

FLASH

Flexible Laser-Based Manufacturing

D2.1 – Commissioned laser module with 3 lasers, fibre coupling unit & fibre switch

HORIZON-CL4-2023-TWIN-TRANSITION-01-02.



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Flexible Laser-Based Manufacturing

Revision	Date	Author/Organisation	Description
1 st	4 th September 2025	Synova SA	Initial draft



Executive Summary

The purpose of this document is to outline deliverable 4 and its place within the FLASH project along with key results. The deliverable is titled "Commissioned laser module with three lasers, fibre coupling unit & fibre switch". This deliverable is essential to the success of the FLASH project. It permits the combination of three laser beams and the selective beam delivery to three optical heads via a controllable switch.

The key results for this deliverable can be broken down into three parts. The first part is the commissioning of the three lasers sources. The infrared continuous wave source, the green "short" nanosecond source and the green "long" nanosecond source were all found to meet the requirements necessary for the use cases outlined in the project proposal. The "short" nanosecond source was 30% below the power requirements requested in the project proposal, however, the MTC confirmed that they will not exceed this power limitation in their use case tests.

The second part is the design and construction of the laser beam combining unit. This part of the work package has evolved from the initial project proposal. The initial proposal had the three laser sources entering a fibre coupling unit, where the beams would be combined and delivered to a fibre beam switch via an additional optical fibre. Further discussions between Synova, Cailabs, MTC and Prima led to a more robust design with reduced laser power losses. The redesign has consisted in merging the beam combining unit and fibre beam switch within the same optical enclosure, thus removing the need for an additional optical fibre and the unnecessary associated loss. It has indeed been demonstrated that it was possible to direct all three laser beams into the three optical fibres. The transmission at the fibre entry-exit measured 83- 90% for each independent laser.

The third part of the deliverable aimed to demonstrate that the fibre switch is capable of sufficient repeatability to safely deliver the laser beams to the fibre outputs. Static stability measurements of the selected motorized stage demonstrated a good stability of 0.83-0.92 μm , while round-trip measurements gave a repeatability of $< 5 \mu\text{m}$. This level of repeatability is considered suitable for use as a fibre switch for the FLASH project. Additionally, final power measurements were made after switching five times laser light in between the different fibers and also demonstrated a good repeatability.

Some long-term, high-power tests will follow to assess the stability of the system over time before shipping the system. Also, some improvements are planned on the current system for better mechanical stability, higher fibre coupling efficiency and utilization of green and IR laser at the same time. These modifications will be planned during the integration phase (WP 7).

This deliverable was led by Synova and was supported by Cailabs, MTC and Prima.

Commentato [GL1]: To be completed



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General Information

Project	
Title	FLASH
Acronym	Flexible Laser-based manufacturing through precision photon distribution
G.A. number	101138380
Topic	HORIZON-CL4-2023-TWIN-TRANSITION-01-02
Website address	http://FLASHLaserProject.eu/
Start Date	1 st January 2024

Deliverable	
Deliverable name	Commissioned laser module with 3 lasers, fibre coupling unit & fibre switch
Deliverable number	4
Work package	Lasers and fibre coupler
Dissemination level	PU
Date of delivery	Due month 18
Keywords	
Status	

Author	
Authoring partner	Synova SA
Contact person	Jonathan Wood
Email Phone	Jonathan.wood@synova.ch +41 21 55 22 646



1. Introduction

The FLASH project aims to create a new laser processing solution that delivers three different laser beams to three different processing heads. The multiple laser sources and optical heads provide a broad range of machining solutions that include cutting, drilling, welding, cladding and micro-machining. This system will be enclosed inside a single machine with the ability to select the desired laser and processing head for a specific machining application.

This deliverable aims to demonstrate the successful preparation and combination of the three laser sources to be selectively output to the optical heads. The first part describes the commissioning of the three laser sources and their adherence to the requirements outlined in the project proposal. Secondly, the beam combining unit is described in further detail with explanations provided for deviations from the project proposal. Thirdly, the beam switch will be described along with the repeatability measurements to ensure suitable beam delivery to the appropriate optical head. Finally, the unit will be presented as a whole, with all the components from previous sections brought together.

2. Commissioning of laser sources

The three laser sources included in this project are:

1. Infrared, 1080 nm, continuous wave laser (Raycus, RFL-C6000S-HP, 1080 nm CW, QBH 50 μ m fibre, BPP 1.5) – provided by Cailabs
2. Green, 515 nm, short nanosecond (1-10 ns) laser (IPG, GLPN-500-1-50-M, 515 nm, 50 W, 1-10 ns, 1 MHz, free space, $M^2 < 1.3$) – provided by MTC
3. Green, 527 nm, long nanosecond (300 ns) laser (Photonic Industries, DM1-527-40, 527 nm, 70 W, 300 ns, 10 kHz, free space, $M^2 < 16$) – provided by Synova

2.1 Infrared laser source

The project proposal indicated that the infrared laser source should have an average power of 2 kW to permit the machining requirements for the use cases. The IR laser source was shown to meet the requirements as can be seen in Figure 1. For these measurements the power meter was limited to measurements below 1.5 kW, which did not allow a full characterisation of the entire range of the laser. However, from extrapolating the points the trend shows that the laser should reach and exceed the 2 kW average power defined in the project proposal.

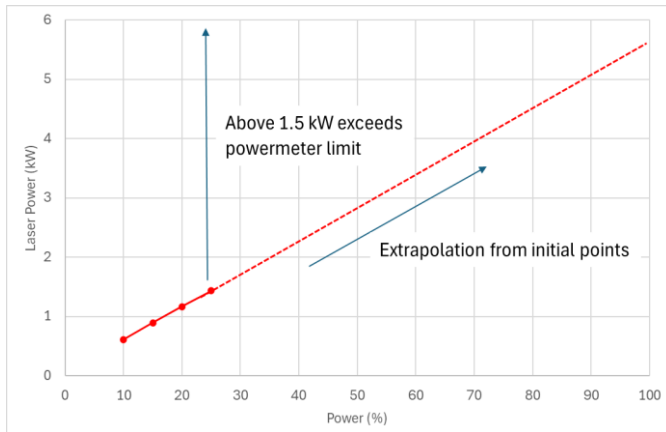


Figure 1: Characterisation of the infrared laser source with the dashed red line showing extrapolated points

2.2 Short nanosecond laser source (green)

The project proposal indicated that the short nanosecond laser source should have a pulse width of 1-10 ns and output an average power of 50 W. The characterisation of this laser source can be seen below in Figure 2 for the 3 different pulse durations. In this case, the short pulse laser is demonstrated to reach a maximum of ≈ 35 W, which is 30% lower than the requested 50 W. However, after discussions with MTC it was agreed that their application tests for this laser source would not exceed 35 W. Therefore, likewise, this laser meets the specifications required for the FLASH project.

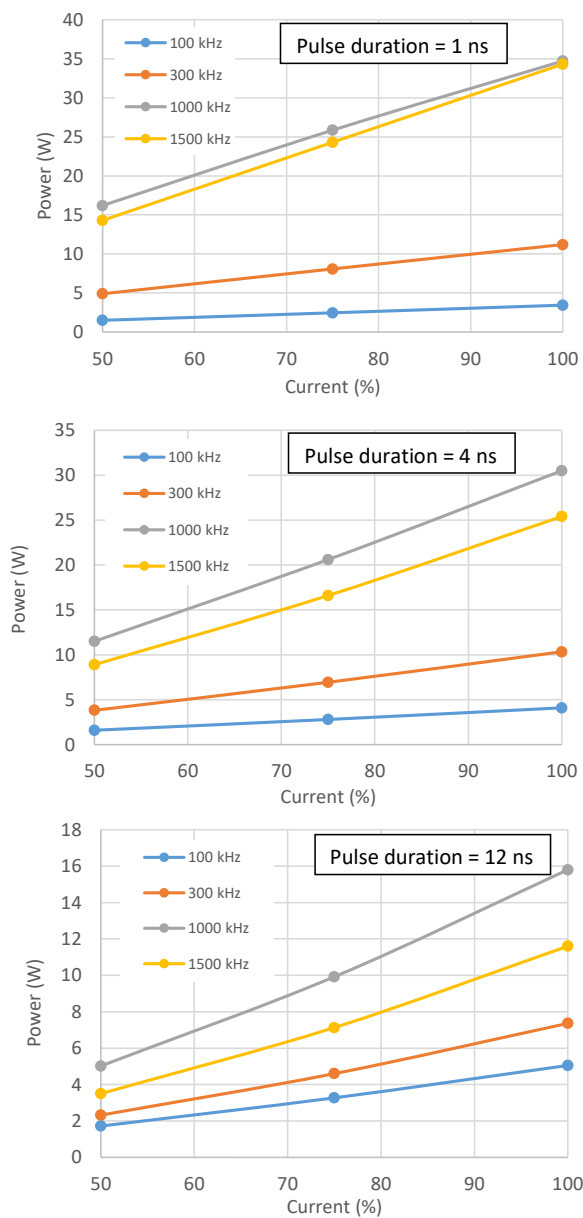


Figure 2: Characterisation of the short nanosecond laser source for 1-12 ns pulses



2.3 Long nanosecond laser source (green)

The project proposal indicated that the long nanosecond laser source should have an average power of 100 W at 10 kHz with pulse lengths of approximately 300 ns. However, after further discussions the required average power was reduced to 70 W and the other parameters remained the same. This was deemed to be sufficient for the use cases associated with this laser source. The characterisation of this laser source can be seen below in Figure 3 and confirms that all three laser sources meet the requirements for the FLASH project.

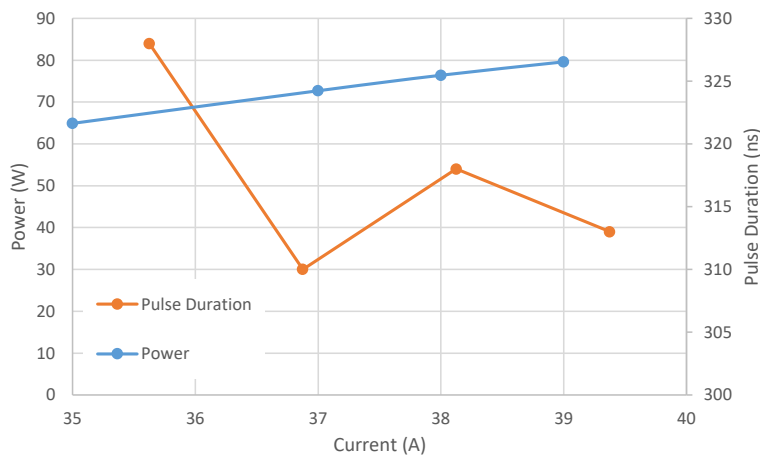


Figure 3: Characterisation of the long nanosecond laser source at 10 kHz

3. Laser combining unit

The laser beam combining unit is an integral part of the FLASH project and combines the three laser sources together for selective delivery to the three optical heads. This technology is based on knowledge from Synova, where a standard product consists of two laser beams combined together to create a dual laser system. This project introduces a third, high power, laser source that adds an additional layer of complexity that needs to be taken into consideration. This section will go into detail on the laser combination process and how the additional complications have been overcome. Furthermore, the general design has been adapted to become more robust and more efficient, which will be described in greater detail.



3.1 Changes to the initial proposal

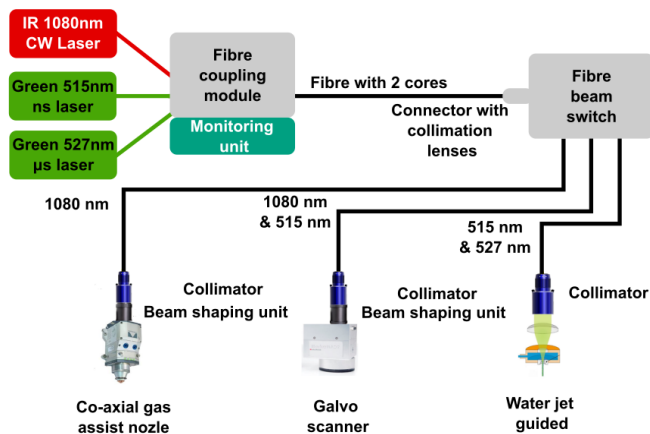


Figure 4: Schematic of the preliminary concept proposed in the grant proposal

The preliminary concept outlined in the project proposal has evolved to become a more robust system with reduced laser power losses. The initial proposal can be seen in the schematic in Figure 4. The schematic shows the laser sources entering the fibre coupling unit, where the laser beams are combined. The three laser beams would have been coupled into a dual core fibre and directed to the beam switch, where they would again have been coupled into the output fibres. The additional optics required to implement this would have added an extra layer of complexity to an already delicate system. Additionally, the optical fibre between the beam combining unit and the fibre beam switch would have added laser power losses.

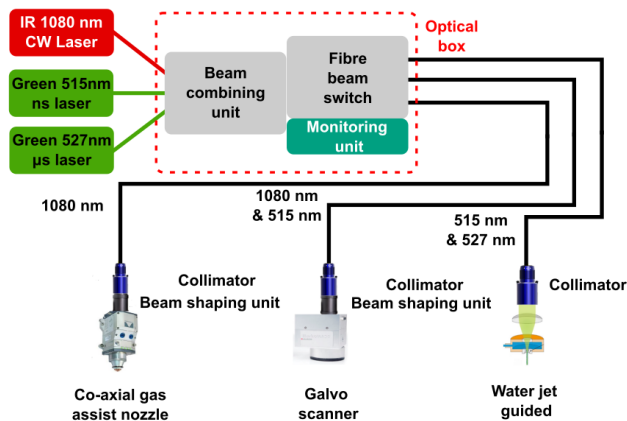


Figure 5: Schematic of the updated concept agreed upon by project partners



The redesign of the system was discussed with project partners Prima, Cailabs and the MTC and can be seen in Figure 5. The key change is the removal of the optical fibre connecting the beam combining unit and the fibre switch. This results in all the optical components being enclosed inside a single optical box. Additionally, the position of the monitoring unit has been modified, however, this is beyond the scope of this deliverable and will not be discussed here. It is important to note that there is no change to the delivery of the three lasers beams to the three optical heads.

3.2 Combination of laser beams

A schematic of the beam combining process can be seen in Figure 6. The green laser paths demonstrate the standard method employed by Synova to make a dual laser system and the red optical path shows the added complexity of the infrared beam.

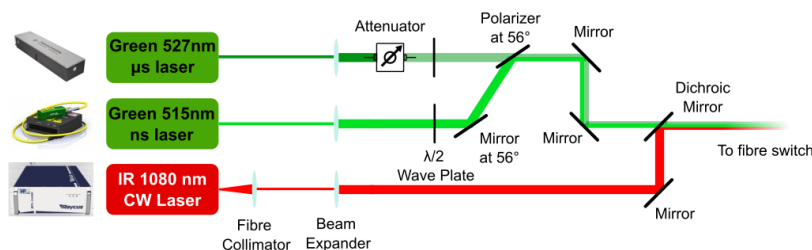


Figure 6: Schematic of the beam combining unit

Starting with the green lasers, both pass through beam expanders to control the beam size. The “long” nanosecond laser passes through an attenuator, allowing variation of laser power independently of the pulse duration, which is key for certain applications. Both green lasers then pass through half-wave plates to control their polarization. The “short” nanosecond laser is incident on a mirror set to 56° (close to the Brewster angle), which preserves its linear polarization orientation. This beam is then incident on the polarizer at 56° , resulting in a reflected beam toward an alignment mirror. The p-polarized “long” nanosecond laser is transmitted through the polarizer, which has an anti-reflective coating on the backside to maximize transmission. At this point, the two green laser beams are combined along the same optical path.

Introducing the IR laser beam is, in theory, not technically difficult, however, the high powers used generate concerns about damage thresholds for optical components. Therefore, precautions are duly taken where possible. The IR laser initially passes through a fibre collimator to collimate the divergent beam that exits the fibre and, like the green lasers, passes through a beam expander. The laser then is reflected onto a dichroic mirror that transmits green light and reflects IR light. The combined lasers are then directed towards the fibre switch, which is described in the next chapter.



4. Fibre switch

The fibre switch within the laser beam delivery system selectively directs the laser beam to one of the three optical fibre outputs. The fibre switch consists of a translation stage with a mirror and three defined positions that align the laser beam to the outputs. The requirements for the fibre switch are high-precision and high repeatability. There is a specifically tight tolerance for coupling the infrared laser with a spot size of $40\text{ }\mu\text{m}$ into a $50\text{ }\mu\text{m}$ fibre; this leaves minimal margin for error.



Figure 7: Picture of the fibre switch and associated mirror mount

The fibre switch module can be seen in Figure 7. Static stability measurements were made by Cailabs and showed a stability of 0.83 to $9.2\text{ }\mu\text{m}$, i.e. a depointing of $8.3\text{ }\mu\text{rad}$ in x and $9.2\text{ }\mu\text{m}$ in y . Further, round trip measurements showed a precision of $< 5\text{ }\mu\text{m}$. In conclusion, the repeatability of the translation stage makes it suitable for use as the fibre switch.

	Reposition number				
	1	2	3	4	5
Power (W)	42.3	42.2	42.3	42.2	42.3

Table 1: Repeatability of power at fibre exit after repositioning of fibre switch

Additional measurements were made by Synova, whereby, the power was measured at the fibre output once the stage had been moved. A consistent power would indicate a consistent position on the stage. The results are displayed in Table 1, which shows a variation of 0.1 W (0.23%) for the PI laser.



5. Laser delivery unit

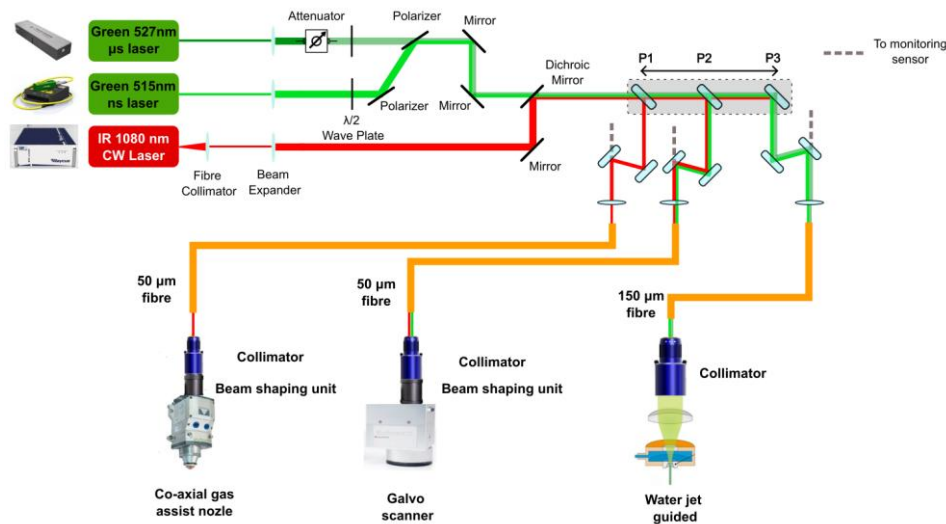


Figure 8: Schematic for the overview of the entire laser delivery unit

This section brings the parts from previous sections together and describes the laser delivery unit as a whole. The overall schematic for the laser delivery unit can be seen in Figure 8 and will not be described in more detail as they have been covered in depth in earlier parts.

To have a concrete idea of the spatial constraints on the system a CAD was made of the anticipated optical pathway and various optical components, see Figure 9. The figure shows custom designed optical mounts for the three beam expanders and the three fibre connector mounts: essential for securely holding these optical components. An additional complication for this system is the complex cooling that is required for: the short nanosecond laser head, the IR laser head, the fibre collimator, the power meter and the beam dumps. The custom designed beam dumps are placed behind each mirror that reflects the IR laser beam. This was necessary because even if 0.1% of the IR light is transmitted, there would still be a significant amount of energy that needs to be dissipated.

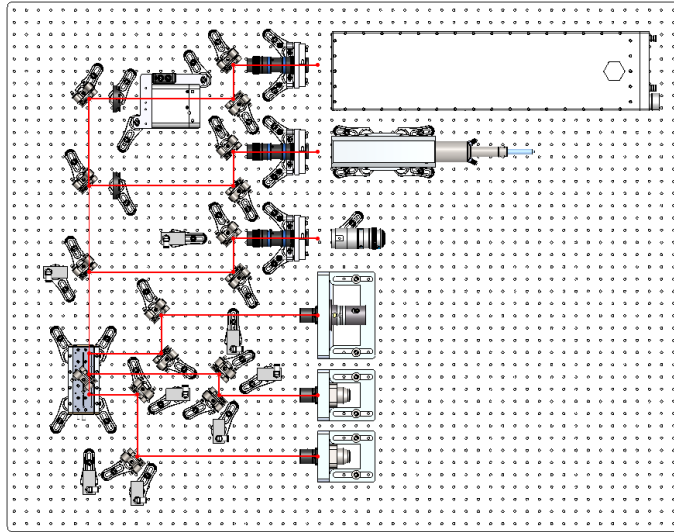


Figure 9: CAD of the optical path and optical components for the laser delivery unit

A custom-made optical box was constructed to protect optical components from outside material and to enclose the laser light to protect users from the high-power lasers. This included silicone sealing of the joints to allow minimal light leakage from the optical box. The CAD of the optical box can be seen in Figure 10 A, while Figure 10 B shows the physical optical box.

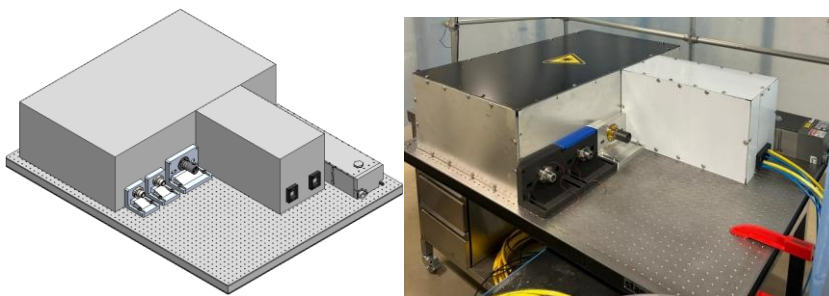


Figure 10: Left: (A) CAD of optical box. Right: (B) Physical optical box

The final optical arrangement of the laser delivery unit can be seen in Figure 11. The three laser inputs can be seen and an optical path can be traced as per Figure 9. The blue tubing here is the complex cooling system that has been secured to the optical table. Additionally, the electrical outputs can be seen that control the fibre switch and attenuator components.

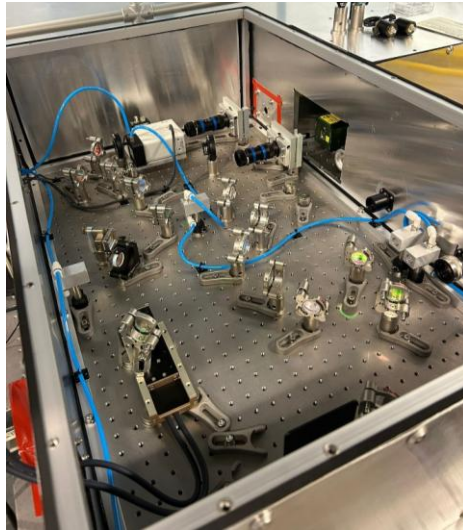


Figure 11: Laser combining unit composed of the optical arrangement within optical box

The lasers followed a complex alignment procedure that results in a final lens focussing the laser beam into the optical fibre. It is possible to couple the “long” nanosecond laser and “short” nanosecond laser into the 150 μm fibre and the “short” nanosecond laser and infrared laser into the 50 μm fibre. However, due to chromatic aberration, the focal length of the lens for the green and infrared lasers differs by ≈ 2 mm. On the contrary to the plan, the compensation of the foci positions by with the beam expanders was not sufficient. The result is that it is currently not possible to use these two lasers simultaneously. Solutions are currently explored and are planned to be implemented during the integration of the system on the machine (WP 7).

Commentato [GL2]: To be completed

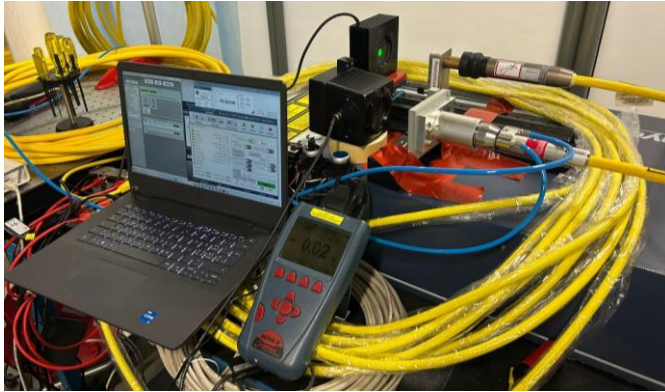


Figure 12: Picture of the power transmission measurement for the two different fibres

Power transmission measurements were made to measure the quality of the coupling of the lasers into the optical fibres. The results are presented in Table 2 & 3 for the 150 μm fibre and 50 μm fibre respectively. This demonstrates that for the two laser-fibre instances the transmission is between 83-90%. This may be improved, but it is considered a strong baseline measurement. As a benchmark Synova typically loses 12% of power in the 20m long fibre.

"Long" Nanosecond Laser		
Power Before Fibre (W)	Power After Fibre (W)	Transmission (%)
0.42	0.38	90.48
6.6	5.9	89.39
26	23.2	89.23
48	42.6	88.75
58.1	51.5	88.64
"Short" Nanosecond Laser		
Power Before Fibre (W)	Power After Fibre (W)	Transmission (%)
0.8	0.7	87.50
4.1	3.5	85.37
9.4	7.9	84.04
13.6	11.3	83.09

Table 2: Transmission of "short" and "long" nanosecond laser for the 150 μm fibre



"Short" Nanosecond		
Power Before Fibre (W)	Power After Fibre (W)	Transmission (%)
0.84	0.71	84.52
4.25	3.45	81.18
9.35	7.9	84.49
13.7	11.4	83.21
Continuous Wave IR		
Power Before Fibre (W)	Power After Fibre (W)	Transmission (%)
50	40	80.00
155	140	90.32
265	235	88.68
375	333	88.80
485	425	87.63
590	507	85.93

Table 3: Transmission of "short" nanosecond and continuous wave infrared laser for the 50 μm fibre

6. Conclusion

In conclusion, for this deliverable we have demonstrated that all three lasers are functional and meet the requirements for the use cases within the FLASH project. The updates to the preliminary concept for laser integration have been explained in detail. The technique behind laser combination was described and demonstrated by the construction of the laser beam combining unit. The fibre switch was shown to meet the necessary precision and repeatability requirements for beam delivery to the three outputs. The transmission of the three optical outputs was found to be 83-90%, meeting the requirements outlined in the project proposal.