FURTHER READING

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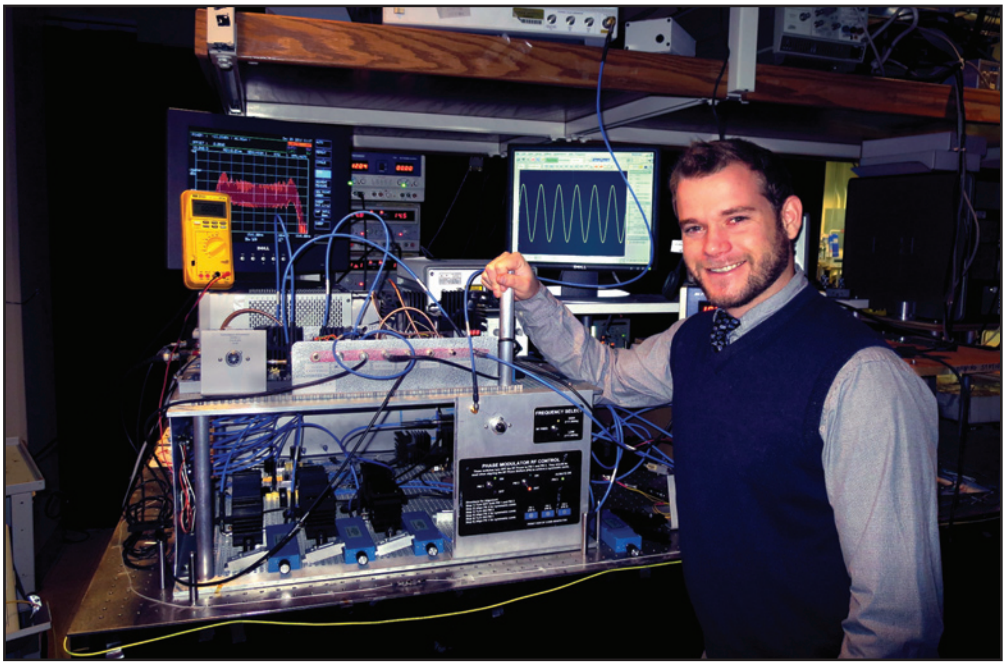
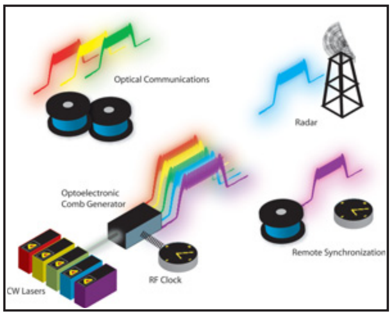
'Broadly tunable, low timing jitter, high repetition rate optoelectronic comb generator', A. J. Metcalf, F. Quinlan, T. M. Fortier, S. A. Diddams, and A. M. Weiner

Frequency combs can exhibit low jitter but still allow for frequency tuning

inside view*

Researchers at Purdue University and the National Institute of Standards and Technology (NIST) have generated a frequency comb with low jitter that still allows for frequency tuning. The comb also does not require cavity locking. One of the authors, Andrew (AJ) Metcalf, tells us more.





TOP: AJ Metcalf in one of the Ultrafast Optics labs at Purdue. Next to AJ is an optoelectronic frequency comb generator (bottom) and some other optoelectronics set up for RF-photonic filtering experiments
BOTTOM: Optical frequency combs have a wide variety of applications, from clocking to radar

Tell us about optical frequency combs

An optical frequency comb is a spectrum made up of evenly spaced frequency components that share a fixed phase relationship. Although the absolute frequencies of the comb lie in the optical regime, their relative spacing is in the microwave range, providing a direct connection between the two disparate regions of the electromagnetic spectrum. This relationship has been leveraged to generate radiofrequency and microwave signals with unmatched precision.

Combs can be formed directly in short pulsed laser sources or through external modulation of a CW laser. The latter is often used for applications that require mode spacing greater than 10 GHz, which is difficult to achieve directly from short pulsed lasers. In this regime, comb formation is typically accomplished through nonlinear mixing in a mirroring resonator or through strong electro-optic modulation of a single frequency laser. In our Letter, we use commercially available electro-optic phase and intensity modulators driven by a low-noise RF source to produce a frequency comb from a single frequency laser. These combs have the unique property of independent tuning of both the centre frequency and the repetition rate.

Such frequency ranges must make them versatile…

Ever increasing data demands, and more stringent synchronisation requirements, have exceeded the capabilities of current electronic oscillators and synthesisers. The challenges faced for generating and processing broadband electrical signals can be circumvented by working at much higher optical frequencies, where the relative signal bandwidth is a smaller fraction of the carrier frequency and therefore more manageable. Frequency combs with mode spacing from 10–100 GHz can provide solutions in the generation, processing, and down converting of high frequency electrical signals. Applications include high speed communication, radar, sensing, and metrology. Optoelectronic modulation not only offers a direct method to generate high repetition rate combs, but also provide a unique flexibility which has opened the door for many novel techniques not possible with traditional comb sources at any repetition rate.

In one such example, reported in the journal Nature, our Purdue group exploited the reversibility property of electro-optic comb generators to open up and close temporal gaps in time. This effectively acted as a temporal analogue to spatial cloaks that have been popularised in sci-fi movies, but with real world applications in secure communications.

What are the current issues?

A high degree of frequency stabilisation is difficult to achieve when working at large repetition rates. In mode-locked lasers, frequency stabilisation is achieved by comparing a beat note between two frequencies separated by an octave. In order to get this broad a comb, short, high intensity pulses are passed through a nonlinear medium to create new frequency components through non-linear mixing. This poses a challenge at high repetition rates, where the intensity of each pulse is much lower.

Furthermore, many applications in optical communications and RF photonics do not require that much bandwidth. Other optoelectronic based methods have used resonant cavities to improve stabilisation and increase bandwidth but this comes at the cost of flexibility. Our aim is to achieve a low noise stable source while maintaining ideal properties for RF-photonic applications, like a flat optical spectrum, variable bandwidth, and choice of centre frequency and repetition rate.

And that's what you've reported in your letter?

Our research shows that we can produce robust high repetition rate frequency combs with extremely low phase noise of -100dBc/Hz at 1 Hz offset and sub 10 femtosecond timing jitter while maintaining the simplicity and flexibility afforded by optoelectronics.

Before these experiments, we knew the phase noise of an electro-optic comb could be no better than the RF source used to drive the modulators. However, we wanted to characterise any noise the comb generation process added and determine a lower bound for the stability of our source. The results indicate the comb generation process does not significantly impact the phase noise inherited by the RF drive signal, and provides a rout to low noise frequency synthesis and waveform generation. In addition, these results were achieved without a resonant cavity which reduces the stability requirements placed on the CW seed laser.

What next for the group and the field?

The co-authors at NIST have used this type of comb source to synthesise ultra-low noise signals from RF to 100 GHz of bandwidth with a precision and flexibility that cannot be accomplished electronically. This fits into our broad goal of leveraging photonic techniques to enable future high frequency applications which are beyond the limit of established approaches.

Increasing data demands will require greater bandwidth capacity in the telecom industry and will fuel advancements in optical components such as modulators and detectors. We will start to see optical devices play a larger role in data-hungry electronics like personal computers and HD TVs. As a result, integrated optical components will become cheaper, enabling cost effective implementation of novel photonic techniques like ours. Applications like high resolution radar, state of the art navigation, and advanced telecommunication systems will likely be the first to adopt optical frequency comb technology in the field.