interview

Single-laser high-volume transmission

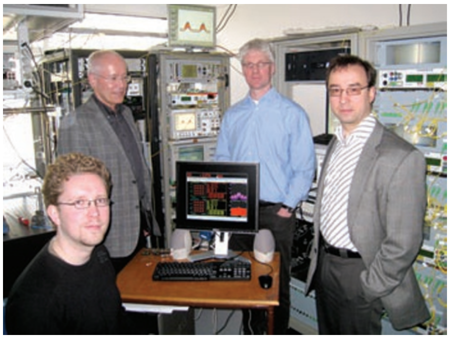
Researchers in Europe have demonstrated that an optical fast Fourier transformation technique can be used to efficiently encode and decode information at rates of terabits per second in a single laser source.

What is your work about?

Over the past 10–20 years, one of the main challenges in optical communication has been to increase transmission bit-rates. Much effort has been made to reduce component sizes and increase spectral efficiencies, which are measured in terms of bits per second per spectral bandwidth. Our experiments have demonstrated that information can be encoded in a single laser source at rates of 26 Tbit s^{-1}, transmitted over a distance of 50 km and then viably and energy-efficiently decoded. The trick is to exploit the power of high-speed optical processing while simultaneously utilizing the versatility of low-speed electronic processing. Our work demonstrates that possible future solutions for achieving encoding/decoding rates of terabits per second might not involve solely optics or electronics, but could instead synergistically exploit the best of both.

What is your approach?

We first exploit the versatility of electronics to perform low-bit-rate quadrature amplitude modulation on 325 subcarrier signals, and then use an optical implementation of the inverse fast Fourier transform to encode these subcarriers in a terabit-per-second orthogonal frequency-division multiplexed data stream. Conversely, at the receiver end we use the optical fast Fourier transform (FFT) to process the terabit-per-second data stream in real time. Such speeds are far beyond the capabilities of today's electronic components. To perform real-time FFT processing in the optical domain, we simplified the FFT to such an extent that it could be implemented in the optical domain. We discovered that the discrete Fourier transform could be rewritten such that it would correspond to a simple cascade of delay interferometers followed by a pulse carver — what we call an optical time gate. We also discovered that deriving a single Fourier coefficient would require only a few delay interferometers, a single optical gate and a broadband filter. This approach allows us to easily perform the FFT on optical signals at almost arbitrary speed. In addition, the associated mathematical operations can be performed with little power consumption because the set-up is mostly comprised of passive filters and a single time gate.



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The synergetic exploitation of both optics and electronics could be the solution for future terabit-per-second encoding and decoding. From left to right: David Hillerkuss, Wolfgang Freude, Christian Koos and Juerg Leuthold.

What have you achieved?

We have encoded information at a rate of 26 Tbit s^{-1} onto a single source with a spectral efficiency of 6.3 bit s^{-1} Hz^{-1}. To achieve this, we created a frequency comb derived from a mode-locked laser with more than 325 spectral lines. The line quality was high enough such that more than 80 Gbit s^{-1} of information could be encoded on each line, thus achieving the highest bit-rate data stream ever encoded in a single light source. We then transmitted the signal over 50 km of standard single-mode fibre and decoded it using our novel all-optical FFT approach. Finally, we demonstrated that such an implementation does not require significant power because the optical FFT is extremely efficient. Our current set-up uses approximately 1.5 W per subcarrier, but 90% of this energy is spent on cooling the electro-absorption modulator that we use as a time gate. Future integrated optical solutions might be much more efficient.

Have you encountered any difficulties along the way?

The biggest difficulty was finding an optical source that could generate an optical spectrum comprising more than 325 subcarriers, each with sufficiently high optical signal-to-noise ratio. This task took us at least two years. However, we eventually found the proper combination of high-quality mode-locked laser and a matching highly nonlinear fibre for spectral broadening. In addition, we employed a simple but powerful spectral slicing technique that was made possible by recent 'wave-shaper' techniques.

What are the implications of your findings?

First, our work shows that implementing mathematical functions in the optical domain may provide unprecedented processing speeds. The suggested FFT scheme might therefore stand as an example for implementing other useful mathematical functions. Our work also shows that performing operations at high speed does not necessarily require excessive power. Indeed, optical techniques may even be the key to achieving highly energy-efficient processing. It is our conviction that high-speed processing need not necessarily come at the price of increased environmental pollution. It is rather a matter of choosing the proper techniques — and optics is one of the choices. In the field of optical communication, we believe that our work shows a reasonable path towards the implementation of super-channels with bit-rates higher than 1 Tbit s^{-1}. For the field of all-optical processing and computation, our work has shown that optics can offer unprecedented processing speeds that could be useful for pipeline processing or massively parallel applications.

How can the work be improved?

Our work has shown that there is not yet an upper limit for encoding information in a single laser beam. Encoding a 100 Tbit s^{-1} data stream seems within reach, although this may not be simple. Our transmission experiment is currently limited by the 50 km fibre set-up available in our university lab, but we are now looking at demonstrating longer-distance transmission.

INTERVIEW BY RACHEL WON

Juerg Leuthold and co-workers have an Article on single-laser terabit-per-second data transmission on page 364 of this issue.