Abstract. LMJ is a 240 high power laser beam facility for achieving laser matter interaction experiments, high energy density science, including the demonstration of fusion ignition through Inertial Confinement. The Laser Integration Line (LIL) facility is currently a 4-beam prototype for LMJ. In order to achieve precisely specified energies over a wide range of energies, power, temporal shapes and pulse lengths, a computational model has been developed and optimised on every LIL shot. This optimisation is based on the best fit possible between the predicted performances and the measured ones. It is therefore possible to predict the characteristics of a given shot in the 4-beam LIL configuration.

1. Introduction
The Laser Integration Line (LIL) facility is currently a 4-beam prototype for LMJ. The purpose of LIL and of these experiments is to show that the previously untested features of the LMJ laser design will perform as projected at LMJ scale and that the laser is therefore ready for final engineering design. LIL Quad beam waist was recorded for various pulse durations, smoothing techniques and for a wide range of laser intensities up to LMJ-nominal ones [1].

The characteristics of each LIL and LMJ beam line may vary due to slight differences in beam line gain and transmission. In order to achieve precisely specified energies over a wide range of energies, power, temporal shapes and pulse lengths, a computational model has been developed and utilized on every LIL shot. This Laser Performance Operation Model contains a description of each beam line (optical losses, gain variations, amplifier and frequency conversion configurations). The program uses feedback from LIL’s diagnostics (input and output sensors both at 1ω and 3ω) to optimise laser set-up. A full 4 dimensional (3 spatial and 1 temporal) model would take too much computer time and memory to predict a many beam configuration and set-up. The program can be optimised for a wide range of data: output energies and powers at 1 and 3ω whatever the number of laser slabs are pumped in the main amplifier sections. This optimisation is based on the best fit possible between the predicted performances and the measured ones.

2. LIL single beam simplified model
From a power balance point of view, the laser baseline can be restricted to 3 main sections or subsystems (see figure 1):

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• the front end that delivers and controls the input energy per beam and the temporal pulse shaping per quadruplet,
• the main amplifier section made of two amplifiers with 9 laser glass slabs each in a 4-pass layout;
• the final optic assembly where both frequency conversion and focusing take place; frequency conversion efficiency is managed per beam through the detuning angle of both doubler (KDP) and tripler (DKDP) crystals.

Figure 1. LMJ beamlet layout including laser diagnostics located at the input, at the main amplifier section output and inside the FOA. E stands for energy and P(t) for power.

CEA has developed a Beam Propagation Code called MIRO [3] that is used to predict the performances of a single beamline but because the LMJ overall system is quite complicated, we have developed a 1D-temporal analytical model that can be used on most common personal computers. This model is made in two steps, at first a structure of model is defined with a priori knowledge (or the first results of the exploitation of the system), and second those parameters are estimated by a comparison of the model and the system (Figure 2). During the estimation, the output error (OE) is minimized. This output error is the norm of the difference between the output of the simulation ($P_{simu}$) and the output of the system ($P_{exp}$) for the same input ($P(t)$).

$$OE = \sqrt{\sum_t (P_{simu}(t) - P_{exp}(t))^2}$$ (1)

The main amplifier section is defined as a collection of elements having different gains and transmission coefficients. Gains are modelled using Frantz-Nodvik theory [4]. An example is given figure 3. The solid curve is the record of the main amplifier output power (twelve laser slabs are fired), the dotted curve is the result of the model with the initial parameters and the plain curve is the result of the model with optimized parameters. For the frequency conversion stage, the equations describing the interaction of the three harmonics have been solved by Armstrong et al. [5].
Figure 2. Principle of the estimation of the parameters

Figure 3. Results of the estimation of the parameters: a 6 kJ 5 ns square pulse at 1ω

3. LIL 4 beam simplified model: application to LMJ quad
A typical LMJ four beam setup is shown figure 4. There are one oscillator and two pre-amplifier modules (PAM). The model contains the following variables:
- Input energy (E)
- Normalized input power as delivered by the pulse-shaping system or average waveform generator (AWG)
- PAM Gain (G1 and G2)
- Transmission of the beam splitters (T1 and T2)

For each beam, the main amplifier and frequency conversion settings are defined as explained above (see second paragraph).

4. LPOM algorithm for a typical LMJ quad
The LPOM model calculates the pulse shape required at injection into each of the 2 PAMs to achieve the desired 3ω pulse shape and provides this to the front-end at the AWG.

There are 3 steps in the algorithm:
• Inverse problem from 3\(\omega\) to 1\(\omega\) : to determine the energy and the AWG at 1\(\omega\) for a quadruplet, we interpolate the total required power at 3\(\omega\) with a curve \(P_{1\omega} = f(P_{3\omega})\). It is supposed that the quad energy is known or has been measured. The main assumption is that the average energy per beam at 1\(\omega\) is one fourth of the total (or quad) energy.
• Energy Balance : set \(G_1, G_2, T_1, T_2\) to obtain the required energy at 1\(\omega\) with the same energy for each beam,
• Determine AWG settings to obtain the shaped pulse required at 1\(\omega\) (Figure 5).

Because of the differences between PAM’s, it is expected that a single shaped pulse as given by the AWG can not fit both PAM’s. Our strategy is to set equal energies while tuning the transmission of the beam splitters (T1 and T2). So far, shaped pulses at the PAM’s output are homothetic, but shaped pulses will be different at the main amplifier output.

An example of adjustments of injected power at 3\(\omega\) for a quadruplet is given figure 6. In this case, energies at 1\(\omega\) at the main amplifier output are set equal to better than 0.1%. Powers are slightly different in the foot of the pulse (25%) and at the peak (12%), where saturation occurs differently.

![Figure 5. AWG algorithm at 1\(\omega\)](image)

![Figure 6. Results expected at the main amplifier output when the energies are set equal to 4.6 kJ](image)

5. Conclusion
In order to achieve precisely specified energies over a wide range of energies, power, temporal shapes and pulse lengths, a computational model has been developed and optimised on every LIL shot. This optimisation is based on the best fit possible between the predicted performances and the measured ones. It is therefore possible to predict the characteristics of a given shot in the 4- beam LIL configuration.

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