Spectral Beam Combining (SBC)

Combining Laser Beams to Gain Power

One of the architectures implemented for the construction of a high-power fiber laser is the possibility of combining different laser beams. Knowing that today a single fiber laser can deliver a power of the order of a kilowatt, or even ten kilowatts, the optical combination by phasing multiple sources results in a new laser delivering powers of up to several hundred kilowatts. There are several techniques for combining lasers. Among them, two require the use of phase modulators: the spectral combination of laser beams and the coherent combination of beams. For each of these architectures, iXblue Photonics has managed to develop a dedicated product (bandwidth, driving voltage, suppression of non-linear effects, etc…).

Spectral Beam Combination of Lasers

In the Spectral Beam Combination technique (SBC), the different laser power beams emitting a continuous signal, centred on distinct wavelengths, are superimposed by adaptive optics. The result of the laser system is a uniform intensity distribution and an optical signal with a power proportional to the number of laser beams combined. The method of spectral combination of laser beams therefore requires a plurality of laser sources.

Each of these lasers integrates frequency modulation through an electro-optical phase modulator. The latter is indeed necessary to suppress non-linear Brillouin effects in the optical fiber (also known as SBS for Simulated Brillouin Scattering). Indeed, an excessive power transmitted in the fiber causes an acoustic vibration in the glass structure. This vibration induces a Bragg grating that limits optical transmission: a significant part of the light is reflected and can damage the optical source and its gain medium. A proven strategy to suppress the Brillouin effect is to widen the width of the laser line (frequency modulation). This technique is made possible by the integration of an electro-optical phase modulator. Thus, each laser module is equipped with a phase modulator in this configuration.

In general, SBC of narrow linewidth sources by wavelength selective devices has lower requirements on phase stability, spectral purity at the expense of spectral brightness. However, to facilitate the diffraction limited focusing, and to preserve the beam quality of each individual channel after a dispersive combining element (due to spatial dispersion), it is still necessary to maintain a narrow spectral width. In the SBC architecture, the gain bandwidth of Yb DC fibers is sub-divided into 30, 50 or 100 channels of narrow linewidth fiber laser sources to be combined. Each channel is scaled to 1 kW – 2 kW to achieve an overall target of 30 kW, 50 kW or 100 kW laser system when combined.

12/22 / V2 / KC-IF / lc/application-reports/ixblue/spectral-beam-combining

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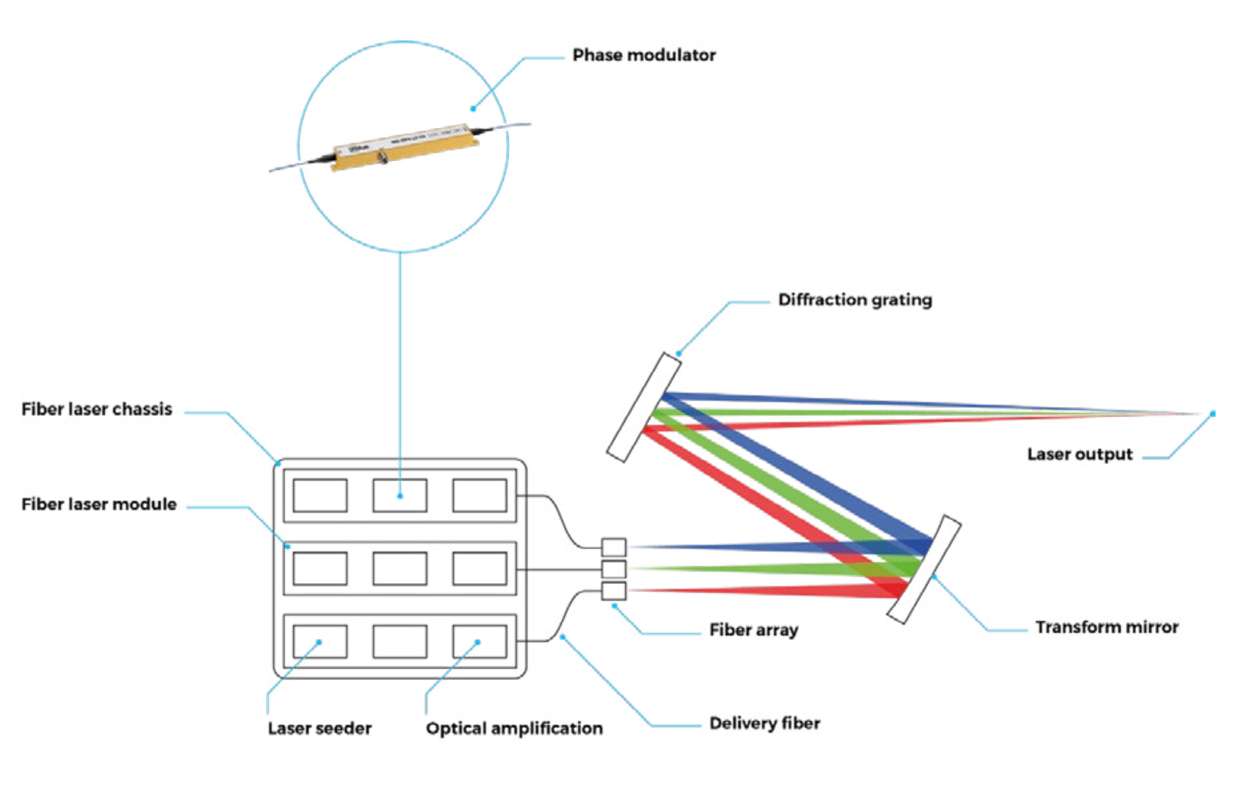

Fig. 1: Spectral Combination of Laser Beams
In order to broaden the spectrum of the optical source sufficiently, and thus ensure Brillouin-free transmission to increase the nominal power of each laser beam before recombination, a modulator with several GHz bandwidth and low control voltage is required. This modulator must also be insensitive to temperature variations.

For phase modulation, it is often achieved using the following configuration:

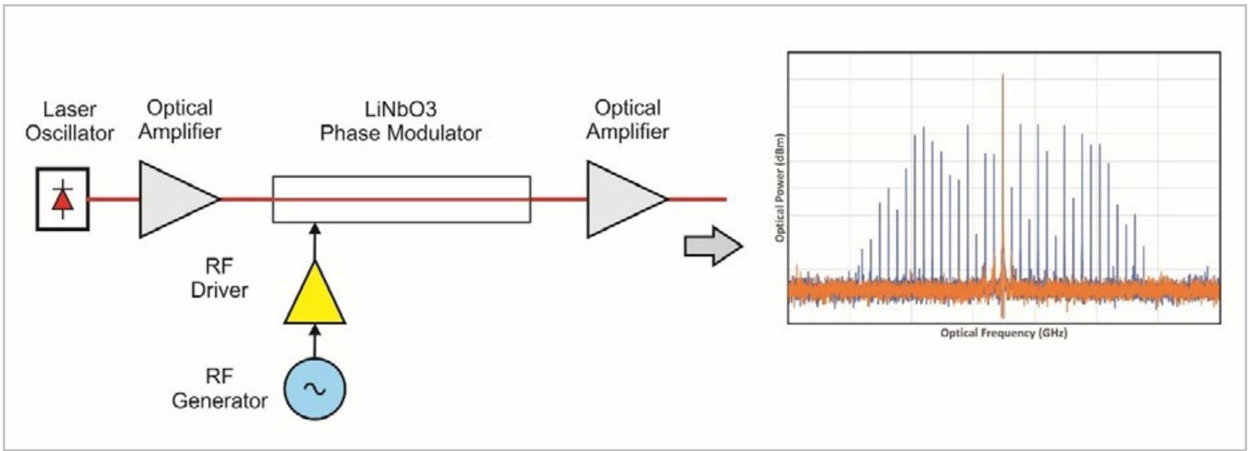

Fig. 2: Spectrum broadening set-up based on electro-optical phase modulator mean

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There are also a few variations in this general architecture, depending on practical and engineering considerations.

One of the main considerations is the Double Clad (DC) high power fiber amplifier that needs to be saturated for high efficiency power extraction. Typical saturation input power is of the range of 100 ~ 200 mW depending on the actual design of the DC optical amplifiers. Above the saturation power, the Amplified Spontaneous Emission (ASE) is also suppressed. This requirement forms a critical criterion for selecting the Phase Modulator (PM): the tolerance to high optical input power. For Phase Modulator with 3dB insertion loss, the input power to achieve 150 mW for input saturation, the input to the PM needs to be above 300 mW!

The choice of the DC fiber and the configuration of the DC amplifier will determine the spectral broadening necessary to achieve SBS suppression. The spectral broadening is kept to a minimum to preserve the beam quality for subsequent combination and to maximize the number of channel/slots available within the gain bandwidth of Yb amplifiers.

The other considerations involve the type of RF input signals applied to the phase modulators. Popular variants are White Noise Source (WNS), Pseudo Random Bit Sequence (PRBS) and multitone sinusoidal waves.

The main modulator criteria for an efficient broadening effect are:

- low driving voltage (Vp) and high RF power handling capability to generate a large number of side bands,
- low insertion loss and high optical input power handling capability to relax the amplifier gain effort and reduce the ASE noise source,
- insensitivity to the temperature variation as the laser system is intending to operate in outdoor purposes,
- high Polarization Extinction Ratio (PER).

The NIR-MPX-LN-02 and its matching high voltage RF amplifier DR-AN-10-HO have both been developed for spectral combination. The NIR-MPX-LN-02 fulfills all the SBC laser system requirements. Such phase modulator comes with more than 5 GHz bandwidth, a very low driving voltage of 1.5 V, more than 33 dBm electrical and 300 mW optical powers handling capabilities. iXblue Photonics phase modulators NIR-MPX developed in the near infrared at 1064 nm benefit from the technological mastery of the „Annealed Proton Exchange" (APE) waveguide manufacturing process (also used for modulators integrated in our own gyroscopes). Thus, APE waveguides can withstand optical flows of several hundred milliwatts.

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Electro-optic bandwidth	5 GHz typical
Vπ @ 2 GHz	1.5 V
Input optical power	up to 300 mW
Input electrical power	up to 33 dBm
Bandwidth	10 GHz
Gain	27 dB
Saturated output power	27 dBm

The figure 3 displays the optical insertion loss for various optical power levels.

The top line is the insertion loss (left scale) over time for various color coded optical input levels:

- orange: 10 mW,
- blue: 100 mW,
- green: 200 mW,
- purple: 300 mW.

The red curve is the measured optical output power (right scale).

The constant value for the insertion loss demonstrates that our technology is very stable with up to 300 mW of optical input power.

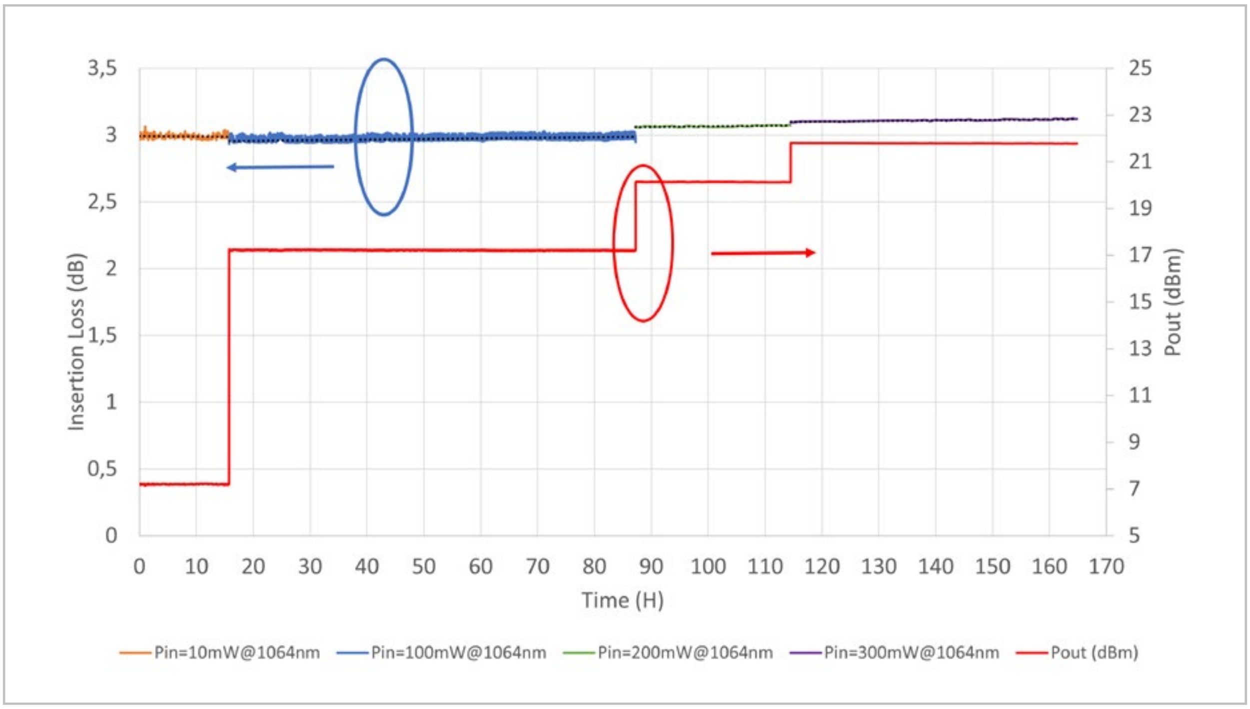

Fig. 3 - iXblue Photonics modulator NIR-MPX stability versus optical input power

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Because the laser system will likely need to operate outdoors and in challenging environments, the modulator was tested over temperature.

The temperature (blue curve) is cycled from -40 °C to +85 °C, and the output power (orange curve) is recorded.

Thanks to our technological choices, the modulator is very stable, and we observe only minor variations of 0,2 dB over the entire range of temperature.

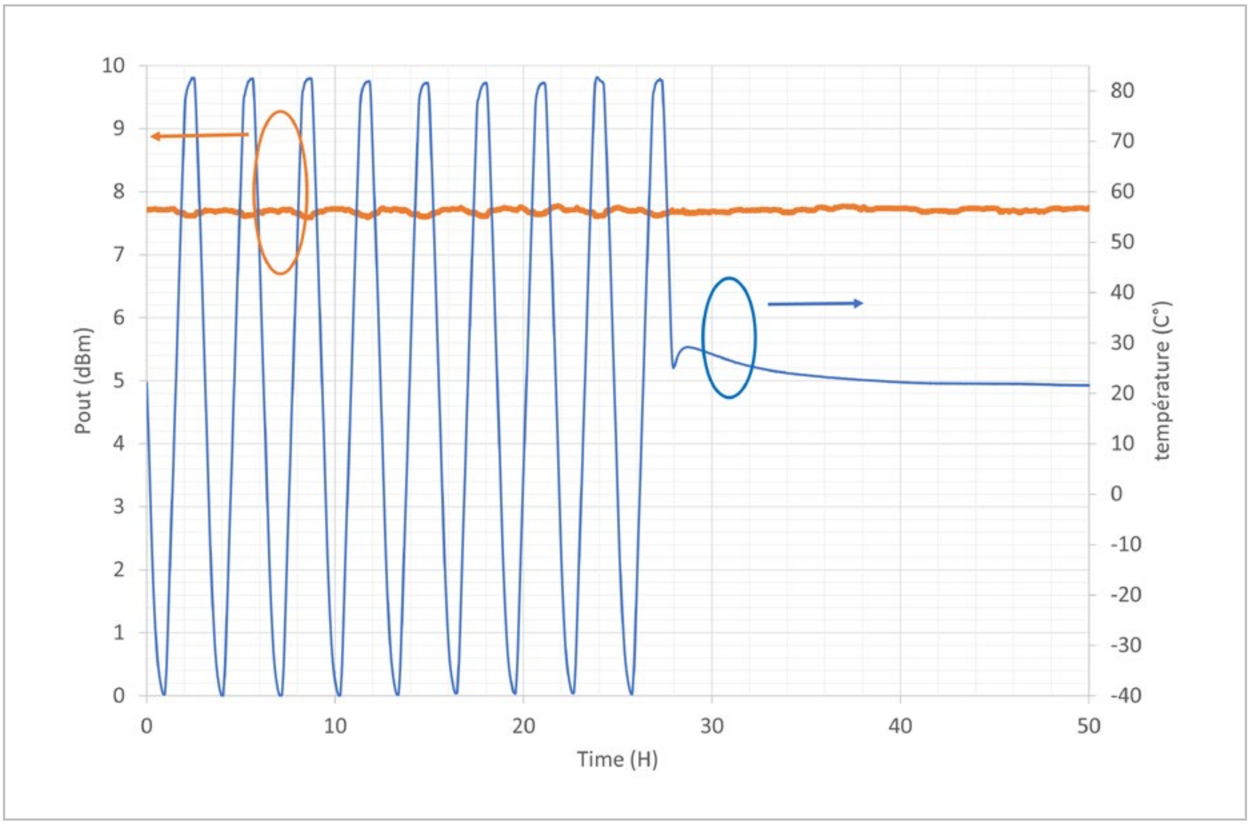

Fig. 4: Modulator stability versus temperature

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