# HIBISCUS: Simulator for the development of control strategies for coherent beam combining lasers with PISTIL technique

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**Abstract.** CBC (Coherent Beam Combining) is a key technology for the realisation of intense lasers. In this context, PISTIL (PISton and TILt interferometry), a precise metrology tool for measuring segmented wave surfaces, has been developed and used in particular to characterise and diagnose CBC ultrafast and digital laser in the framework of the XCAN (X Coherent Amplification Network) project at the École Polytechnique. We propose here to use it in a way to help the optimisation of control techniques by including PISTIL in an XCAN type CBC laser simulator. This will allow an easy tuning of the control laws, outside the clean rooms in which these large lasers are deployed and without the need to start them up.

## 1 Scientific context

Research on intense lasers with high peak and average power or digital laser is one of the major challenges of the 21$^{st}$ century, particularly for applications in fundamental physics (particle acceleration), defense (laser weapons) or medicine (proton therapy). However, there are some challenges regarding single intense lasers, such as cost, tap efficiency or non-linear effects.

### 1.1 CBC as a means of high laser power

It is in this context that many laboratories are working on active coherent beam combining [1, 2], such as the LULI laboratory at the École Polytechnique, in the framework of the XCAN project [3–5]. CBC consists in placing several laser fibres side by side in order to make them cooperate together to obtain an intense beam in the far field. This technique requires co-phasing with a precision of at least $\lambda/20$, and therefore a control loop coupled with a high-performance metrology system, in order to apply a real-time correction.

The demand for control loops has therefore increased significantly in recent years. However, the implementation work is not practical to use on a real laser system. Indeed, these are often very resource-intensive installations, requiring clean room work and regular maintenance periods. A real-time analysis tool is proposed to allow the verification of the different control strategies implemented.

### 1.2 PISTIL metrology tool

On this last point, the PISTIL interferometer [6] was developed, based on the coupling of a mask and a diffraction

grating, as illustrated in Figure 1. The analysis of the resulting image, called a pistilogram, allows to determine the values of piston, tip and tilt differences between two neighbouring surface elements, thanks to Fourier transform processing. The absolute phase of the wave surface can also be found using a generalised inversion reconstruction [6].
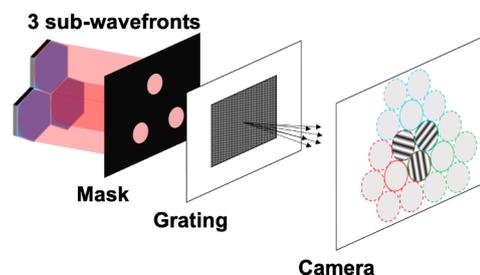


**Figure 1.** Schematic diagram of PISTIL: the beam, split by the mask, propagates through the grating in 3 pairs of ± 1 orders before interfering at a given distance.

## 2 The HIBISCUS bench

An experimental bench named HIBISCUS has been developed to test PISTIL as a high-performance phase metrology tool. Thanks to a segmented mirror, the bench allows, with an adapted laser source, to simulate a fragmented wave surface representative of the juxtaposition of several laser fibres found at the output of CBC lasers. It thus makes it possible to test various architectures of the analyser and develop the associated processing techniques without having to use the real CBC laser.

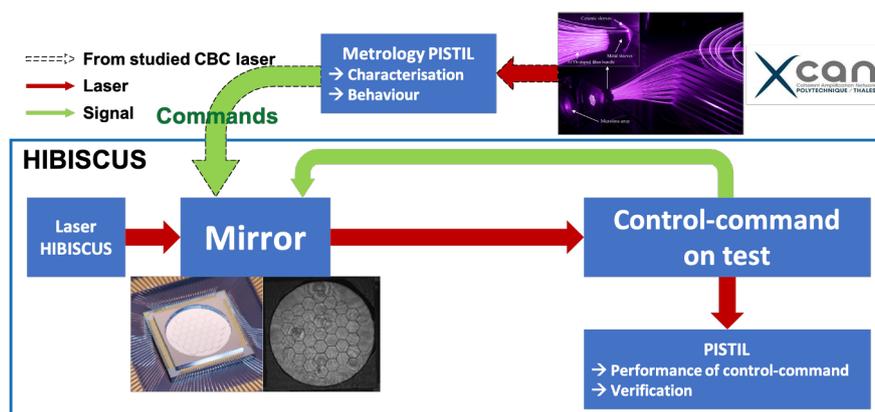---

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**Figure 2.** Schematic diagram of the HIBISCUS bench. The top part represents the phase drift measurements on the real laser by a metrology PISTIL. On the HIBISCUS bench, the behavioural command is sent to the mirror, illuminated by a working laser, to test the control system. Another PISTIL can be used for verification purposes.

### 2.1 Bench composition

The HIBISCUS bench is equipped with a laser source with a wavelength of 1064 nm (close to the wavelength of the XCAN laser which is 1032 nm). Other laser sources can easily be integrated depending on the type of laser that is simulated. An important element of this CBC simulation is the use of a 37-segment mirror "Hex-111-DM" from *Boston Micromachines*. Each segment can be moved in piston with an excursion well beyond the laser wavelength, in tip and tilt independently from other segments, and with a frequency of a few tens of kHz. The mirror is delivered with a software development kit, programmable on Python, which allows easy dialogue with the pistilogram processing program. This will also facilitate the improvement of the processing speed to reach high rate. Finally, a PISTIL interferometer is integrated to measure relative phase differences in real time and verify control strategies.

### 2.2 Procedure for high-speed CBC laser simulation

The first step in simulating the CBC ultrafast laser is to know the frequency and shape of the phase drift defects of the simulated laser. For this purpose, a plug-and-play metrology PISTIL is used, which is integrated to the real laser system to measure the representative open-loop defects.

The measurements are conducted onsite, with an accurate tool, in an absolute manner, with the fidelity of the real system. From these measurements, temporal phase drift curves are extracted. Then we combine the drift data with the analysis of the power spectral densities and a phase structure function (that allows the quantification of the average phase accumulation as a function of time) to program the mirror of the HIBISCUS bench with the representative signals of the laser phase drift, in amplitude and frequency. The wavefront emerging from the mirror thus accurately mimics the near-field wavefront of an CBC ultrafast laser at recombination.

The HIBISCUS bench is then ready to perform the dimensioning and control tests of the laser. Another PISTIL is eventually used to verify the performance of the control strategy. Figure 2 illustrates the use of PISTIL on the HIBISCUS bench to create the CBC ultrafast laser simulator.

In particular, in the case of our bench, we use a PISTIL specially dimensioned for real-time speed in order to carry out at the same time the control function.

Thus, the HIBISCUS bench becomes a laboratory tool for accurately simulating the behaviour of the XCAN CBC ultrafast laser source, and offers the possibility of designing, testing and improving the phase control strategy for CBC laser beams, while preserving the laser installation.

In addition to this, the Hibiscus bench is a modular tool that can accommodate a "client" system to test its control strategy for verification purposes. This is useful in particular to help the digital laser user to better control his beam and to shape it.

## 3 Perspectives

Once the PISTIL control-command is implemented and validated on the HIBISCUS bench, an adapted version will be integrated on the XCAN bench in order to carry out the loop on the real CBC system.

## References

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