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**BLOG ARTICLE**

# Design challenges of industrial femtosecond lasers – Part 4: Pulse duration

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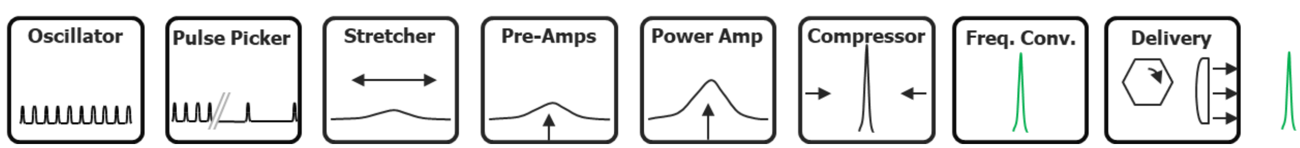
*In this series of articles, I lay down a few of my thoughts about the constraints influencing the design of femtosecond industrial lasers and parameters I believe should be considered before even starting the design process. I'd like to state that I am not a laser design expert; I spent the last 15 years developing and commercializing components for high-power and ultrafast lasers. The observations I write about come from my own experience and discussions I held with different stakeholders over the course of the last few years. I hope they will lead to interesting discussions and hopefully help a few of you with the design of your lasers.*

The pulse duration required for a specific application has a profound impact on the laser design because it defines the required spectral bandwidth to be managed throughout the laser. For most ultrafast lasers, the duration of a pulse is directly linked to its spectral width. The duration is inversely proportional to the bandwidth; shorter pulses have a wider spectrum, as more spectral content is needed to shorten pulse durations. Without careful management of the spectral content, the ultrafast laser may not fulfill the bandwidth requirements up to the laser output, leading to an inadequate pulse duration. Conversely, over-designing the bandwidth requirements may contribute to a significant cost adder and a non-competitive product. Managing the bandwidth must be taken into consideration at every step of the design process to get the best performance-cost ratio throughout.

Once the minimal bandwidth required to get the desired pulse duration has been determined, a bandwidth budget must be managed for each building block. It needs to take into consideration the impact on component size, cost, performance and interaction with other blocks. At the output of the laser, while a Fourier Transform Limited pulse is a theoretical ideal, it is impossible to attain. So an additional 10-20% of bandwidth should be budgeted. As I discussed in Design challenges of industrial femtosecond lasers – Part 2 – Pulse energy, I believe the best way to design a laser is to start from the application requirements and work backwards along the chain of building blocks, starting with the pulse compressor..



## Pulse compressor/stretcher

As the stretcher and compressor are typically matched, I will discuss them together. Because it is the last building block of a NIR ultrafast laser, the compressor should be designed for the exact spectral bandwidth needed by the application. Additionally, it should be properly matched to the main amplifier gain bandwidth because losing spectral content that has already been amplified is very costly. To avoid this, it is important to make sure that the compressor provides sufficient passband not to clip the amplified pulse.

The primary purpose of the stretcher and compressor is to add and then remove dispersion on the path of the pulse to reduce its peak power through the amplifier. As I elaborated in Design challenges of industrial femtosecond lasers – Part 3 – Amplification technologies, a low peak power at the amplifier level minimizes non-linear effects and allows an increase in pulse energy. Unused passband reduces the dispersion capacity of pulse stretchers and compressors, leading to larger and more expensive components or less stretching/compression for the money spent.

## Amplification chain

Two important parameters must be taken into consideration when managing the spectral content in the amplification chain: the choice of gain medium and the gain narrowing phenomenon.

Depending on the pulse duration to achieve, different gain mediums will be used. Femtosecond lasers require more spectral content (a larger emission bandwidth) than picosecond lasers. For example, Nd:YVO4 amplifiers (0.3 nm typical emission bandwidth) are good for picosecond lasers but are not suitable for femtosecond lasers as they do not provide sufficient bandwidth. In order to reach femtosecond durations, amplifiers such as Yb fiber amplifiers with typical emission bandwidths of tens of nanometers are needed.

Another important effect that must not be neglected is gain narrowing. Gain amplifiers don't have a flat amplification response across the whole spectrum. The intensity at the edges of the spectrum is not high enough to trigger the amplification. The result is a loss of spectral content and sometimes a slight shift in its center wavelength due to the asymmetrical response of the amplifier. More amplifiers in the chain lead to a stronger gain narrowing phenomenon.

## Seed laser

A fine balance between optical performance and cost is needed at every stage and the seed laser is no exception. It can be tempting to use a seed laser that generates pulses with the largest possible bandwidth; that way, it would be almost impossible to lack bandwidth at the output! But using an overdesigned seed laser could impact the cost of the laser. In an ideal world, the bandwidth of the seed laser would be tailored to the final pulse duration, like every other laser building block we've seen so far, in order to provide just the needed bandwidth to reach this pulse duration.

However, there is at least one scenario for which using an overdesigned seed laser could prove right. Let's imagine a project for which different lasers are developed to address multiple applications/markets. Using a very broadband seed laser and shaping its spectrum with the pulse stretcher would make it possible to address many markets using the same seed laser and leverage its cost.

As we saw, managing the bandwidth throughout the laser to reach the right pulse duration is not that simple. Parameters such as optical performance, cost and size, along with the interaction that components have on each other must be masterfully balanced in order to deliver a laser that will have commercial success.



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