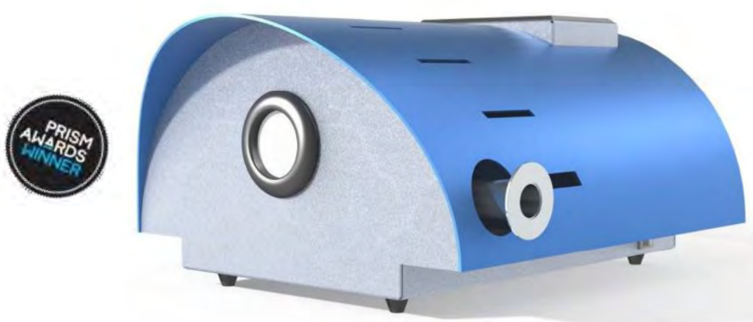
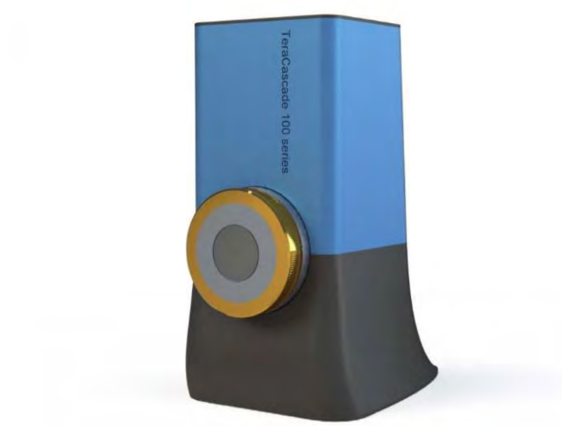
Advanced Photonics from THZ to SWIR Sources, Sensors & Optics





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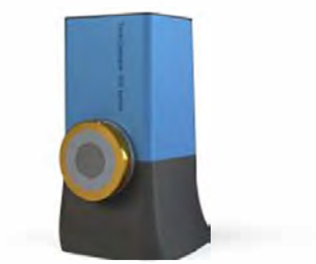
Terahertz

From 1THz to 10 THz / From 300um to 30um

High Power Terahertz sources



Cost effective Terahertz sources

Terahertz sensors

Multi-band THz source

TeraCascade 2000 series

The high-performance solution of the TC series range

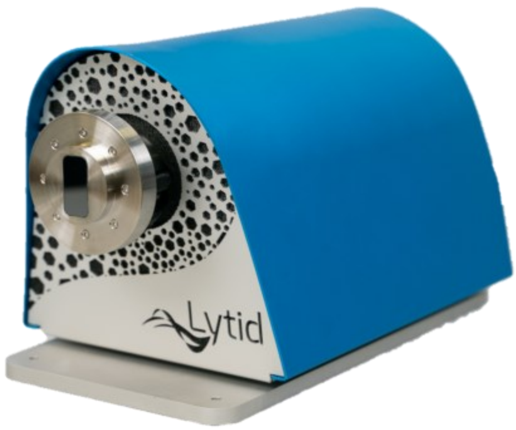
Powerful with >1 mW average power garanteed

Up to six (6)electronically switchable bands from 2 to 5 THz

Permanent vacuum with cryogenic-free cooling

Programmable with dedicated software

Powerful QCL technology



Lytid's award-winning TeraCascade 1000 series now is upgraded! Based on state-of-the-art quantum cascade laser technology, TeraCascade 2000 series is the new perfect tool to explore the supra-THz frequency range. It has kept all advantages of former generation: multiple frequency options, powerful output, automatedly-controlled cooling process. In addition, a higher/permanent vacuum level is achieved with the new design, giving rise to a low-maintenance device. Pumping step is no more required during the daily use of the source. In combination with automatically controlled cryogenic-free cooling, TeraCascade 2000 is a literally plug and play, ease-of-use system. With up to 6 chips at selected frequencies between 2 to 5 THz in one system, TeraCascade 2000 series guarantees average output power of more than 1 milliwatts in CW or QCW for each band. The integrated custom QCL driver provides instantaneous electronic switching between the frequency bands and it is fully programmable with dedicated software to control all input parameter via a USB connection to a PC. An automated beam collimator module for multi-band operation is available separately. As conclusion, TeraCascade 2000 is a flexible and powerful instrument for supra-THz applications.

Front side

Back side

Easy multi-band access:

- ✓ Electronic switching between the bands
- ✓ Remote control using dedicated software via USB

Connectivity:

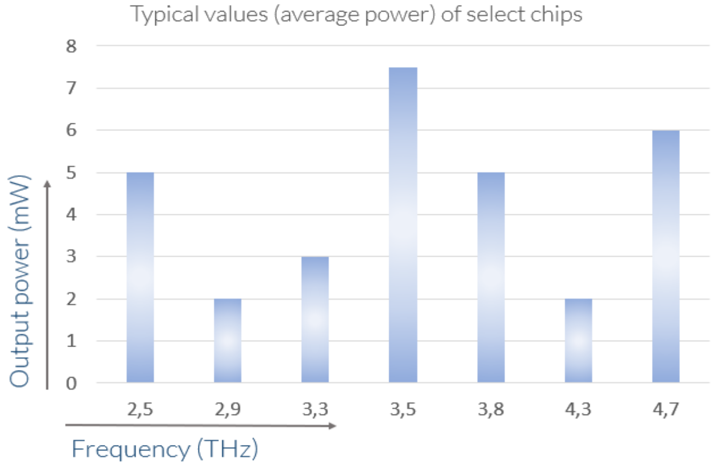
- ✓ GATE IN: Slave input for THz cameras
- ✓ GATE OUT: Elec. chopper signal to lock-in
- ✓ LASER IN: Direct connection to the QCL chip

Cryogen-free:

- ✓ Automatically controlled Stirling engine

Compact:

- ✓ Tabletop device
- ✓ Weight : 10 Kg



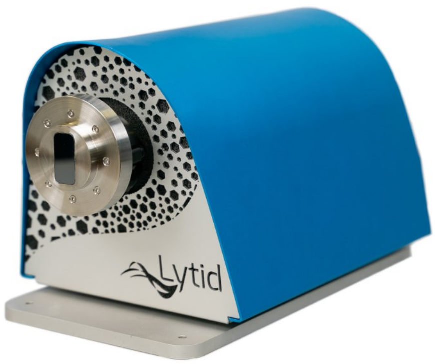
Features:

- Multi-band THz QCL source
- Milliwatts level average power
- Cryogen-free cooling
- Permanent vacuum chamber
- Easy configuration
- Fully programmable
- Compact, plug and play system

Applications:

- Real-time THz imaging
- High-definition THz imaging
- Heterodyne instrumentation
- High-resolution spectroscopy

Specifications	TC2000
Optical data	
Frequency bands	Up to 6 in the range 2-5 THz
Wavelengths	From 150 to 60 mm
Average output power	> 1mW
Spectrum	Multimode or single-mode
Output beam	~35° FWHM
Operating data	
Cooling system	Stirling engine (cryogen free)
Operating temperature	40 K
Dimension and weight	
Dimensions	23 x 23x43 cm
Weight	<10 Kg
Options	
Vacuum pump and adapters	✓
6-band auto-alignment module	✓



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Lytid

Empower your application

Characteristics of the equipment: TeraCascade 2000 with all options

Lytid's core technology is the terahertz quantum cascade laser or THz QCL. QCLs are electrically pumped unipolar semiconductor lasers. Their operation mechanism differs fundamentally from standard semiconductor diodes as they exploit intersubband transitions in cascaded quantum well structures to generate terahertz radiation between 2 to 5 THz or 150 to 60 μm in wavelength. TeraCascade 2000 is the 2nd generation of THz laser source based on state-of-the-art Quantum Cascade Laser technology, providing up to six discrete frequencies with mW level output power.

TeraCascade2000 is a compact plug-and-play system which can include up to six QCL chips delivering six different frequencies. Seven available frequencies to date are 2.5, 2.9, 3.3, 3.5, 3.8, 4.2 and 4.7 THz. The delivered power depends on each frequency and a maximum output power can reach up to 7.5 mW.

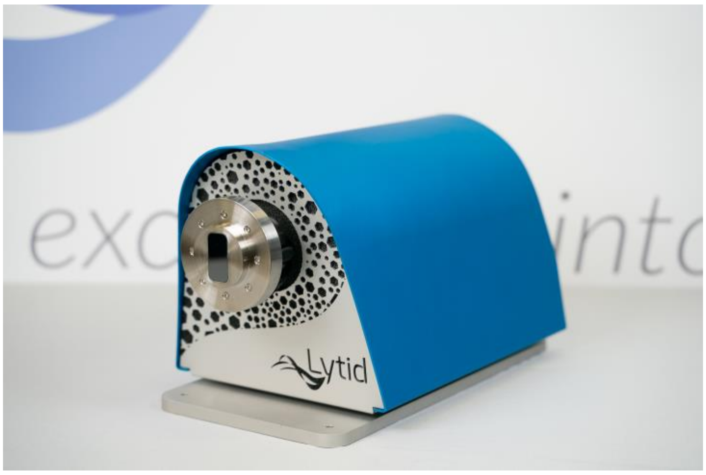

Fig 1. TeraCascade2000

Available QCLs and working regime

Table 1 resumes the available QCLs chips and their specifications. Each QCL emits a discrete frequency, with a spectral width of few GHz, and typical values of output power are shown in figure 2. All available chips to date provide single-mode emission and can work in CW regime. QCW (quasi-CW) regime is also obtained by modulating the current supply of the QCL.

Frequency (THz)	Mode	Min. power (mw) CW regime	Typical power (mW)
2.5(± 0.1)	Single	1	4
2.9(± 0.1)	Single	1	1
3.3(± 0.1)	Single	1	2.5
3.5(± 0.1)	Single	1	7.5
3.8(± 0.1)	Single	1	5
4.2(± 0.1)	Single	1	1.25
4.7(± 0.1)	Single	1	6

Table 1 Available QCLs and their specifications

High performance of this source is attained thanks to a significant cooling of the QCL chips while maintaining an exceptional compacity of the system. In this latest generation of TeraCascade source, the cooling process is achieved within a semi-permanent vacuum chamber. The high-level vacuum allows customers to perform cooling process directly, simplifying the daily use.

THz QCLs operate at cryogenic temperature (around 40 K). To achieve cryogen-free cooling in our TeraCascade2000 series, we use highly reliable Stirling engines developed for space programs. The QCLs are mounted on a cold tip, integrated in a cryostat, that is cooled to 40 K, by the space-qualified, cryogen-free Stirling engine. Stirling motor provides a suitable condition for QCL emission. The motor is included in the housing of the source, resulting in an ultra-compact (23 cm x43 cm, <10kg) design. Only a small place on the optical table is required for installation.

The cooling procedure as well as the laser switching on procedure are fully automated: TeraCascade2000 is ready to be used in about 20 minutes. Complete control of the source is achieved via dedicated software through USB connection, ensuring easy and plug-and-play use. Through dedicated software, user can choose the desired output frequency among the six options by a simple click. The fast switching between different frequencies ensures flexibility of the laser emission. All QCL chips proposed for TeraCascade 2000 can work in CW regime, and the modulation frequency can be tuned directly via the software.

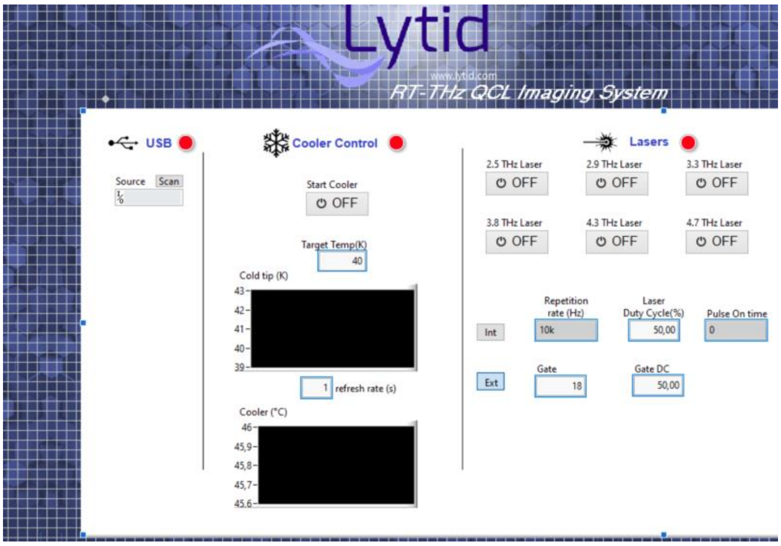

Fig 2. Software of TeraCascade2000

Connections

All necessary connections are included for easy integration of TeraCascade into a setup of end-users. A USB connector can be found on the rear panel of TeraCascade 2000, allowing to communicate with PC for parameter setting. The source can work in master/slave mode. In particular, "Laser in" can connect an external signal generator (e.x. Avtech pulse generator) directly to QCL chips, making it possible to further boost laser performance by taking advantages of high-end high-speed signal generator. A faster modulation and extremely stable laser emission is achievable then.

Auto-alignment module

The auto-alignment module is a complementary tool for automating and optimizing the emission from Lytid's multi-QCL source, TeraCascade2000. The latter is an ultra-compact THz source allowing for integration of up to six QCLs for narrow band tunable emission in the THz range. Each QCL's emission is centered at a specific frequency within 2 and 5 THz. The QCLs, manufactured on a dedicated chip, are integrated on a 3*2 matrix support placed in the vacuum chamber and the QCLs are separated by few millimeters. Since different QCLs are spatially separated, laser emission occurs at different position for different QCLs within the same source. Moreover, QCL emission is naturally divergent.

In order to spatially auto-align and collimate the laser emission and thus fully exploit the potential of TeraCascade2000, Lytid designed the auto-alignment module. This system provides collimation and stabilization of THz emission from different QCLs. No realignment is required when switching frequencies: thanks to the auto-alignment module, alignment is maintained for different QLCs emission. The auto-alignment module is remotely controlled by the dedicated software of TeraCascade 2000 and it is totally transparent for users. Once a user selects a frequency on the software, auto-alignment module will get the information and change the position automatically to ensure the collimated beam stay at the same position. As a result, alignment and beam shaping are preserved when sweeping frequencies.

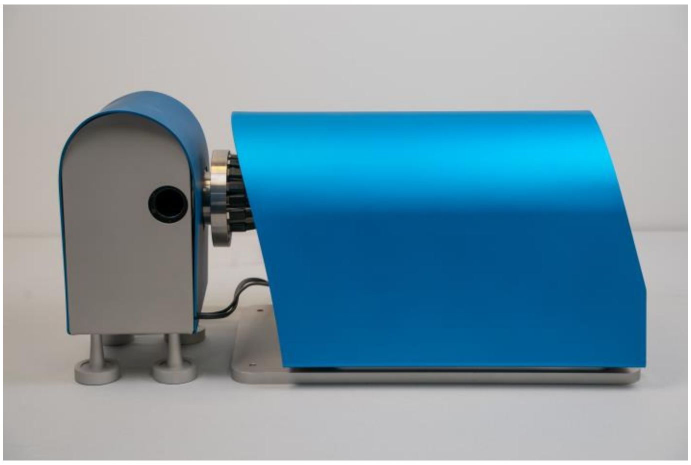

Fig3. TeraCascade 2000 with auto-alignment module

Figure 4 shows different frequency's beam profiles after transmission through the auto-alignment module and a focusing lens captured using our TeraLens and a micro-bolometric THz camera. As expected, the beams are aligned at the same output position. Furthermore, one can clearly see the effect of the spot size with varying emission frequency. Given the focal length of the focusing lens, for increasing frequency the beam size decreases, being proportional to the wavelength.

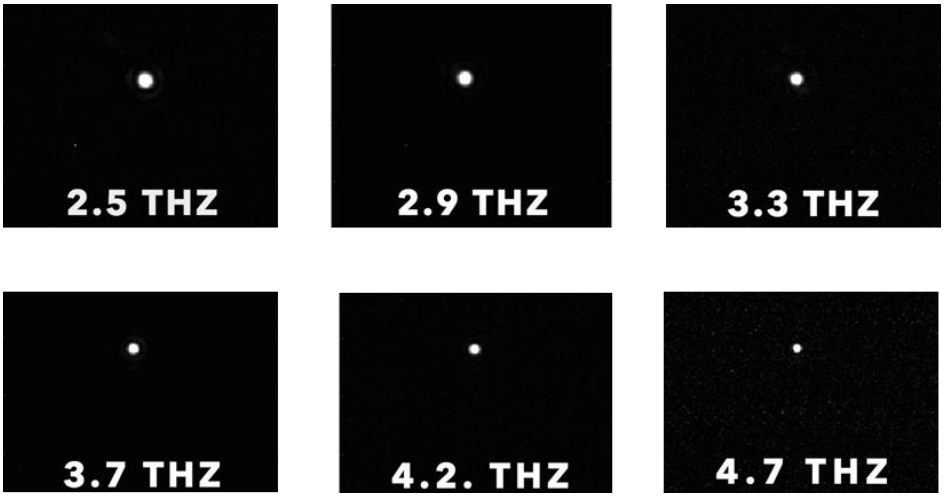

Fig 4. Measurement of focused beam for six different frequencies, after the auto-alignment module

Application note

Beam characteristics

The Tera Cascade QCL source provides a high power, highly coherent and quasi-gaussian laser beam. The latest, being a critical criterion for imaging, beam shaping or other sensing techniques, is detailed in this application note.

The following characterization have been realized in a non-controlled environment displaying temperatures variations higher than 1°C, variation of the hydrometric level up to 5% over the typical measurement's times and ambient lightning in order to reproduce typical operating conditions.

The following measurements have been performed using two optical setups. The first one (see figure 1.a) consist of a Φ1" f/1 coated HRFZ-Si lens for the beam collimation and a Φ1" f/2 coated HRFZ-Si lens for focusing while two Φ2" f/1 golden parabolic mirrors are used for the second one (see figure 1.a), leading to higher focusing angle and so spot size.

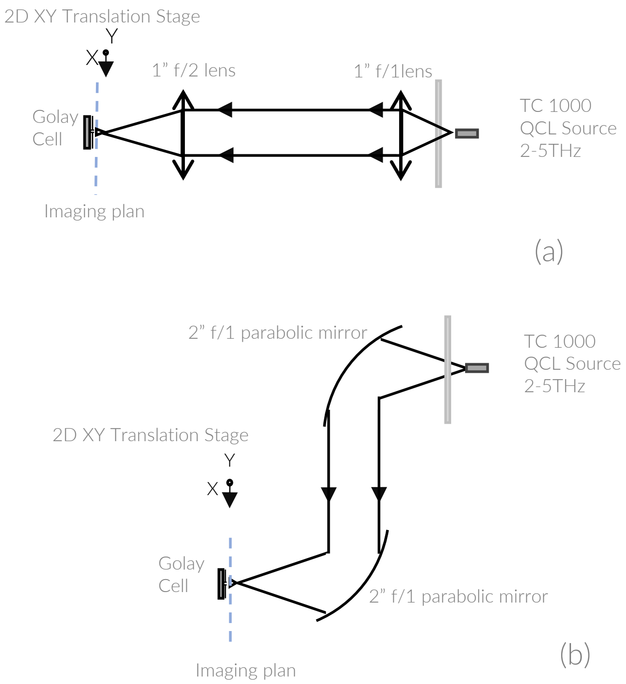

Figure 1 Optical setups schematics

A sensitive Golay cell detector, with a pinhole aperture, mounted on a motorized 2D translation stage for raster scan, is placed behind the optical setup around the focus point. A lock-in amplifier is used to recover proper signals and sensitive amplitudes variations at each point measurement over the area of interest.

Near gaussian beam profile of the focused beam

A perfect gaussian beam intensity distribution profile is dictated by the following equation.

$$I(r) = I_0(z)e^{\frac{-2r^2}{w^2(z)}}$$

The beam radius, ω(z), element of interest in this note, is defined as the distance for which the electric field amplitude is decreased by a factor of 1/e and so the intensity by a factor of $1/e^2$ as illustrated on Figure 2.

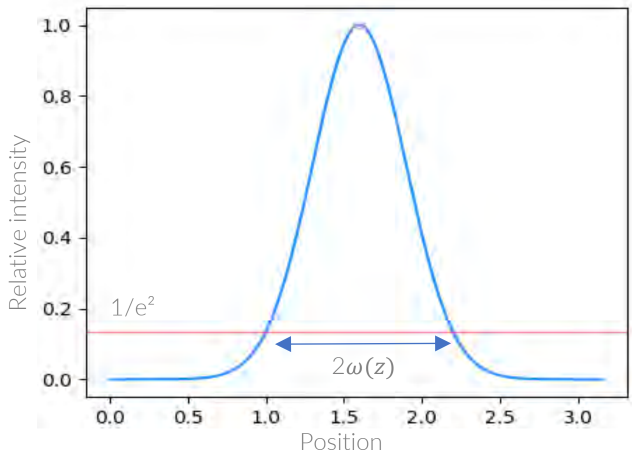

Figure 2 Theoretical gaussian beam distribution

At the optimum focalization position, the beam spot size is minimal and called the waist radius, ω_0.

The following figures display the 2 dimensions beam profiles at the waists of the two optical setups as well as their respective cross sections completed with their theoretical gaussian profiles.

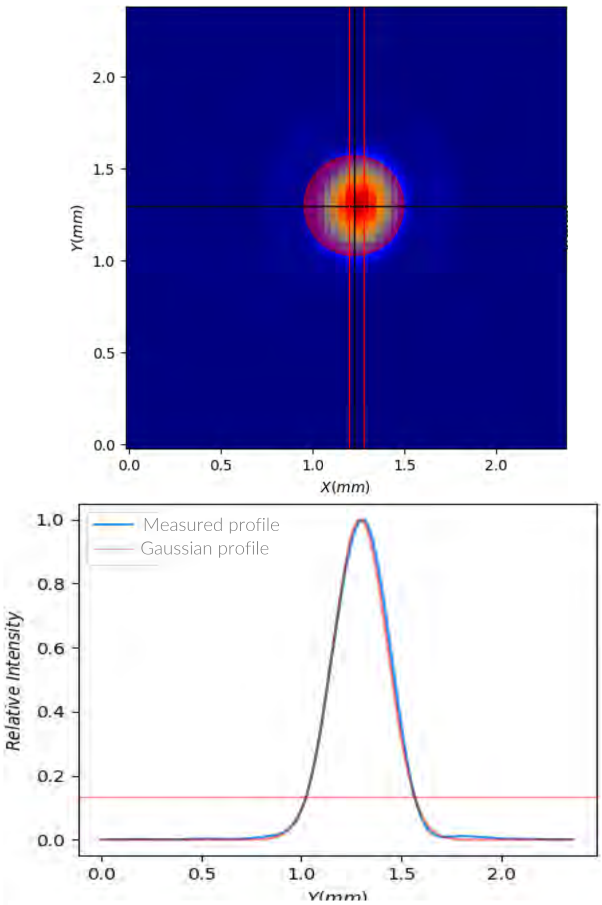

Figure 4 Beam profile at the lenses optical setup's waist

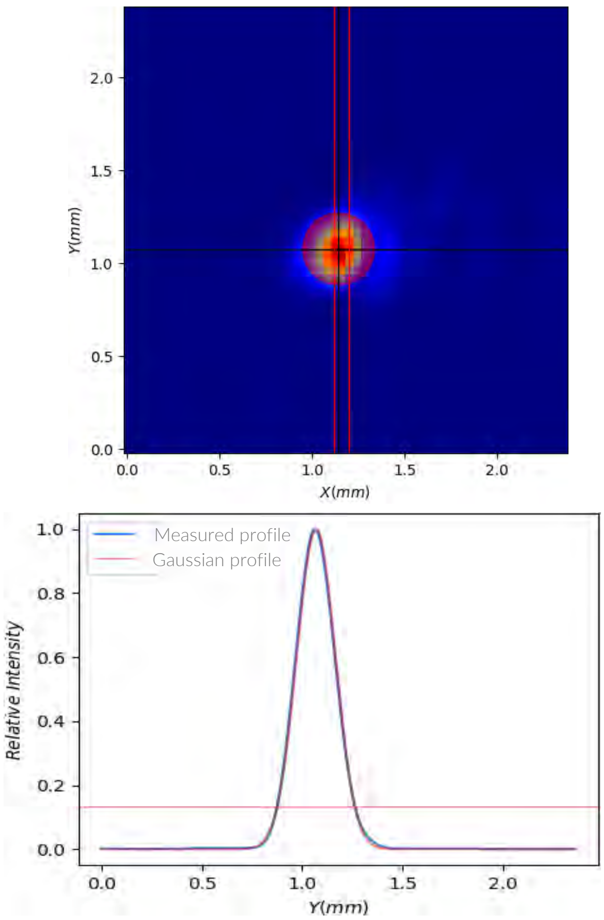

Figure 3 Beam profile at the parabolic mirrors optical setup's waist

A 0.27mm waists radius have been obtained for the lens setup, while, thanks to the larger focusing angle, a $1/e^2$ radius of 0.19mm is reached using the parabolic mirrors optical setup.

Gaussian beam propagation

Beside the spot profile study, a gaussian beam follows a proper propagation scheme. In the case of a perfect first order gaussian beam, its $1/e^2$ radius along the propagation direction, z, is

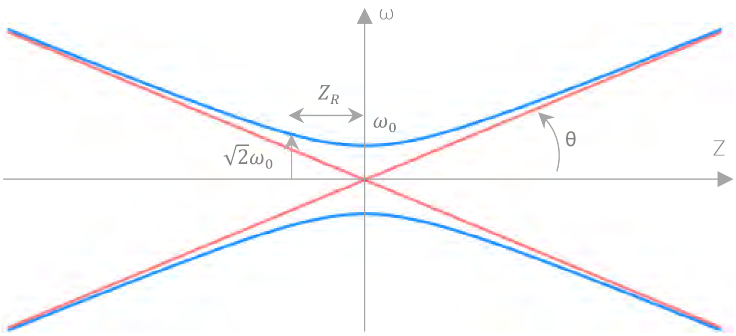

Figure 5 Beam diameter propagation

dictated by the following equation and is illustrated in Figure 4.

$$\omega(z) = \omega_0 \sqrt{1 + \left(\frac{\lambda\, z}{\pi\, {\omega_0}^2}\right)^2}$$

The propagation proprieties of a gaussian beam can dictate the optimum spot dimensions that can be achieved using a source according to a given optical setup.

The Rayleigh distance Z_R is the distance from the waist for which the radius has been multiplied by a factor of $\sqrt{2}$. It gives an order of magnitude of the range for which the beam keeps a relatively constant diameter and can be expressed as follows:

$$Z_R = \frac{\pi {\omega_0}^2}{\lambda}$$

A direct link between the far field divergence of the beam (θ for z>>Z_r) and its waist radius (minimum radius) can also be derived and is given by the following equation.

$$\Theta = \frac{\lambda}{\pi \omega_0}$$

In the case of non-first order gaussian beams or imperfect gaussian beams, a quality factor M² is introduced in order to account for the higher order diameters that are given by $\omega_{mn}(z) = M\,\omega_{00}(z)$ with M constant. The beam radius propagation equation is then changed as follows:

$$\omega(z) = w_0 \sqrt{1 + \left(\frac{M^2\,\lambda\,z}{\pi\,{\omega_0}^2}\right)^2}$$

The M² factor is given by the ratio of the measured divergence angle with respect to the theoretical angle calculated from the measured waist size.

$$M^2 = \frac{\Theta}{\dfrac{\lambda}{\pi\omega_0}}$$

Knowing the M² factor of a source, it is then possible to derive the minimum spot size on an optical setup for a given divergence and vice versa.

The two following figures display the results for the M² factor measurements performed using the TeraCascade 1000 series 2.5THz chip with both optical setups. The raw measurements points have been completed by the theoretical propagation profile that take into account their respective calculated M² factors.

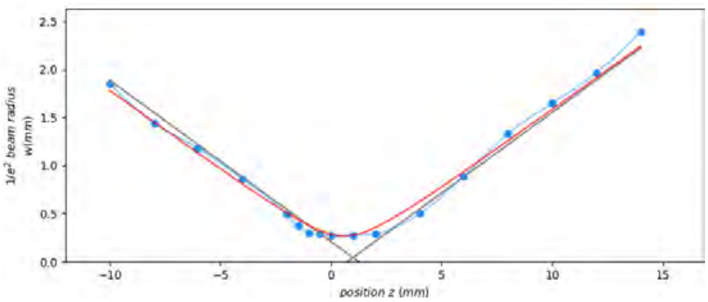

Figure 6 Beam propagation for the lenses optical setup

In the case of the lenses optical setup, the M² factor of 1.17 for a divergence of 166mrad (9.5°) ensures a quasi-diffraction limited beam, highly suitable for high quality imaging systems or sensing setups and proper beam shaping.

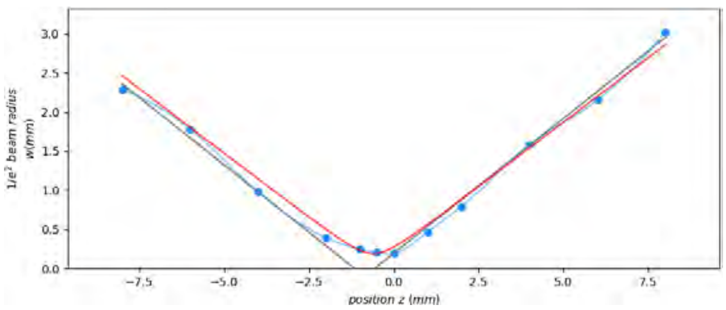

Figure 7 Beam propagation for the parabolic mirrors optical setup

The higher M² factor of 1.62 obtained by the mirror optical setup could be explained by the larger focusing aperture of 331mrad (19°) used in this setup, leading to much more sensitive alignment requirements.

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Multi-band THz source

TeraCascade 1000 series

The high-performance solution of the TC series range

Powerful with >1 mW average power garanteed

Up to six (6) electronically switchable bands

Select frequencies between 2 and 5 THz

Fully automated vacuum system

Powerful QCL technology

Cryogen-free cooling

The TeraCascade 1000 series is an award-winning THz source based on state-of-the-art quantum cascade laser technology. It is the perfect tool to explore the supra-THz frequency range. With up to 6 chips at select frequencies between 2 to 5 THz in one system and a guaranteed average output power of more than 1 milliwatts in CW or QCW for each band, it is a flexible and powerful tool for any supra-THz applications. The unit is fully integrated and with its automated vacuum control loop and cryogen-free cooling system it is truly plug and play. The integrated custom QCL driver provides instantaneous electronic switching between the frequency bands and is fully programmable using a user-friendly graphical user interface on a 4.3" capacitive touchscreen or remotely via a USB connection to a PC. With the integrated signal generator and output signal connector, electronic chopping is possible and requires no external device. Beam collimators and beam extenders can be provided as standard components or tailored for a specific application. An automated beam collimator module for multi-band operation is available separately.

Application note

Laser stabilisation and stability in QCW mode

The Plug&Play aspect of the TeraCascade 1000 ensures a short laser output power stabilization time to allow the user to expect a highly stable laser soon after it has been switched on. Moreover, a high level of stability over long time spans is obtained, with deviation levels lower than 1% over hours.

The following characterizations have been realized in a non-controlled environment displaying temperature variations higher than 1°C, variations of the hydrometric level up to 5% over the typical measurement's times and ambient lightning in order to reproduce typical operating conditions.

A calibrated THZ 20 Pyroelectric detector from Sensor und LaserTechnik (sensitivity of 65.9 V/W calibrated at PTB, Berlin) paired with a collection HRFZ-Si lens aligned at the output of the laser have been used to perform those measurements on a 2.5 THz QCL chip. A lock-in amplifier is used to recover proper signals and sensitive amplitude variations.

- Emission scheme in QCW Mode

In order to reach high performances levels with the TeraCascade 1000 QCL chips, a Quasi Continuous Wave (QCW) driving signal is generated thanks to a pulsed square signal at high frequency (typically around 10 KHz) with an adjustable duty cycle (see figure 1). For most kind of THz thermal detector, this modulation frequency remains completely un-detectable, therefore, tuning the duty cycle parameter only sets the averaged emitted power.

An overmodulation of typically 5-1000 Hz is then used to electrically chop the optical signal into a square signal (fixed 50% duty cycle).

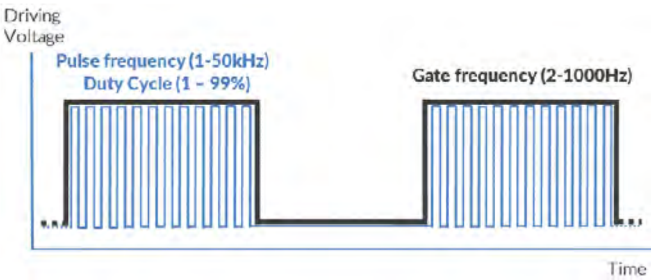


Figure 1 Driving signal scheme for QCL chips in QCW mode

- Stabilization characteristics

The TeraCascade 1000 source reaches instantaneously a nominal output level once turned on without gradual rise time. A short oscillatory stabilization time yet needs to be taken into account to reach a perfectly stable regime (see figure 2 below that displays a typical output power evolution during the stabilization phase).

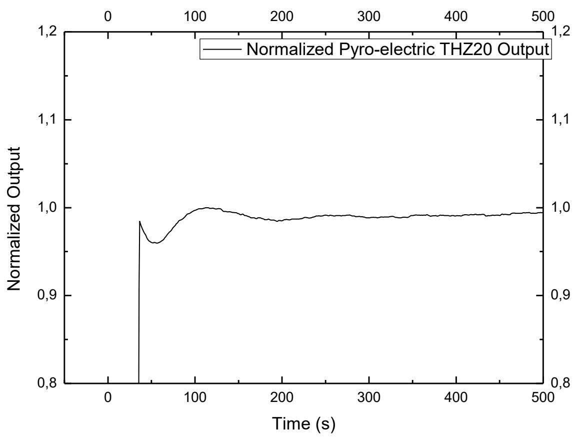


Figure 2 Stabilisation regime for a 50% duty cycle sub-modulation corresponding to 1.7 mW output power on a 2.5 THz QCL

The following table indicates the typical duration of this oscillatory phase as a function of the duty cycle and the corresponding emitted power.

Specifications		TC1000
Duty Cycle	Emitted power	Stabilisation time
10%	0.5 mW	150 s
25%	1.1 mW	200 s
50%	1.7 mW	300 s
80%	2.2 mW	2000 s

The the stabilization time increase regarding the emitted power is due to the longer thermal stabilization of the cryogenic cooling system. Indeed, QCL emission power is highly sensitive to the operating temperature of the chip. The larger the required optical power, the more heat will be generated by the QCL chip that needs to be overcome by the close loop cooling system to stabilize the cold tip temperature.

Nevertheless, power fluctuations during this stabilization phase should not exceed 10% of the nominal emitted power.

- High stability performances

Once the stabilization phase is completed, the stability of the TeraCascade 1000 enables any sensitive measurement over long periods of time thanks to very low fluctuation levels in the emitted power. Indeed, the TeraCascade 1000 maintains nominal power deviations lower than 1% over 1 h and lower than 2% over 12 h in a standard non-controlled environment.

The signal obtained from a typical stability measurement of the laser output power is showed in figure 3 and have been performed on a 2.5 THz QCL chip.

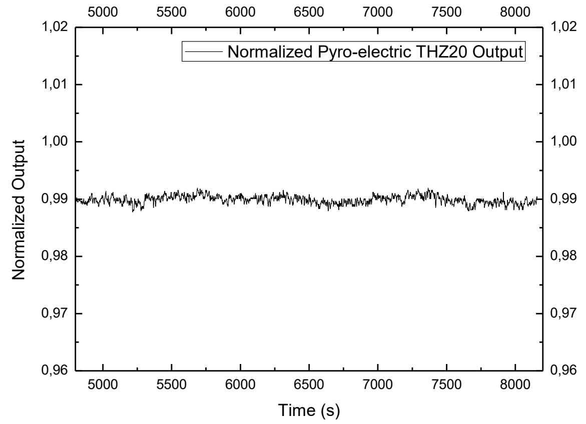


Figure 3 Stable regime for a 25% duty cycle sub-modulation corresponding to 1.1 mW output power on a 2.5 THz QCL

Typical values for the absolute variation over one hour as a function of the duty cycle and the corresponding output powers are displayed in the table below.

Specifications		TC1000
Duty cycle	Emitted power	Stability deviation over 1h
10%	0.5 mW	0.55%
25%	1.1 mW	0.27%
50%	1.7 mW	0.42%
80%	2.2 mW	0.63%

This reliability is ensured by the accurate thermal stabilization capabilities of the integrated Stirling Engine cooling system and the long-term stability of the power supply when used under normal operating conditions.

Technical note

Presenting the auto-alignment module

The auto-alignment module is a complementary tool for stabilizing and optimizing the emission from Lytid's multi-QCL (Quantum Cascade Laser) source, TeraCascade1000.

The latter is an ultra-compact THz source allowing for integration of up to six QCLs for narrow band tunable emission in the THz range. Each QCL's emission is centered at a specific frequency within 2 and 5 THz.

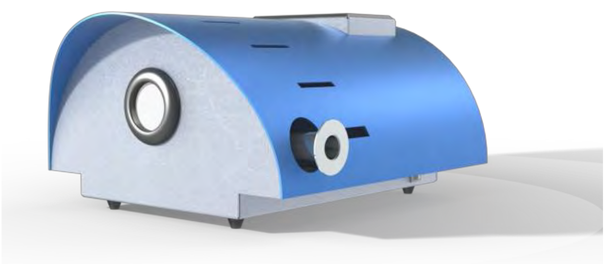


Figure 1 TeraCascade1000 : multi-QCL THz source

Each QCL being manufactured on a dedicated chip, these integrated on a 3*2 matrix support, the laser emission occurs at different position for different QCLs within the same source. Note that emission from different QCLs is not simultaneous. Moreover, the emission from a QCL is naturally divergent.

The source is a powerful tool of multi-band THz emission. However, its intrinsic multi-laser architecture imposes an added complexity to those experimental setups requiring simple and fast switching between the different frequencies offered by the source.

Figure 2 Shifted and divergent emission at six different frequencies of TeraCascade1000

In order to spatially stabilize and collimate the laser emission and thus fully exploit the potential of TeraCascade1000, Lytid designed the auto-alignment module.

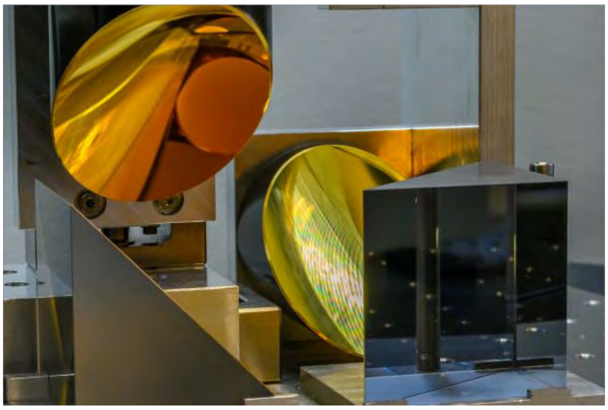


Figure 3 Detail of auto-alignment module

This system provides collimation and stabilization of THz emission from different QCLs. No realignment is required when sweeping frequencies: thanks to the auto-alignment module, alignment is maintained for different QLCs emission.

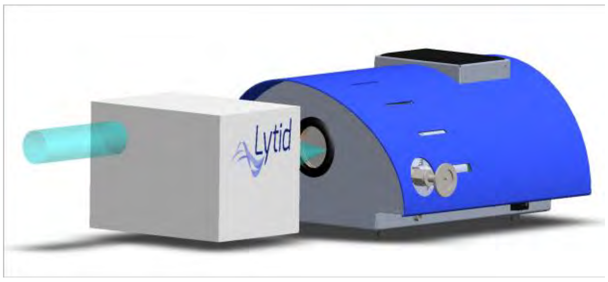


Figure 4 Emission of TeraCascade1000 with the auto-alignment module integrated at the output of the source

The auto-alignment module is remotely controlled by a dedicated software. The user chooses the desired emission frequency through the TeraCascade1000 touch screen. The same value is entered to the driving software of the auto-alignment module. The latter would ensure collimated and stabilized output, whatever frequency the user might choose.

As a result, alignment and beam shaping are preserved when sweeping frequencies.

Figure 5 Measurement of the beam profile for three different frequencies, after the auto-alignment modules and a focusing lens

Figure 5 shows different frequency's beam profiles after transmission through the auto-alignment module and a focusing lens. As expected, the beams are aligned at the same output position.

Given the focal length of the focusing lens, for increasing frequency the beam size decreases, being proportional to the wavelength.

The auto-alignment module allows to speed up applications where multi-frequency emission is required and relieves the user from time-consuming re-alignment procedures.

In addition, integration compactness (only 125 x 133 mm) of the auto-alignment module and full automation grant a simplified user experience.

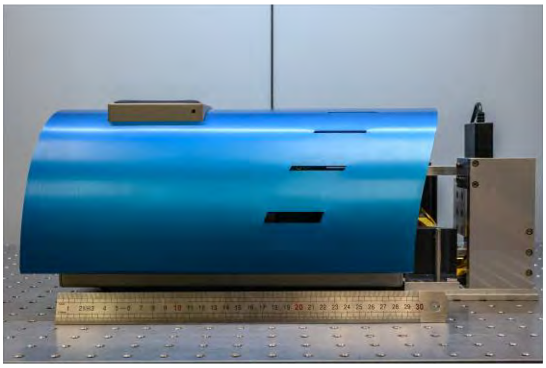


Figure 6 TeraCascade1000 with integrated auto-alignment module at its output.

Beside the TeraCascade1000 optical handling simplification, the versatility of this module is ensured by the broadband design for multi-frequency uses and its customizable output components. The modular beam collimator allows for different output profiles dimensions thanks to 1/2" up to 3" diameter beam shaping optics.

Terahertz laser source

TeraCascade 100 series

The cost-effective solution of the TC series range

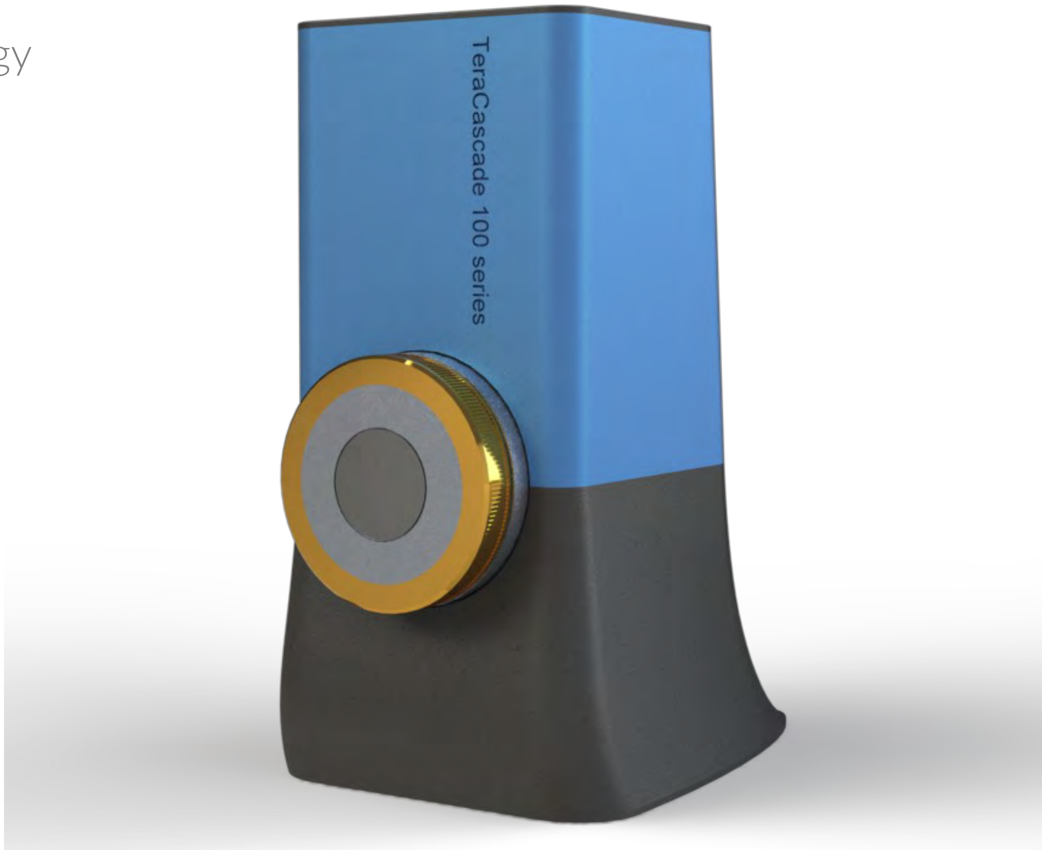
Based on QCL technology

Powerful with > 100µW

Single or Multi-mode

From 2 to 5 THz

Modular system



The TeraCascade 100 series is a cost-effective THz source based on state of the art quantum cascade laser technology. It is the perfect tool to explore the high THz frequency range. With an average output power of more than 100 microwatts from 2 to 5 THz, single or multimode emission, you can perform many applications such as high resolution THz raster scan imaging, detector characterization or calibration. The system is safe and easy to use even with a nitrogen cooling system, thanks to the custom-made driver and electronics of the TC Driver, available separately. It which allows to control via a touchscreen or remotely via a computer all laser parameters, making it the most flexible and user-friendly QCL system on the market. The TC100 series is the perfect tool to explore the high THz frequency range.

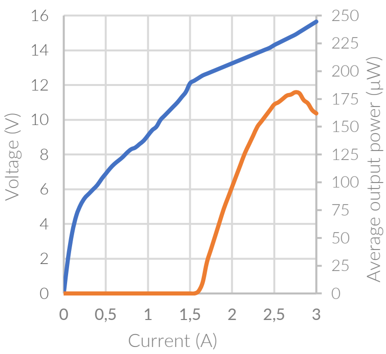
Control:
- ✓ Fully compatible with TC Driver (available separately)
- ✓ Local (Touchscreen) or Remote (USB)

Connections:
- ✓ Vacuum connector ¼ inches
- ✓ 4 pins power connector to TC Driver
- ✓ Dewar Nitrogen filling via opening on the top (compatible with a continuous flow system)

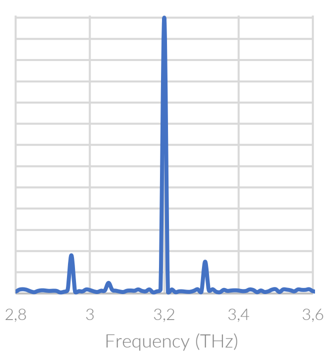
Mechanical:
- ✓ Magnets for quick setup on optical table
- ✓ M6 screws for permanent setup

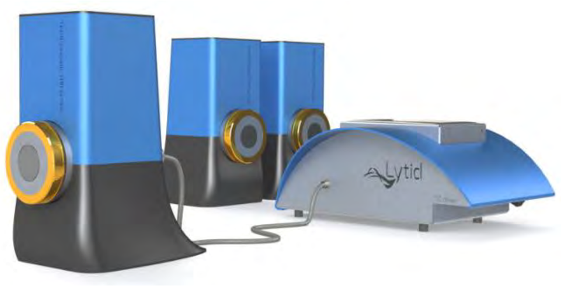
Typical value for TC100 with a 3.2THz chip

Light-Current-Voltage



Spectrum





TC 100 with TC Driver

Features:

- More than hundred microwatts
- High quality beam shape
- Integrated Si lens with AR coating centered at the chosen frequency
- Easy configuration and fully programmable locally or remotely via a computer (with TC Driver)

Applications:

- High definition raster scan imaging
- Detector characterization in the THz range
- Power calibration in the THz Range

Specifications	TC100
Optical data	
Frequency range	From 2 to 5 THz
Wavelength	From 150 to 60µm
Average output power	> 0.1mW
Spectrum	Single or multi-mode emission
Output beam	Si HRFZ lens
Beam shape	20° FWHM
Functional data	
Vacuum autonomy	3 months
Cooling system	Nitrogen
Dimension and weight	
Height	220mm
Width	120mm
Length	180mm
Weight	2,5 Kg
Options	
TC Driver	✓
Vacuum turbo pump	✓

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Terahertz pyroelectric sensor

TeraPyro

A high-performance solution for THz sensing

High responsivity (up to 2 kV/W) and low NEP

Broad spectral range from 0.1 - 30 THz

Interchangeable pre-aligned optics

High quality THz integrated optics

Responsivity and bandwidth switch

The TeraPyro sensor is a compact and highly sensitive device, based on the combination of a high-quality absorbing black coating, paired with a $LiTaO_3$ pyroelectric crystal. The broad absorption range of the coating allows the use of this sensor over a large spectral range (from 0.1 to 30 THz). The high sensitivity and low NEP offer no compromise on performances. The integrated, prealigned, high quality THz optics based on AR coated Si-lenses ensures maximized optical coupling to the sensor. The highly modular optics allow three configurations: bare sensor, collimated input or focused input with 50 mm working distance. A responsivity switch allows to gain in response time for faster measurements. A BNC output ensures fast and standard connectivity for data recovery. The sensor operates on a common +/-12 V DC power supply.

Connection:

- ✓ BNC output connection
- ✓ +12/-12 V DC Power supply

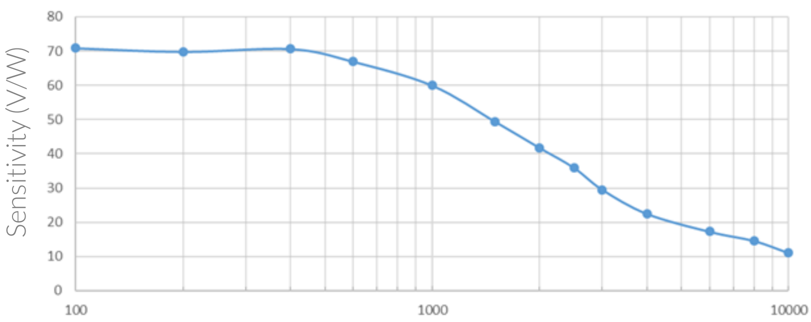
Plus

- ✓ Interchangeable optics
- ✓ Sensitivity selection switch
  - >3 positions: High, Medium, Low

Performances

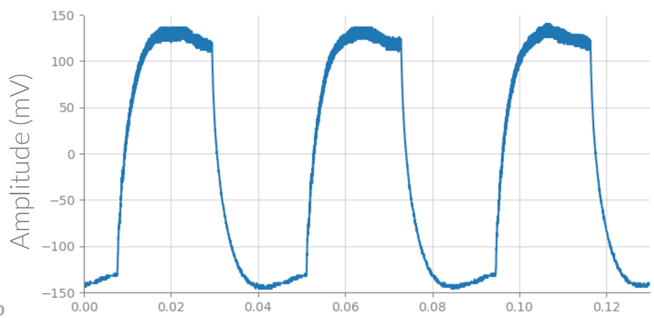
- ✓ Stability: < 1% over 1h
- ✓ SNR on lock in: > 300
- ✓ Detection up to 2.5 kHz mod.

Sensitivity on low gain channel



Modulation Frequency (Hz)

Typical waveform



Time (s)

Features :

- 3 responsivity switch for optimized gain and response time
- High quality HRFZ-Si THz optics with AR coating or boradband Zoenex polymer optics
- Modular optics
  - ➢ Bare sensor
  - ➢ Collimated input
  - ➢ Focused input with 50mm working distance
- Standard M4 optical post assembly

Applications :

- THz sensing
- High definition imaging
- Optical sources characterization
- Power measurements

Specifications	TeraPyro		
Optical data			
Frequency range	From 0.1 to 30 THz		
Wavelength	From 10 to 3000 um		
Maximum power density	50 mW/cm²		
Noise equivalent power	1.6 nW/ $(Hz)^{1/2}$		
Responsivity switch	High	Medium	Low
Sensitivity at *2.5 THz	1.8 kV/W	390 V/W	70 V/W
Rise time	80 ms	10 ms	1.5 ms
Maximum chopper frequency	15 Hz	150 Hz	2.5 kHz
Options			
Calibration service	✓		
Optical collection lenses	✓		
Power supply connector	✓		
Optical post assembly	✓		
Dimension and weight			
Working distance	50 mm		
Sensor area	Ø 5 mm		
Diameter	67 mm		
Length	125 mm		
Weight	300 g		

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Application note

Sensitivity and Bandwidth Selection

Technical Notes

The TeraPyro sensing device is based on an absorbing black coating deposited on top of a 2mmx2mm $LiTaO_3$ pyroelectric sensitive crystal. Absorbed THz radiation induces thermal variations in the black coating which is then converted into electrical signals by the pyroelectric crystal. The absorbing layer's optical typical absorption characteristic is displayed on figure 1.

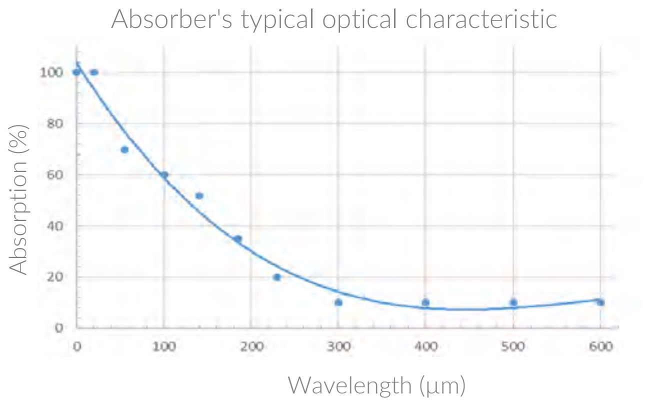


Figure 1 Absorption vs frequency of black coating

The pyroelectric effect generally occurs as minor voltage generation, the high sensitivity of the detector is enabled by the integration of a tunable low-noise op-amp stage located close to the pyroelectric crystal.

The integrated capacitors/resistors for the control of the gain of the amplification stage, selected through the 3-positions switch of the TeraPyro, allows the user to tune the sensitivity and the response time of the detector. The different detection characteristics, depending on the channel, are investigated in this application note.

The following characterizations have been implemented in a non-controlled environment displaying temperature variations higher than 1°C, variations of the hydrometric level up to 5% over the typical measurement times and ambient lightning in order to reproduce typical operating conditions.

A tera pyro sensor, paired with a two collimation and focalization HRFZ-SI lens aligned at the output of the laser have been used to perform those measurements at 2.5 THz for an emitted power of 0.82mW using the TeraCascade 1000 Integrated QCL source. Depending on the measurement, an oscilloscope, a lock-In amplification stage and a spectrum analyzer are used to recover proper signals. A calibrated THZ 20 Pyroelectric detector from Sensor und LaserTechnik (sensitivity of 65.9 V/W) have been used for power calibration.

Emission scheme of TC 1000 in QCW Mode

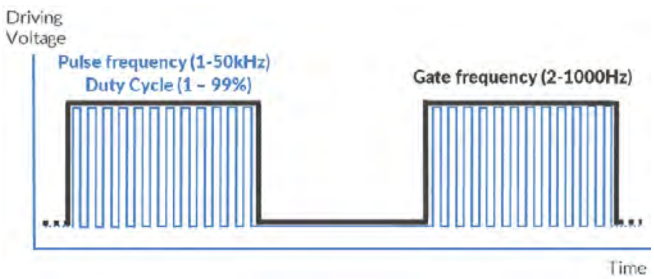


Figure 2 Driving signal scheme for QCL chips in QCW mode

The emission scheme of the source used in those characterizations is an important in order to reach high performances and power levels with the TeraCascade 1000 QCL chips, a Quasi Continuous Wave (QCW) driving signal is generated using a pulsed square signal at high frequency (typically from 10 to 50 KHz) with an adjustable duty cycle (see figure 2). For most THz thermal detectors, this frequency range remains completely un-detectable, therefore, tuning the duty cycle parameter only sets the averaged emitted power.

An exploitable signal for detectors is then obtained by adding a gate signal overmodulation of typically 5-1000 Hz to electrically chop the optical signal into an even square signal (fixed 50% duty cycle).

Sensitivity selection

The choice of the sensitivity channel among the 3 positions of the TeraPyro sensor, allows for the user, to select a tradeoff between the sensitivity and the bandwidth of the detector. Indeed, due to the amplification stage, the higher the sensitivity, the lower the detection speed and vice versa.

This effect is due to the fact that the rise time of the signal is directly linked to the RC constant that have been set on the amplification stage. Bellow the recommended maximum chopper frequency for a given switch position, no sensitivity variation will be observed.

Typical scope signals from square modulated waveforms at 2Hz and 23 Hz (with a pulse frequency at 10 kHz and 40% Duty cycle) are respectively displayed in figure 3 and 4 with adequate sensitivity selection (high sensitivity channel à 2Hz and medium sensitivity channel at 23Hz).

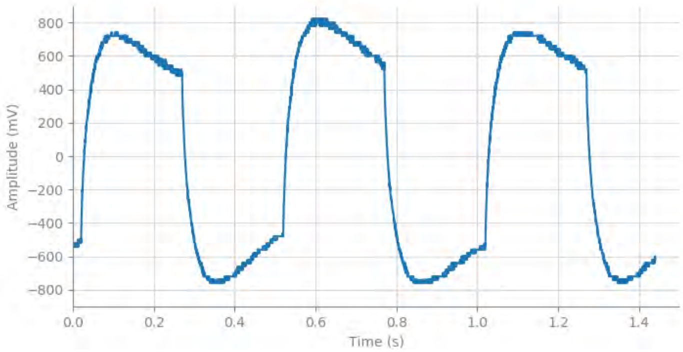


Figure 3 Typical measurement for a 2 Hz square modulation signal in high sensitivity mode

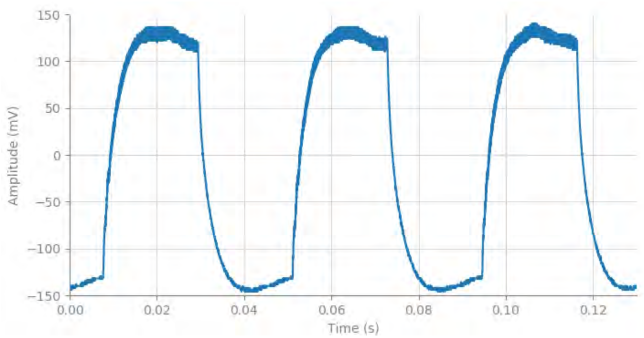


Figure 4 Typical measurement for a 23 Hz square modulation signal in medium sensitivity mode

At higher modulation frequencies, the detection will then be limited by this RC rise time and will give rise an incomplete charge-discharge detection scheme (as showed in Figure 5). The main effect on the detection is the lowering of the sensitivity when increasing the chopping frequency (this effect is highlighted in the High-speed use section of this application note in the case of the low sensitivity channel).

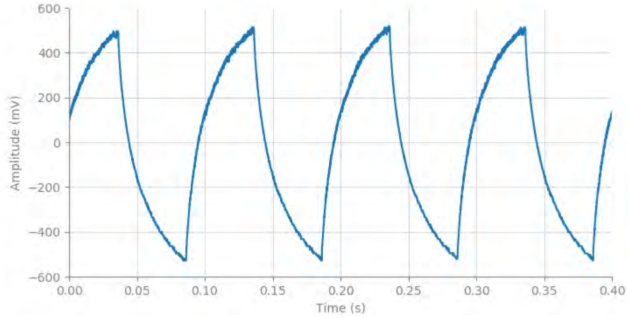


Figure 5 Typical measurement for a 10 Hz square modulation signal in high sensitivity mode

The thermal relaxation of the sensor is noticeable when using the TeraPyro sensor at too low modulation frequencies for a given sensitivity channel. A typical example is displayed on Figure 6 in the case of the use of the medium sensitivity channel for the detection of a signal modulated at 5Hz.

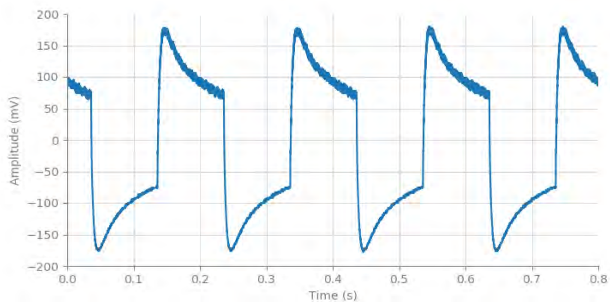


Figure 6 Typical measurement for a 5 Hz square modulation signal in medium sensitivity mode

High Sensitivity use

On the amplification stage, an open circuit configuration ($R \rightarrow \infty$) could be set and would give access to an extremely sensitive detection at really low chopping frequencies (up to 10kV/W @ 2.5THz for measurements using a few Hz chopping frequency). Nevertheless, the major drawback in this configuration comes from the extreme responsiveness to any external environmental disturbance, from air flow, to temperature changes, minor sound disturbances, vibrations or disturbances from the operator. This setting is not included in the TeraPyro sensor.

High speed use

On the other hand, when using the low sensitivity channel of the TeraPyro sensor, very fast detection can be achieved. Indeed, due to the lower RC time constant of the amplification stage, despite the lower sensitivity (~70V/W), detection up to a few kHz chopping frequencies is achievable with an oscilloscope.

Different waveforms have been acquired on the low sensitivity channel at different modulation frequencies from 100Hz to 10 kHz on an oscilloscope, (using a 50kHz sub modulation and 50% duty cycle for an average output power of 0.82 mW). Some of them are displayed in Figure 8. No filtering or additional processing have been applied to those raw oscilloscope signals.

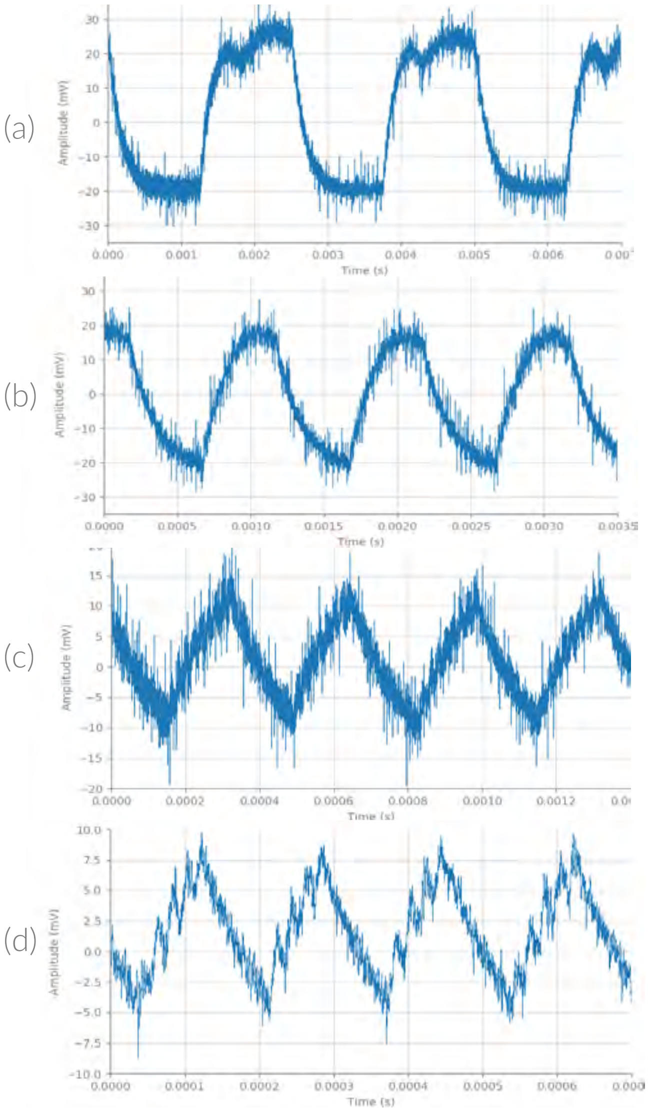


Figure 8 Typical waveform at (a) 400,(b) 1000, (c) 3000, (d) 6000 Hz respectively in low sensitivity mode

The measured peak to peak sensitivity is reported in figure 7 where we can see a constant sensitivity bellow the recommended maximum chopper frequency (400Hz), and a decrease in responsivity beyond, due to the incomplete charge-discharge detection profile, giving a 3dB bandwidth higher than 2.5 kHz and detectible signal up to more than 10 kHz.

In the previous waveform for a 6kHz Gate frequency, the sub modulation at 50kHz is even noticeable on the rising edge of the signal, when the source emits. This point is issued bellow in this section.

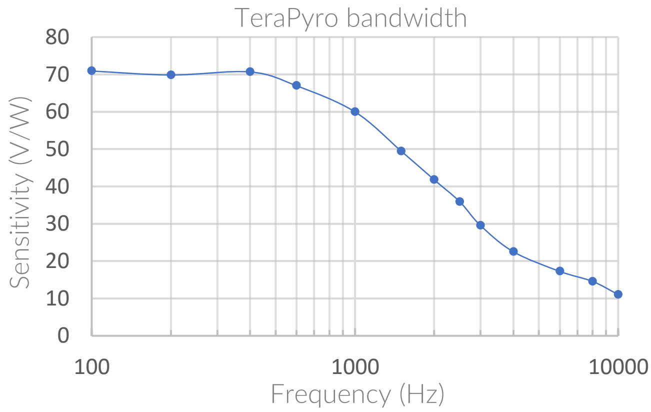


Figure 7 Sensitivity as a function of the gate frequency

Using then more sensitive measurements tools such as spectrum analyzer or lock in amplifiers it is clearly possible to detect signals up to tens of kHz. While Figure 9a and 9b display respectively the gate voltage and the detected time evolution signals, figure 9c represents related spectrum measurement, performed with a spectrum analyzer, for a 5kHz gate modulation with 40kHz pulse frequency. We can clearly identify the gate fundamental frequency and harmonics (odd orders due to the triangular profile of the waveform) as well as the higher frequency pulse fundamental frequency at 40 kHz. Two sideband beating peaks with quite high amplitudes are noticeable at 35 and 45 kHz and originate from the combination of the 7^{th} and 9^{th} order gate harmonics and a frequency beating between the two fundamentals (gate and pulse frequencies).

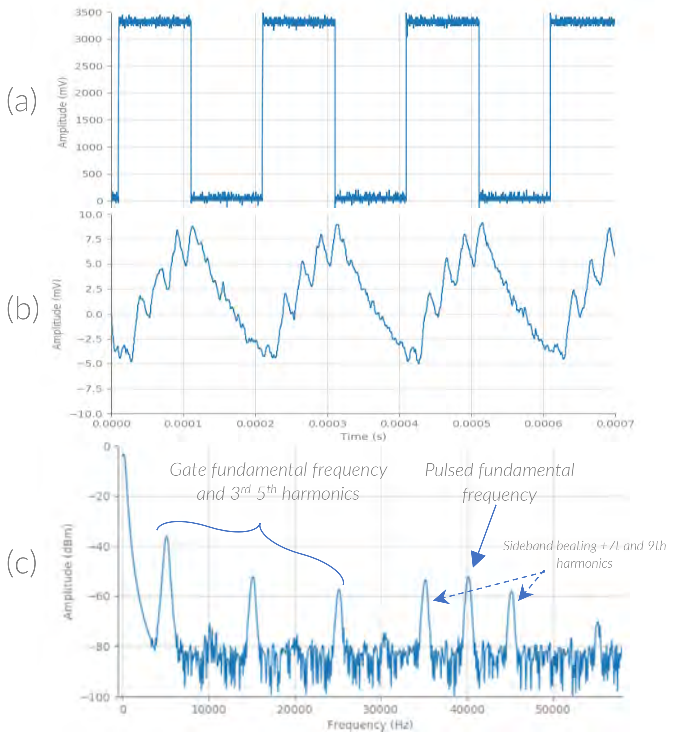


Figure 9 Typical signals for a 5kHz modulation and 40kHz sub modulation: (a) Laser Trigger signal, (b) tera pyro Waveform, (c) related spectrum

An extra filtering step (low pass up to 125kHz) have been performed on the waveform (figure 8b) in order to remove most of the oscilloscope measurement noise and allows a clear visualization of those two components: the combination of the 5kHz main modulation and the high frequency oscillations of the 40kHz sub modulation when the laser is active (rising edge of the triangular signal).

Focusing then on the gate fundamental component, the following powers have been measured at different modulations frequencies and are represented on figure 10 and giving a -3dB bandwidth at 1.1 kHz. The slight difference with the sensitivity bandwidth might be due to the evolution of the signal waveform from a quasi-square signal at low frequencies to quasi-triangular signal due to the incomplete charge-discharge detection signal at high frequencies.

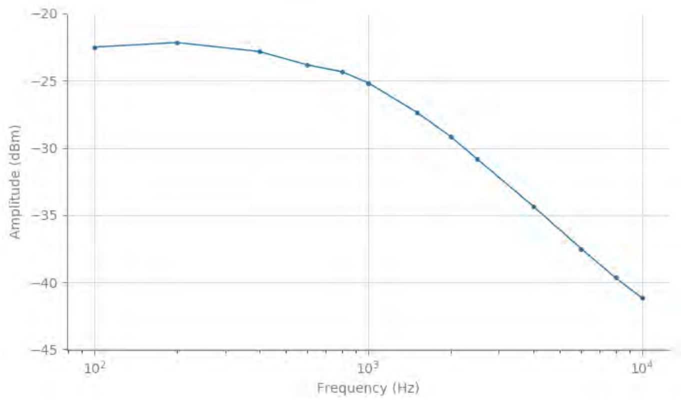


Figure 10 Detected gate fundamental amplitude as a function of the gate frequency

The following table summarizes the different characteristics of the tera pyro sensor for the 3 ranges and especially the recommended modulation frequencies in light of all the elements that have been presented on this application note.

Specifications	TeraPyro		
Sensitivity switch	High	Medium	Low
Sensitivity at 2.5 THz	1.8 kV/W	390 V/W	66 V/W
Rise time	80 ms	10 ms	1.5 ms
Recommended maximum usage frequency	5 Hz	50 Hz	400 Hz -3dB at 2.5 kHz

High-versatility real-time THz imaging system

TeraEyes-HV

Full-field real-time imaging @ 25 FPS

Ultra high resolution down to 250 µm

Multi-spectral THz imaging (2-5THz)

Customizable illumination pattern

1 click optical configuration

Transmission / Reflection imaging

THz Imaging acquisition software

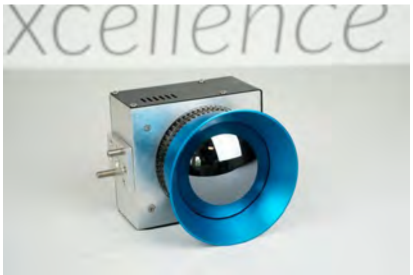
TeraEyes-HV is a high-versatility, real-time THz imaging system, suitable for full-field high resolution applications. Based on Lytid's powerful CW THz source, TeraCascade2000, a multifunctional imaging unit and a focal plane array detection unit, TeraEyes-HV is the ultimate, fully-integrated THz imaging solution. The source provides up to six frequencies in the THz range to satisfy the needs of customer. Integrated auto-alignment module delivers a collimated beam, while providing beam pointing stability after frequency switch. The beam homogenizer included in the imaging unit, ensures a high-quality, homogeneous illumination area, which can be user customized. The detection unit includes an uncooled microbolometer THz camera and TeraLens, Lytid's high resolution optimized THz imaging lens. TeraEyes also includes a programmable secondary output with a collimated beam for multi-spectral raster scan imaging or sensing outlining the system's versatility. Being an user-friendly, plug and play system, all parameters of TeraEyes-HV can be remotely adjusted by the dedicated PC software, allowing customers to focus on their application .

THz QCL source

- Multiple frequencies from 2–5 THz
- mW level output power
- Fully-automated cooling system
- Programmable and remote control

Imaging unit :

- Customizable homogeneous illumination options
- Auto-alignment module for multi-frequency source
- Single Gaussian beam output option



Detection unit

- Uncooled microbolometer cam-era
- TeraLens with adjustable working distance and depth of

Features :

- High resolution (250 µm*)
- Real time imaging (25 fps)
- Homogenous illumination
- Transmission/ reflection mode
- Multiple frequency option with auto-alignment module
- Compact, fully-integrated units
- Automate operation with dedicated software, ease of use

Applications :

- Resolution–demanding imaging
- Real-time & Point-to-point imaging
- Non-Destructive testing
- Quality control
- Tomography & 3D image reconstruction

Specifications	TeraEyes-HV
Source—TeraCascade2000	
Type	THz QCL source
Frequencies (THz)	2.5/2.9/3.2/3.8/4.2/4.7
Output power	2-3 mW typ.
Operation	Fully-automated
Illumination pattern	
Type	-Square, rectangular, linear -gaussian beam
Size	-mm to 8 cm side (OUT1) - collimated or focused (OUT2)
Detection Unit	
Camera Type	Uncooled microbolometer FPA
Pixel Pitch	50 micron
Frame-rate	25 Hz
Detector size	320x240 pixels
THz Objective	TeraLens
Performance	
Resolution	250 µm* in real-time mode
Imaging	Real-time/Raster-scan
Configuration	Transmission/Reflection

* achieved at the frequency of 4.7 THz

PRELIMINARY DATASHEET

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Millimeter Waves & Sub-Terahertz

From 1GHz to 1 THz / From 300mm to 300um

Sub-Terahertz sources

Sub-Terahertz components

Sub-Terahertz sensors

Sub-Terahertz source

TeraSchottky

Ultra compact, reliable sub-Terahertz source

High power with up to hundreds of mW

Frequency extensions up to 600 GHz+

Fast frequency switching speed

Lightweight : only 800g

Broad tunable range

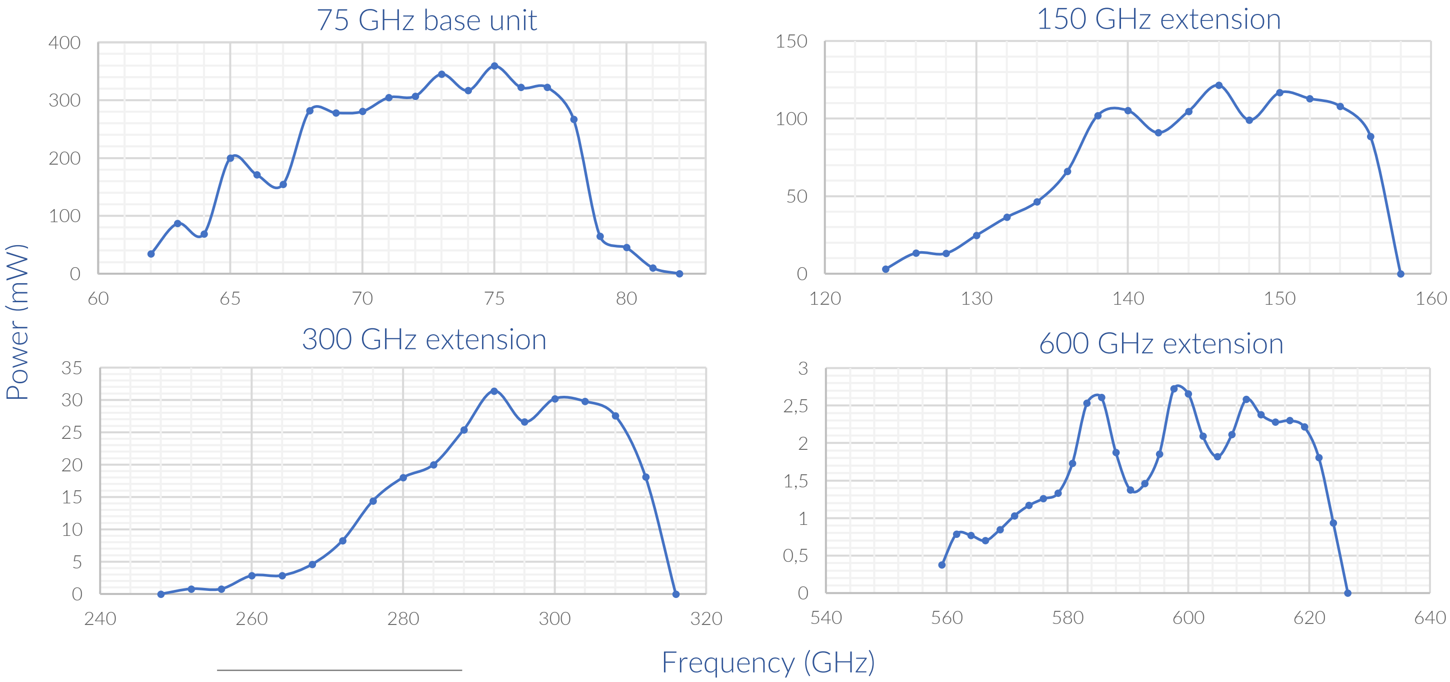
100% Plug & Play

The TeraSchottky is a low frequency THz source based on state-of-the-art Schottky diodes multipliers chains. The base unit is available at 75GHz and frequency extension at 150, 300 and 600GHz are available for upgrade. With up to hundreds of mW of average output power, TeraSchottky provides the best compromise between tunability and output power on the market for multiplier-based sources. TeraSchottky is a fully integrated, plug and play system and remotely controlled via a userfriendly software for the best user experience. Derived from European space programs, TeraSchottky guarantees maximum reliability. Lytid's award winning approach to the design of terahertz sources is once again the driving spirit behind TeraSchottky.

Control:
- ✓ Remote with dedicated software via USB

Connectivity:
- ✓ TRIGGER: SMA with CMOS 3.3 V level
- ✓ 12 V Power supply

Typical performances:



Features:

- Up to hundreds of mW of output power
- Very broad tunable range
- Fast frequency switching
- Easy configuration with the dedicated software
- Fully programmable frequency sweeps, pulse and FM modulations
- Fully integrated & plug and play
- External trigger for: lock-in amplifier, THz cameras, slave mode

Applications:

- High penetration THz imaging
- Detector characterization
- High resolution THz spectroscopy

Specifications	TeraSchottky
Output data	
Operation	CW / ext. trigger
Modulation frequency	Max. 5 kHz
Frequency switching	4 ms
Tunability	>12%
Control	Remote USB
Power supply and operating parameters	
Voltage	12 V
Temperature range	15 – 25 °C
Power consumption	< 50 W
Dimension and weight	
Height	55 mm
Width	130 mm
Length	110 mm
Weight	800 g

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Lytid
Empower your application

Schottky-diode based radar system

Sub-THz FMCW Radar transceiver

Ultra compact, reliable sub-THz radar transceiver for NDT applications

High dynamic range up to 100 dB, high measurement rate of 7.6 kHz

High spatial resolution up to 2 mm, positioning accuracy ±5 μm

Integrated ultra-stable linear hybrid-digital PLL

Integrated FPGA-based signal pre-processing

Refractive index extraction algorithm

Monostatic architecture

The FMCW radar transceiver is a sub-THz device based on state-of-the-art Schottky diode technology. Being a FMCW radar (frequency-modulated continuous-wave), it provides both amplitude and phase information contained in reflected signals along with a longitudinal profile, making it an excellent candidate for in-depth sensing. NDT radar has a remarkable dynamic range up to 100 dB, allowing to inspect various geometries from thick samples to absorbent materials. In addition, the high measurement rate (7.6 kHz) of NDT radar matches on-line quality control requirements for industries, ensuring optimal capabilities. Specifically, tailored imaging module options, scanning kits and dedicated signal processing software, are also available to suit specific applications. NDT radar is a fully integrated, plug and play system and remotely controlled via a user-friendly software, guarantying the best user experience. The combination between excellent penetrating and high imaging resolution achieved by NDT radar makes it a versatile sensing tool.

Control:
- ✓ Remote with dedicated software via USB

Connectivity:
- ✓ Power supply: 100-240 V AC
- ✓ Ethernet link

Features :
- Compact & reliable FMCW transceiver
- Up to 100 dB dynamics
- Fast measurement rate of 7.6 KHz
- 2 mm spatial resolution in air
- Fully integrated, plug & play
- Custom imaging & scanning modules
- Advanced signal processing software

Applications :
- In-depth sensing for dielectric materials (Polymers, woods, ceramics, papers, composites, foods, rubber..)
- Volumetric imaging for quality control (Packing inspection, welding defect…)
- Contactless thickness measurement
- Precision positioning
- Material analysis
- Security screening

Specifications	FMCW radar transceiver	
Transceiver	Monostatic	
Operation mode	FMCW	
Frequency band	150 GHz	
Dynamic range	Up to 100 dB	
Measurement rate	7.6 KHz	
Positioning precision	< 5 µm	
Control	Remote USB	
Power supply	100-240 V AC	
Temperature range	0– 40 °C	
Dimension and weight		
H x L x W	25 cm x 25 cm x 10 cm	
Weight	3 Kg	
Extensions		
3D imaging		
Operation mode	Translation stages / robotic arm	
Software	Data visualisation, data processing	
Optics (THz lenses)	2'' f= 5 cm	2''f=10 cm
Spatial resolution X/Y	2 mm	4 mm
Thickness measurement		
Thickness range	Sub-mm up to tens of cm	
Accuracy	±5 µm	

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Published March 2022

Empower your application

Sub-Terahertz components

High-power high-bandwidth multipliers

Based on planar GaAs Schottky diodes

High-power components

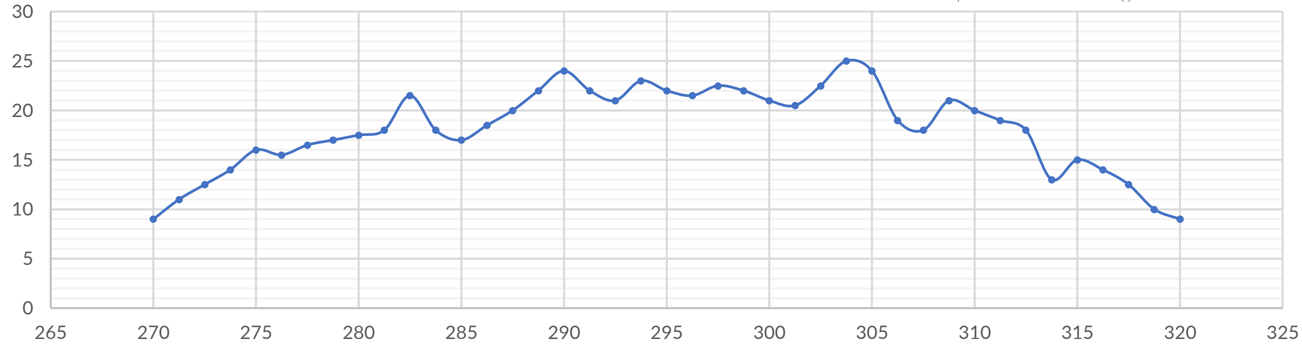
High bandwidth >12%

300 GHz and 600 GHz

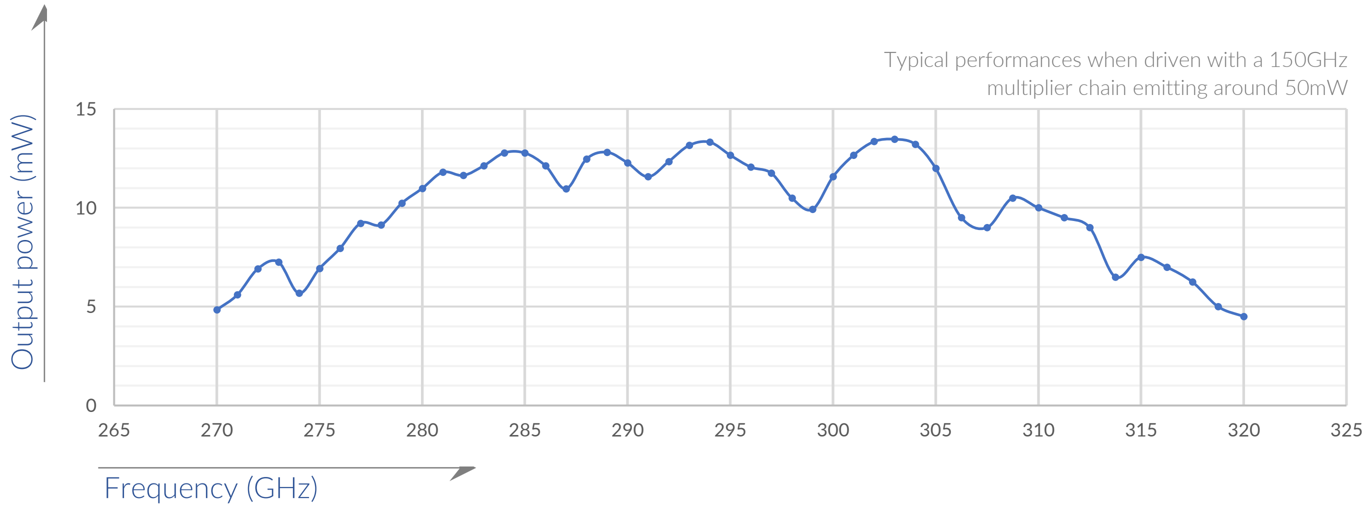
Lytid's range of high power frequency multipliers provide state-of-the-art performances across the sub-terahertz band. These frequency doublers are commonly used to extend the frequency range of microwave and mmW sources towards higher frequencies. The doublers are based on planar GaAs Schottky diode technology derived from European Space Programs. The frequency coverage of more than 12% of the central frequency and the conversion efficiencies are unmatched on the market. These cutting edge sub-terahertz components will help you extend your current setup by providing unparalleled performances and possibilities.

300 GHz doubler

Typical performances when driven with a 150GHz multiplier chain emitting around 100mW



Typical performances when driven with a 150GHz multiplier chain emitting around 50mW



Features:

- Fullband operation
- Planar GaAs Schottky diode technology
- No mechanical tuners
- Bias required for optimum performances

Applications:

- Frequency extension of microwave and mmW sources
- Detector characterization in the sub-THz range
- High spectral purity spectroscopy

Technical specifications	300GHz doubler
Electrical data	
Bias	3-6V DC typ.
Connector	SMA
Input port data	
Frequency	135 – 160 GHz
Port	WR6.5 (UG387/UM)
Power	<100mW
Output port data	
Frequency	270 – 320 GHz
Port	WR3.4(UG387/UM)
Power	Typ. up to 25mW
Performances	
Conversion Efficiency	25%

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Lytid
Empower your application

Sub-Terahertz components

High-power high-bandwidth multipliers

Based on planar GaAs Schottky diodes

High-power components

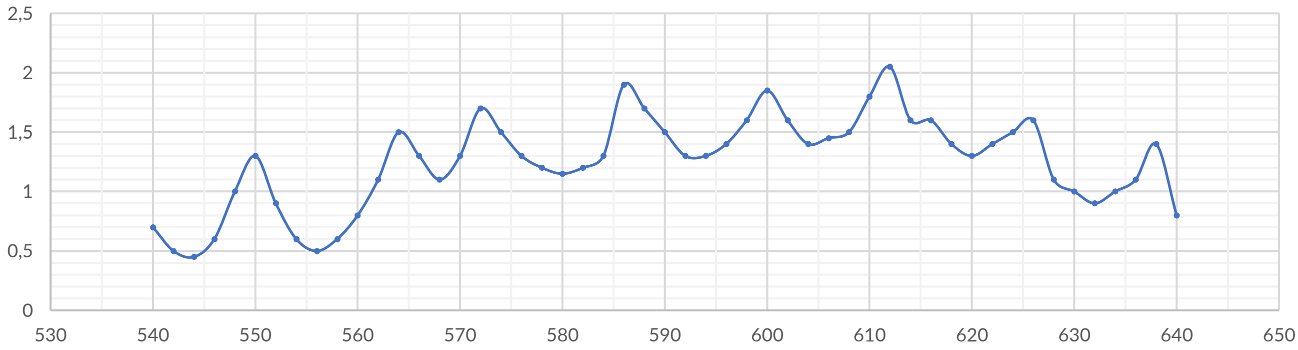
High bandwidth >12%

300 GHz and 600 GHz

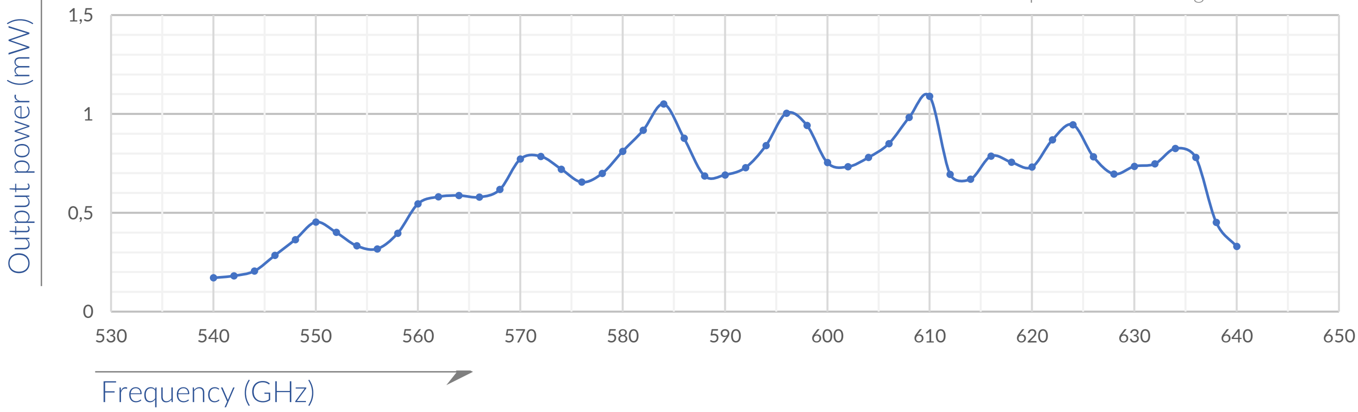
Lytid's range of high power frequency multipliers provide state-of-the-art performances across the sub-terahertz band. These frequency doublers are commonly used to extend the frequency range of microwave and mmW sources towards higher frequencies. The doublers are based on planar GaAs Schottky diode technology derived from European Space Programs. The frequency coverage of more than 12% of the central frequency and the conversion efficiencies are unmatched on the market. These cutting edge sub-terahertz components will help you extend your current setup by providing unparalleled performances and possibilities.

600 GHz doubler

Typical performances when driven with a 300GHz multiplier chain emitting around 20mW



Typical performances when driven with a 300GHz multiplier chain emitting around 10mW



Features:

- Fullband operation
- Planar GaAs Schottky diode technology
- No mechanical tuners
- Bias required for optimum performances

Technical specifications	600GHz doubler
Electrical data	
Bias	3-6V DC typ.
Connector	SMA
Input port data	
Frequency	270 – 320 GHz
Port	WR3.4(UG387/UM)
Power	<25mW
Output port data	
Frequency	540 - 640 GHz
Port	WR1.5(UG387/UM)
Power	Typ. up to 2mW
Performances	
Conversion Efficiency	10%

Applications:

- Frequency extension of microwave and mmW sources
- Detector characterization in the sub-THz range
- High spectral purity spectroscopy

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Infrared

SWIR camera

Boston Electronics

Lytid

Deep-cooled scientific SWIR camera

SIRIS

InGaAs sensor FPA 640x512, 0.9- 1.7 µm

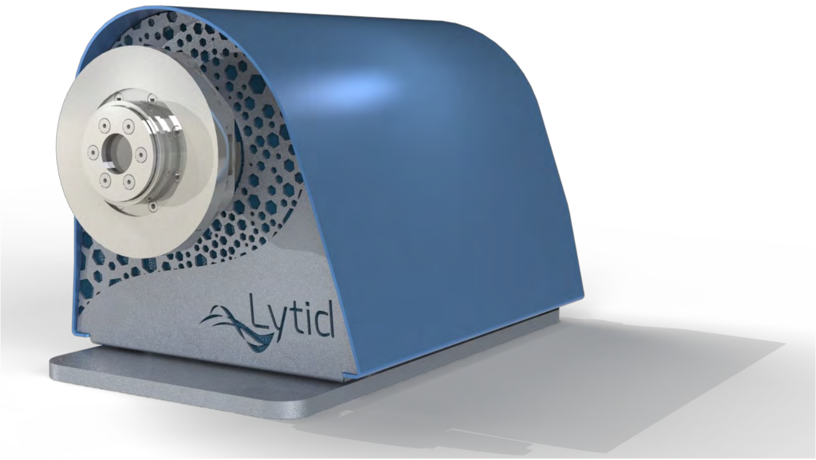
Ultra-high dynamic in lin/log mode, > 120 dB

Vibration-free cryogenic-free cryocooler down to 50 K

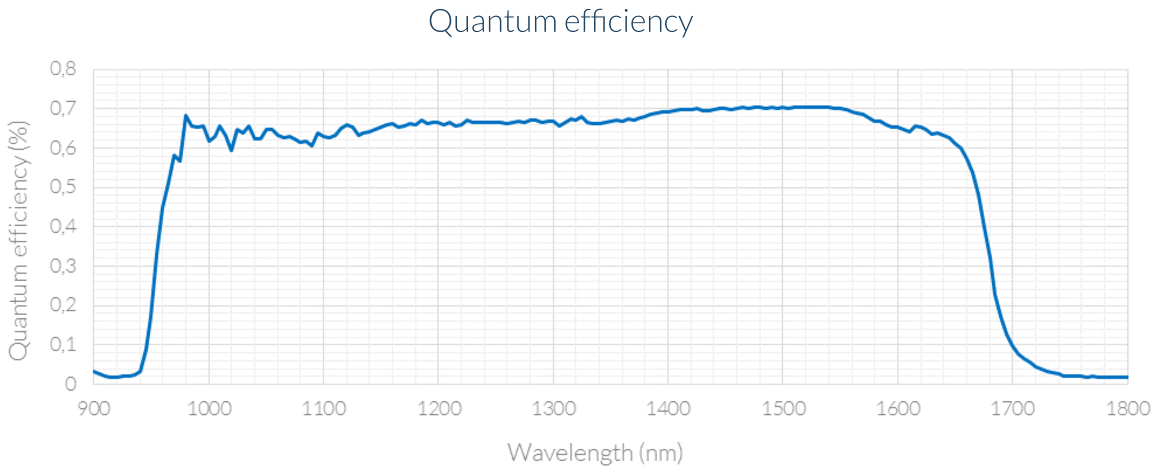
Ultra-low Read-Out Noise < 10e-

Ultra-low dark current

200 fps full frame



The **SIRIS** (**S**hort-wave **I**nfra**R**ed **I**maging **S**ystem) is the most versatile SWIR camera on the market, providing high speed with ultra low noise performances. **SIRIS** provides two read-out modes, full linear and linear/logarithmic, that combines with non-destructive read-out (NDRO) allows for class-leading dynamic range. Three adjustable gain levels ensure flexibility to suit broad variety of illumination conditions. Long exposure time up to one hour is achievable, and selectable region-of-interest on the detector allows exceptional frame rate values. **SIRIS** camera is ready to be used in a few minutes thanks to a closed cycle vibration-free maintenance-free space-qualified cryogenic –free cooler. Standard connectivity is available through a full speed Camera-link data interface and C-mount optics. Thanks to its high-edge performances, **SIRIS** is the perfect tool for ambitious scientific applications, such as astrophysical observations, hyper-spectral and biological imaging, spectroscopy and semiconductor failure detection.



Features :

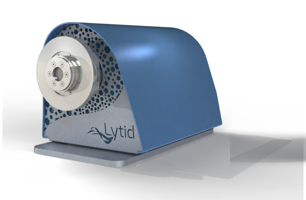
- Vibration-free cryogenic– free cooler
- > 10 000 FPS in ROI mode
- Three pixel-gain levels

Applications :

- Astrophysical observations
- Semiconductor Failure Analysis
- Medical imaging, including microscopy (cellular, fluorescence)
- Spectroscopy
- Hyper spectral imaging

Options :

- HDR mode
- Bandpass filters



Specifications	SIRIS
Detector	
Type	InGaAs
Resolution	640 x 512
Spectral Response	0.9 – 1.7 µm
Pixel size	15 µm
Dual-mode sensor	CTIA-linear Lin/Log
Performance	
Dark signal	<10e-/s @ 150 K
Gain	3 pixel-gain levels
Read-out modes	Standard & NDRO
Read-out-Noise	<50e- lin mode, high gain <10e- NDRO
Well depth	300ke-, lin mod, low gain
Dynamics	>120dB, lin/log
Digitization	16-bit
Shutter	Global & NDRO
Region-of-interest	ROI on detector, configurable
Frame-rate	200 fps full frame > 10 000 fps with ROI
Exposure time	From 1 µs to 1h
Trigger	Trig. In and Out (to 10ns)
Software	Camera link
Cooling	300 K– 50 K, cryocooler
Accessory	C-mount

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Optics

From 1 GHz to more than 10 THz / From 300mm to less than 30um

Terahertz optics

Camera lens

Optical Modules

Terahertz camera Lens

TeraLens

A high-performance solution for real-time camera THz imaging

Focus ring and depth of field control through iris aperture

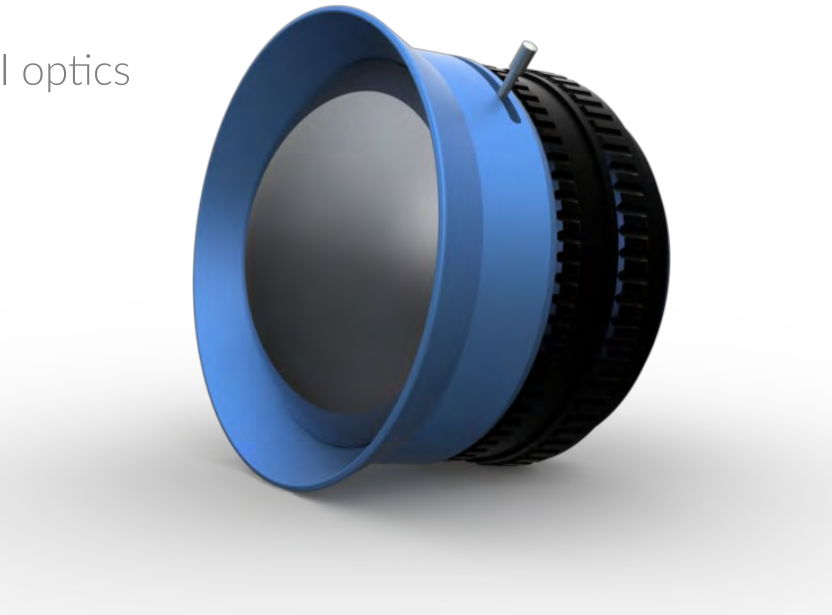
High numerical aperture for optimum power collection

High quality HRFZ-Si THz aspherical optics

Broad spectral range (0.1 to 5THz)

High quality parylene AR coatings

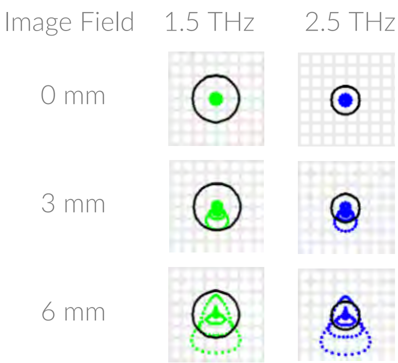
Focal length 40mm



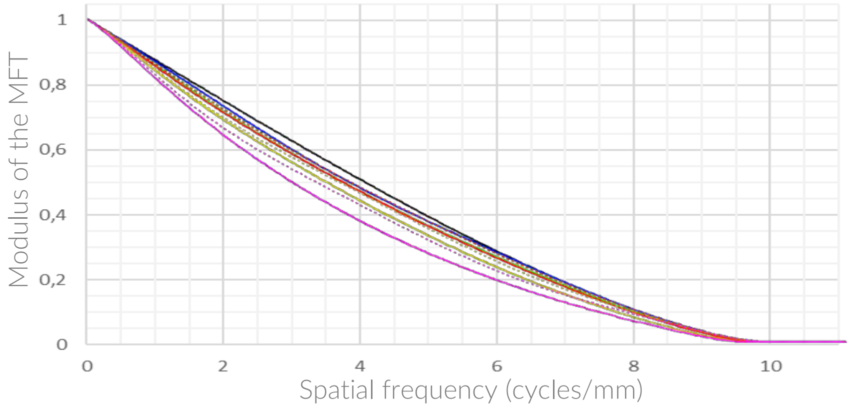
The TeraLens is an optimized aspherical solution for real time THz imaging using dedicated camera sensors. Its low f/0.83 ensures an optimum power collection while the low distortion level and low vignetting provide high quality imaging. The constant optical index of HRFZ-Si makes it suitable for a broad spectral range (from 0.1 up to 5THz) and ensures diffraction limited imaging up to 4 THz thanks to the aspherical design. Customized AR coatings, tailored to your specific application, will guarantee excellent power transmission. A focusing ring allows to obtain sharp images from 13 cm to 50 cm with an optimum working distance of 20 cm. A variable aperture allows to increase the depth of field. The imaging field is 55 mm at 20 cm working distance for a 12mm sensor. The mechanical assembly, either through an adaptation mount for camera modules, or through a standard optical post assembly makes it a versatile and simple to use camera lens.

40mm - f/0.83 - x0.22

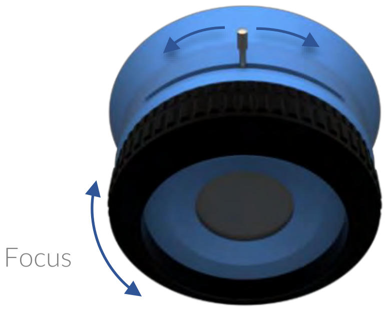
Spot diagrams



Optical MTF at 2.5 THz for 0 to 6 mm image fields



Iris aperture control



Features:

- High collection power
- Anti-reflective coated surfaces
- High quality, aspherical, diffraction limited optics
- Low distortion and vignetting
- Focusing ring and aperture control
- Available camera adaptation ring and optical post assembly mount

Applications:

- High resolution, real time THz imaging
- Nondestructive testing
- 3D profiling and objects reconstruction
- Camera sensors characterizations

Specifications	TeraLens
Optical data	
Frequency range	From 0.1 to 5 THz
Wavelength	From 3000 to 60 µm
Focal length	40.8 mm
Working f-number	0.83
Optimum working distance	20 cm
Magnification	x0.22
Object field dimension	55mm (12mm sensor)
Depth of field	1.75mm
Optical distortion	<1.3%
Vignetting	<10%
Frequency at 10% MFT	8 cycles/mm
Frequency at 10% MFT Full field	7.4 cycles/mm
Options	
Adapter ring	✓
Optical post assembly mount	✓
Dimension and weight	
Diameter	95 mm
Length	59-73 mm
Weight	<450 g

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