MULTIFUNCTION LASER SOURCE FOR GROUND AND AIRBORNE APPLICATIONS

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ABSTRACT

Multiple ground and airborne vehicles could share common and multifunctional laser modules. The host system constraints and requirements have similarities making a laser modular concept interesting. Among the desired functions, the core ones are the designation and the rangefinding capabilities. A diode pumped laser source at 1µm with a switchable OPO stage for wavelength conversion fully satisfies the designation and rangefinding tasks.
Over the last years, CILAS has developed the key technologies for the improvement of the main system parameters with the imperative constraints to be International Traffic in Arm Regulations Free (ITAR Free). Particularly, this novel architecture avoids thermo electric cooler (TEC) generally used to stabilise the wavelength of the laser diode pump source within the entire operational thermal range.

Keywords: Active imaging, CILAS, Designation, Diode-pumped laser, Rangefinding,

1. INTRODUCTION

Since is discovering, laser is involved in lots of military platforms and for very different applications or functions. Some of them such as rangefinding were soon generalized on all platforms and are still used nowadays. Others, such as guiding munitions designation, were used by elites and for specific missions. There is a clear tendency to democratization of laser function while customer asks for smart price. Except for US market, the required quantities for each function are always in the range of 10 or multiple of and do not allow benefiting of large quantity effect. One of the solution to overcome this problem is to offer a standard product dedicated to cover most of the requirements.
We propose here firstly, to recall the main operational requirements, secondly to summarize the technology drivers and thirsty to present the performances obtained.

2. OPERATIONAL REQUIREMENTS

Laser technologies are now widely used on military platforms for very diverse functions including detection, identification, surveillance, protection, targeting, damaging.
We propose in this first paragraph to summarize the main functions fulfilled by available laser sources regarding military platforms groups.

- The eye-safe laser rangefinding is a highly accurate, hardened system for the fire control sight. The laser system gives the gunner the ability to determine target ranges in all battlefield conditions. The laser shall emits at a wavelength between 1,4 µm and 1,7 µm. CILAS has manufactured many military rangefinder through the last 20 years for armored vehicle, fighting aircraft, fighting helicopter (mounted in HOT sight for viviane gazelle, STRIX and OSIRIS sight for tiger helicopter)
- The target laser designator provide targeting for laser guided bombs, missiles, or precision artillery munitions, such as the MBDA/Matra Baé dynamics or Paveway series of bombs, Lockheed-Martin's Hellfire, Sagem's AASM, Krasnopol, Copperhead…
  The laser designator places coded laser energy on stationary or moving targets. Reflected coded laser energy provides guidance information for terminal homing munitions. CILAS has a strong experience in airborne targeting, providing the designator mounted in ATLIS pod and for ground designation with the DHY307.

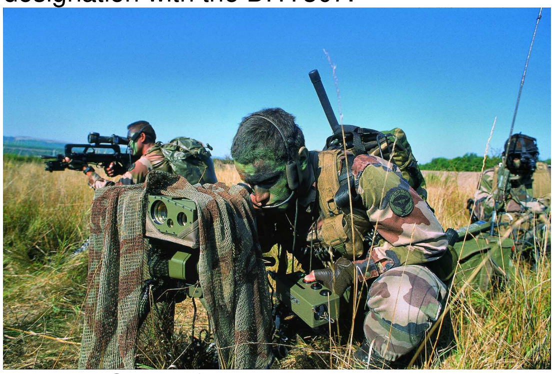

Figure 1: Special forces using ground target designator DHY307 (CILAS product)

- The pointing provides illumination capabilities for target marking visible with night vision devices
- Active imaging for ID (identification) provides 2D or 3D gated images very useful for locating

and identifying objects in all weather conditions. The spatial resolution is enhanced compared to thermal infrared passive imaging.

- Optical sight detection is based on the cat'eye effects: when illuminated by a laser beam, an optical system returns some back-scattered energy. SLD400 and SLD500 provided by CILAS adresse this application.

Figure 2: SLD500 used as a remote display unit for sniper detection from a VAB (CILAS product)

- Laser dazzling consists in irradiating an enemy with light of sufficient power to disrupt its ability to aim at a given target.
- Laser decoy is a technique used to defeat weapons involving target designators. It essentially consists in creating a false target away from the vehicle.

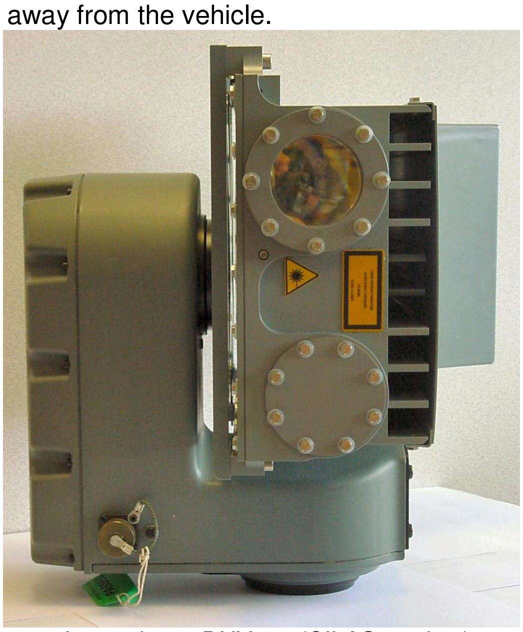

Figure 3: Laser decoy DHY322 (CILAS product) mounted on wasp turret for naval platform protection

- Missile counter measure such as laser jamming uses a laser to blind the infrared sensor of the man-portable surface-to-air missiles.

  CILAS has recently tested a demonstration prototype that fulfills all jamming requirements

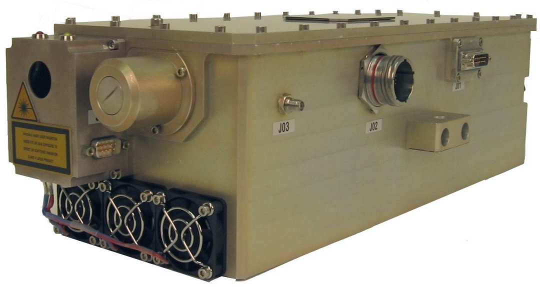

Figure 4: Mid Infrared Laser source for DIRCM application (CILAS product)

- Obstacle detection: One of the major challenges in designing intelligent vehicles capable of autonomous travel on highways is reliable obstacle detection. Laser range scanners, or ladars, have been used for many years for obstacle detection. Laser scanners operate by sweeping a laser across a scene and at each angle, measuring the range and returned intensity.
- See mine detection use a laser imaging system to detect, classify and localize floating and near-surface moored mines using blue/green wavelength
- Biological and chemical agent detection by laser (LIDAR): a short laser pulse is transmitted through the atmosphere, and then a portion of that radiation is reflected back from a distant target or from atmospheric particles such as molecules, aerosols, clouds, or dust. The laser emits in the IR or UV bands.
- Optical damaging: This application requires high level of energy to damage the optics or the sensors of any Optronics system.

The typical functions for each platform are analyzed in Table 3 of annex 1.

The most important and common functions across both airborne and ground platforms are the ability to perform eye-safe rangefinding and to designate targets. These core functions must be addressed.
Others functions such as active imaging, pointing, missile countermeasure, optical sight detection, biological and chemical detection receive medium priorities. Some can be considered as additional functionalities of the core functions. Active imaging, optical sight detection, laser decoy and pointing belong to that category. Some others require specific performances. Missile countermeasure requires laser in the 3 µm to 5 µm IR bands with high repetition rate (several tens of kHz) while

biological and chemical detection required laser in the UV and IR bands with high spectral quality.
Optical damaging, optical dazzling, mine detection, obstacle detection receive the lowest priority.
Operational requirements showed strong similarities between rangefinding, designation, optical counter measure and flash imaging such as wavelength, repetition rate, divergence, volume, thermal operational range.

3. FUNCTIONAL ARCHITECTURE AND TECHNOLOGY DRIVERS

Laser crystals:
The designation has to be done at 1064 nm and at specific repetition rates (such as STANAG 3733) between 8 to 22 Hz. The required wavelength is set by the infrared detector and the accurate optical filter in the semi active seeker of the guided munitions. The choice of this wavelength, done in the 70' during Vietnam War, would be discussed regarding eye-safe issue and atmospheric transmission. However, the retrofit of all the guided munitions through the world is a serious obstacle for such an up grade.
There is a few kind of host material lasing close to 1064 nm.
Yttrium Aluminum Garnet (YAG) has emerged as the most widely produced laser gain host. The YAG host is a stable compound, mechanically robust, physically hard, optically isotropic, and transparent from below 300 nm to beyond 4 µm. YAG single crystals are able to accept trivalent laser activator ions from both the rare earth and transition metal groups, and can be grown with very low strain.
Vanadate crystals have been known for a long time but became popular only many years later, because for a long period it was difficult to grow them with high optical quality in sufficiently large size. Apart from progress in crystal growth, the advent of diode pumping increased the interest in vanadate also because smaller crystals could be used. Nd:YVO_4 is one of the most popular vanadate crystals. Its large stimulated emission cross-section at lasing wavelength, high absorption coefficient and wide absorption bandwidth at pump wavelength, high laser induced damage threshold as well as good physical, optical and mechanical properties make Nd:YVO_4 an excellent crystal for cost-effective diode pumped solid-state lasers. However, as its thermal conductivity is very low, thermally induced stresses as well as thermal lensing can be very serious in high power operation. Compared with Nd:YVO_4, Nd:$GdVO_4$ has a similar thermal conductivity, a slightly shorter emission wavelength (1063 nm), a somewhat larger gain bandwidth, lower emission cross sections, and still higher pump absorption. Note, however, that the published data concerning thermal conductivity of vanadate crystals differ considerably, so there are some significant uncertainties. The following table summarizes the main properties of the Nd:YAG, the Nd :YVO_4 and the Nd:$GdVO_4$ (see [7]):

Parameters for 1.1 atm%,	Nd :YAG	Nd :YVO4 p pol	Nd:GdVO4 p pol.
Lasing wavelength (nm)	1064.2	1064.3	1062.9
Absorption bandwidth (nm)	10	31	
Absorption coefficient at peak (cm^{-1})	7.1	31,4	74
Fluorescence lifetime (µs)	230	90	90
Effective emission cross section (cm^2)	2,3 · 10-19	11 · 10-19	7,6 · 10-19
Thermal Conductivity Coefficient (W/cm/K)	14	5	8 to12

Table 1: Comparison of the Nd:YAG, the Nd :YVO_4 and the Nd:$GdVO_4$

For Q-switched lasers, Nd:YVO_4 does not allow for pulse energies as high as for Nd:YAG, because its capability for energy storage is lower than that of Nd:YAG due to the lower upper-state lifetime and the high gain efficiency. On the other hand, Nd:YVO_4 is better suited for high pulse repetition rates, where it still allows the generation of fairly short Q-switched pulses.

Master oscillator power amplifier configuration :
Longer is the expected designation range, higher is the output energy and lower is the output divergence. Fortunately, airborne targeting pod that require long designation capability have also bigger output aperture than portable system. On the over hand, output energy shall be adapted to each platforms. A master power oscillator and amplifier (MOPA) permits to address each energy requirements by providing better flexibility for energy sharing.
Output energy bellows 90 mJ are dedicated to portable designator and fighting armored vehicle.
Medium output energy between 100 mJ to 150 mJ for fighting UAV and helicopter.
High output energy (150 mJ to 300 mJ) for fighting aircraft.

Pumping configuration and cooling:
Two major technologies are available to optically pump the amplifier media: Flash pumping and diode pumping.
Flash lamp is a cheaper component than laser diode but requires liquid cooling for continuous

operation or for repetition rate higher than 10 Hz. Diode pumping has a triple advantage:

- o Compactness : 1 kW are currently available in a stack of bars of 2 mmx10 mmx20 mm
- o Electrical to optical efficiency: Close to 55 %
- o Less thermal load in the amplifier medium.

Moreover, the laser diodes offer more flexibility for arrangement with the laser crystal and many configurations have been studied in order to optimize both the beam quality and the optical to optical efficiency. Usually, the diode modules are mounted on a heat sink coupled to a thermoelectric cooler (TEC). The aim of the TEC is to stabilize the temperature of the laser diodes because the spectral characteristics of the pump beam are a function of the temperature (around 0,3 nm/°C). For efficient matching of the pump beam and the laser media, the temperature of the laser diodes bars shall be usually controlled at ±3 °C. The heatsink is used to extract and dissipate the thermal load. This kind of architecture has a dramatic impact on the power consumption of the laser source. The integration of the TEC introduces globally more thermal load than one expects to remove locally. As a rule of thumbs, the TEC usually consumes twice the thermal load to remove in the operational thermal range.

For avoiding this drawback, CILAS has developed an athermal scheme [1] allowing spectral drift of the pump while keeping constant absorption in the host crystal. The principle used is very simple: The pumping arrangement is designed for maximizing the absorption length. When the spectral emission coincides with the peak absorption, the absorption length is reduced. When the spectral emission moved, the absorption length increases but the mode matching is preserved. With this design, up to 200 mJ are demonstrated with a beam quality factor less than 3, without thermal stabilisation of the laser diode modules over a wild range of temperature.

Wavelength conversion for eye-safe:

Optical Parametric Oscillator (OPO) have been used generally to convert from 1064 nm laser to the eye-safe region, but this process is not the only one. Raman shifting in solid or in gas could also be an option with several advantages: The Raman process is a third order non linear process and do not require phase matched condition. As a consequence, this process is less sensitive to thermal variations or angular misalignments. Brillouin scattering is well-known to limit the efficiency of such a process and can either produce optical damage but CILAS has demonstrated [2] that in contrary and under specific conditions, this effect can enhanced the efficiency and clean the pump beam. The methane is the most popular gas for 1,54 µm generation while the $Ba(NO_3)_2$ crystal is generally preferred for all solid solution. For rangefinding application, these solutions begin to disappear gradually because but high pressure chamber are bulky and costly to industrialize and Raman shifting in solid crystal required laser pump at 1320 nm. As OPO crystals of high quality are now available, OPOs are generally preferred as very compact solution compatible with 1064nm pump beam. Thirty percent conversion efficiencies of Nd:YAG at 1064 nm laser radiation into eye-safe region (at 1.57 µm) is obtained today in 20 mm OPO with KT_iOPO_4 (KTP) crystals even with highly multimode pump lasers. High beam quality OPO conversion (bellow 20 mmxmrad) has been demonstrated in a reasonable size cavity (60 to 80 mm). Short OPO cavities are compact and efficient but result in a low brightness OPO laser output: As the Fresnel number of the cavity is very high, the divergence is increasing. In that case, beam quality of more than 30 mm.mrad has been demonstrated in a 30 mm length cavity.

The choice of the OPO crystal is a critical issue as it determines the performances of the conversion process. The usual criteria of choice are the followings:

- o Wavelength at non critical phase matching (NCPM) condition/ atmospherical transmission
- o High d_{eff} (effective non linear coefficient)
- o High crystal quality
- o High damage threshold
- o Stable properties under wide temperature range (-40 °C to +70 °C)
- o Mass production, cost

Potassium titanyl phosphate (KTP) and its isomorphs (KTA, RTP, RTA…) have received enormous attention in the last 2 decades since this crystal responds to most of those criteria's recalled.

The following table summarizes the characteristics of those crystals ([3] to [7]):

Parameters given for pumping at 1064nm in non critical phase matching conditions (NCPM)	**KTP**	**KTA**	**RTP**	**RTA**
λ_{signal} (nm)	1572	1534	1616	1610
λ_{idler} (nm)	3292	3476	3115	3137
d_{eff} (pm/V)	3,6[5]	3,2[3]	2,6[5]	3,4[3]
Damage Threshold (MW/cm²)	600	600	600	600
Atmospherical transmission (%/km)	89%	88%	90%	90%
Cost/quality	🙂	🙂	🙁	🙁

Table 2: Relevant characteristics for KTP crystal and

isomorphs for rangefinding application

OPOs based on KTP and its isomorphs under non NCPM schemes have the advantage of high transmission at pump and signal wavelength, a large acceptance angle, large effective non linear coefficient, no walk off and being applicable for multimode pumping beam. Among those crystals, KTP is generally preferred because more widely marketed and less expensive.

KTA and RTA have very similar properties to KTP with a much higher transmission to 4 µm without loss. That characteristic is useful for high repetition rate. RTP has a several orders of magnitude higher electrical resistivity and, therefore, no signs of electrochromism when used as Pockels cell.

Optical switch:

The optical switch allows the wavelength selection output at 1,06 µm or at 1,5 µm. The major constraints of this subsystem are:

- 1,5 µm laser beam to 1,06 µm laser beam coboresight less than half of the divergence of designation function
- Switching time bellow 1 s
- Compactness
- Compatible with vacuum level for avoiding pollution of the laser component

CILAS a developed electromechanical device fully compliant with this requirement. Some are based on polarized selection beam: Depending on the switch selection a half wave plate intercepts the beam or not. Coupled to a polarizer, the pump beam is injected in the OPO stage or emitted out of the laser transmitter. Thanks to the low weight and low misalignment sensitivity of the half wave plate, the optical component is easily displaced.

Rangefinding detector:

The top priority of this function is to provide high sensitivity particularly at 1,5 µm where the energy of the laser is the lower one. Receiver detectors may be common across applications and platforms, and can be optically remote upon request. Photodiodes PIN InGaAs, APD Ge, APD InGaAs are available for many years with high level of performances and reliability. This component shall be highly selected as is not the cost driver but equally participates in the performances of the rangefinding function with the laser transmitter (very more complex and costly). Diameter of this component varies from 50 µm to 300 µm. Avalanche photodiodes (APD) gives better performances than PIN ones. The sensitivity is increased by a factor 10 or more even if APD requires a bias voltage close to 100 V. NEP between 5 nW to 100 nW were demonstrated depending of the chosen technology.

Active imaging detector:

Recent developments on gated Focal Plane Array (FPA) detector technology are very promising for 2D or 3D active imaging. HgCdTe (Mercury Cadmium Telluride / MCT) is a suitable material because offering dual mode capability: Active imaging at 1,5 µm (SWIR band) and passive imaging in the MWIR band. For low flux application, the sensibility can be improved using MCT Avalanche Photodiodes Detector (APD). It has been demonstrated that an avalanche gain higher than 500 could be obtained on such detectors biased with 10 Volts without increasing the noise factor F (close to 1) up to this bias voltage. Moreover the spectral and spatial response of detector is unchanged in this operating regime.

Coupling to a 1,5µm laser of 35 mJ, this type of detector provide recognition and identification capability in a wide range of bad weather conditions for multi kilometers range.

4. PERFORMANCE OBTAINED AND FINAL ARCHITECTURE

The Figure 7 shows the functional diagram of the multifunction laser for ground and airborne application. Laser sub emitter and electrical modules are selected as required to enable laser designation, eye-safe rangefinding (and optical imaging as an option). An infrared laser pointer module is integrated in the output channel. Components off the shelf (COTS) are now available to provide laser emission with compatible beam quality up to 1 W and more.

The final beam shaper or expander, the electric and mechanical interfaces will be designed upon request. Depending on the firing sequence duration (burst mode or continuous operation), the thermal hardware (heatsink) is sized accordingly.

As explained before, the designation requirement drives the 1064 nm output energy, repetition rate, thermal hardware and divergence. The architecture is based on the association of an oscillator and an amplifier that respectively provide 80 mJ and 150 mJ output energy without TEC for diode wavelengths stabilisation. The same pumping head (diodes modules+ laser rod) is used for the oscillator and the amplifier. High communality is then achieved. Higher energy can be obtained by adding a second amplifier but is considered as an extended option. The natural divergence of the output beam is less than 1 mrad but shall to be reduced to 200 µrad at system output. With athermal scheme, the laser system do not need usual “warm up time” and is ready for firing immediately after power-on.

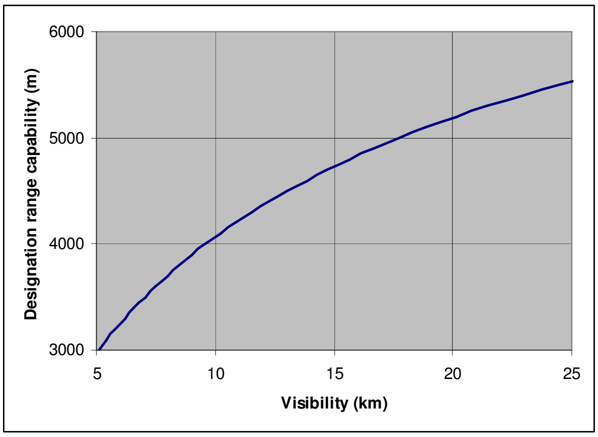

Figure 5: Designation range capability function of the atmospherical visibility (NATO target, munition and designator at same distance from the target)

Eye-safe ranging function implies no laser safety hazard at the output apertures of the laser system leading to class 1 or Nominal Ocular Hazard Distance (NOHD) of 0 (depending of the customer requirements). Class 1 is the most stringent requirement and limits the output energy to 8 mJ. NOHD of 0 enables output energy of 35 mJ. Our OPO stage can be configured for satisfying this both cases.

At 8 mJ, the beam quality factor is lower than 4. This level of energy is reached for pump energy of 50 mJ. The divergence of the eye-safe beam is set to 400 µrad. The output beam is 20 mm containing 86 % of the optical energy. The aperture of the receiver module is equal to 80 mm. The ranging capability can be improved with the 35 mJ version but beam diameter is increased due to the degradation of the beam quality.

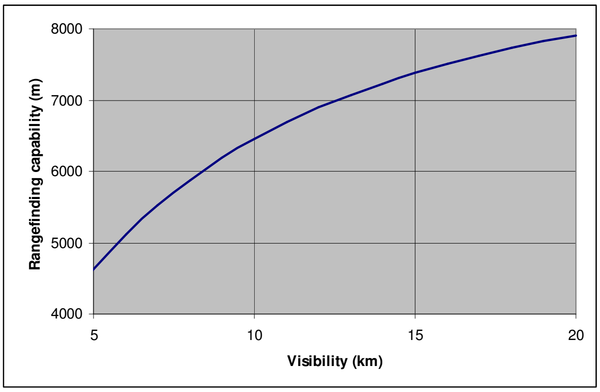

Figure 6: Rangefinding capability function of the atmospherical visibility (NATO target) for an output energy of 8mJ

Straw man design has shown that our designator, rangefinder and illuminator can be assembled in a volume in the range of 5 to 8 liters depending of the interface conditions.

5. CONCLUSIONS

CILAS has developed the key technologies for providing efficient and compact multifunction laser platforms for designation, rangefinding and illumination (LDRFI).

Using novel athermal scheme, thermoelectric cooler are avoided leading to a compact device, ready for firing immediately after power on. No warm up time is required. This laser is particularly adapted for application where volume and weight are highly challenging (ground target designation, designator for UAV or helicopters…)

6. REFERENCES

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7. ANNEX 1

Platforms / Operational functions	Naval ship	Fighting helicopter	Fighting aircraft	Fighting UAV	UGV	Fighting armored vehicle	Land soldier	Special ground soldier
Eye-safe rangefinding (<5km)					x		X	
Eye-safe rangefinding (>10km)	x	x	x	x		x		x
Target designation	x	x	x	x		X		X
Pointing for night vision device		x	x	x		x		x
Active imaging for ID			x					x
Optical sight detection (<5km)	x					x		x
Laser decoy (<5km)	x							
Missile countermeasure (<5km)		x						
Obstacle detection					x			
Mine detection	x							
Biological and chemical agent detection								x
Optical dazzling	x					x		
Optical damaging						x		

Table 3: Operational requirements wildly used on military platforms (relevant for laser applications)

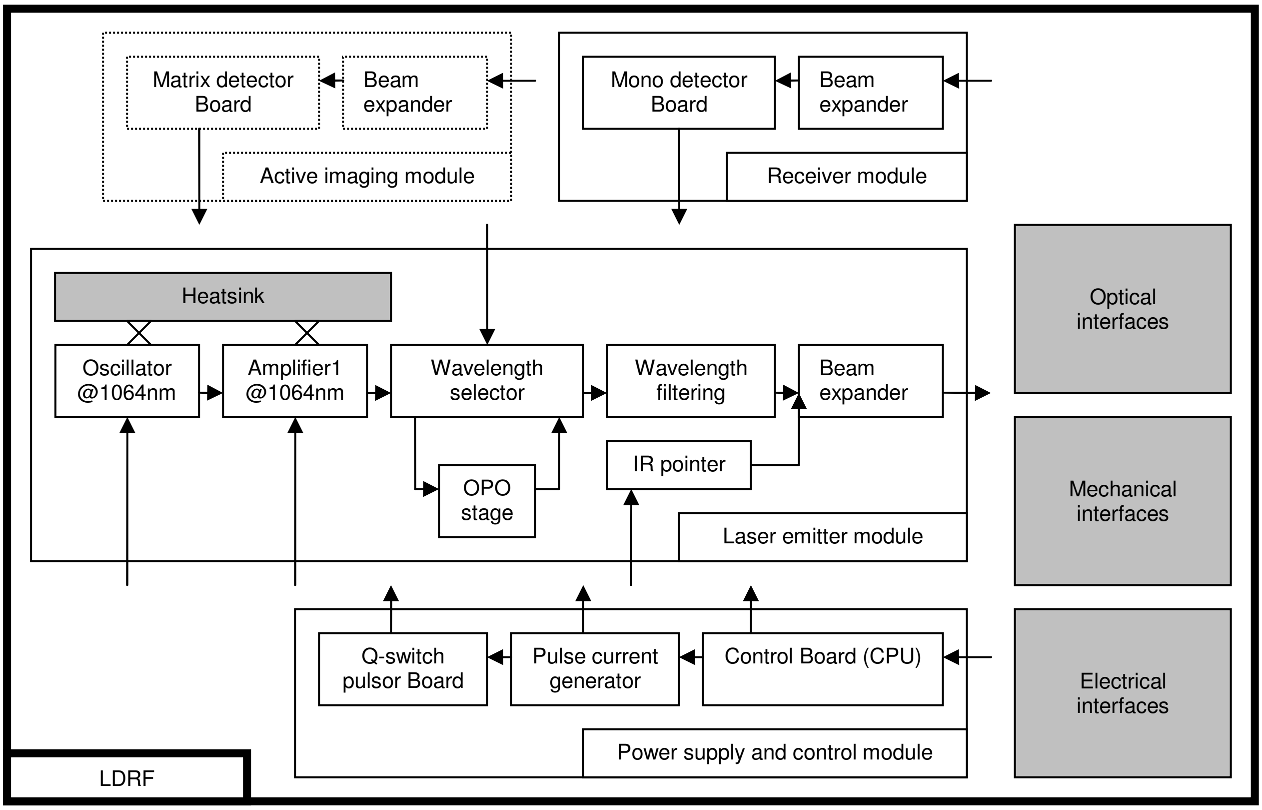

Figure 7: Functional diagram of the multifunction laser source module

Main sub system modules	Critical parameters	Volume (mm3)	Power consumption (W)
Laser emitter@1064 nm	>150 mJ, <4 mm.mrad, PRF20 Hz	210x85x45	110
OPO stage	8 mJ, <8 mm.mrad or 35 mJ, PRF20 Hz,	25x25X160	0
Wavelength selector	Switching time 500 ms	55x80x140	4
IR pointer	1W CW, 0,8 µm	55x15x20	3
Receiver module	NEP 10 nW	30x30x10	4
Pulse current generator	150 A for η=70 %	50x50x90	33
Control board	RS422 remote control	100x100x10	6
Q-switch pulsor	2800 V, 20 ns	80x30x10	2,5

Figure 8: Estimated main characteristics of the main sub systems of the multifunction laser source