Designing for Femtosecond Pulses

White Paper

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Overview

Calmar's femtosecond laser sources are passively mode-locked fiber lasers. Passive mode-locking makes these lasers easier to operate than actively mode-locked lasers, as no external RF clock signal is required, and little or no warm-up time is needed. Temperature control is also less of an issue with passive mode-locked lasers.

Calmar's passively-mode-locked lasers produce pulses as narrow as 80 fs wide. Repetition rates are fixed in the range 10 - 100 MHz. The peak output power of a femtosecond laser is, of course, high due to the short pulse durations, and peak powers up to 10 KW can be achieved using an integrated amplifier. Figure 1 shows a simplified schematic of a passively mode-locked fiber laser.

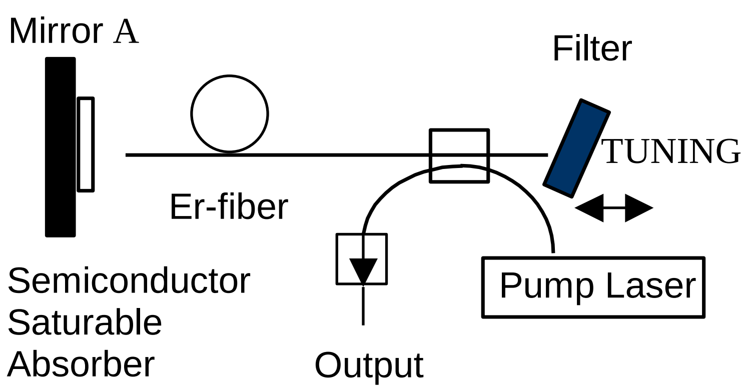


Figure 1 – Schematic of Passive Mode-locked Fiber Laser

Since Calmar's fiber lasers are manufactured from discrete components, dispersive and non-linear effects can be carefully controlled. Pulse shape is transform-limited, and the pedestal is typically 20dB lower than the signal.

The RZ pulses from Calmar's lasers are ideally suited for testing and characterization at 40 Gb/s and higher.

The capability to phase-lock the repetition rate to an external clock is available as an optional upgrade. In this scenario, a low jitter phase lock loop precisely tracks the laser repetition rate to an external clock. This feature is particularly useful for optical sampling applications.

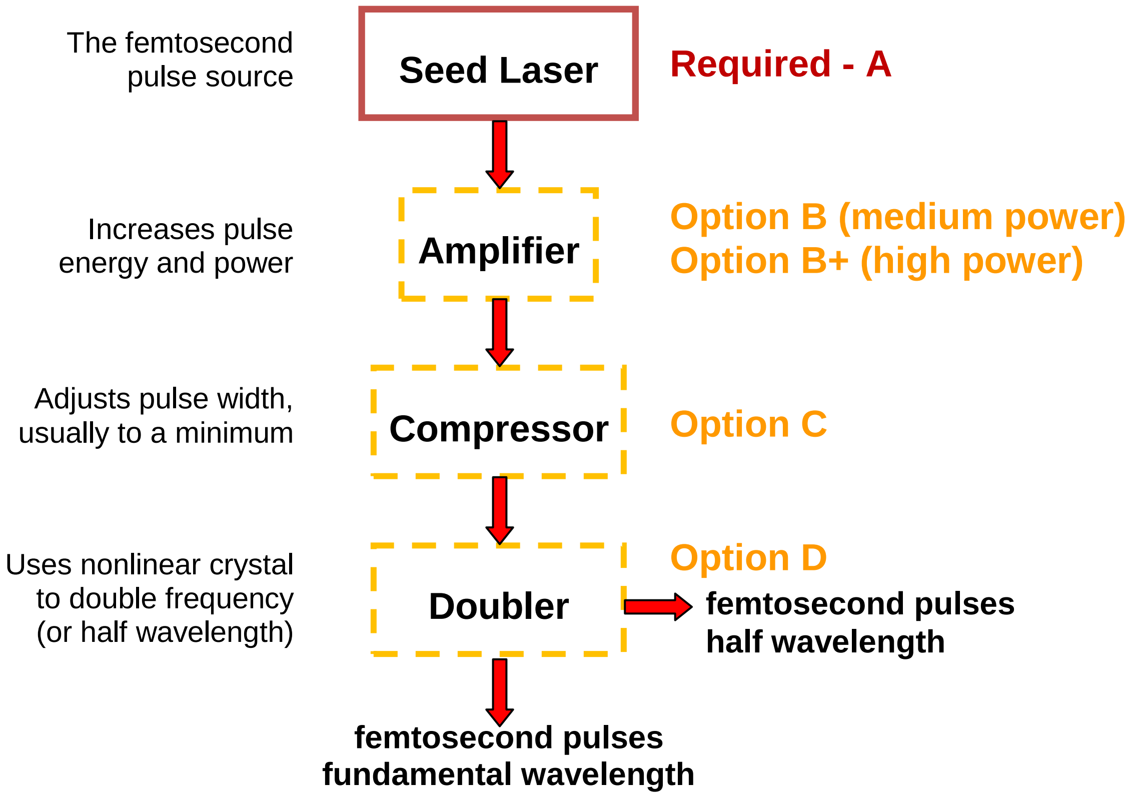
Calmar's lasers are recognized for their stability, as demonstrated by their low timing jitter and low amplitude noise, thereby ensuring that the quality of the laser output meets even the most stringent test requirements.

For more technical information see Calmar's "FPL White Paper Rev 1.3 010109" on our web site.

System Design Considerations

Any femtosecond source starts with a seed laser that generates femtosecond pulses or pulses that can be compressed to femtoseconds. From there, one may want different powers, frequencies pulse widths, or wavelength. This is achieved by building a system from the seed laser as follows:

Elements of a fs Laser System



Examples of Calmar's Bench Top and Module laser systems:

Selection Guide

General Principles

- A fiber optical Seed Laser typically outputs a few mW of power at 20-50 MHz.
- An amplifier can increase output power, but is limited by nonlinearities in the fiber.
- A compressor can compensate for pulses broadened by spectral chirp. Generally it's best to compress after amplification due to nonlinear optical issues from high peak power.
- A Doubler can generate half the wavelength, such as 780 nm light from 1550 nm pulses.

How to use Selection Table below:

1. Use first or second column, depending on wavelength needed.
   (For 780 nm wavelength, just go to Section D.)
2. Move down table until reaching required average power.
3. Use Pulse Width requirement for reference to relevant section of this guide.

Selection Table

Power (1030-1065 nm)	Power (1550 nm)	Pulse width	See Section
2 mW	4 mW	< 1 ps	**A**
50 mW		< 7 ps*	**B**
	100 mW	0.1 ps	**B**
50 mW		0.2 ps	**C**
400 mW		6 ps*	**B+**
	3000 mW	80-800 fs	**B+**
	780 nm wavelength		**D**

* Pulse width may be made shorter with compressor, as per section C.

Related Products

<u>Cazadero – High Energy Pulses</u>

The Cazadero laser is optimized for higher energy femtosecond pulses, in the 1 to 20 µJ range, using Chirped Pulse Amplification. With a typical repetition rate of 100s of kHz the Cazadero can generate average optical powers of a few Watts. The high energy femtosecond pulses are ideal for many applications, such as athermal machining or biological cutting without collateral damage. The Cazadero is available in 1030 and 1550 nm wavelengths, with highest energy at 1030 nm.

<u>Carmel – High power 780 nm with small laser head</u>

The Carmel laser is designed for producing very short pulses, <100 fs, at 780 nm wavelengths with high average power, over 500 mW. The typical 50 MHz repetition rate leads to 10 nJ pulse energy. The Carmel laser is ideal for multiphoton imaging and generating 3D structures in appropriate materials. A compact laser head (3x13x9 cm) is connected to the controller by an 80 cm long optical fiber, of value in applications needing scanning of the fiber coupled head.

A. Seed Laser – Low Power

The seed laser is an essential requirement for any femtosecond laser system, as it's the source of the femtosecond pulses. Calmar's seed lasers utilize a saturable absorber to deliver excellent stability and reliability, with turnkey operation.

The seed is available in two forms, a module for OEM integration or bench top for lab use. The module (FPL-M) features a robust architecture that is insensitive to shock and vibration, providing exceptional stability and reliability for OEM applications. Advanced engineering design and consistent manufacturing process ensure the highest quality standards for OEM volume production.

With power up to 2 mW (at 130-1065 nm) or 4 mW (at 1550 nm) the seed laser is the most economical solution for applications requiring low level power, such as a femtosecond source.

An RF synchronization output is provided as a trigger signal. No external RF input is required.

Typical parameters for Calmar Seed Lasers:

Specifications	1030-1065 nm	1550 nm
Central Wavelength (nm)	1030-1065 (selectable)	1550 (1535-150 tunable)
Average Power (mW)	0.5-2	1-4
Pulse Width (ps)*	0.7 – 1.2	0.5
Repetition Rate (MHz)	27 or 50 (20 to 80 available)	20-50 (10-100 available)
Spectral Width (nm)	2-5	5
Timing Jitter (fs)	60 (100 Hz to 1 MHz)	60 (100 Hz to 1 MHz)
Polarization Extinction Ratio (dB)	>20	>20
Termination	Fiber pigtail or free space	SMF-28 or PM fiber
Dimensions (cm)	Bench top:34(w) x 40(d) x 9(h) Module: 9.5(w) x 12.7(w) x 2.5(h)	

*A Gaussian pulse shape (convolution factor = 0.7) is used to determine the pulse width from the autocorrelation trace.

B. Seed Laser with Integrated Amplifier – Medium Power

A seed laser may be integrated with a fiber optical amplifier can for increased power output. The bench top system is the same size as the seed laser alone, but the module becomes slightly larger. Like the seed module, the amplified module retains exceptional stability and reliability for OEM applications.

With power up to 20 mW (at 130-1065 nm) or 100 mW (at 1550 nm) the amplified see laser is the most economical solution for applications requiring medium level power, such as seeding amplifier systems.

With the amplifier, the spectrum becomes larger, which can be an advantage to create a smaller pulse width.

For wavelengths in the1030-1065 nm range, the pulse width will become larger, but the pulse can be compressed to smaller values (next section). For a 1550 nm wavelength, the pulse width can be designed to naturally become smaller after amplification, due to the nature of the fiber dispersion.

As with the seed laser, an RF synchronization output is provided as a trigger signal.

Typical parameters for Calmar Seed Lasers with integrated amplifier:

Specifications	1030-1065 nm	1550 nm
Central Wavelength (nm)	1030-1065 (selectable)	1550 (1535-150 tunable)
Average Power (mW)	10-50	10-100
Pulse Width (ps)*	3 - 7	0.1
Repetition Rate (MHz)	27 or 50 (20 to 80 available)	20-50 (10-100 available)
Spectral Width (nm)	10-20	30-40
Timing Jitter (fs)	60 (100 Hz to 1 MHz)	60 (100 Hz to 1 MHz)
Polarization Extinction Ratio (dB)	>20	>20
Termination	Fiber pigtail or free space	SMF-28 or PM fiber
Dimensions (cm)	Bench top:34(w) x 40(d) x 9(h) Module: 20.3(w) x 12.7(w) x 4.3(h)	

*A Gaussian pulse shape (convolution factor = 0.7) is used to determine the pulse width from the autocorrelation trace.

C. Seed Laser with Integrated Amplifier and Compressor – Medium Power

The pulse out of an amplified system may need compression. The bench top and module system are the same size as a medium power system.

With the amplifier, the spectrum and pulse width become larger, but the pulse can be compressed to smaller values (next section).

Typical parameters for Calmar Seed Lasers with integrated amplifier and compressor

Specifications	1030-1065 nm
Central Wavelength (nm)	1030, 1064
Average Power (mW)	20-50
Pulse Width (ps)*	0.2
Repetition Rate (MHz)	25- 50
Spectral Width (nm)	20
Timing Jitter (fs)	60 (100 Hz to 1 MHz)
Polarization Extinction Ratio (dB)	>20
Beam Quality	$M^2 < 1.2$
Beam Diameter (mm)	~1.5
Termination	Collimated beam in free space
Dimensions (cm)	Bench top:34(w) x 40(d) x 9(h) Module: 20.3(w) x 12.7(w) x 4.3(h)

*A Gaussian pulse shape (convolution factor = 0.7) is used to determine the pulse width from the autocorrelation trace.

B+. Seed Laser with Integrated Amplifier – High Power

A seed laser may be integrated with a highest power fiber optical amplifier can for maximum power output.

The bench top system is the same size as the seed laser alone, but the module becomes slightly larger. Like the seed module, the amplified module retains exceptional stability and reliability for OEM applications.

With the amplifier, the spectrum and pulse width become larger, but the pulse can be compressed to smaller values (next section).

Typical parameters for Calmar Seed Lasers with integrated high power amplifier

Specifications	1030-1065 nm	1550 nm
Central Wavelength (nm)	1030-1065 (selectable)	1550 (1535-150 tunable)
Average Power (mW)	400	500 - 3000
Pulse Width (ps)*	>6 (compressible to 0.15)	0.08 to 0.8
Repetition Rate (MHz)	40 (10-50 available)	20-50 (10-100 available)
Pulse Energy (nJ)	Up to 10 nJ	Up to 50
Spectral Width (nm)	30-40	30-40
Timing Jitter (fs)	60 (100 Hz to 1 MHz)	60 (100 Hz to 1 MHz)
Polarization ER (dB)	>20	>18
Beam Quality	$M^2 < 1.2$	$M^2 < 1.2$
Beam Diameter (mm)	~1.5	~0.5-1
Termination	Collimated beam in free space or pigtail fiber with FC/APC connector	SMF-28 or PM fiber
Dimensions (cm)	Bench top:34(w) x 40(d) x 9(h) Module: 20.3(w) x 12.7(w) x 4.3(h)	Head: 3x13x19 Controller: 48(w) x 50(d) x 18(h)

*A Gaussian pulse shape (convolution factor = 0.7) is used to determine the pulse width from the autocorrelation trace.

D. Seed Laser with Integrated Amplifier and Doubler

The pulse out of a 1550 nm laser system can be sent through a nonlinear crystal that doubles the optical frequency, or halves the wavelength to a nominal 780 nm.

Calmar offers a full system integrating this option with high energy output as indicated.

Typical parameters for Calmar Seed Lasers with integrated amplifier and doubler

Specifications	Free Space Output	
Central Wavelength (nm)	775-785 (selectable)	
Average Power (mW)	10-20	Up to 50
Pulse Width (ps)*	>6 (compressible to 0.15)	0.08 to 0.8
Repetition Rate (MHz)	30 (10-50 available)	50 (<50 available)
Pulse Energy (nJ)		
Spectral Width (nm)	~8	
Timing Jitter (fs)	60 (100 Hz to 1 MHz)	60 (100 Hz to 1 MHz)
Polarization ER (dB)	>18	
Beam Quality	$M^2 < 1.2$	
Beam Diameter (mm)	<2	
Termination	Collimated beam in free space	
Dimensions (cm)	Bench top:34(w) x 30(d) x 9(h) Module: 18.4(w) x 15.9(w) x 6.5(h)	Head: 15.2(w) x 12.7(d) x 6(h) Controller: 34(w) x 30(d) x 9(h)

*A Gaussian pulse shape (convolution factor = 0.7) is used to determine the pulse width from the autocorrelation trace.

Additional Optional Capability

The Mendocino systems have the following optional capabilities. See individual data sheets for each product for details. In general, these options are more available in bench top systems than modules.

<u>External Synchronization</u>
A seed laser can be synchronized to an external source, such as needed for probing synchronous signals.

<u>Wavelength Tuning</u>
The bench top system can integrate a tuning element to adjust the output wavelength

<u>Pulse width Tuning</u>
Systems with a compressor (see section C) can have a tunable pulse width option.

Applications

Femtosecond laser sources are used in a wide variety of application. These include the following:

- Biophotonics
- Terahertz Radiation
- Seeding Ti: Sapphire laser amplifiers
- Materials characterization
- Optical Metrology
- Multiphoton imaging microscopy
- Optical Receiver Characterization
- High Speed Sampling
- Optical Impulse Stimulus
- Optical Networking R&D

For more information on our Picosecond Fiber Laser series, Femtosecond Fiber Laser series, or any other Calmar products, please contact us.

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