Exoplanets to medical tests: Tiny frequency devices open up new applications

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Accurately measuring frequencies of light is required for timekeeping. It's also a critical component in many science experiments and technologies, from military defense to detecting air pollution, tests of fundamental physics to the detection of exoplanets. "There are few human enterprises that are both more fundamental and more important for technology," says Curtis Menyuk, professor of Computer Science and Electrical Engineering at UMBC.

Since its invention in 2000, a special measurement device called an optical frequency comb has emerged as a powerful tool for completing these measurements. A frequency comb consists of many regularly-spaced frequencies that are like the teeth in a comb. These teeth function like the lines in a ruler, making it possible to measure frequencies with unprecedented accuracy and speed. Frequency combs have proven so important that half of the Nobel Prize in Physics in 2005 was awarded to John Hall and Theodor Hänsch for developing them and demonstrating their usefulness.

However, "A difficulty with most of the comb systems is that they require expensive, laser-based equipment," says Menyuk. In 2009, a research group in Switzerland showed that it is possible to use tiny millimeter-sized resonators, called microresonators, to generate frequency combs. That led to a worldwide effort to develop these combs for applications. In the United States, this effort has been supported by NSF, NASA, and DARPA.

However, this effort has faced significant challenges, too. One challenge is that the power of each "tooth" of the comb is too weak without significant amplification, which requires a large, external system. Another challenge is generating the comb in the first place, "which again requires an elaborate start-up system," Menyuk explains. "As a result, the system is not compact, which defeats the purpose of using microresonators."

A new paper in *Optica*, co-authored by Menyuk, his graduate student Zhen Qi, and their colleagues at Technological University of Pereira and Purdue University, describe an approach that can potentially solve both of these problems using novel light waveforms.

All the frequency comb systems to date have used special light waves called solitons, which Menyuk has been studying for more than thirty years. He, Qi, and their co-authors suggested that unusual lightforms known as cnoidal waves or Turing rolls are better adapted than solitons to the small size of the microresonators. They demonstrated theoretically that combs using these waveforms can be obtained by just turning on the power source for the microresonator, unlike soliton combs, and yield far more powerful comb teeth—which would solve both of the major challenges bogging down microresonator development.

"The successful development of compact, on-chip frequency combs will greatly expand the range of applications for frequency combs," Menyuk says. "In particular, they would greatly increase the rapidity with which data could be synchronized across distances, enabling applications that right now we can only imagine."

More information: Zhen Qi et al, Dissipative cnoidal waves (Turing rolls) and the soliton limit in microring resonators, *Optica* (2019). DOI: 10.1364/OPTICA.6.001220

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