Transfer of an optical frequency comb over the JANET-Aurora network

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What is an optical frequency comb?

A femtosecond frequency comb is a laser that produces a train of extremely short pulses (from tens to hundreds of fs).

In the frequency domain the pulse train corresponds to a comb of equally spaced frequencies with spacing equal to the inverse of the time interval between pulses.

Frequency spacing = \frac{1}{\text{Time interval between pulses}}
What they are used for?

- Ultra accurate measurements of optical frequencies
  - Optical clocks
  - Tests of fundamental physics
- Fast spectroscopy (many lines at the same time)
- Astrophysics (spectrogram calibration)
- Attosecond physics

**Telecommunications?** Maybe soon…
Femtosecond optical frequency combs at NPL

- Ultrastable Nd:YAG lasers
- Sr lattice clock
- Sr\(^+\) optical clock
- Yb\(^+\) optical clock
- Fibre links to optical clocks at other European NMIs
- Hydrogen spectroscopy
- Iodine-stabilised HeNe lasers
- Acetylene-stabilized lasers
- Microwave standards (Cs/Rb fountains)
Frequency comb dissemination

- Ultra stable and accurate optical frequency combs can be generated in frequency metrology laboratories

  The frequency of each optical mode can be stabilized below 1 Hz
Comb transfer = Optical + Microwave frequencies
Can an ultra stable comb be disseminated to remote laboratories via optical fibre?
Fibre noise degrades the phase and amplitude stability of the transmitted signal.

Sources of noise:
- Vibrations
- Temperature changes

LAB A

long fibre

LAB B
By returning a portion of the signal back to the transmitter, the fibre noise can be measured.
The JANET–Aurora optical network

It links 5 Universities, total span ~800 km

There are two fibres between the University of Southampton and the hub at Crawley Court: by joining the two fibres in the hub we can make a 86 km span with both ends in the laboratory.
Results: frequency stability of the repetition rate

15,000 equally spaced optical frequencies

+ 100s of equally spaced microwave frequencies (as many as the photodetector BW allows)

Fractional frequency stability vs. Averaging time (s)
Measurement setup

- 1.55µm Mode Locked Laser
- Optical-to-microwave conversion + phase comparison
- Fibre Stretcher (actuator)
- Dispersion compensating fibre
- Partial reflector
- Installed fibre
- Timing jitter analysis

NPL
National Physical Laboratory

Southampton

43 km

Crawley Court
Results: phase noise and timing jitter

<table>
<thead>
<tr>
<th>Range (Hz)</th>
<th>Jitter (fs)</th>
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<tbody>
<tr>
<td>0.1-1</td>
<td>2.9</td>
</tr>
<tr>
<td>0.1-10</td>
<td>6</td>
</tr>
<tr>
<td>0.1-10²</td>
<td>12.2</td>
</tr>
<tr>
<td>0.1-10³</td>
<td>17.4</td>
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<td>0.1-10⁴</td>
<td>77.9</td>
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<tr>
<td>0.1-10⁵</td>
<td>82.2</td>
</tr>
</tbody>
</table>

- SSB Phase Noise (dBc/Hz)
- Frequency (Hz)
- Timing Jitter (fs)

- free running
- noise suppression active
Conclusions

We propagated an optical frequency comb over a 86 km-long installed optical fibre link. By actively cancelling the noise introduced by the fibre we demonstrated that:

**Time domain**
- it is possible to transfer an optical pulse train with timing jitter lower than 100 fs (measured over short and long time scales)

**Frequency domain**
- it is possible to transfer a 30 nm-wide optical comb (15,000 optical modes) where the mode frequency spacing is preserved at parts in $10^{17}$

What can we do with this technique?

- We can transfer ultra stable microwave frequencies (such as those generated at NPL) over long lengths of fibre

- Science fields where ultra precise timing signals are required could benefit from this technique (such as particle accelerators and arrays of radiotelescopes)

Possible applications in the telecommunications field?

Open to discussions!
The National Measurement System is the UK's national infrastructure of measurement Laboratories, which deliver world-class measurement science and technology through four National Measurement Institutes (NMIs): LGC, NPL the National Physical Laboratory, TUV NEL The former National Engineering Laboratory, and the National Measurement Office (NMO).