Photonic Switching Devices Using Light Bullets

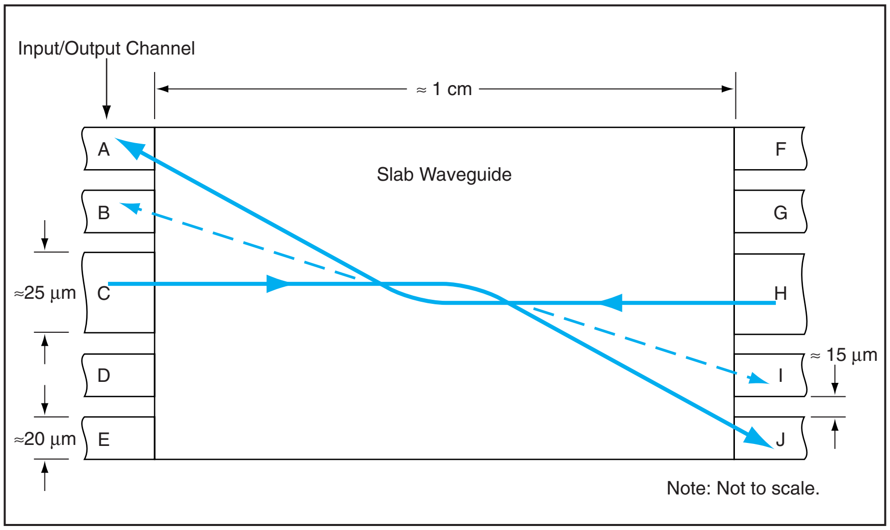
Light bullets would be used to deflect each other.

Ames Research Center, Moffett Field, California

A class of proposed photonic switching devices would utilize interactions among light bullets that have been studied theoretically. Because they function at speeds much greater than those of electrically, magnetically, and acoustically actuated switching devices, these and other photonic switching devices are attracting increasing attention as potential solutions to the problems of switching in the development of advanced communication networks, signal-processing systems, and digital computers.

The concept of a light bullet is a special case of the more general concept of a soliton: A light bullet is a small pulse of light that, in a suitable optically nonlinear material, retains its shape and is guided along its path of propagation by virtue of a balance among diffraction, group-velocity dispersion, and nonlinear self-phase modulation. To be suitable for supporting light bullets, a material should have a negative group-velocity dispersion and a sufficiently large nonlinear index of refraction.

Computational simulations have shown that two counterpropagating light bullets that approach each other within approximately the width of one of them would attract each other enough to change their directions of propagation by appreciable amounts: This phenomenon would be exploited to effect switching in the proposed devices. The figure schematically depicts a typical proposed device comprising a rectangular slab waveguide with multiple input/output channels at both ends. In one example, a light bullet would enter along a horizontal path through a central channel (channel C) simultaneously with another light bullet entering along a slightly laterally displaced horizontal path through the opposing central channel (channel H). Upon passing each other near the middle, the two light bullets would attract each other, causing the upper one to be deflected onto a downward slant and the lower one to be deflected onto an upward slant. The amount of attraction would increase with the intensity of either light bullet and would decrease with increasing lateral separation. Hence, by suitable choice of the intensities and the lateral separation between entry paths, one could cause the light bullets to travel to chosen output channels (A or B for the leftward-propagating light bullet, and I or J for the rightward-propagating bullet). Of course, if no light bullet were to enter through channel H, then the light bullet entering through channel C would propagate without deflection and leave through channel H.



Light Bullets Entering Through Opposing Channels would pass close to each other near the middle, where an attraction between them would deflect them to desired output channels. The dimensions shown here are for the example of doped glass described in the text. The dimensions would scale with the proposed nonlinear material.

There are many potential variations on the basic theme described above. For example, one light bullet could be made to enter horizontally through channel C and the other light bullet made to enter through channel I at a slant chosen to make the two light bullets pass near each other, deflecting each other to chosen output channels. Yet another variation would be to time the entering light bullets so that they would meet at a location other than the middle, the location being chosen in conjunction with the intensities and the lateral displacement to deflect the light bullets to the desired output channels.

A proposed material for a device like that shown in the figure is a commercial doped glass that has a nonlinear index of refraction of 1.11×10^{-14} cm^2/W and a group-velocity dispersion of –220 ps^2/km for light at a wavelength of ≈3.5 µm. It is estimated that this material would handle light bullets with a duration of ≈100 fs. The light bullets would be ≈10 µm wide in the plane of the figure, with a thickness about equal to that of the waveguide slab (≈2 µm).

The peak power needed to obtain a nonlinear effect strong enough to support a light bullet is an important consideration in designing a practical photonic switching device of this type. The peak power needed in this theoretical example has been estimated to be 150 kW. At a duration of 100 fs, the corresponding energy in a light bullet would be 15 nJ. These power and energy parameters are within the capability of currently available lasers.

However, it may be possible to reduce the power and energy requirements through the choice of a different nonlinear optical material. For example, the estimated required peak pulse power for a suitable semiconductor nonlinear optical material would be about 15 kW. The required power might be reduced even more sharply by use of multiple-quantum-well semiconductor structures: it has been estimated that such a structure might support the propagation of a light bullet at a peak power of only about 0.01 W.

This work was done by Peter M. Goorjian of **Ames Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com*** *under the category.*

This invention has been patented by NASA (U.S. Patent Nos. 5,963,683 and 5,651,079). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-14057.