TN – Introducing the ModBox–

Front End

exail

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Introduction

Underpinned by its unique in-house technologies, Exail developed the ModBox-FrontEnd – a fully turnkey system - the ideal solution to generate energetic arbitrary shaped pulses. The ModBox-FE is a complete front end laser system designed to be used as a seed source in high energy density laser facilities for applications such as inertial confinement fusion, interaction of intense light with matter, laser plasma interaction, laser implosion and interaction of ion beam with High Power laser.

The ModBox-FE offers the ultimate performance for the end user by integrating screened and selected components. Those components are controlled by a dedicated software interface for intuitive control to provide reliable and stable operation. A multiyear collaboration experience with famous intense laser facilities all over the world allows Exail to propose high performance, reliable and easy to use systems perfectly suited to the various applications related with high energy optical pulse generation.

Figure 1: Picture of the ModBox-FE

Continuous product development is central to Exail activities. This focus on innovation has enabled the company to establish and maintain a leading position in the strategic laser market. This Technical Note introduces the ModBox-FrontEnd and its performances.

Building Blocks of the ModBox-FE

Exail specializes in the design and production of fiber pigtailed electro-optic modulators (EOM) and their matching components including microwave amplifiers, biasing electronic boards, as well as optical devices such as optical fibers and optical amplifiers.

By mastering all the building blocks of an efficient modulation system, Exail is capable of offering complex optoelectronic modulation solutions based on proprietary designs. Our hardware is combined with an innovative and intuitive controllable human-machine interface and the ModBox-FrontEnd stands out as the solution of choice for premium performance and user-friendliness.

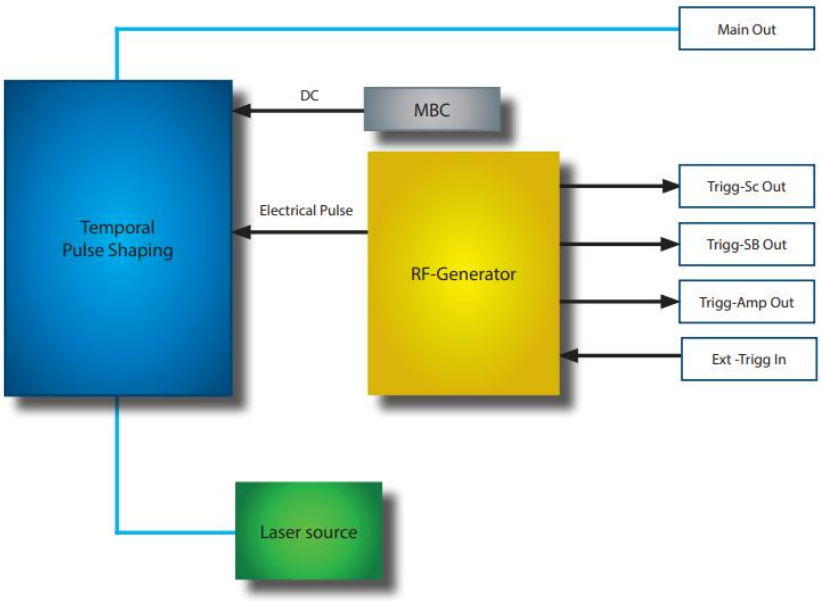

Figure 2: Functional block diagram

The short pulse generation is based on the combination of a high-performance continuous laser source combined with a large bandwidth modulation stage. This modulation stage is achieved with high extinction ratio $LiNbO_3$ modulators. An automatic bias control circuitry (MBC) guarantees the extinction ratio stability over time and the optical pulses are carved out thanks to a high-resolution Arbitrary Waveform Generator (AWG).

Two configurations are possible for the ModBox-FE depending on the desired Extinction Ratio (ER):

- For applications requiring ER around 40 dB - a single stage EOM with one modulator, one driver and one MBC is used.
- For applications requiring ER around 60 dB – a dual stage EOM with two cascaded modulators, their drivers and MBCs have to be used to achieve such an ER.

Key parameters

The performances of the ModBox-FE are critical to generate 125 ps to 100 ns, custom shaped optical pulses with high stability and high extinction ratio. The optimized parameters are:

- Very high extinction ratio and stability (power, contrast, long term and short term).
- Low rise & fall times.
- Pulse Shaping Fidelity.
- Maximum Peak Power.
- Low jitter.

Very High Extinction Ratio and Stability

Once a very high extinction ratio modulator has been identified, an additional test consists of measuring the modulator's extinction ratio stability (which is related to the modulator drift) over time. Figures 3 and 4 show the stability of Exail ModBox-FE: the ER is stable over a whole day of experiments.

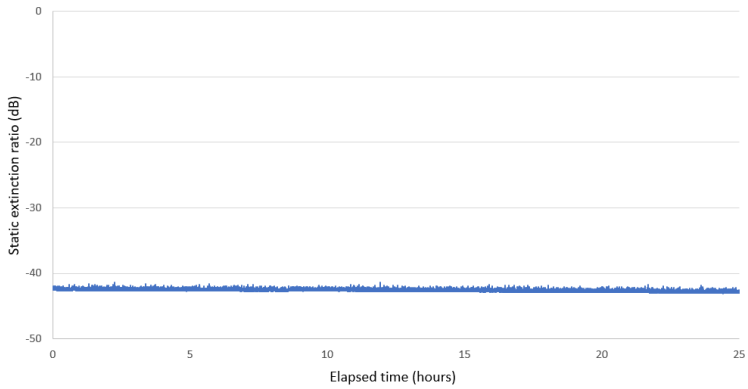

Figure 4: Extinction Ratio curve for more than a day of the ModBox-FE-40dB

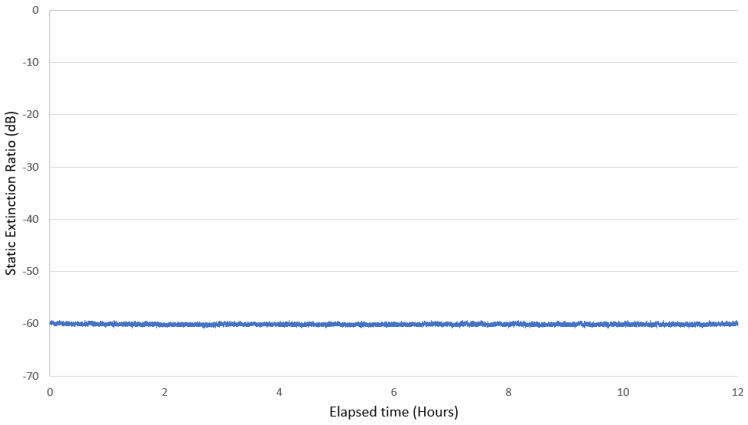

Figure 4: Extinction Ratio curve for 12 hours of the ModBox-FE-60dB

Low Rise & Fall Time

We recall first that the electrical pulses will be characterized with the 20-80% rise and fall time, since the electrical pulse is converted by the sinusoidal shape of the modulation transfer function of the Mach-Zehnder modulator. Thus, the 20-80 % rise and fall times are converted into 10-90 % rise and fall times in the optical domain as described by figure 5.

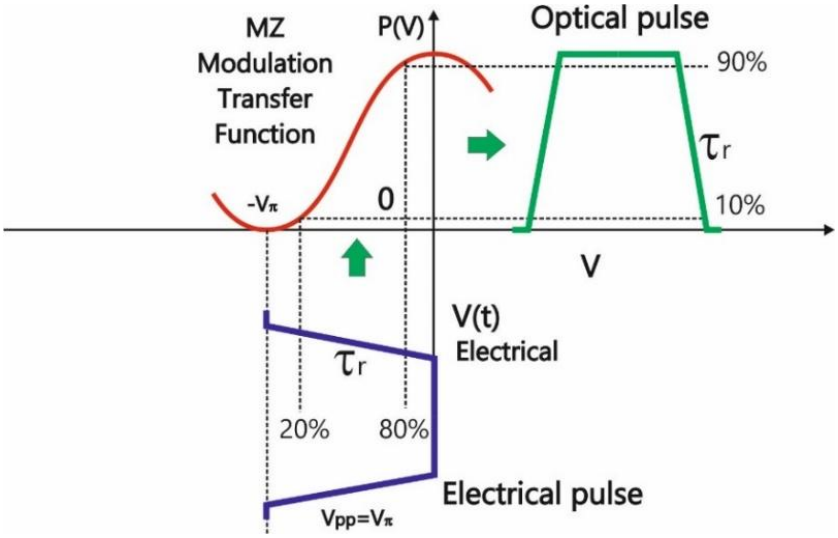

Figure 5: Electrical to optical conversion of a pulse through a Mach-Zehnder modulator.

We take into consideration the following components for the ModBox-FE

- The Arbitrary Waveform Generator (AWG).
- The electrical amplifier: Exail Modulator driver DR-VE.
- The Near Infra-Red Mach-Zehnder amplitude optical modulator NIR-MX-LN-20.

We obtained the following results in terms of Rise & Fall times:

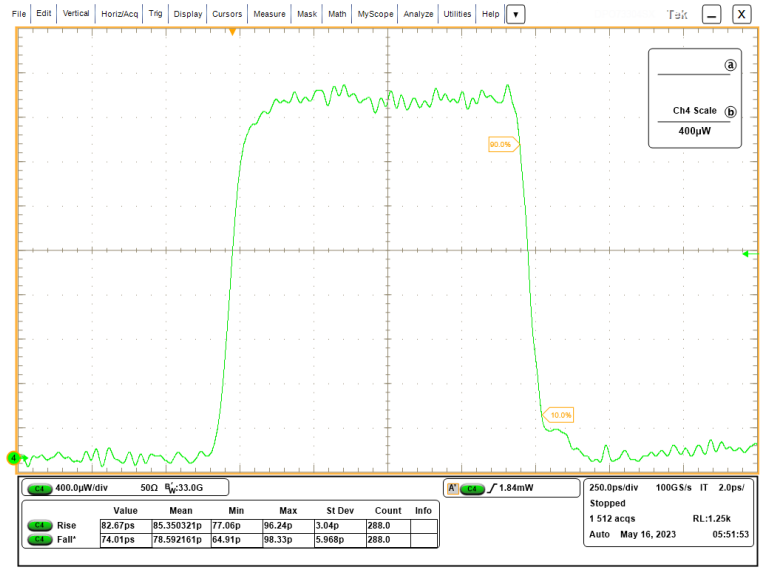

Figure 6: Electric response of a 1 ns optical pulse

The 10-90% optical pulse (see figure 6) is characterized by

- Rise time is **82 ps.**
- Fall time is **74 ps.**

Pulse shaping fidelity

The ability to shape the pulse temporally is of critical importance: ModBox-FrontEnd will challenge the state of the art of temporal pulse shaping performance. It relies on three components:

- An Arbitrary Waveform Generator (AWG).
- A RF Amplifier.
- A Mach-Zehnder Modulator.

Based on an extensive modeling of this RF chain in the frequency domain, Exail is able to propose an advanced correction capability to increase the fidelity of the pulse shaping and to get an output optical signal as close as possible to the user input. An example is given with a ramp in figure 7.

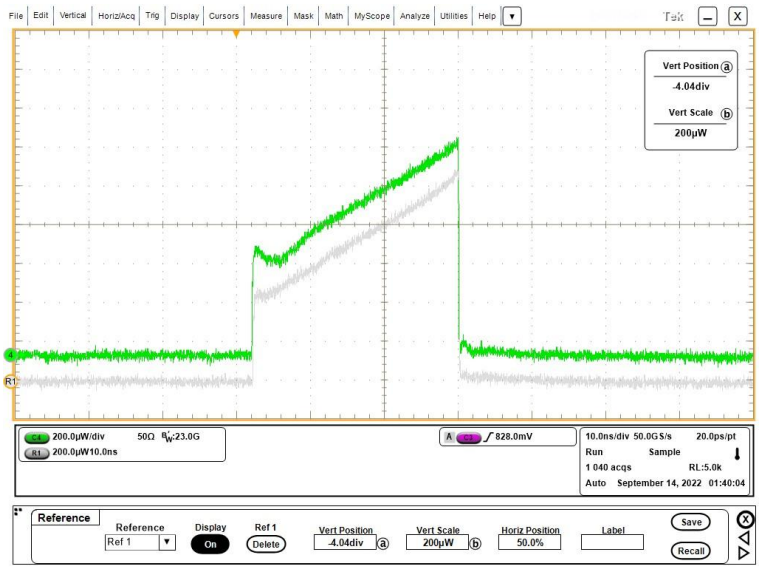

Figure 7: Electrical signal corrected to achieve fidelity of the optical pulse (in grey the signal of a ramp chosen by customer and in green the corrected signal to compensate distortion and have a clean optical ramp)

The ModBox embeds the last generation of human-machine interface. It allows speedy downloads, pulse shape changes and updates. It also comes with a high-capacity library for a large number of shapes to be registered. Finally, we would like to emphasize that waveforms can be changed “on the fly” without system interruption via an intuitive, real-time, easy to use, point-to-point precision graphic interface. A waveform change will not cause dropped pulses or significant fluctuations in the output energy, other than the energy change caused by the adjustment itself. This is because only the EOM (which is associated to the AWG and waveform change) affects the optical output power level.

An other possibility offered by Exail ModBox is to draw waveforms directly from the View window (see figure 8) using a mouse or the touchscreen - although using a mouse would provide enhanced precision. A correction button allows specific corrections to be applied to the original curve in order to obtain an optical pulse as close as possible of the drawn pulse.

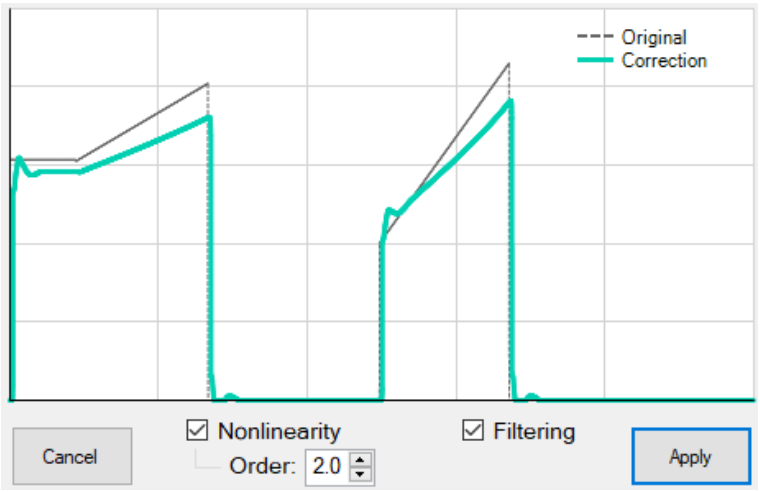

Figure 8: Picture of the ModBox interface Control

Maximum Peak Power

The ModBox-FrontEnd is based on a high-power amplifier combined with high optical power handling EOM modulator. This modulator is moreover screened and selected for its low insertion losses. During the components' assembly, a special care is also taken on the quality of the fibers splicing. We can therefore expect a minimized impact of the insertion losses on the optical power budget.

Because the amplifier and the optical modulator are still in their standard operating conditions, the limits of the system are not reached. Thus, the other system performances (power and energy stabilities for instance) and system reliability are not affected (see figure 9).

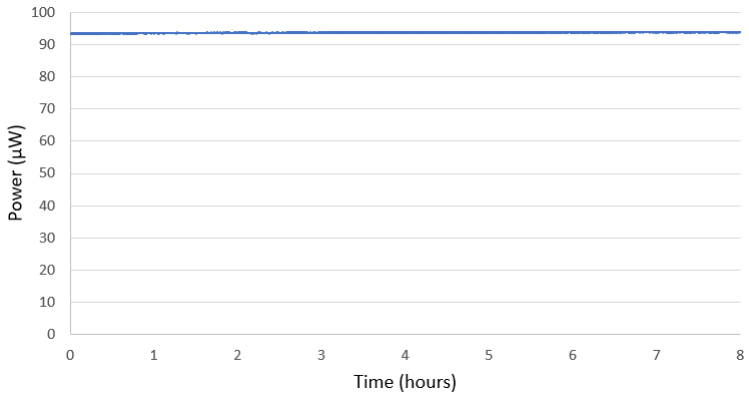

Figure 9: Power stability for 10 ns rectangular pulse at 10 kHz

The system stability shows indeed that it operates in a comfortable operating zone, and far from its damage threshold which may also affect the system lifetime.

Low jitter

The Arbitrary Waveform Generator and the Delay Generator are both selected for their very low jitter values. These two equipments are key to reach a low jitter at the ModBox system output.

Additionally, a lot of care is taken on the integration, and a set of very short RF cable (Exail team handmade) are used and help to minimize the ModBox internal jitter as low as possible (14 ps - see figure 10).

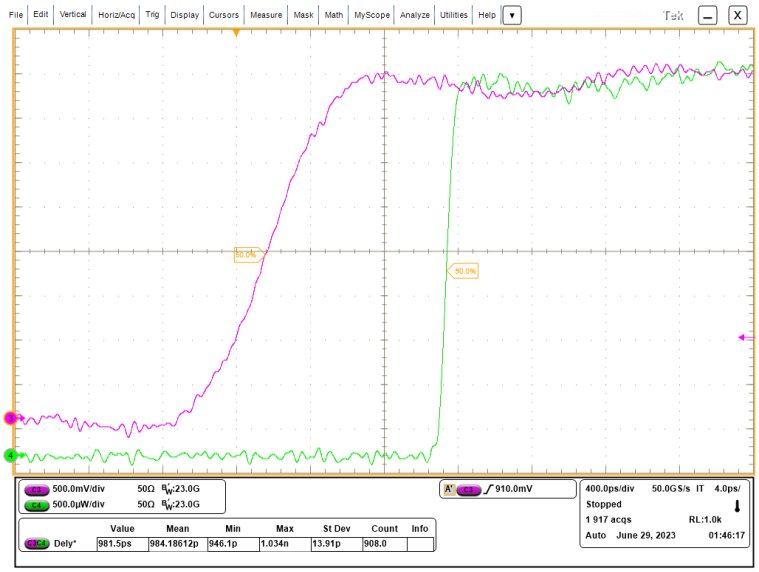

Figure 10: Jitter measurement on the ModBox-FE output port (pink is trigger signal, green is optical signal)

Related Equipment

Exail Modbox-Pulse-Shaper is an Optical Modulation Unit only (no optical amplification is provided) to generate short bespoke shaped pulses with high extinction ratio. It allows dynamic extinction ratio from 40 dB to above 60 dB with user adjustable pulse duration, repetition rate and temporal pulse shape. The main benefit is to pre-compensate the pulse distortion that occurs in the amplifiers chains that operate in saturated regime.

Exail ModBox-FE can be combined with Exail other ModBox to combine their different purposes:

- Exail ModBox-SB for spectral broadening of optical signals is a solution to suppress the Stimulated Brillouin Scattering (SBS) caused in optical fibers by high fluxes of highly coherent light. Under certain conditions, when amplification occurs for instance, the SBS can lead to the destruction of the fiber and the optical components along or forward the fiber. When the temporal coherence of the signal is destroyed by spectral broadening effect, the SBS power threshold is significantly increased and thus its effects can be eliminated.
- Exail Modbox-PA is an optical amplification unit to amplify shaped pulse from a ModBox-FE from few nJ level up to 10µJ at repetition rate up to 1 kHz. It can replace the amplification stages in

multi-pass solid state laser architecture with the benefit of compactness, stability and ease of use.

The Heritage: from Research to Industry

The first Modbox-FrontEnd was created more than 10 years ago. Since the first unit shipped, Exail has continuously improved its solution integrating higher performance hardware in a more compact design, adding new functionalities, and software features such as the real-time pulse design interface.

The ModBox-FrontEnd is a convenient and tailor-made solution from the market leader to meet customer distinct needs. It is not a product: it is a carefully tuned turnkey solution dedicated to a specific High Energy or High-Power class laser. The ModBox-FrontEnd is used to seed high power amplifier chains to produce a master laser or an OPCPA pump laser. Applications range from scientific research and academic activities to industrial market needs. The ModBox-FrontEnd operates in many different fields such as particle acceleration, inertial confinement fusion, radiation therapy, X-ray generation, for sensor test applications, laser-driven shock compression for laser peening or dynamic compression. Exail offers dedicated industrial grade Fiber Front End Seed Sources for all industries including R&D, Defense or production.

Conclusion

The Exail ModBox-FE is a complete front end laser system designed to be used as a seed source in high energy density laser facilities. It allows to generate fast and custom shaped optical pulses with high stability and high extinction ratio.

The short pulse generation is based on the combination of a high-performance continuous laser source combined with a large bandwidth modulation stage based on a high extinction ratio external $LiNbO_3$ modulator. An automatic bias control circuitry (MBC) guarantees the extinction ratio stability over time and the optical pulses are carved out thanks to a high-resolution Arbitrary Waveform Generator.

A multiyear collaboration experience with famous intense laser facilities all over the world allows Exail to propose high performance, reliable and easy to use systems perfectly suited to the various applications related with high energy optical pulse generation. This turn-key solution stays at the state-of-the-art thanks to a desire from Exail to improve its technology.

For more information, please have a look at our webpage on Optical pulse shaper & laser front end.