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Petabit-per-second data transmission using a chip-scale microcomb ring resonator source

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Petabit per second data transmission using a chip-scale microcomb ring resonator source Supplementary Information

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Supplementary Note 1.
Comparison of optical frequency comb sources for transmission demonstrations.

Many different types of integrated micro ring resonator based comb sources have been used in data transmission experiments. They all have different merits in terms of bandwidth, conversion efficiency, threshold power, power handling and line spacing. The three main types of integrated Kerr combs we discuss in the main text are bright solitons, dark pulse Kerr (DPK) combs and Soliton crystals. Supplementary table Tab.1 contains a summary of the key information of 5 different transmission experiments using Kerr comb sources. We calculate the spectral efficiency as the total data rate divided by the combined width of all used channels, which might differ from how the authors originally calculated it.

Supplementary Table 1 | Comparison of optical frequency comb sources for high-capacity transmission demonstrations.

	Fiber type	Datarate per core	Total rate	Number WDM channels	Spectral efficiency	Total bandwidth	Channel spacing	Modulation Rate	Source
Bright soliton (Two interleaved comb sources)	75 km SSMF	50.2 Tbit/s	50.2 Tbit/s	179	5.61 bit/s/Hz	10 THz	50 GHz	40 Gbaud	Ref 1
Bright Soliton	82 km SSMF	12 Tbit/s	12 Tbit/s	52	10.44 bit/s/Hz	1.24 THz	22.1 GHz	21.5 Gbaud	Ref 2
Dark Pulse Kerr Comb	80 km SSMF	4.4 Tb/s	4.4 Tb/s	20	0.96 bit/s/Hz	3.8 THz	230 GHz	20 Gbaud	Ref 3
Soliton crystals	75 km SSMF	44.2 Tb/s	44.2 Tb/s	160	11.28 bit/s/Hz	3.92 THz	24.5GHz	23 Gbaud	Ref 4
Dark Pulse Kerr comb	7.9 km SM-MCF	49.7 Tb/s	1.84 Pbit/s	223	8.92 bit/s/Hz	7.8 THz	35 GHz	32 Gbaud	This work

Supplementary Note 2.
Experimental setup for data transmission

Supplementary Fig. 2a. shows the setup which was used in the data transmission experiment discussed in the main paper, where a DPK comb was used as a source to transmit 8251 independent channels.

A single extended cavity laser is used to pump the micro ring in order to generate the DPK comb with a line spacing of 105 GHz. The pump laser is a CoBrite type NX with a linewidth of 10 kHz. It is amplified by a high power EDFA to 32 dBm and a narrow optical band pass filter is used to remove the ASE from the EDFA. A polarization controller is used to align the polarization of the fibre with the polarization of the waveguide on the micro ring. The light is coupled on and off the ring with a loss of 2 dB per facet using lensed fibres with a working distance of 14 um and a spot size of 2.5 um. The spectrum of the generated comb is shown in Supplementary Figure 2 as Spectrum A.

Two 20-dB optical couplers are used to split the generated optical frequency comb for stabilizing the comb state using on-chip micro-heaters and the fibre coupling to and from the chip using piezo actuated adjustment stages, respectively.

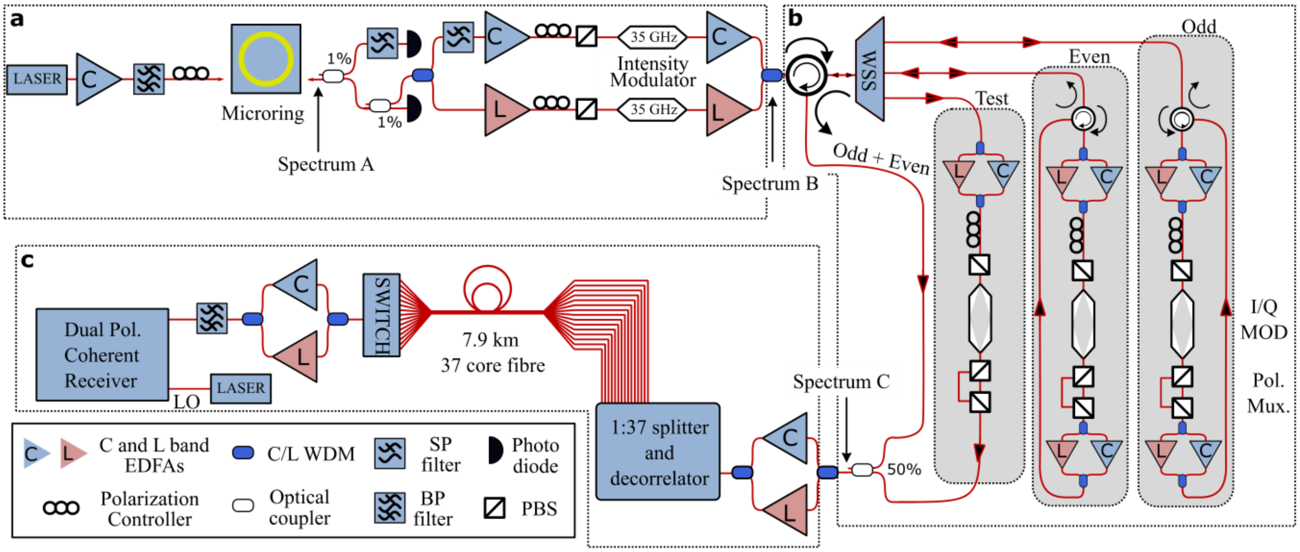
The remaining generated comb light is separated into the C and L bands. The C band part contains an additional filter to further reduce the pump line intensity. The C and L bands are then amplified and then modulated by a Mach-Zehnder intensity modulator to generate two sidebands on each comb line. This reduces the line spacing to 35 GHz at the cost of a 10 dB loss. The bias voltage of the modulators is adjusted such that they operate in the linear regime to ensure that no significant higher order sidebands are generated.
The two bands are then amplified again before being combined and sent through a circulator to the wavelength selective switch (WSS). The spectrum of the tripled comb, before we send it into the waveshaper, is shown on supplementary figure 2 as Spectrum B.

The comb lines are divided into three groups, namely odd, even, and channel-under-test. All three groups are modulated at 32 Gbaud using I/Q modulators and then polarization multiplexed using polarization multiplexing emulators. The odd and even channels are amplified and passed back through the WSS. The channel-under-test is then coupled with the odd and even channels using a 3 dB power coupler. There is noticeable crosstalk for the channel-under-test from this WSS setup, which is detailed in Supplementary Notes 3.The spectrum of the comb with all channels combined is shown on supplementary figure 2 as Spectrum C.

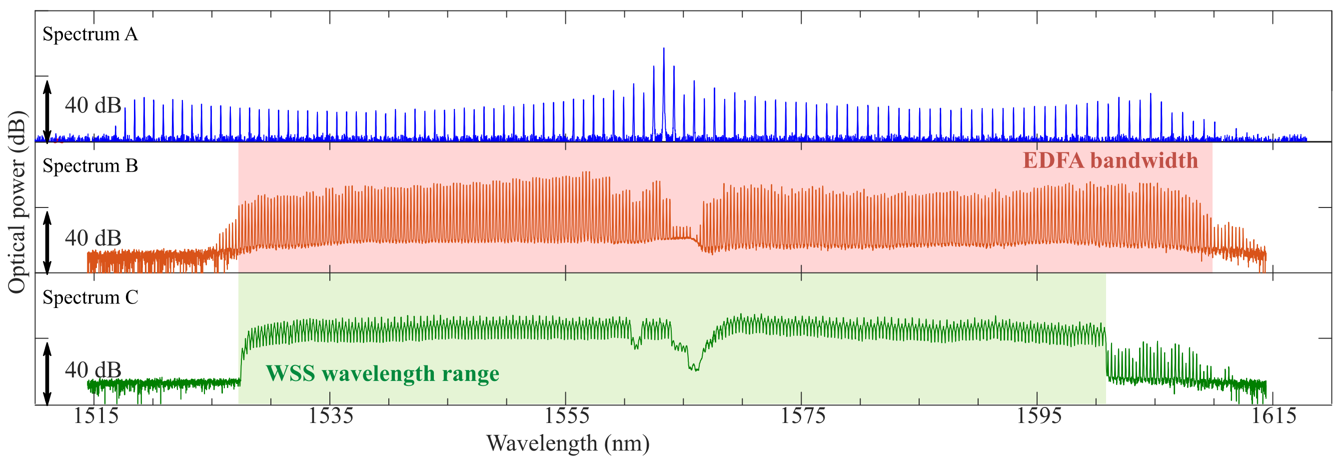
The combined WDM signal is amplified and launched into a 1:37 power splitter. The 37 spatial channels are decorrelated and fanned into the fibre using a combination of free space optics.

After propagating in the 7.9 km 37-core fibre, the spatial channels are fanned out in free space again and fed into a fibre switch for the extraction of the target spatial channel. The total loss from the input of the 1:37 splitter to the output of the fibre switch is 26 dB on average and within the range from 25 dB to 27.8 dB.

The channel-under-test is filtered out by an optical bandpass filter and finally detected by a dual-polarization coherent receiver with a local oscillation (LO) laser identical to the pump laser.

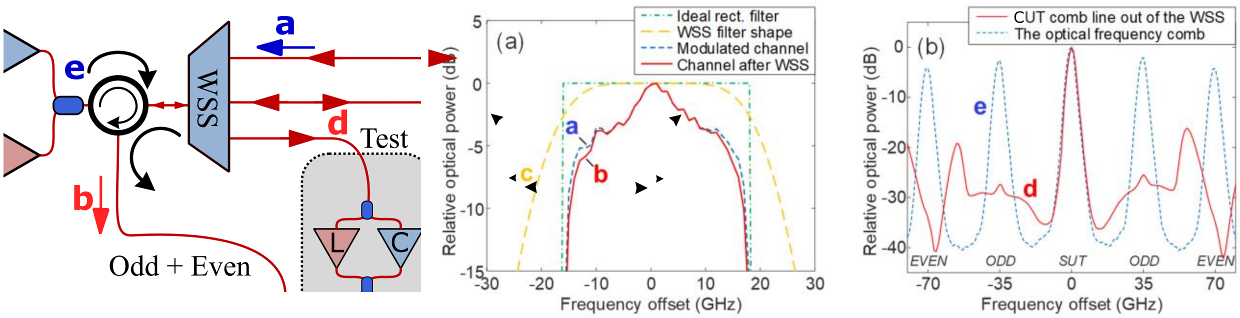


Supplementary Figure 1 | Detailed setup for data transmission experiment using the Dark Pulse Kerr comb. ***a*** *is the 35 GHz linespacing comb source generation.* ***b*** *is the data modulation,* ***c*** *is the transmitter and receiver.*



Supplementary Figure 2 – Spectra of the Dark Pulse Kerr comb at three different points in the experiment as indicated in Supplementary Note 2. The shaded areas illustrate the bandwidth limitations of the EDFAs and the waveshaper.

Supplementary Note 3.
Waveshaper crosstalk



Supplementary Figure 3 - Waveshaper crosstalk. The waveshaper demonstrates some crosstalk between input and output ports which becomes visible in the test channel neighbors when we send the odd and even channels back through the waveshaper.

Fig 3(a) shows the WSS filter shape and the shape of one of the dummy channels before and after the second pass of the WSS. Here we see a negligible distortion of the spectral shape.

Fig 3(b) shows the spectrum of the channel-under-test after splitting the comb using the waveshaper. A crosstalk level of -25 dB is observed from the neighboring channels, which limits the achievable OSNR of the test channel. The cause of this crosstalk is due to limited isolation between the input and output ports of the WSS and it can be avoided if a second WSS is used to interleave the channels.

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