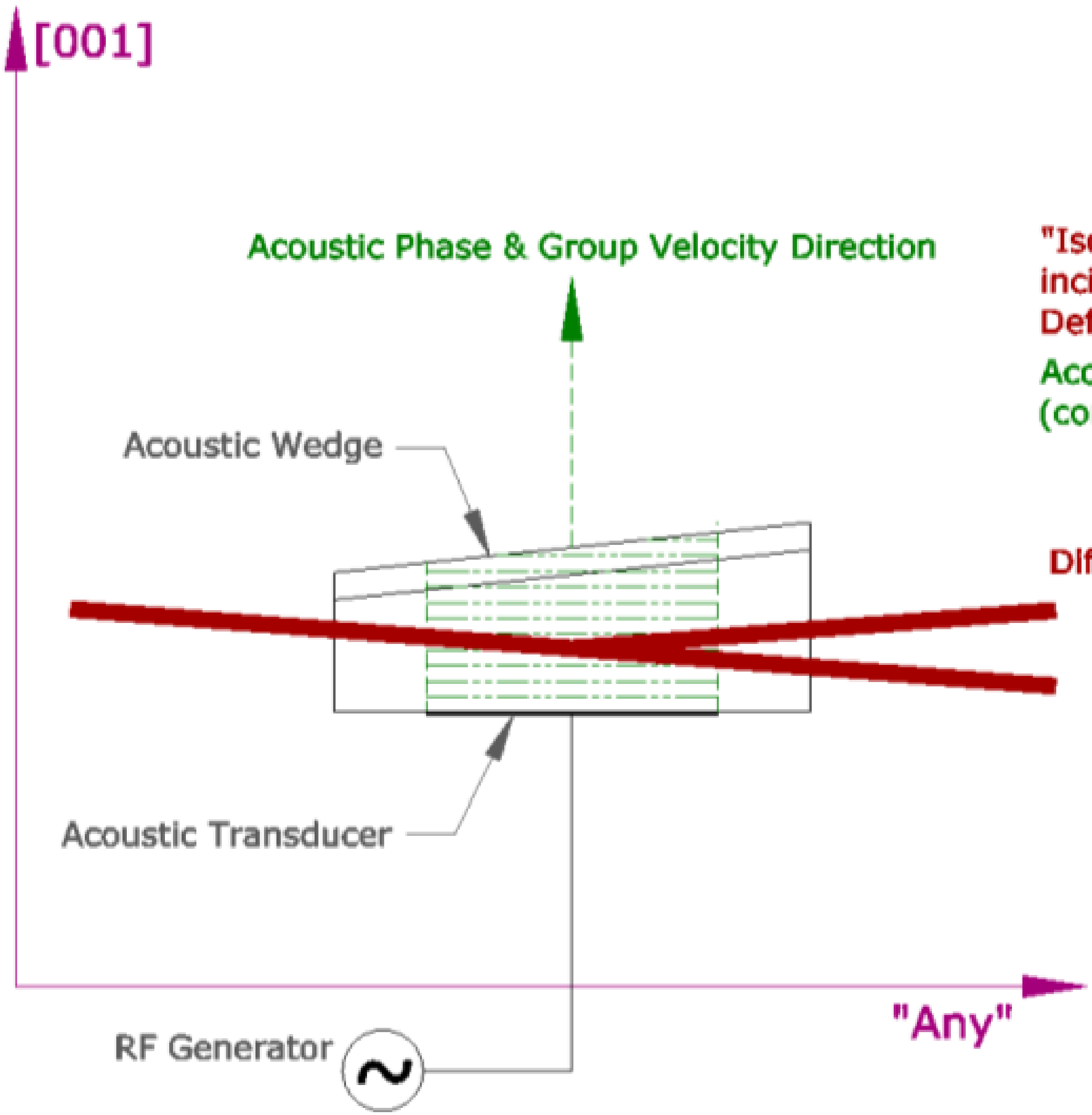
- Single Crystal Tellurium Dioxide (TeO_2)
  - 400nm – 4·5μm
  - Grown along the "t" [110] direction; ie rotated at 45º about the [001] direction





TeO2 transmission, 20 mm thick sample
1 - O-polarization, 2 - E-polarization

AO Interaction in TeO_2 (isotropic)



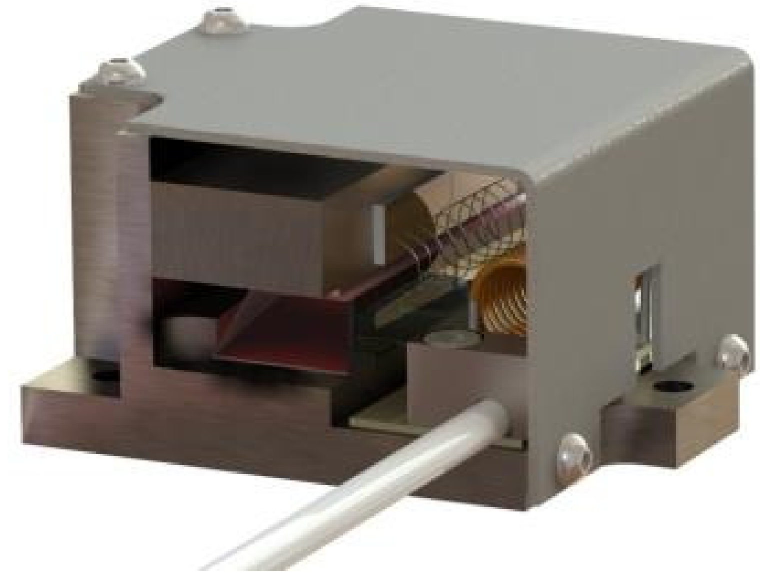
"Isotropic interaction";
incident angle is Bragg Angle (θ_B)
Deflection angle is 2 x θ_B
Acoustic Velocity is longitudinal (compressional) mode

$$\sin(\theta_B) = \lambda f / 2v$$

AOQS (2·9µm)

Q-Switching of laser

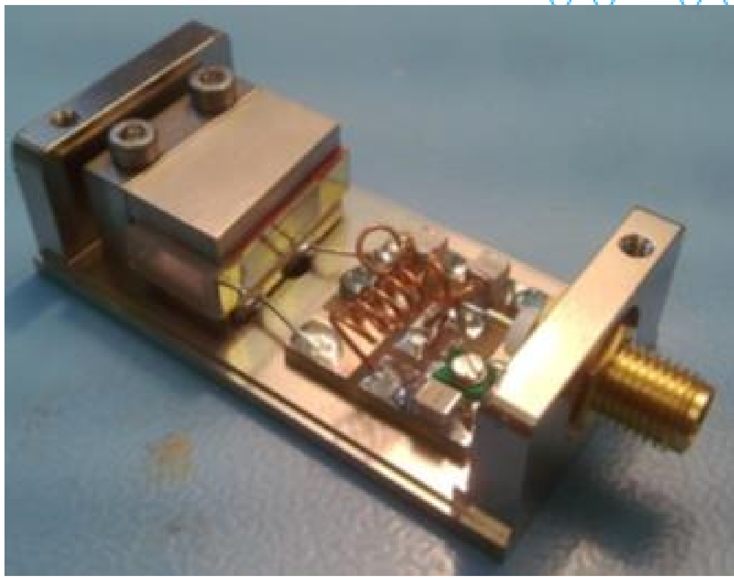
Interaction material:	**Tellurium Dioxide**
Wavelength:	2750 < λ < 3000nm
Damage threshold:	> 50MW/cm^2
AR coating reflectivity:	< 0·5% per surface
Transmission:	> 95·0%
Frequency:	40·68MHz
Optical polarisation:	Random
Active aperture:	1·5mm
Acoustic mode:	Compressional
Separation angle:	27·7mrad @ 2·9µm
Rise-time (10-90%):	153ns/mm
Loss modulation:	≥ 80%
Maximum RF power:	10W

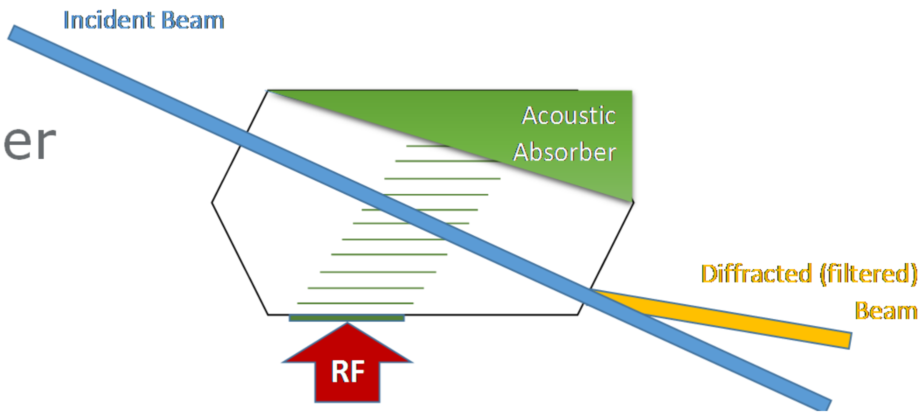


Demonstrated by Lisa Laser in their Er:ZBLAN fibre laser.
Pulse energy 560µJ at pulse rep-rate of 1kHz, pulse-width 69ns
Peak power 10·6kW.

AOTF: What is an AOTF?

- An AOTF (Acousto Optic Tunable Filter) is an optical passband filter that is tunable
- Ultrasound diffracts light that satisfies certain matching conditions; especially optical and acoustic wavelengths (and therefore acoustic frequency).
- As a result, the key filter parameters - centre wavelength & throughput (ie intensity of diffracted light) - are under complete electronic control.
- There are no moving parts, no maintenance, and an indefinite lifetime.





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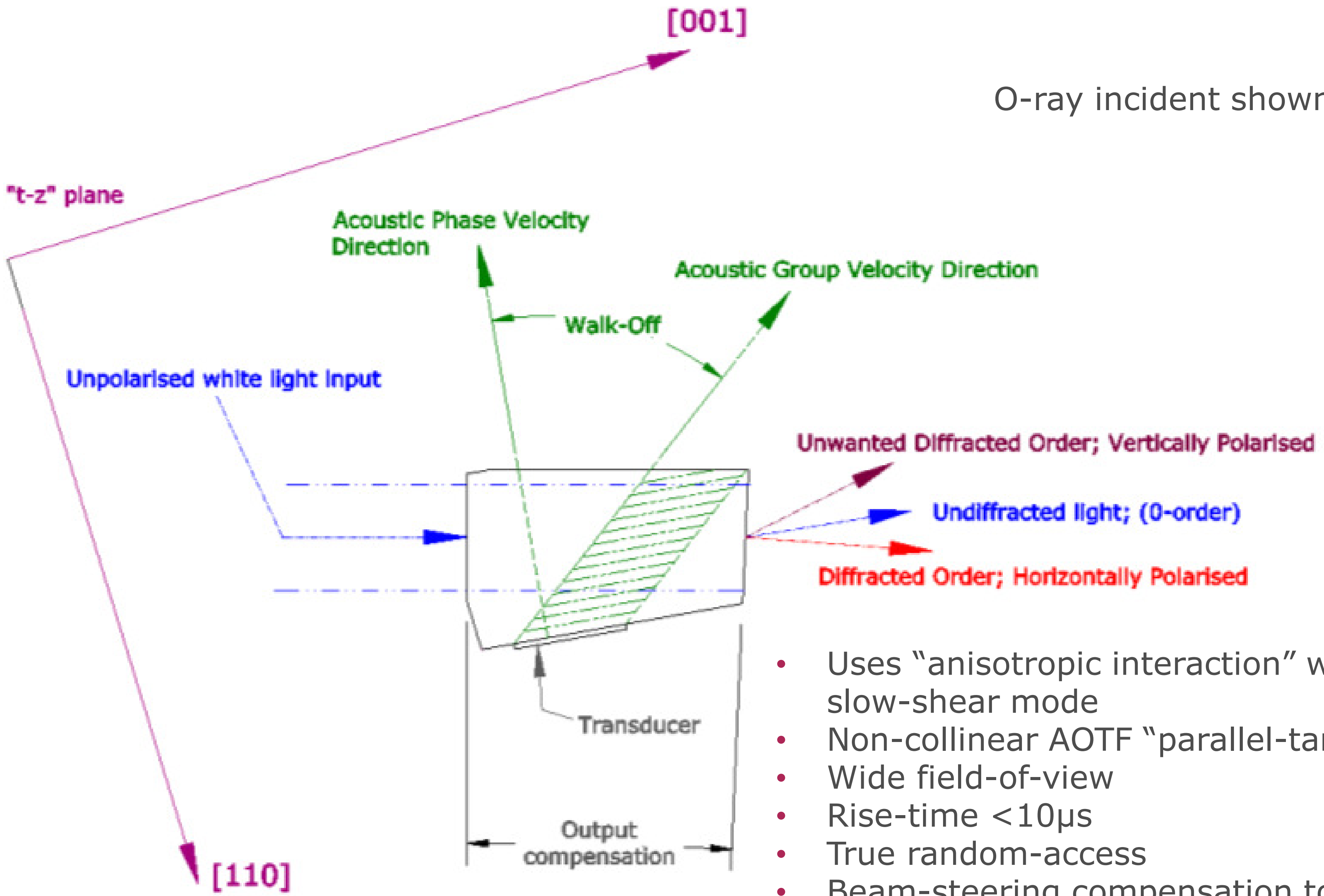
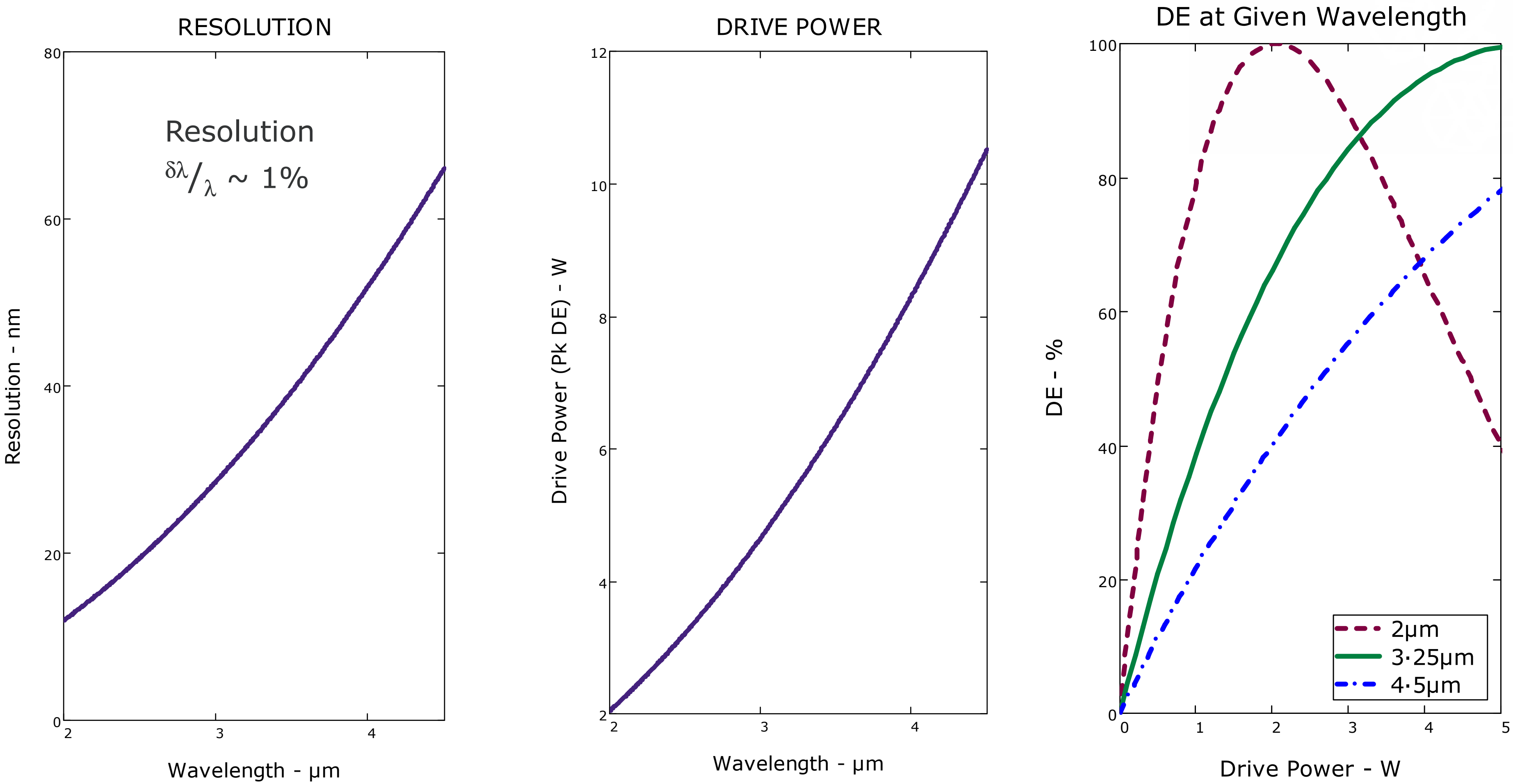
Schematic (typical general-purpose AOTF)



O-ray incident shown

- Uses "anisotropic interaction" with acoustic slow-shear mode
- Non-collinear AOTF "parallel-tangents" design
- Wide field-of-view
- Rise-time <10μs
- True random-access
- Beam-steering compensation to maintain pointing-stability

"Conventional" AOTF: wavelength range 2–4·5μm



Active aperture 8mm x 8mm
Wavelength range: 2 – 4·5μm
Transducer length: 24mm

RF Drive-Power > 5W
Thermal Management Issues!

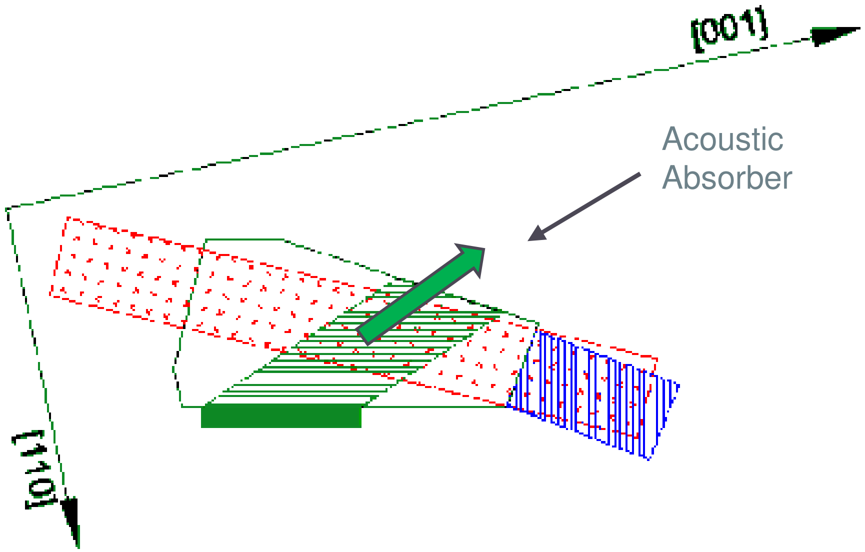
Acoustically Resonant AOTF

Conventional AOTF:

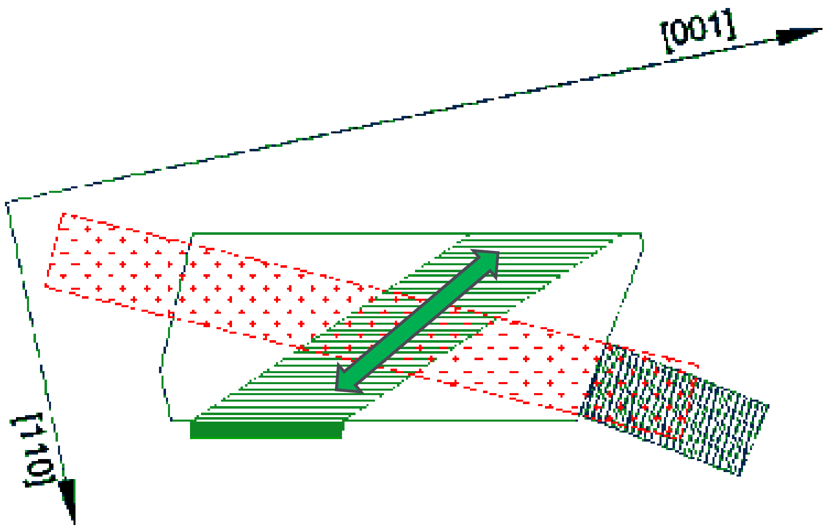
- The sound is deflected by an acoustic wedge followed by an acoustic absorber

Resonant AOTF:

- The sound is totally internally reflected at an air-boundary parallel to the transducer.
  - This allows the sound to be "recycled" giving an advantage in drive-power efficiency

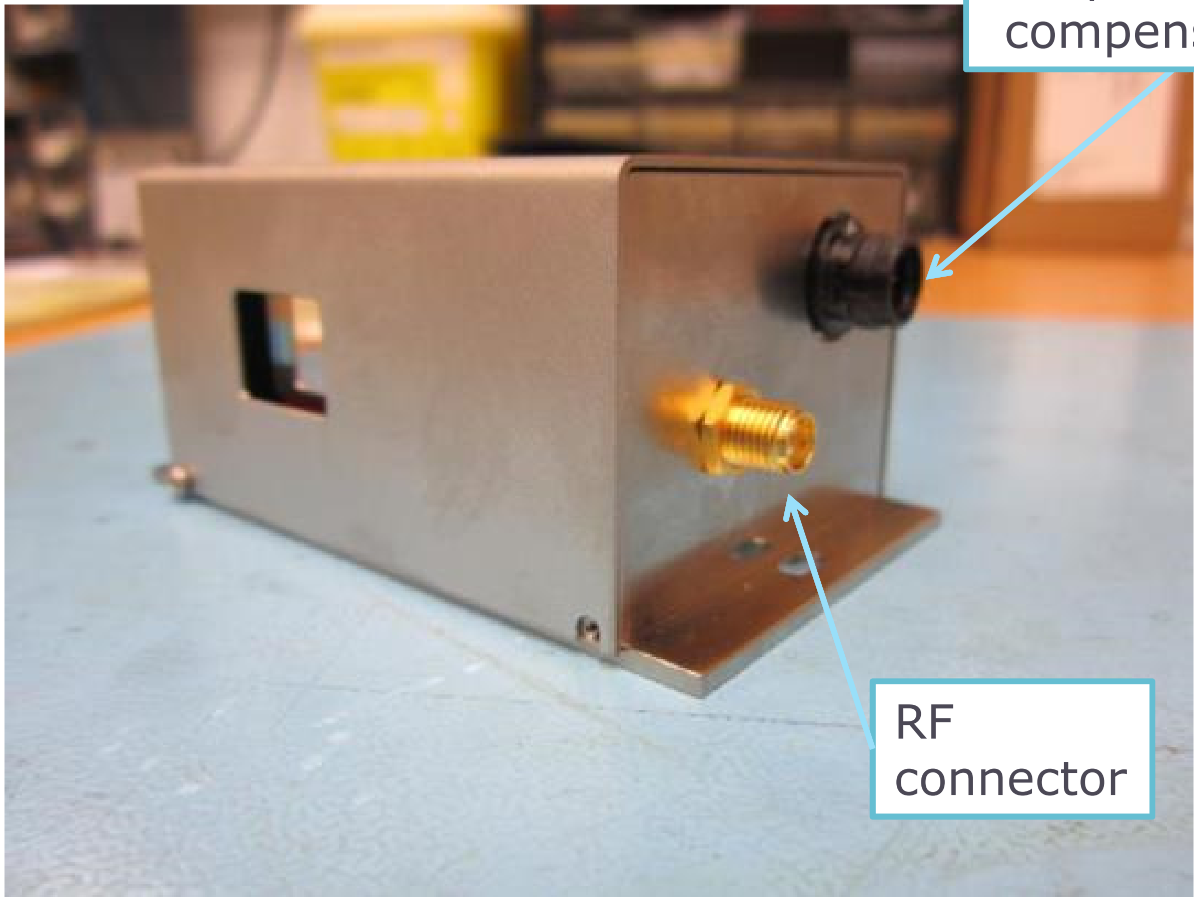


Conventional Configuration



Resonant Configuration

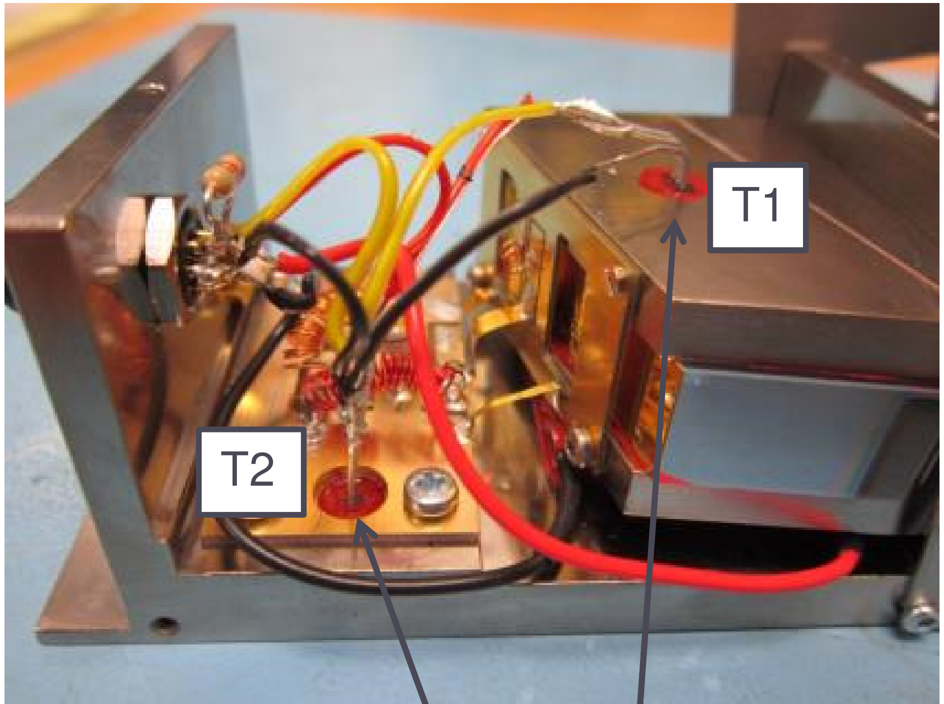
Resonant AOTF - External View



Data cable for temperature compensation

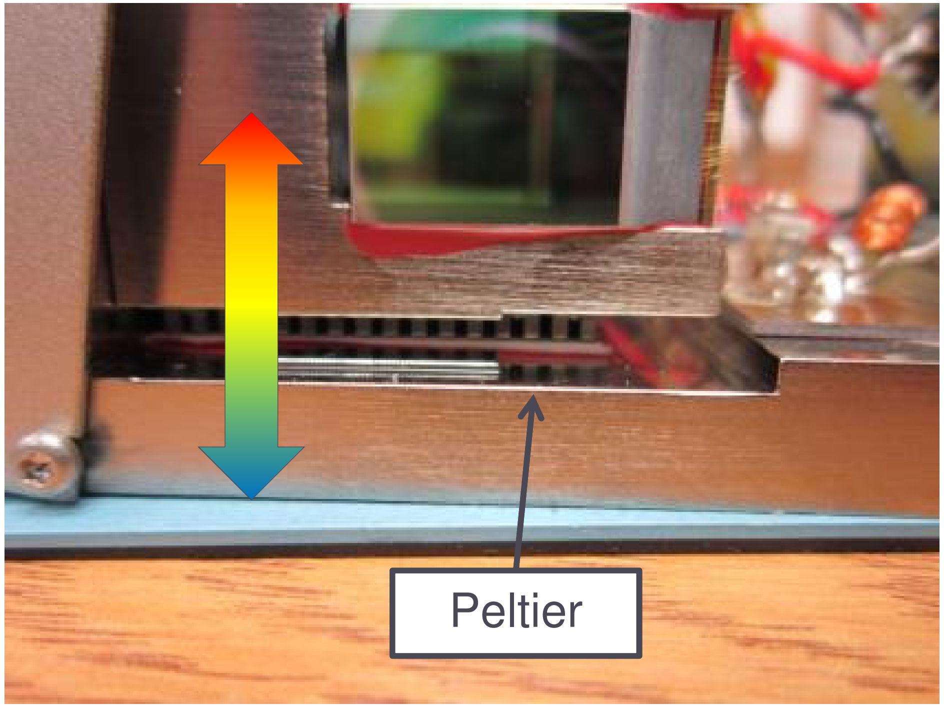
Resonant AOTF – Internal View

Temperature sensors



Digital Temperature Sensor (±0.03°C)

Heat Pump



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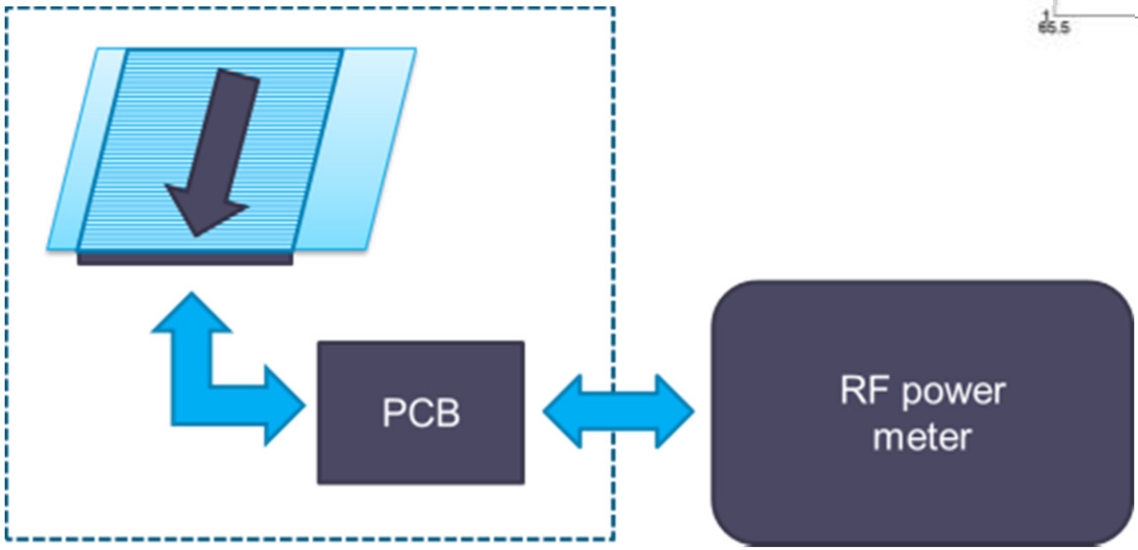
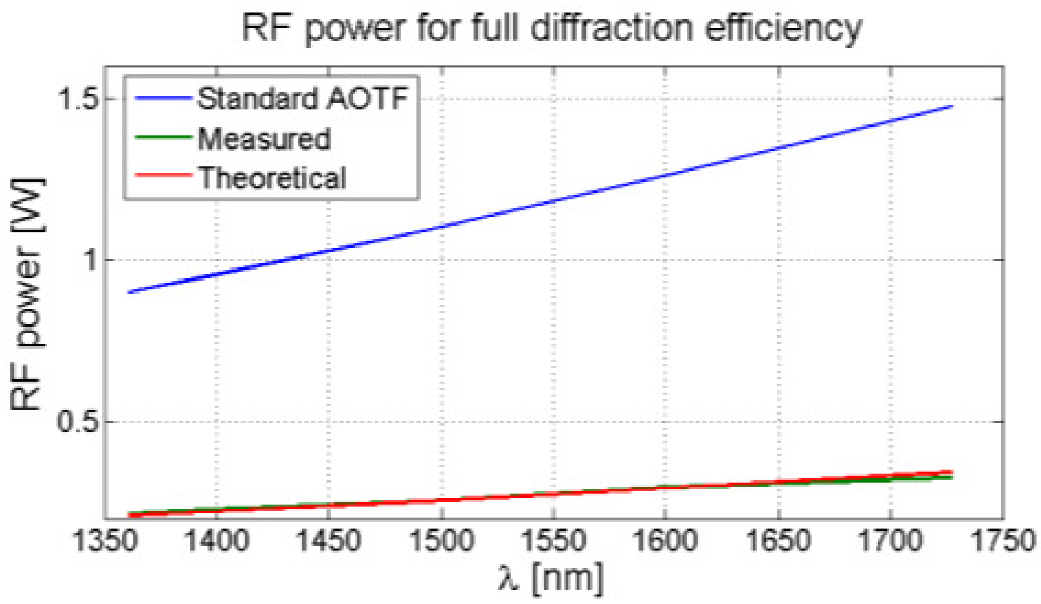
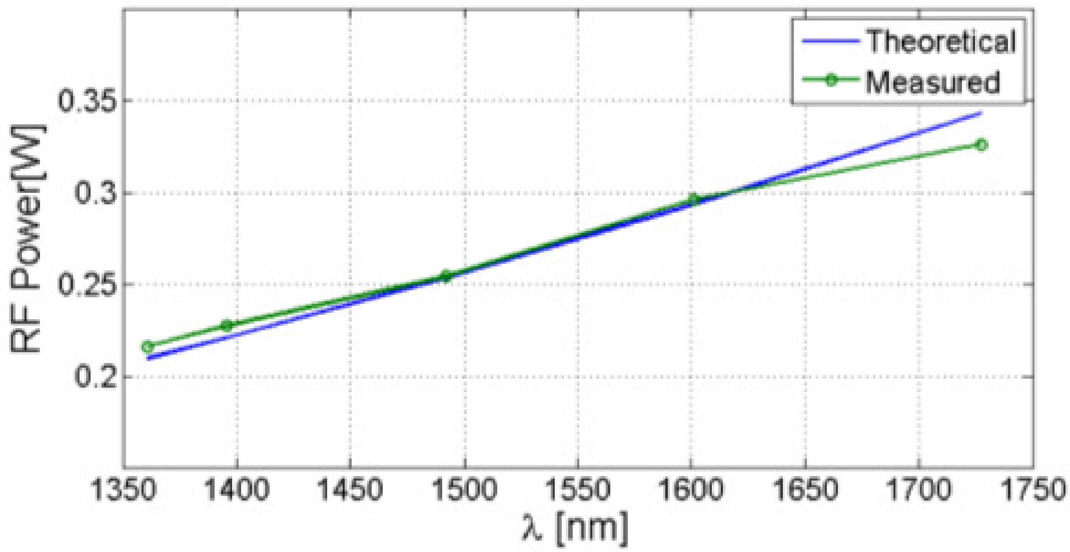
Effect of the resonant acoustic cavity on the RF impedance-matching

- On resonance : no feedback signal from ultrasonic transducer
- Off resonance: feedback signal from ultrasonic transducer; VSWR goes high(>3:1)



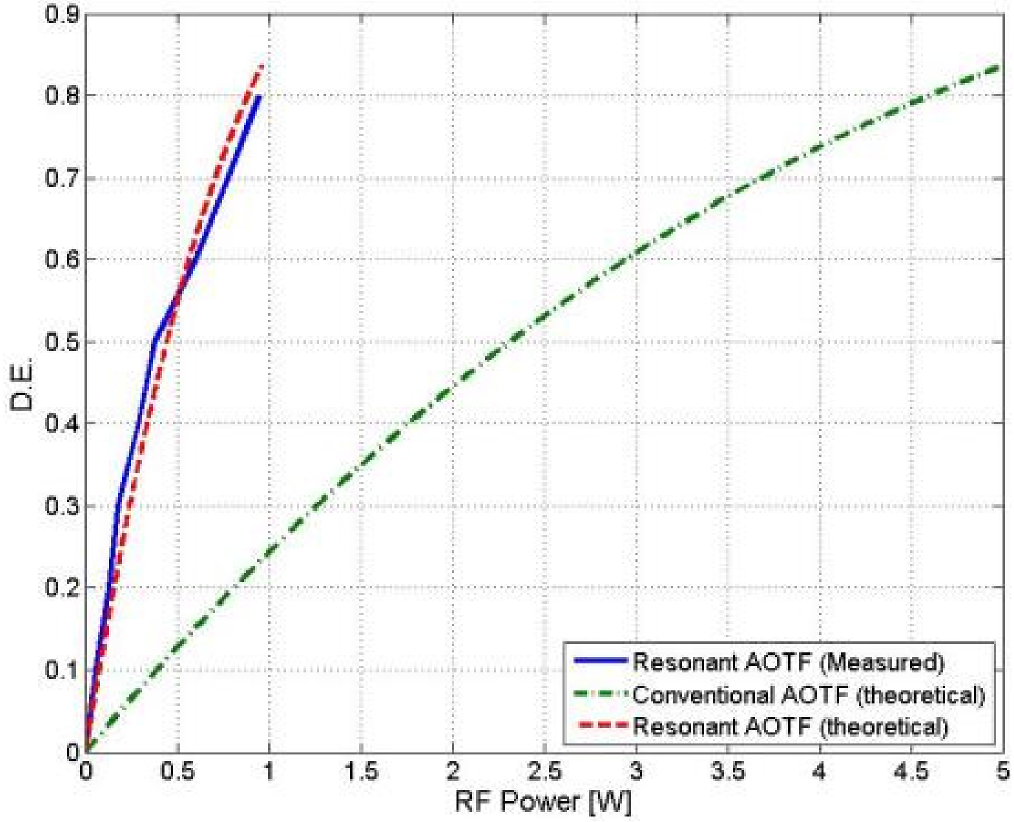
Resonant AOTF: results (λ = 1μm-2μm)



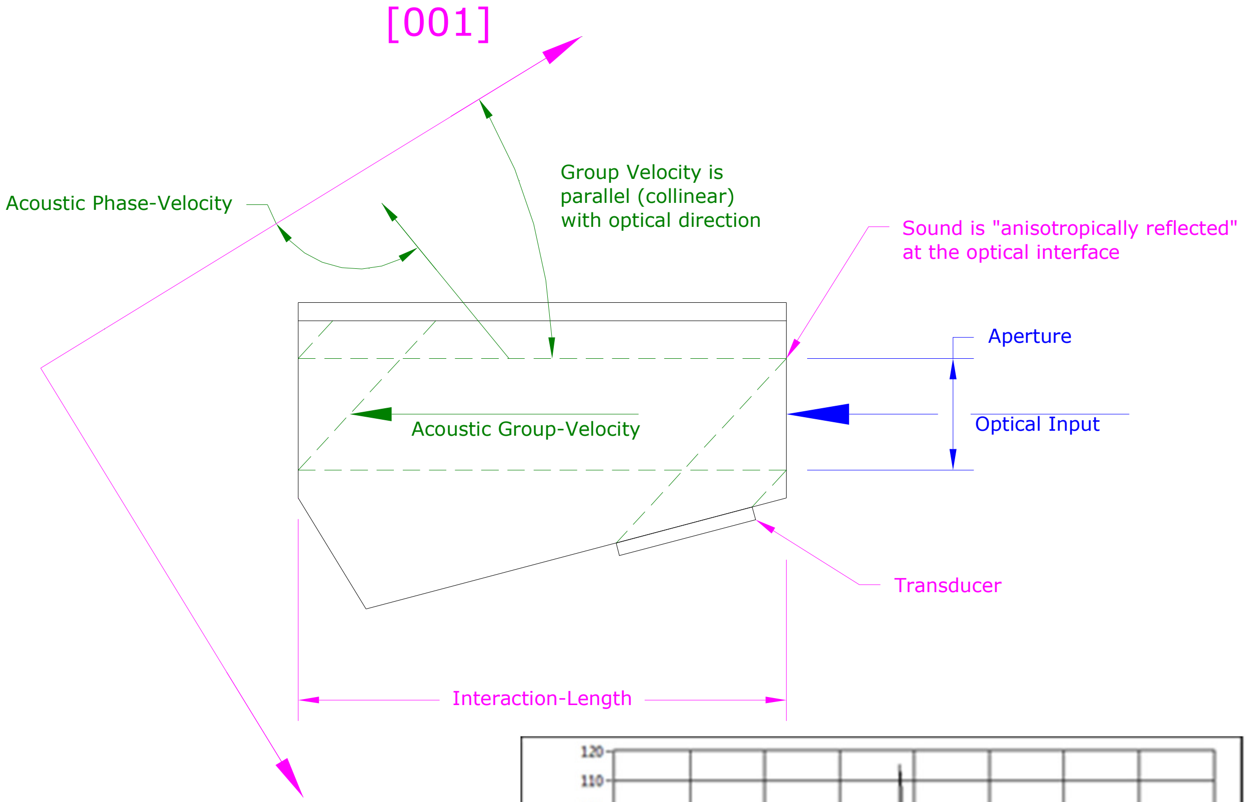


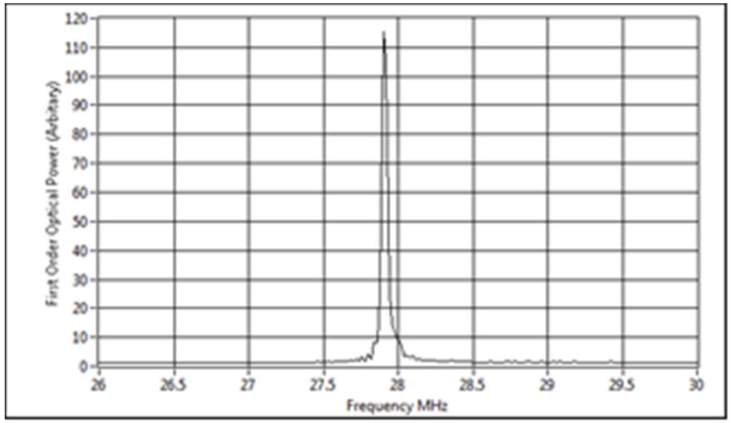
Resonant AOTF: DE Vs. RF power

- **Laser source: 3390nm**
- **Advantage factor predicted: 5**
- **Advantage factor measured: 4.8 – 5.6**
- **Temperature compensation: used**



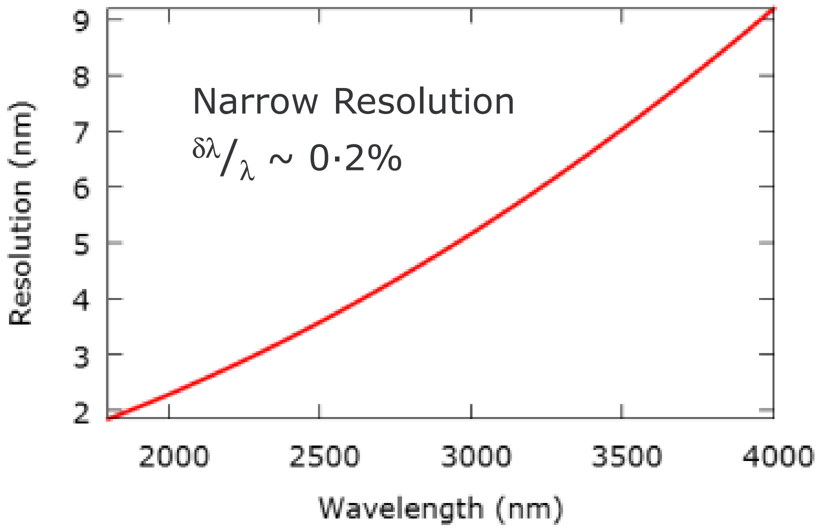
AOTF Technology – Quasi-Collinear Configuration

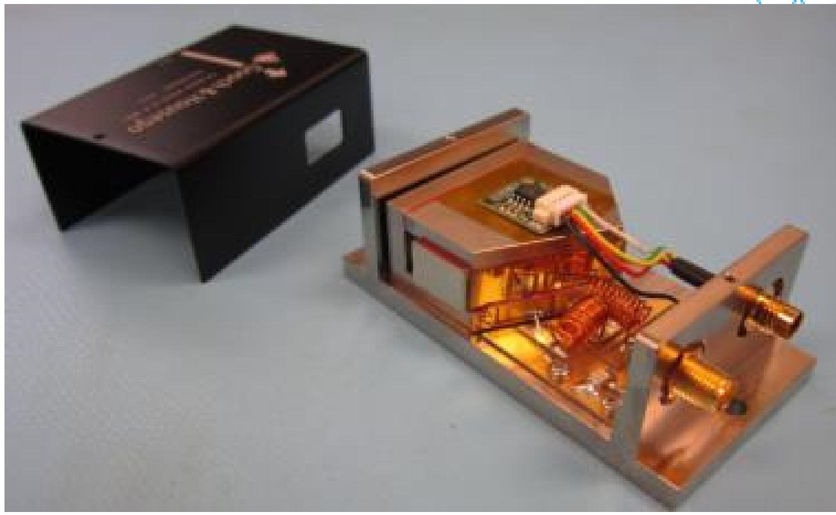


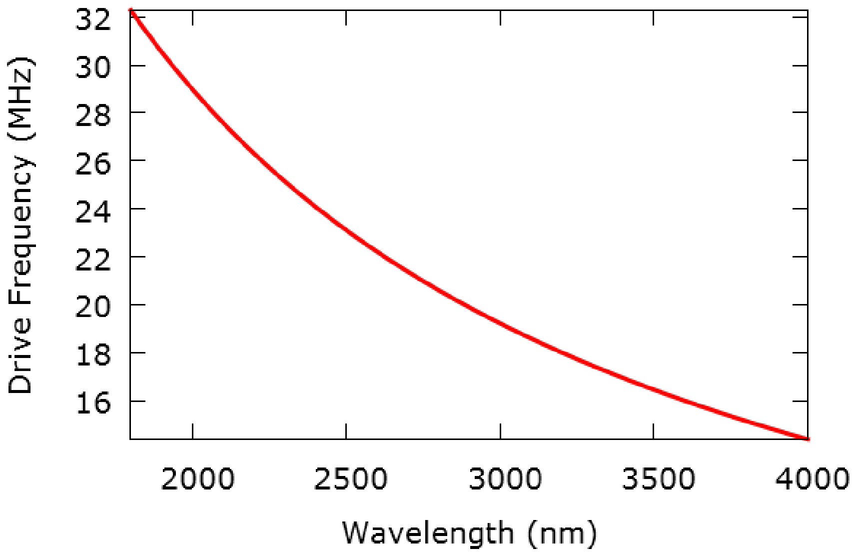


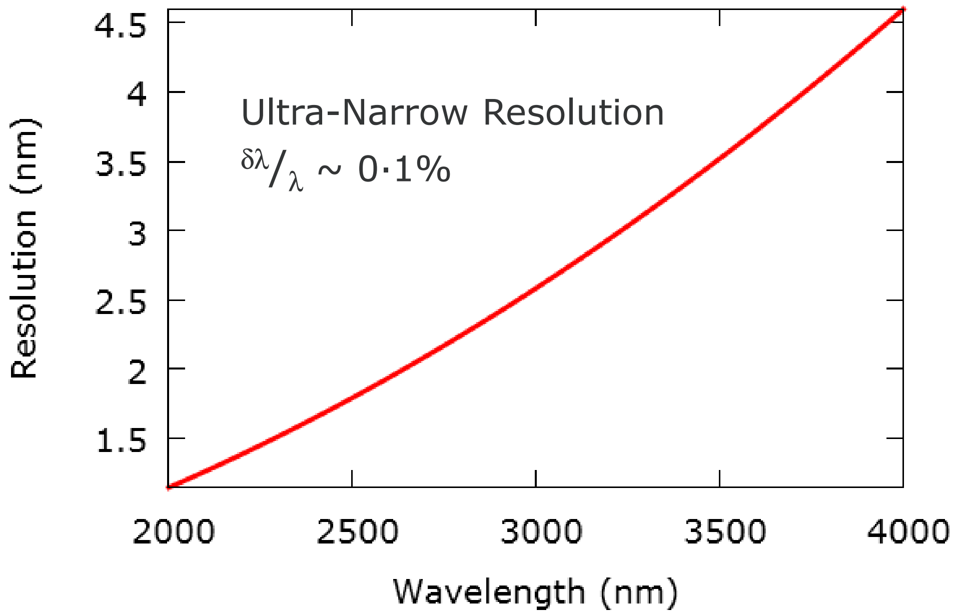
- AOTF is Configured so that the direction of acoustic energy propagation is collinear with the optical direction.
- This is not a true collinear interaction since the acoustic & optic phase-velocity directions are not parallel, and the diffracted beam separates spatially from the 0-order
- RF power consumption is low as there is efficient acoustic/optical overlap
- Resolution is narrow for longer interaction-lengths
- Acceptance angle is restricted; diffraction-limited optics required for narrow resolution.
- Inherently low side-lobes since natural apodisation due to acoustic attenuation

Quasi-Collinear AOTF – Realisation

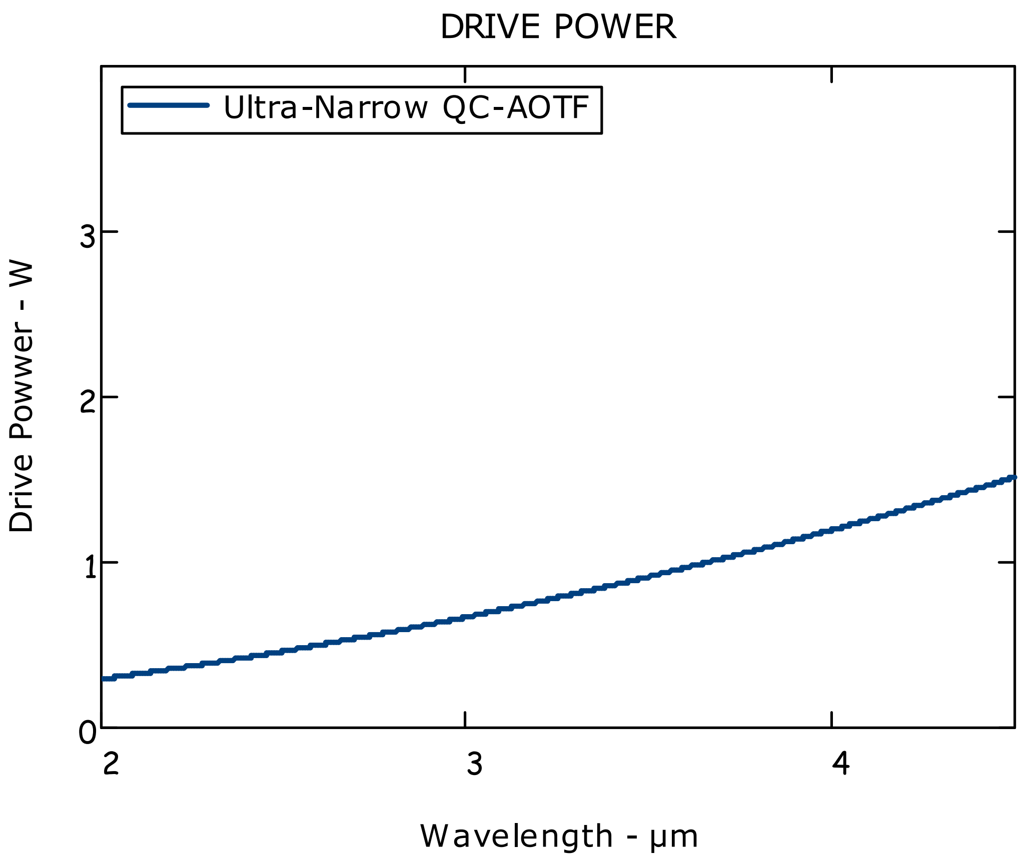








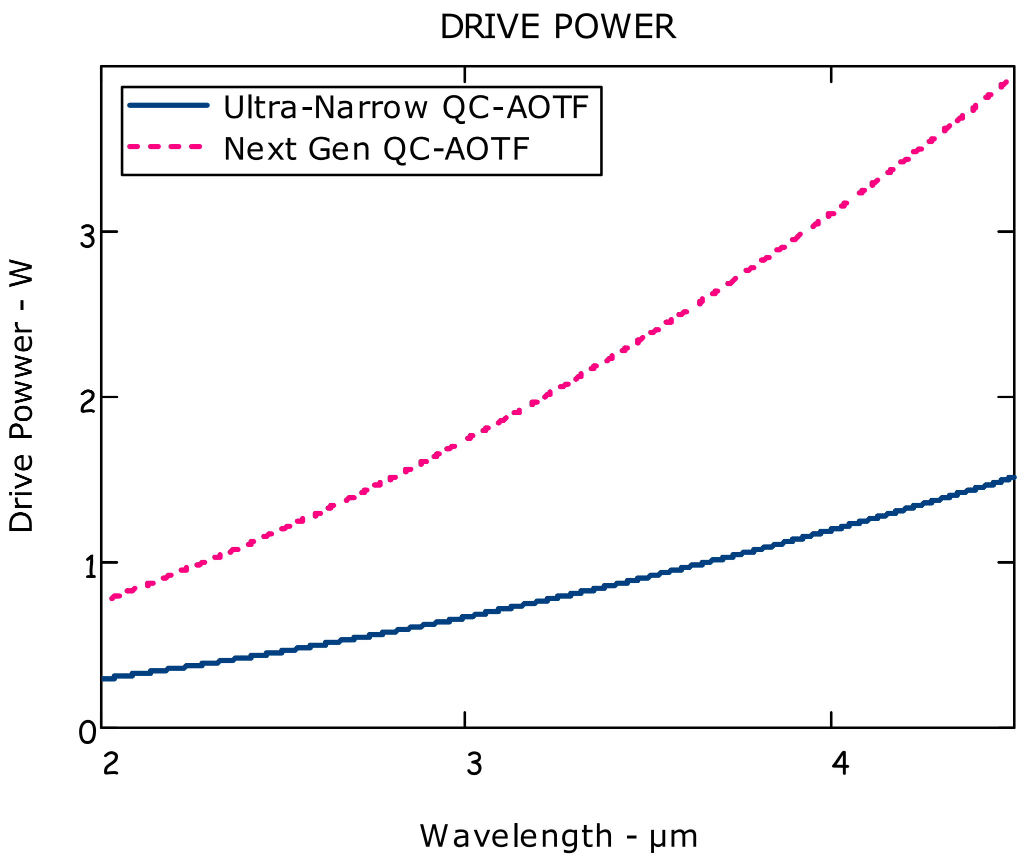
Next Generation QC-AOTF

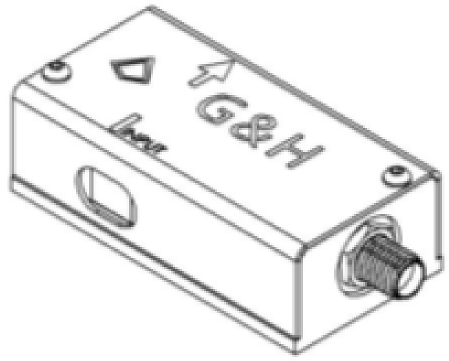


Narrow resolution QC-AOTF
- Beam Diameter – 2·5mm (diffraction-limited)
- Drive Power – 2W
- Length – 20mm

Ultra-Narrow resolution QC-AOTF
- Beam Diameter – 5mm (diffraction-limited)
- Drive Power – 2W
- Length – 40mm

Next Generation QC-AOTF





Narrow resolution QC-AOTF

- Beam Diameter – 2·5mm (diffraction-limited)
- Drive Power – 2W
- Length – 20mm

Ultra-Narrow resolution QC-AOTF

- Beam Diameter – 5mm (diffraction-limited)
- Drive Power – 2W
- Length – 40mm

Next Generation QC-AOTF
(Ultra-Narrow resolution)

- Beam Diameter – 1·8mm (diffraction-limited)
- Drive Power – 4W
- Length – 20mm

Thank you for your attention

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