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Scientists Build First 'Frequency Comb' To Display Visible 'Teeth'

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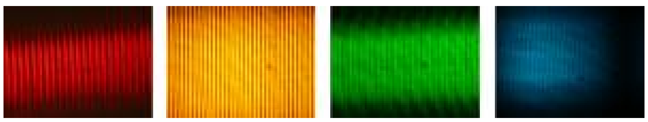

Photographs of four different regions of the new optical frequency comb. The light is filtered through a grating spectrometer and photographed with a digital camera through a microscope. Each visible line or "tooth" is an individual frequency in the comb, which spans the visible spectrum from red to blue. More than 1,500 such photos would need to be lined up to show the entire comb. Credit: S. Diddams/NIST

(PhysOrg.com) -- Finally, an optical frequency comb that visibly lives up to its name. Scientists at the University of Konstanz in Germany and the National Institute of Standards and Technology in the U.S. have built the first optical frequency comb -- a tool for precisely measuring different frequencies of visible light -- that actually looks like a comb.

As described in the Oct. 30 issue of *Science*, the "teeth" of the new frequency comb are separated enough that when viewed with a simple optical system—a grating and microscope—the human eye can see each of the approximately 50,000 teeth spanning the visible color spectrum from red to blue. A frequency comb with such well-separated, visibly distinct teeth will be an important tool for a wide range of applications in astronomy, communications and many other areas.

A basis for the 2005 Nobel Prize in physics, frequency combs are now commonplace in research laboratories and next-generation atomic clocks . But until now, comb teeth have been so closely spaced that they were distinguishable only with specialized equipment and great effort, and the light never looked like the evenly striped pattern of the namesake comb to the human eye.

Each tooth of the comb is a different frequency, or color (although the human eye can't distinguish the very small color differences between nearby teeth). A frequency comb can be used like a ruler to measure the light emitted by lasers, atoms, stars or other objects with extraordinarily high precision. Other frequency combs with finer spacing are highly useful tools, but the new comb with more visibly separated teeth will be more effective in many applications such as calibrating astronomical instruments.

The new comb is produced by a dime-sized laser that generates super-fast, super-short pulses of high-power light containing tens of thousands of different frequencies. As in any frequency comb, the properties of the light over time are converted to tick marks or teeth, with each tooth representing a progressively higher number of oscillations of light waves per unit of time. The shorter the pulses of laser light, the broader the range of frequencies produced. In the new comb described in Science, the laser pulses are even shorter and repeated 10 to 100 times faster than in typical frequency combs. The laser emits 10 billion pulses per second, with each pulse lasting about 40 femtoseconds, or quadrillionths of a second, producing extra-wide spacing between individual comb teeth.

Another unusual feature of the new comb is efficient coupling of the laser pulses into a "nonlinear" optical fiber, which dramatically expands the spectrum of frequencies in the comb. Since details of the unusually powerful dime-sized laser were first published in 2008, scientists have doubled the average pulse power directed into the fiber, enabling the comb to reach blue colors for the first time, producing a spectrum across a range of wavelengths from 470 to 1130 nanometers, from blue to infrared. The 50,000 individual colors become visible when the light emitted from the fiber is filtered through a grating spectrometer, a common laboratory instrument that acts like a souped-up prism.

The broad spectrum spanned by the comb—unusual for such a fast pulse rate—enables all the frequencies to be stabilized, using a NIST-developed technique that directly links optical and radio frequencies. Stabilization is crucial for applications.

The ability to directly observe and use individual comb teeth will open up important applications in astronomy, studies of interactions between light and matter, and precision control of high-speed optical and microwave signals for communications, according to the paper. NIST scientists previously have shown, for example, that this type of frequency comb could boost the sensitivity of astronomical tools searching for other Earthlike planets as much as a hundredfold. In addition, the new comb could be useful in a NIST project to develop optical signal-processing techniques, which could dramatically expand the capabilities of communications, surveillance, optical pattern recognition, remote sensing and high-speed computing technologies.

The laser was built by Albrecht Bartels at the Center for Applied Photonics of the University of Konstanz. The frequency comb was built and demonstrated in the lab of NIST physicist Scott Diddams in Boulder, Colo.

More information: A. Bartels, D. Heinecke, and S.A. Diddams. 10 GHz Self-referenced Optical Frequency Comb. *Science*. Oct. 30, 2009.

Source: National Institute of Standards and Technology (news : web)