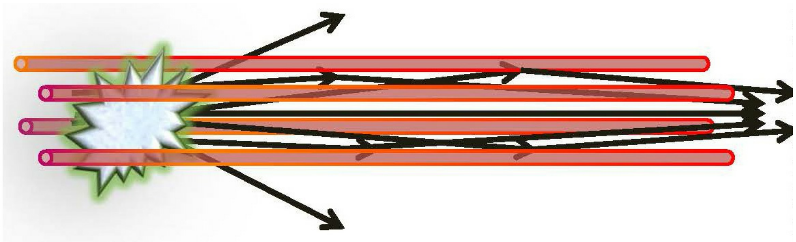
Creating Optical Cables Out of Thin Air

COLLEGE PARK, Md. – Imagine being able to instantaneously run an optical cable or fiber to any point on earth, or even into space. That's what Howard Milchberg, professor of physics and electrical and computer engineering at the University of Maryland, wants to do.

In a paper published in the July 2014 issue of the journal Optica, Milchberg and his lab report using an "air waveguide" to enhance light signals collected from distant sources. These air waveguides could have many applications, including long-range laser communications, detecting pollution in the atmosphere, making high-resolution topographic maps and laser weapons.



Because light loses intensity with distance, the range over which such tasks can be done is limited. Even lasers, which produce highly directed beams, lose focus due to their natural spreading, or worse, due to interactions with gases in the air. Fiber-optic cables can trap light beams and guide them like a pipe, preventing loss of intensity or focus.

Typical fibers consist of a transparent glass core surrounded by a cladding material with a lower index of refraction. When light tries to leave the core, it gets reflected back inward. But solid optical fibers can only handle so much power, and they need physical support that may not be available where the cables need to go, such as the upper atmosphere. Now, Milchberg's team has found a way to make air behave like an optical fiber, guiding light beams over long distances without loss of power.

Milchberg's air waveguides consist of a "wall" of low-density air surrounding a core of higher density air. The wall has a lower refractive index than the core—just like an optical fiber. In the Optica paper, Milchberg, physics graduate students Eric Rosenthal and Nihal Jhajj, and associate research scientist Jared Wahlstrand, broke down the air with a laser to create a spark. An air waveguide conducted light from the spark to a detector about a meter away. The researchers collected a strong enough signal to analyze the chemical composition of the air that produced the spark.

The signal was 1.5 times stronger than a signal obtained without the waveguide. That may not seem like much, but over distances that are 100 times longer, where an unguided signal would be severely weakened, the signal enhancement could be much greater.

Milchberg creates his air waveguides using very short, very powerful laser pulses. A sufficiently powerful laser pulse in the air collapses into a narrow beam, called a filament. This happens because the laser light increases the refractive index of the air in the center of the beam, as if the pulse is carrying its own lens with it.

Milchberg showed previously that these filaments heat up the air as they pass through, causing the air to expand and leaving behind a "hole" of low-density air in their wake. This hole has a lower refractive index than the air around it. While the filament itself is very short lived (less than one-trillionth of a second), it takes a billion times longer for the hole to appear. It's "like getting a slap to your face and then waiting, and then your face moves," according to Milchberg, who also has an appointment in the Institute for Research in Electronics and Applied Physics at UMD.

On Feb. 26, 2014, Milchberg and his lab reported in the journal Physical Review X that if four filaments were fired in a square arrangement, the resulting holes formed the low-density wall needed for a waveguide. When a more powerful beam was fired between these holes, the second beam lost hardly any energy when tested over a range of about a meter. Importantly, the "pipe" produced by the filaments lasted for a few milliseconds, a million times longer than the laser pulse itself. For many laser applications, Milchberg says, "milliseconds is infinity."

Because the waveguides are so long-lived, Milchberg believes that a single waveguide could be used to send out a laser and collect a signal. “It’s like you could just take a physical optical fiber and unreel it at the speed of light, put it next to this thing that you want to measure remotely, and then have the signal come all the way back to where you are,” says Milchberg.

First, though, he needs to show that these waveguides can be used over much longer distances—50 meters at least. If that works, it opens up a world of possibilities. Air waveguides could be used to conduct chemical analyses of places like the upper atmosphere or nuclear reactors, where it’s difficult to get instruments close to what’s being studied. The waveguides could also be used for LIDAR, a variation on radar that uses laser light instead of radio waves to make high-resolution topographic maps.