Controlling the group velocity of a Bessel Beam

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Bessel beams are a family of beams resulting from interference between plane waves propagating at an angle θ in a conical geometry. The result is a needle-like intense central spot along the optical axis. In some applications, such as terahertz generation [1], controlling the group velocity of the Bessel beam is fundamental. It is well known that the group velocity of the Bessel beam is influenced by its spatio-temporal profile [2]. Two examples are the Bessel X-pulse and the pulsed Bessel beam with a velocity of $\frac{c}{\cos(\theta)}$ and $c\cos(\theta)$ respectively [3]. However, Bessel pulses can have an infinite number of spatio-temporal profiles, and simulating their profile could give us the velocity of the Bessel beam. Although some existing programs can simulate spatio-temporal coupling in a setup [4], they are computationally intensive.

Here, we present a program that simulates the spatio-temporal profile of any Bessel beam in an arbitrary optical setup. Using a Zemax ray-tracing simulation of the optical setup, the program retrieves the optical path length, the incidence angle, and the transverse position x of each ray for a fixed longitudinal position z. We then compute the integral of the cw-contributions to the total pulse amplitude in space and time, as shown in Fig.1.

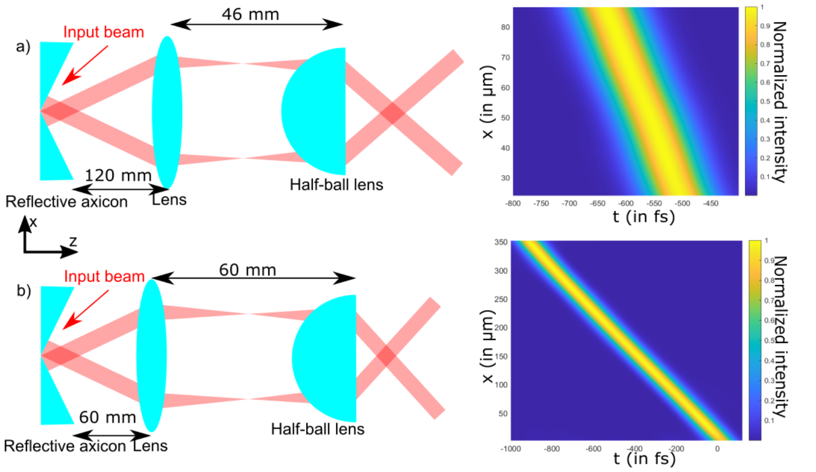

Fig. 1 : [left] Optical setup generating a high-angle Bessel beam. Different distances separate the components of the optical setup in a) and b). [right] Simulation result of the spatio-temporal intensity $I(x,t)$ of the upper part of the pulse at a fixed longitudinal position, just before the interference field for the arrival time t in function of the transversal position x at a given longitudinal position z for each optical setup. The group velocity for (a) is $2.3c$ while for (b) it is $1.6c$

We first validated our program with axicons and spatial light modulators to generate Bessel X-pulses and pulsed Bessel beams respectively. Figure 1 shows a more sophisticated setup, composed of a reflective axicon, a lens, and a half-ball lens, generating a high-angle Bessel beam [5]. In the top and bottom rows, the relative distances between optics are modified and we see, on the right side, the upper-half of the pulse just before the interference field. We see that the design overall has a strong impact on the spatio-temporal shape. We could compute the respective group velocities, which are respectively $2.3c$ and $1.6c$. This shows that the group velocity of a Bessel beam can be quasi-arbitrarily changed without changing any of the components in the optical setup.

In conclusion, we have developed a program to simulate the spatio-temporal shape of pulses in complex optical setup and demonstrate it is particularly useful to evaluate the effective group velocity of the Bessel beam. Our effective approach will impact on future design of of ultrafast Bessel beam shaper for a wide field of applications.

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