

Exploiting a Centrally Powered Coherent Microcomb for Lightweight Optical Transmission

Corresponding Author: Professor Jian Wang

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

This paper presents the use of a self injection locked microcomb as a source for coherent optical fiber transmission in the C-band achieving a net rate of 8.4 Tbps in WDM scheme and a net 200 Tbps in a WDM + MCF configuration. Additionally, MDM transmissions are also demonstrated achieving net 9.57 and 8.37 Tbps. The authors claim a 10-fold reduction in resource requirements for similar capacity architectures. The paper is well organized but could improve in the following areas.

Please specify in more details the exact DSP that was used at both the transmitter and at the receiver. It would be interesting to know filter lengths, equalization and pre-emphasis used, etc.

The authors claim the first coherent single-lambda comb-based transmission results over 1 Tbps, however their citation [8] (Bernal S, et al.) includes a single-lambda demonstration of 1.6 Tbps in the O-band. Please adapt the claim accordingly.

The authors compare the performance of the comb lines vs commercial ECLs for different OSNR values. It would be valuable to add a discussion on the amount of gain needed in their proposed architecture since it requires more optical amplification than a single laser WDM scheme.

The authors claim their design is lightweight as it only uses one optical source, however their WDM transmission still requires 16 DP-IQMs, EDFAs, mux/demux, etc. to be integrated into the same chiplet. I recommend the authors carefully justify the full size of their proposed architecture. It would also be interesting to see a discussion on their proposed architecture being used in a bi-directional link.

The discussion section provides a good summary of the obtained results as compared to previous works but does not provide an impactful argument explaining why this type of comb source is ideal for their proposed architecture. A more detailed comparison between the limitations of this type of comb source compared to others would be of great interest. Additionally, system sensitivities to temperature would be of value to the study.

Other comments:

Please specify for all the throughput values if they are net (after FEC) or not.

In the Noise compression for ultra-high carrier capacity section, two laser output powers are mentioned. Please clarify which is the output of the laser diode and which is the output of the optical comb.

Please fix minor spelling errors such as "combine" instead of "comb line".

Figure 2(g) shows two curves labeled 1 Tbps results each. It might be better to remove that label as every point on those curves does not equal a net 1 Tbps throughput.

In Parallel node-to-node data transfer, ECL1 and comb are both described as (gray dots) for Figure 3(b)

(Remarks on code availability)

Reviewer #2

(Remarks to the Author)

In this manuscript, "Exploiting a Centrally Powered Coherent Microcomb for Lightweight Optical Transmission", the authors use the comb lines of a microcomb to demonstrate:

- 1 Tbps (115 GBd 32 QAM-DP) with one of the lines;
- 8.4 Tbit/s with 16 lines (70 GBd 16QAM-DP) over 160 km of SSMF;

- 200 Tbps with 16 lines (40 GBd 16QAM-DP) over 2 km of a 24-core fiber;
- 9.5 Tbps with 16 lines (40 GBd 16QAM-DP) over 25 km of a 2-mode (LP) fiber;
- 8.4 Tbps with 16 lines (70 GBd 16QAM-SP) over 50 m of a 2-mode (OAM) fiber.

The authors make use of such high symbol rates thanks to the low noise properties of each comb line, which is achieved by self-injection locking of the DFB pump laser. While the high on-chip conversion efficiency of 60% is associated with the type of comb.

The manuscript is clearly written, and the topic and results are relevant for the scientific community. My major concern relates to the novelty impact of this work. First, regarding the comb the authors employ, this seems to be the same as the one reported in Ref. 22, where the noise reduction is already analysed (as well as in other references) and the comb is already used for data transmission: 30 GBd, 32QAM-DP. The authors, thus need to clarify if this is the same comb and what is the main novelty with respect to that work. Otherwise, the work feels that it is an incremental enabled by using better components such as modulators and AWGs.

Second, when it comes to the 1 Tbps claim, this is shown only for one of the comb lines, i.e., the pump line. The authors should also characterize other lines in the same way (Fig. 2g). Will there be a penalty due to the lower power / higher noise? With only one line, their 1 Tbps is not that novel, see ,e.g., [Buchali, 1-Terabit/s Net Data-Rate Transceiver Based on Single-Carrier Nyquist-Shaped 124 Gbaud PDM-32QAM], or [First Single-Carrier Transmission at Net Data Rates of 1.6 Tb/s over 9075 km and 2.4 Tb/s over 1210 km Using 300 GBd Dual-Polarization Signals and Probabilistic Constellation Shaping]. If the selling point is to also demonstrate the high data rate with MCF, FMF, RCF, there has been already works bringing this approach to the extrem: [22.9 Pb/s data-rate by extreme space-wavelength multiplexing] with a few-modes MCF providing 114 spatial channels (30 Tbps/wavelength).

Finally, the authors claim 200 tbps to be the highest with an integrated source, but already Ref.21 in 2018 showed 600 tbps, and maybe I am missing other examples.

In summary, the authors would need to position their work a bit more fairly and more clearly with respect to the state of the art in a meaningful way before the manuscript can be accepted.

Other comments:

- The manuscript, including methods and supplementary material, does not provide detailed description of: microresonator used (although I assume is the one from Ref 22), the soliton state, all equipment used, DSP, etc. The lack of details prevents properly evaluating the veracity of their results and questions its reproducibility.
- The authors highlight the power conversion efficiency, but what about the wall-plug efficiency? How does it compare to other similar approaches?
- The authors performed several transmission demonstrators with different symbol rates, modulation formats, with SMF, MCF, FMF, RCF. They could consider having a simple way to indicate them, e.g, table or in the respective figures.

Some typos:

- line 140: "combines"
- line 247 : "include"
- Line 293 "perabit"
- Line 252

Fig. 5 : this should be just for comb-based transmission experiments.

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

This manuscript reports technically work demonstrating high-speed multidimensional optical communication utilizing a self-injection-locked (SIL) dark-pulse microcomb. The authors ascribe the achieved high baud rate and 1 Tbps per-channel performance to the noise suppression facilitated by injection locking. However, in comparison with existing literature, this study does not introduce a fundamentally novel device architecture or a system-level innovation of transformative significance. Rather, the primary contribution appears to be the enhancement of single-carrier transmission rates, achieved at the cost of a reduced number of utilized channels, without providing substantial forward-looking perspectives. Consequently, I believe the scope and impact of this work might be more appropriately aligned with the focus of specialized journals in photonics or communications. The reasons I'm not entirely convinced by this work are listed below.

1. The authors attribute the high baud rate and 1 Tbps/channel performance to noise suppression via injection locking, but this claim lacks quantitative support.
 - (a) Please provide comparative data (OCNR, linewidth/phase noise, combine power) between the SIL and non-SIL combs. How do these differences translate to single-wavelength capacity?
 - (b) The explanation for setting the baud rate based on OCNR (lines 186-187) is unclear. What is the precise relationship between OCNR and maximum baud rate per channel? Why does the SIL comb achieve higher baud rates than other sources? Supporting analysis is required.
 - (c) The 1 Tbps record relies on a single high-power comb line. This does not represent the system's parallel performance and weakens the claim of a system-level breakthrough based on the microcomb.

2. The authors frequently emphasize the "lightweight" nature of the system, attributed to the compactness and conversion efficiency of the SIL comb.

(a) However, reliance on external EDFA amplification and WSSs for spectral shaping/equalization (Supplementary Note 4) contradicts the compactness claim. The authors should propose mitigation strategies or quantify the hardware overhead.

(b) Furthermore, the use of EDFAs and WSSs may negate the noise benefits of SIL combs. How does ASE noise impact OCNr, linewidth, and BER? Is the performance comparable or inferior to simpler pump-plus-filter approaches? This trade-off needs clarification.

(c) While a 61.5% conversion efficiency for 15 lines is reported, power distribution is uneven. Spectral flattening for power equalization introduces additional insertion loss. The authors should recalculate an "effective" conversion efficiency considering usable lines post-equalization.

3. The manuscript mentions injection-locked amplification as a future improvement but this contradicts earlier claims that such techniques are less suitable for lightweight systems. Furthermore, prior work (e.g., Ref. [22]) has already demonstrated injection-locked amplification of SIL microcombs with comparable or better performance. The authors should re-evaluate their novelty claim and clarify the meaningful differences of their implementation compared to these prior studies.

4. Minor issues and editorial errors:

(a) Line 202: "gray dots" should be "purple dots".

(b) Supplementary Note 4, line 65: "Fig.1(e)" reference is unclear.

(Remarks on code availability)

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

I would like to acknowledge the authors for addressing my comments in a careful and thorough manner. The additions to the text are reasonable and fairly convincing. I would be happy to see this paper published after these requests and other reviewer comments are fully addressed.

1. In rebuttal comment 2: The authors state a simulated transmission; however, I believe they show an experimental result. Please clarify if these 1 Tbps results are experimental or simulation.

2. Please specify in text what FEC each raw (net) transmission result is using as some plots use the 7% HD-FEC, while other use a 9.1% overhead

3. In rebuttal comment 4: The authors show a on-chip size comparison for multiple components; however, they still emulate a real system by using an even/odd modulation scheme which only requires 2 DP-IQMs. It would be more useful to know the size and performance of the full system using on chip MUX/DEMUX pairs and individual modulators instead of an IWC.

(Remarks on code availability)

Reviewer #2

(Remarks to the Author)

The reviewed manuscript now adds additional experimental data: impact of linewidth and OCNr, the BER achieved with all the comb lines and comparison with ECL, and data transmission replacing EDFA and AWG by SOA and IWC, respectively. These experiments and the associated data clarify some of the concerns raised from the prior manuscript. In addition, the authors have increased the details of their experimental investigations with the added Methods and Supplementary information. I believe the paper contains enough results, however, it does have some issues associated mostly with the new extensive new content.

- The paper includes multiple experiments with different settings, e.g., 70 GBd or 110 GBd, ECL or comb lines or a single line, SOA or EDFAs, and so on. The authors did include two setups in the supplementary document, however it is still not clear if, e.g., the same LO and receiver configuration is used. If so, do the authors observe or expect to observe penalties due to the 10 kHz linewidth of the LO? (I short sentence here would suffice)

- The authors use 2 SOAs. They mention the output power of the first one (10 dBm) but that of the second one is missing.

- The authors continuously refer to OCNr and OSNR values. How are these quantities measured? Are the authors using the optical spectrum analyzer? If so, which resolution bandwidth they consider? Importantly, where are they measured? I believe the authors should clearly indicate everytime where the OCNr and OSNRs are measured.

- If the authors consider a resolution bandwidth of 12.5 GHz, I can't understand how they measured an OSNR of 40 dB (Fig. 5g) if the power of the comb line before the first SOA is already -18 dBm. I would expect a much lower OSNR if that is measured after the second SOA. The authors should clarify this as it questions the validity of this analysis.

Additional suggestions:

- The manuscript seems to have lost the well organized structure from the first version. The authors may want to revise the content for smooth reading and clear transitions between experiments.
- In addition, there quite some grammatical error, e.g., lines 213-215 have some of them. The authors may want to also revise this thoroughly.

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

The authors have made significant improvements to the manuscript, particularly by providing a more compact DFB-laser pumping scheme for the frequency comb. This alternative is a valuable addition. However, it is also clear that this new scheme comes at the cost of substantially worse performance parameters compared to the original EDFA-based approach. While this trade-off between compactness and performance is an important discussion point, the manuscript has been improved enough through the added comparisons to be acceptable for publication. I recommend acceptance.

(Remarks on code availability)

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Manuscript ID: NCOMMS-25-24030

Title: Exploiting a Centrally Powered Coherent Microcomb for Lightweight Optical Transmission

Author: Junhao Han, Guofeng Yan, Kang Li, Bitao Shen, Haowen Shu, Yimeng Wang, Yuchen Zhang, Jiong Xiao, Yichen Wu, Huajin Chang, Chengkun Cai, Xuguang Zhang, Xingjun Wang, and Jian Wang

Dear Editor and Reviewers of Nature Communications,

We sincerely appreciate the careful review by the reviewers and have modified the manuscript in accordance with their suggestions. Here, we present a point-by-point reply (in blue) to the reviewers' comments (in black). All the changes have been highlighted (in red) with corresponding original text provided for comparison (in orange).

Response to the report from the Referee #1

General comments: *"This paper presents the use of a self injection locked microcomb as a source for coherent optical fiber transmission in the C-band achieving a net rate of 8.4 Tbps in WDM scheme and a net 200 Tbps in a WDM + MCF configuration. Additionally, MDM transmissions are also demonstrated achieving net 9.57 and 8.37 Tbps. The authors claim a 10-fold reduction in resource requirements for similar capacity architectures. The paper is well organized but could improve in the following areas."*

Our reply: We are sincerely grateful for the reviewer's favorable comments on our study. In the revised manuscript, we have included design and experimental details and carefully proofread the manuscript. Please find our point-by-point response attached.

Comment 1: *"Please specify in more details the exact DSP that was used at both the transmitter and at the receiver. It would be interesting to know filter lengths, equalization and pre-emphasise used, etc."*

Our reply: Thanks for your valuable comment regarding the insufficient description of our experiments. In response, we have provided a detailed explanation of the DSP aspects:

(Materials and Methods, page 28) In the context of DSP, at the transmitter side, we initially generate a PRBS sequence for QAM mapping, followed by 0.01 Root Raised Cosine pulse shaping, and then resample the signal before sending it to the AWG. On the receiver side, the captured signal undergoes sequential processing including resampling, frame synchronization, dispersion compensation, carrier frequency offset estimation using the fourth-power algorithm, adaptive MIMO equalization, carrier phase recovery through a two-stage blind phase search algorithm (with filter lengths of 32 and 8 for the first and second stages, respectively), demodulation, and BER calculation. It is noteworthy that during the verification of the relationship between OCNr and linewidth versus maximum net rate, DSP section utilized an 81-tap adaptive MIMO equalizer. In other experimental scenarios, the use of a 41-tap MIMO equalizer with reduced compensation capability and the decreased received OSNR per combine caused by WDM collectively lead to a degradation in achievable symbol rate compared to the former configuration.

Comment 2: *"The authors claim the first coherent single-lambda comb-based transmission results over 1 Tbps, however their citation [8] (Bernal S, et al.) includes a single-lambda demonstration of 1.6 Tbps in the O-band. Please adapt the claim accordingly."*

Our reply: Thanks for the correction. Indeed, our work does not constitute the first demonstration of an integrated light source achieving single-carrier 1 Tbps transmission, as we had overlooked prior works in O-band communications. Instead of claiming single-carrier channel rates, in the revised version, we further demonstrate **exceeding 1 Tbps (110 Gbaud DP-32 QAM) data transmission for all 16 available carriers**, an achievement that remains challenging for conventional MLL due to their inherent limitations in linewidth and OCNr. We have updated the newly added experiment in Fig. 3(b) and (c) as follows:

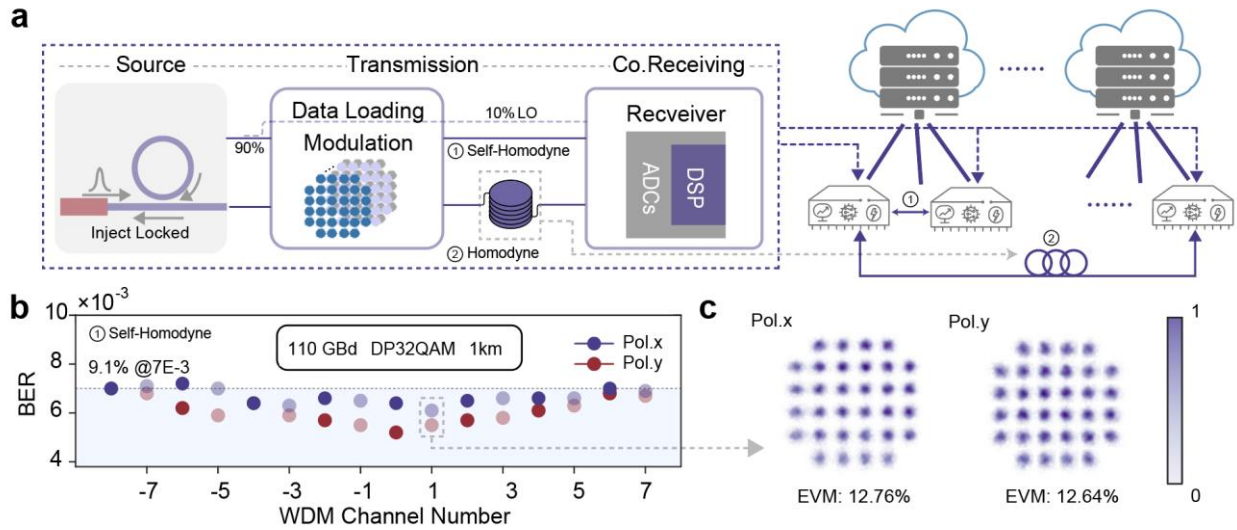


Fig. 3 SMF transmission system. (a) Schematic diagram of the high-speed node-to-node transmission system for short-reach campus/edge networks and metropolitan-scale optical transmission. (b) The self-homodyne-based campus/edge interconnect system achieves per-channel transmission rates exceeding 1 Tbps across all wavelength channels. (c) Constellation diagram of DP-32QAM.

(Introduction, page 6) We simulated short-range campus/edge networks and metropolitan area network transmission separately. In the campus/edge networks, we achieved a transmission capacity of 1 Tbps/λ across all carriers using a self-homodyne system.

Comment 3: "The authors compare the performance of the comb lines vs commercial ECLs for different OSNR values. It would be valuable to add a discussion on the amount of gain needed in their proposed architecture since it requires more optical amplification than a single laser WDM scheme. "

Our reply: We appreciate these valuable suggestions. A comparative analysis has been added in the revised Supplementary Information, as shown in the following figure. In summary, the output power of the integrated frequency comb is lower than that of conventional laser-array-based WDM schemes (assuming 0 dBm output), requiring an additional **13 dB** of gain. While the additional noise influence brought by amplification can be effectively alleviated by the narrow linewidth characteristic.

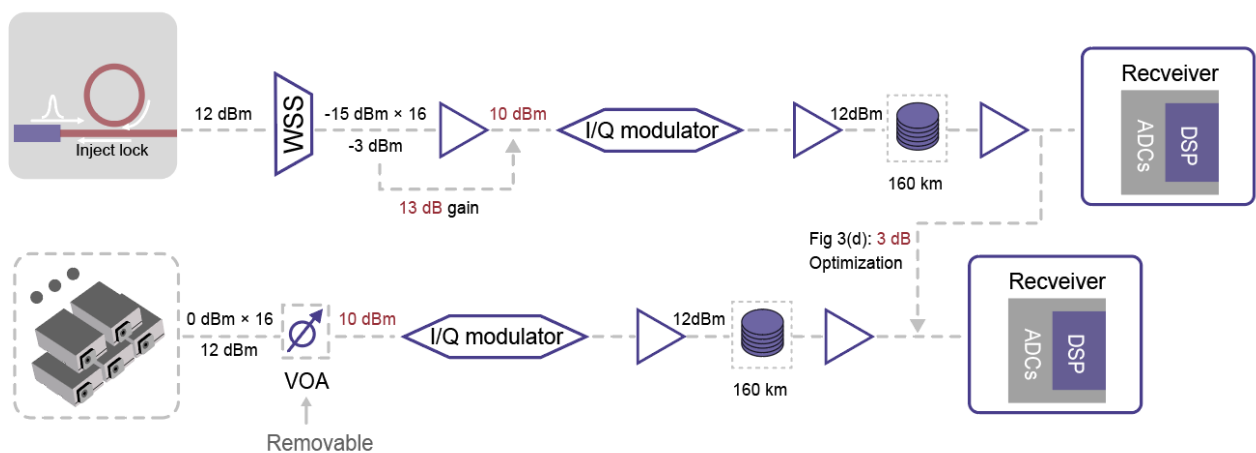


Fig. S2 Gain Comparison: SIL Comb vs. Commercial External-Cavity Laser.

(Supplementary Note 3) Here we present a comparative analysis of the gain requirement between the SIL microcomb and the laser-array schemes. To ensure a fair comparison, the input power to the modulator is fixed at 10 dBm (its optimal operating point) across all configurations. With higher output power, the system with laser arrays eliminates the need for the first-stage EDFA (shown in Fig. S2 bottom panel). And the WSS before IQ modulators for demultiplex is not needed. For

the microcomb-based approach, due to the 5 dB insertion loss introduced by the WSS, this scheme requires an additional 13 dB of first-stage gain compensation, with additional OCNR degradation. However, due to the narrow-linewidth characteristics of the self-injection-locked microcomb, the receiver achieves the same level of BER, despite remaining a 3 dB lower OSNR when compared with the bulky laser approach (main text in Fig 3(d)).

(Discussion, page 20) Owing to the high conversion efficiency and coherence of each combline, the highest single channel net data rate of 1 Tbps/(λ -core) and 523 Gbps/(λ -core) are achieved in wavelength multiplexing and wavelength-space multiplexing schemes, respectively. It means that the single-carrier rate of comb-based transmission has reached the level of high-power bulk lasers⁴⁸. Although the output power of the integrated frequency comb remains lower than that of traditional bulk laser arrays, this limitation is compensated during transmission by the comb's high conversion efficiency and narrow linewidth characteristics.

Comment 4: *"The authors claim their design is lightweight as it only uses one optical source, however their WDM transmission still requires 16 DP-IQMs, EDFAs, mux/demux, etc. to be integrated into the same chiplet. I recommend the authors carefully justify the full size of their proposed architecture. It would also be interesting to see a discussion on their proposed architecture being used in a bi-directional link."*

Our reply: Thanks for the insightful question. In our previous demonstrations, the transmitter primarily consists of a SIL comb, two EDFAs, one WSS, and two DP-IQMs. Based on calculations, the total footprint measures 2300 cm² with a height of 12 cm in the system, with sizes of each individual components are listed below:

Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
EDFA	2	32*25*10
WSS	1	31*24*12
DP-IQM	2	8.8*1.4*1

From the above table, the bulky EDFA and WSS occupy the majority of the volume, making the transmitter appear less "lightweight". To address this, we have replaced the transmitter module with a more integrated solution, combining SOA and silicon photonic waveshaping chips, which maintains >5 Tbps transmission capability while **reducing the system volume by 80 times**, occupying less than 100 cm² with a height of 3 cm (Fig. 5(b)). Although monolithic integration of all 16 channels remains challenging, the proposed all-modular system demonstrates that on-chip architectures can sustain equally high channel rates. This approach simultaneously achieves system miniaturization while meeting inter-node transmission requirements.

Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
SOA	2	3*1.27*1
IWC	2	5.2*4.8*3
DP-IQM	2	8.8*1.4*1

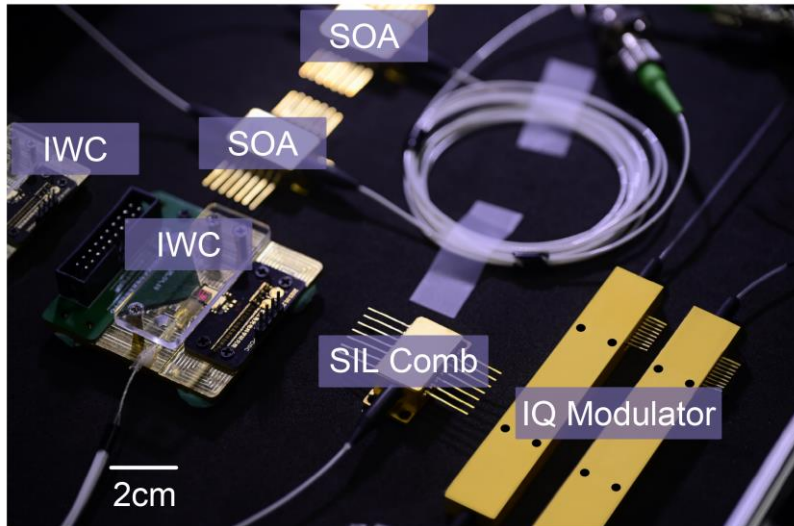


Fig. 5 Highly integrated transmitter demonstration. (b) Physical Diagram of the Transmitter Module.

Also, we completely agree with the reviewer's interesting suggestion about bidirectional link transmission. The integrated coherent receiver can be implemented, as demonstrated in our previous work [*Laser & Photonics Reviews*, 18(1): 2300501, (2024)], with further plans to realize a fully lightweight transceiver link.

(Discussion, page 22) Extending this approach to the receiver side is equally feasible, where the proposed chip-level parallel optical source can serve as local oscillators in combination with integrated photodetectors and demultiplexers⁴⁹. The co-integration of transmitters and receivers would enable a lightweight platform for bidirectional transmission.

Comment 5: "The discussion section provides a good summary of the obtained results as compared to previous works but does not provide an impactful argument explaining why this type of comb source is ideal for their proposed architecture. A more detailed comparison between the limitations of this type of comb source compared to others would be of great interest."

Our reply: Thanks for the valuable insights. Our SIL source indeed offers distinct advantages in terms of the simultaneously achieved high coherence and OCNR, which ensures parallel high-capacity data transmission in a shrunk form factor compared with the traditional bulky laser array and other externally pumped comb approach.

In the revised manuscript, we systematically analyze the influence of OCNR and linewidth on the maximum transmission rate under back-to-back (BTB) conditions, as shown in Fig. 2(e) of the revised manuscript. As seen from the figure, the **higher OCNR and narrower linewidth will result in a higher maximum transmission rate. This is exactly what SIL dark-pulse microcomb can provide**, as we demonstrate in this manuscript. With SIL operation, such parallel sources feature remarkable narrow linewidth, along with simple operation and fully integrated. In the normal dispersion microresonator, the mode-locked dark-pulse state is well-known for the high conversion efficiency, experimentally >60% in this manuscript. Such high conversion efficiency ensures a high single channel power, equivalently a high OCNR. Such **unique combination enables tolerance to higher insertion losses and SNR degradation**, especially when employing lossy on-chip WDM devices and noisy SOAs in a space-constrained scenario.

Compared with other comb sources, semiconductor mode-locked laser chips face inherent phase noise limitations, leading to wide linewidth of ~ 1 MHz and blocking high-coherence transmission. Limited by the long cavity length, bulky mode-locked lasers tend to feature combline spacing < 1 GHz, which require precise filtering to select target comblines for suitable channel spacing. Conventional microcombs demand the delicate frequency alignment between the pump laser and the microresonator. In addition, the coherence is determined by the pump laser, where chip-level lasers are insufficient to provide the pump with both high power and high coherence. Electro-optic combs, while alternative solutions, require additional microwave drivers with high cost and increased complexity, and the coherence also relies on the external sources.

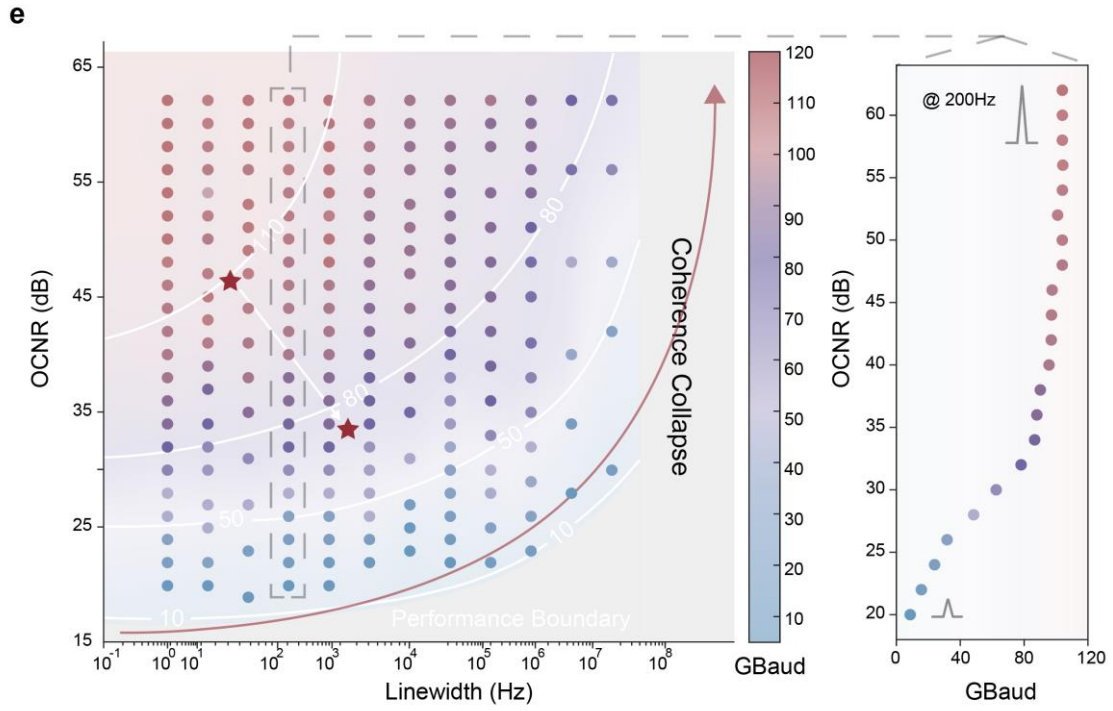


Fig. 2 Integrated coherent comb source generation and the effect of light source on transmission. (e) The influence of OCNR and linewidth on the maximum net symbol rate is evaluated under the error-free condition. The red pentagrams in the figure trace the degradation path of the light source in the communication system.

To further exhibit the superiority of SIL microcomb for lightweight systems, we constructed a transmission system using electro-optic comb (Fig 5. (d)). Except for the larger footprint and higher cost, the transmission performance (black star) is also worse than that based on the SIL microcomb source, when processed through the same SOA and integrated waveshaping chip (IWC).

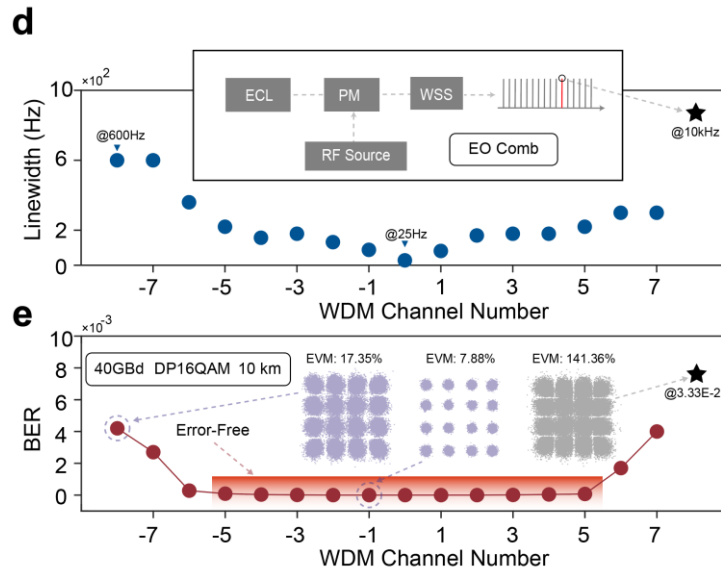


Fig. 5 Highly integrated transmitter demonstration. (d) Intrinsic linewidth characteristics of individual combline. The black pentagrams in the figure denote the combline generated by the microwave-driven electro-optic frequency comb. (e) Transmission with a symbol rate of 40 Gbaud and DP-16QAM modulation format. Partial constellation diagrams and corresponding EVM values are provided. Eleven channels are considered to achieve error-free transmission.

(Results, page 18) For comparison, we implement a reference system using a 45-GHz-spacing electro-optic frequency comb pumped by an N7714A ECL (Fig. 5(d)). Under identical conditions, severely degraded constellation diagrams are obtained due to its poor original coherence (Fig. 5(e) black pentagrams).

(Discussion, page 20) Owing to the high conversion efficiency and coherence of each combline, the highest single channel net data rate of 1 Tbps/(λ -core) , 523 Gbps/(λ -core) and are achieved in wavelength-mode multiplexing and wavelength-space multiplexing schemes, respectively. It means that the single-carrier rate of comb-based transmission has reached the level of high-power bulk lasers⁴⁸. Although the output power of the integrated frequency comb remains lower than that of traditional bulk laser arrays, this limitation is compensated during transmission by the comb's high conversion efficiency and narrow linewidth characteristics. Compared to other integrated light sources, our approach demonstrates superior coherence and noise performance while achieving the highest level of integration - requiring neither bulk laser drivers nor microwave excitation.

Comment 6: "Additionally, system sensitivities to temperature would be of value to the study."

Our reply: Thanks for the valuable suggestion. Aside from the IWC and modulator components, our system incorporates TEC controllers for all critical elements, so it can somehow resist the environmental temperature variations. We have performed additional temperature stability tests, and the detailed experimental results have been included in the revised Supplementary Information. The microcomb device, in summary, operates stably between 22 and 28 ° C. To function in wider ambient conditions, thermal-isolating packaging will be required to suppress temperature fluctuations.

(Supplementary Note 5) In integrated WDM transmission systems, light sources exhibit the most significant susceptibility to temperature fluctuations. By adjusting the TEC temperature of the silicon nitride microring, we simulated real-world environmental temperature variations. The system maintains normal operation within a 22-28°C range (6°C operational window). The corresponding wavelength drift ranges from 1555.34 nm to 1555.42 nm, which does not affect the final frequency offset estimation. This is because: (1) the local oscillator (LO) can be dynamically adjusted with temperature variations, and (2) such drift does not compromise the intrinsic coherence at each specific temperature. In practical transmission scenarios, each component can be thermally stabilized by individual TEC controllers, enabling reliable performance across wider ambient temperature fluctuations.

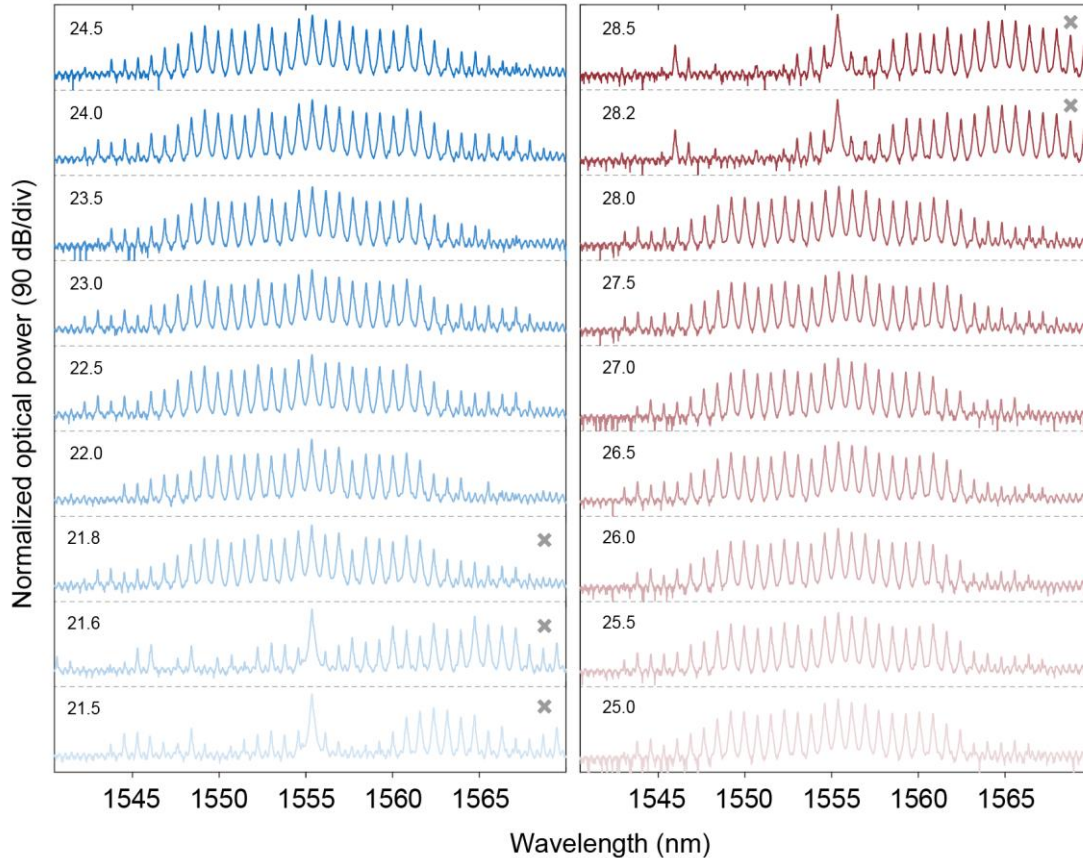


Fig. S4 The optical spectrum varies with ambient temperature from 21.5°C to 28.5°C, where cross markers in the figure indicate failure conditions.

Comment 7: "Please specify for all the throughput values if they are net (after FEC) or not."

In the Noise compression for ultra-high carrier capacity section, two laser output powers are mentioned. Please clarify which is the output of the laser diode and which is the output of the optical comb.

Please fix minor spelling errors such as "combine" instead of "comb line".

Figure 2(g) shows two curves labeled 1 Tbps results each. It might be better to remove that label as every point on those curves does not equal a net 1 Tbps throughput.

In Parallel node-to-node data transfer, ECL1 and comb are both described as (gray dots) for Figure 3(b)."

Our reply: We have meticulously examined all technical details and implemented corresponding revisions. We sincerely appreciate the reviewers' rigorous scientific approach.

(Results, page 13) Thanks to the high OCNR with power levels above -10 dBm, all channels can support 110 GBaud DP-32QAM signal transmissions in the WDM configuration, indicating single-channel rate of 1.1 (net 1.008) Tbps.

(Results, page 14) Overall, this 16-channel WDM scheme achieves a raw (net) aggregated rate of 8.96 (8.37) Tbps.

(Results, page 17) In this case, we achieve a raw (net) transmission rate of 215.04 (200.97) Tbps by loading 70 Gbaud DP-16QAM signals, with only 16 wavelength channels, as shown in Fig. 4(c).

(Results, page 18) Figure 4(e) shows the WDM-MDM transmission results for LP01 and LP02 mode carrying 40-Gbaud DP-16QAM signals transmitted over a 25-km FME, with raw (net) capacity of 10.24 (9.57) Tbps.

(Results, page 18) Similarly, the WDM-MDM transmission performance of 16 comb lines carrying 70-Gbaud SP-16QAM signals with raw (net) rate reaching 8.96 (8.37) Tbps in a 50-m RCF using OAM11 and OAM21 modes, as shown in Fig. 4(f).

(Results, page 9) The output spectrum from the laser chip through the SiN chip to the fiber link is given in Fig. 2(a), with the output wavelength around 1555.37 nm and the output power of 14.86 dBm. Considering the laser diode direct output power of 18 dBm, the total optical insertion loss is estimated as 3.14 dB.

(Results, page 10) The on-chip conversion efficiency from the pump laser to the 15 generated comb lines (excluding the residual pump laser) is calculated to be 61.5%, with the center 16 high-power ~~comb lines~~ comb lines accounting for approximately 99.7% of the converted energy.

(Results, page 14) Figure 3(e) compares the high-performance ECL1 and the 1550.72 nm ~~comb line~~ comb line (-6 channel) for 160-km transmission.

(Results, page 14) Compared with a high-performance tunable ECL1 with a ~10 kHz linewidth (gray dots), the self-injection locking scheme (~~gray dots~~ purple dots) exhibits a 3 dB lower OSNR requirement at the same EVM level due to the parallel high coherence.

Response to the report from the Referee #2

General comments: "In this manuscript, "Exploiting a Centrally Powered Coherent Microcomb for Lightweight Optical Transmission" , the authors use the comb lines of a microcomb to demonstrate:

- 1 Tbps (115 GBd 32 QAM-DP) with one of the lines;
- 8.4 Tbit/s with 16 lines (70 GBd 16QAM-DP) over 160 km of SSMF;
- 200 Tbps with 16 lines (40 GBd 16QAM-DP) over 2 km of a 24-core fiber;
- 9.5 Tbps with 16 lines (40 GBd 16QAM-DP) over 25 km of a 2-mode (LP) fiber;
- 8.4 Tbps with 16 lines (70 GBd 16QAM-SP) over 50 m of a 2-mode (OAM) fiber.

The authors make use of such high symbol rates thanks to the low noise properties of each comb line, which is achieved by self-injection locking of the DFB pump laser. While the high on-chip conversion efficiency of 60% is associated with the type of comb.

The manuscript is clearly written, and the topic and results are relevant for the scientific community."

Our reply: We are deeply grateful for the thoughtful evaluation of our work and sincerely appreciate the considerable time and effort you have dedicated to reviewing our manuscript. All responses to the reviewers' comments and corresponding manuscript revisions have been clearly documented. Please find our point-by-point response attached.

Comment 1: "My major concern relates to the novelty impact of this work. First, regarding the comb the authors employ, this seems to be the same as the one reported in Ref. 22, where the noise reduction is already analysed (as well as in other references) and the comb is already used for data transmission: 30 GBd, 32QAM-DP. The authors, thus need to clarify if this is the same comb and what is the main novelty with respect to that work. Otherwise, the work feels that it is an incremental enabled by using better components such as modulators and AWGs."

Our reply: We sincerely appreciate the reviewer's valuable feedback and would like to clarify the key distinctions between our work and Ref. 22. First, it should be noted that the two studies are based on fundamentally different chip designs (Ref. 22 employs a 100-nm-thick ultra-high Q device, whereas ours employs a 300-nm-thick structure). Below, we systematically outline the key distinctions of our work:

1. **Energy Efficiency:** Reference 22 utilizes an add-drop microresonator, with each comb line exhibiting only **-20 dBm output power**. In this manuscript, with special over-coupling design, we achieve **>60% conversion efficiency, resulting in exceeding -10 dBm power** for each combline.
2. **Channel spacing:** The 100-nm-thick SiN is **hard to get high-Q resonator with larger FSR (>40 GHz)**. This design choice inherently limits their capability to support higher-speed signal at each carrier. Based on 300-nm-thick SiN platform, it is **easy to realize high-Q microresonator with large FSR >100 GHz for high single-channel transmission**. In our revision, rather than relying on single-channel demonstrations, we successfully achieved ultra-high data rates using **110-Gbaud DP-32QAM, corresponding to over 1 Tbps, across all 16 comb lines** (Response to Comment 2), which strongly supports our claims.
3. **Cost:** Reference 22 intended to realize ultra-low-noise sources. To suppress the phase noise as much as possible, the prior work adopted the ultra-low-loss photonic circuits based on 100-nm-thick SiN. **Such extraordinary platform requires complete and costly fabrication processes and is difficult to obtain commercially** at present. By contrast, **the 300-nm-thick SiN is widely available [CUMEC-CSiN300, IMB-CNM & VLC Photonics, LIGENTEC, GLOBALFOUNDRIES]**, and the fabrication process is much simpler. This ensures the universality and low cost of this solution.
4. **Compactness:** Regarding system architecture, Ref. 22 employs multiple DFBs for injection locking, each requiring individual laser drivers (LD) and thermoelectric cooler (TEC) control, which inherently **limits its suitability for lightweight transmission systems**. By contrast, our system fully exploits the inherently high conversion efficiency and low noise of the designed light source, aiming for greater simplicity than other microcomb based systems. To further strengthen this claim, in our revised manuscript, we have conducted additional lightweight transmission experiment

by replacing bulky system components with integrated ones, such as SOAs and integrated waveshaping chip (IWC) for WDM operation (Response to Comment 3). Those compact devices, to the best of our knowledge, have not yet been simultaneously adopted in other comb-based transmission systems. This integration enables a significantly more compact transmitter architecture, achieving nearly an **80-fold reduction in system size** compared with our previous demonstration. Even under the noisy SOA amplification and extra insertion loss from the waveshaping chip, the system still performs a 16 WDM transmission with over 5 Tbps aggregation rate, showing promise in noise tolerance and compact-system suitability of the proposed light source.

5. **Performance analysis with quantified experimental verification:** In our newly revised manuscript, to better clarify how the high OCNR and noise-suppression effect in a comb source affect the transmission results, systematic analysis has been conducted (Response to Comment 2). **The relationship between baud rate and noise-OCNR is experimentally explored** by the substituting light source with different linewidth and varying emission intensity in each of them. The characterization provides critical insights for future high-coherence transmission experiments.

Comment 2: "Second, when it comes to the 1 Tbps claim, this is shown only for one of the comb lines, i.e., the pump line. The authors should also characterize other lines in the same way (Fig. 2g). Will there be a penalty due to the lower power / higher noise? With only one line, their 1 Tbps is not that novel, see ,e.g., [Buchali, 1-Terabit/s Net Data-Rate Transceiver Based on Single-Carrier Nyquist-Shaped 124 Gbaud PDM-32QAM], or [First Single-Carrier Transmission at Net Data Rates of 1.6 Tb/s over 9075 km and 2.4 Tb/s over 1210 km Using 300 GBd Dual-Polarization Signals and Probabilistic Constellation Shaping]. "

Our reply: Thanks for these valuable comments and questions. In our revised manuscript, to better demonstrate the transmission potential of a low-noise comb source, we carried out over **1 Tbps data transmission utilizing all 16 high-power microcomb carriers** under a WDM configuration, as shown in the following Fig. 3(a). All channel achieved BER under $7\text{E-}3$ (Fig. 3(b)). Accordingly, we have added the following description of the new experiments.

(Result, page 11) **SIL combines are divided into odd and even banks to simulate real-world communication scenarios.** First, we build up a 1 km self-hemodyne coherent transmission system to explore the maximum capacity of the comelines. Limited by the channel spacing of 100 GHz, we artificially doubled the spectral interval through WSS, as shown in Fig. 3(b), and distinguish by transparency. Thanks to the high OCNR with power levels above -10 dBm, all channels can support 110 GBaud DP-32QAM signal transmissions in the WDM configuration, indicating single-channel rate of 1.1 (net 1.008) Tbps.

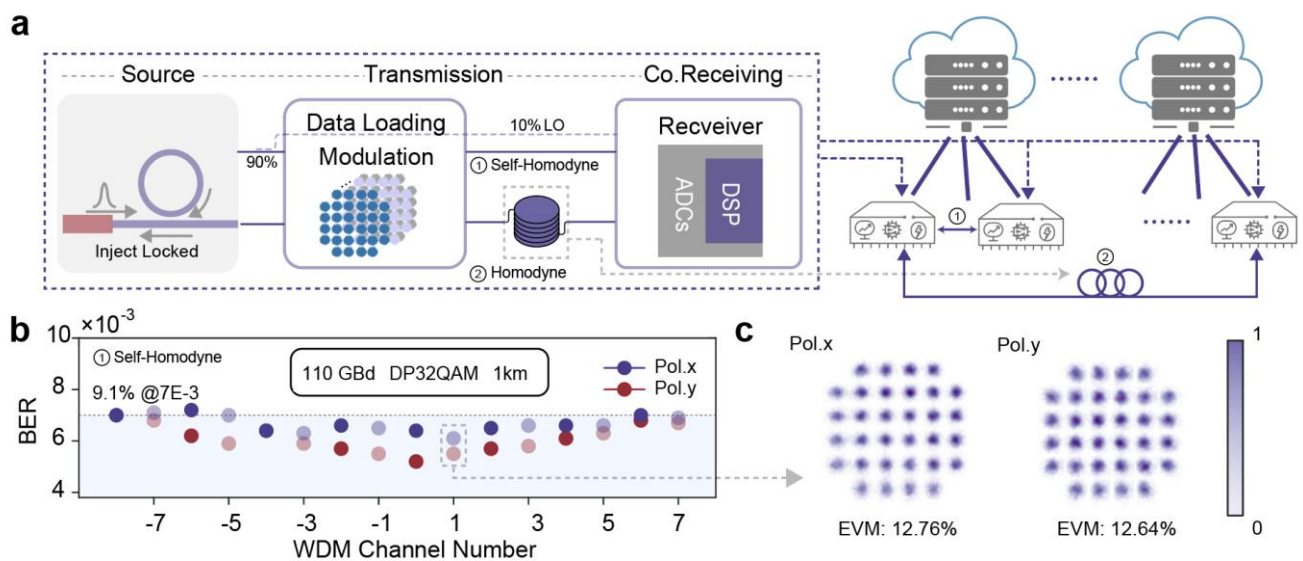


Fig. 3 SMF transmission system. (a) Schematic diagram of the high-speed node-to-node transmission system for short-reach campus/edge networks and metropolitan-scale optical transmission. (b) The self-homodyne-based campus/edge interconnect system achieves per-channel transmission rates exceeding 1 Tbps across all wavelength channels. (c) Constellation diagram of DP-32QAM.

In addition, to provide more **quantitative experimental evidence of how low OCNR and coherence impact transmission performance**, we performed extensive experimental characterization, as shown in the following Fig. 2(e). To emulate different conditions, benchtop lasers with varying linewidths were employed, with the OCNR of each laser tuned through its output power. The results indicate that both high coherence and OCNR are crucial for supporting high transmission speeds, capabilities that our proposed microcomb inherently offers.

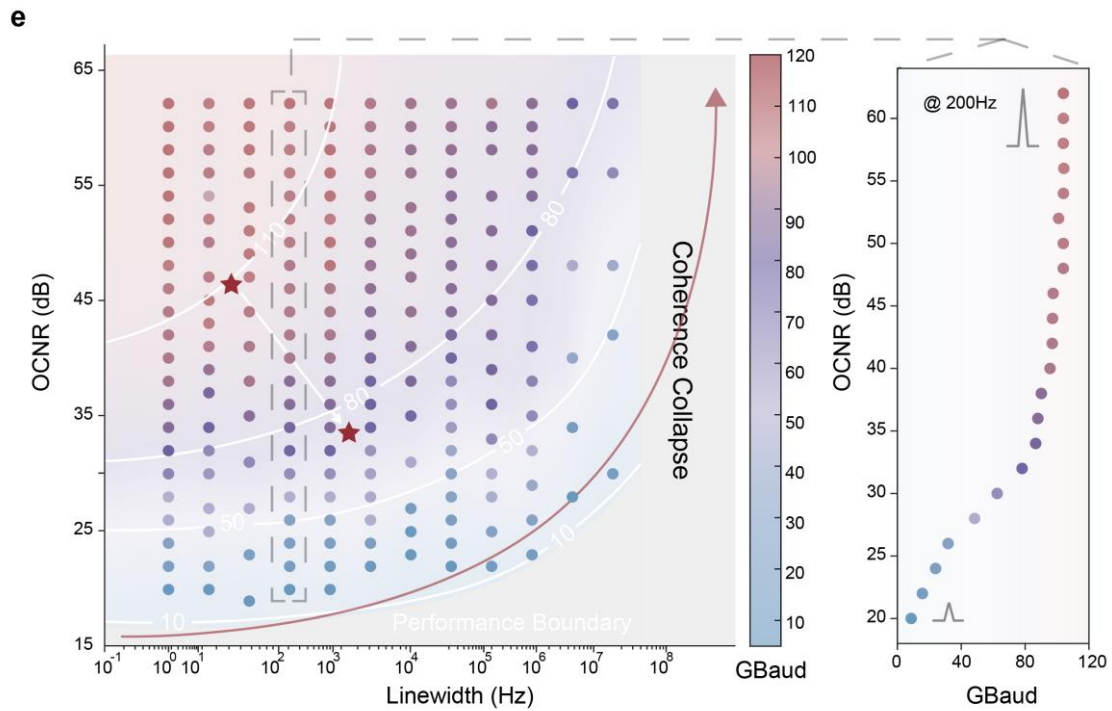


Fig. 2 Integrated coherent comb source generation and the effect of light source on transmission. (e) The influence of OCNR and linewidth on the maximum net symbol rate is evaluated under the error-free condition. The red pentagrams in the figure trace the degradation path of the light source in the communication system.

Comment 3: "If the selling point is to also demonstrate the high data rate with MCF, FMF, RCF, there has been already works bringing this approach to the extrem: [22.9 Pb/s data-rate by extreme space-wavelength multiplexing] with a few-modes MCF providing 114 spatial channels (30 Tbps/wavelength)."

Our reply: We are sorry for any misleading in the original manuscript. Actually, this work aims to provide deeper insights into an **ultra-compact microcomb-based transmission system** capable of supporting high-capacity links between **space-constrained supernodes** of computing units. Multiplexing techniques such as MCF, FMF, and RCF represent potential solutions for enabling multi-node aggregation in transmission networks. Here, we demonstrate that a lightweight transmission system based on a self-injection-locked microcomb source can be organized in this manner.

We thank the reviewer for stimulating our consideration of the key selling points of this work. To further substantiate the "lightweight" claim, **we propose a chip-level transmitter by replacing bulky components with integrated ones**, such as SOAs and integrated waveshaping chips (IWCs) for WDM operation, as shown in Fig. 5(a – c). The results demonstrate **per-channel data rates exceeding 320 Gbps, with an aggregate capacity of over 5 Tbps**, as shown in Fig. 5(e). Moreover, the high conversion efficiency and narrow linewidth of the proposed SIL microcomb source play a critical role in mitigating the degradation induced by additional noise of integrated devices. As analyzed in Fig. 5(f–g), compared with commercial EDFAs, SOA amplification introduces more severe frequency noise and OSNR degradation, yet the SIL microcomb exhibits strong resilience against these impairments.

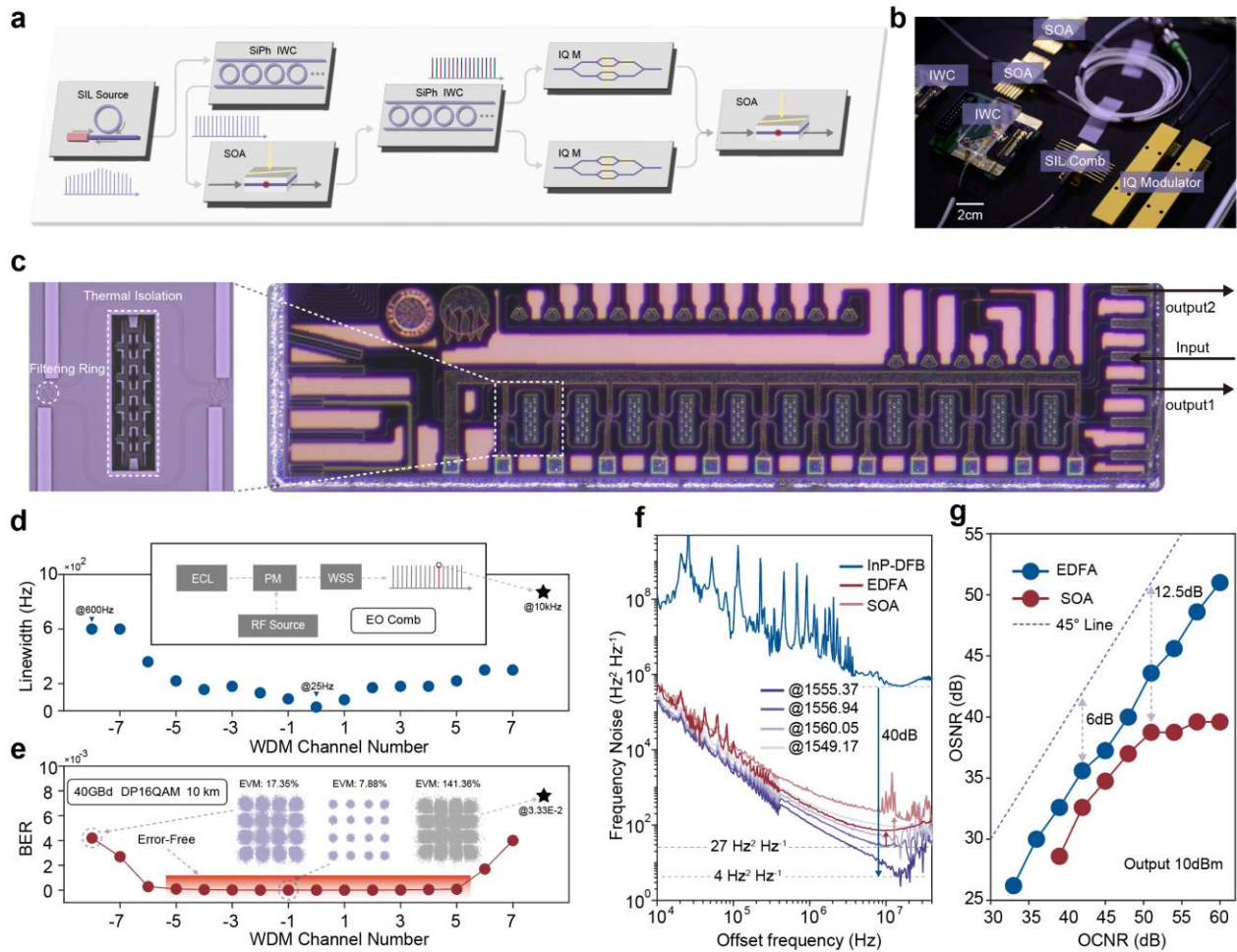


Fig. 5 Highly integrated transmitter demonstration. (a) Lightweight Transmitter Scheme. (b) Physical Diagram of the Transmitter Module. (c) Microphotograph of the SiPh integrated waveshaping chip. (d) Intrinsic linewidth characteristics of individual combline. The black pentagrams in the figure denote the combline generated by the microwave-driven electro-optic frequency comb. (e) Transmission with a symbol rate of 40 Gbaud and DP-16QAM modulation format. Partial constellation diagrams and corresponding EVM values are provided. Eleven channels are considered to achieve error-free transmission. (f) Power spectral density of frequency noise, including components from comb lines (0, 2, 6, and -8), as well as noise levels when the InP-DFB and comb line 6 are amplified to 10 dBm by an SOA and EDFA respectively. (g) OCNr degradation induced by SOA and EDFA at 10 dBm output power.

(Result, page 17) A highly integrated system is essential for realizing lightweight transmission in distributed edge nodes, especially under stringent cost and footprint constraints. In this section, beyond integrated light sources, we present a chip-level parallel carrier generator where bulky WSSs and EDFAs are replaced by SOAs and silicon photonic IWCs. Figure 5(a) illustrates the architecture of the chip-level transmitter module, with photographs of all modules provided in Fig. 5(b). The IWC is fabricated using mature silicon photonics technology, featuring cascaded microring resonators with a free spectral range (FSR) of approximately 1.3 THz. Microheaters placed above the microrings allow tuning of resonant frequencies to adjust the output spectrum, as detailed in Supplementary Information Note 5. To suppress thermal crosstalk, adjacent microrings are physically separated by etched trenches, as illustrated in Fig. 5(c). Since not all combines require power equalization, we achieve uniform power distribution across all spectral lines using only 12 microrings. After the IWC, all 16 combines are equalized to -18 dBm, accounting for an 8 dB insertion loss. The carriers are then amplified by an SOA and routed through another IWC for odd-even channel separation. Separated carriers are modulated by 35-GHz-bandwidth IQ modulators, combined, and then amplified through an SOA before transmission. As demonstrated in Fig. 5(e), a 10-km transmission at 5.12 Tbps (net 5.015 Tbps) is achieved using 40-Gbaud DP-16QAM modulation. The BER trend per channel aligns consistently with the linewidth values as shown in Fig. 5(d), with combines below 300 Hz linewidth achieving error-free operation.

It is noteworthy that the capacity of the present chip-level transmitter is lower than that of systems based on bulky devices. This primarily stems from carrier performance degradation caused by integrated components, which featuring higher noise figures and insertion losses than their benchtop counterparts. Specifically, the IWC contributes an additional 3 dB insertion loss compared to benchtop WSS. SOAs, while far more compact than EDFAs, introduce excessive amplified spontaneous emission (ASE) noise. Meanwhile, their high α -factor and nonlinear effects (notably XPM) further induce cumulative phase noise and waveform distortion in high-speed systems^{46,47}. Figure 5(f) and (g) present the corresponding noise and OSNR degradation after amplification. When amplified to 10 dBm, the linewidth of channel 6 increases of approximately threefold and tenfold via EDFA and SOA respectively. In addition, the OCNr decreases by 6 dB and 12.5 dB respectively. Despite these impairments, the SIL light source still enables >5 Tbps transmission within the chip-level lightweight system, due to its original superior coherence and OCNr. For comparison, we implement a reference system using a 45-GHz-spacing electro-optic frequency comb pumped by an N7714A ECL (Fig. 5(d)). Under identical conditions, severely degraded constellation diagrams are obtained due to its poor original coherence (Fig. 5(e) black pentagrams).

Comment 4: *"Finally, the authors claim 200 tbps to be the highest with an integrated source, but already Ref.21 in 2018 showed 600 tbp, and maybe I am missing other examples."*

Our reply: Thanks for raising this important point. Ref. 21 is a great pioneering work that achieved over 100 Tbps data transmission. While it is worth noting that this work was performed based on supercontinuum generation, where a high-peak-power femtosecond laser is injected into an integrated waveguide. The high-peak-power femtosecond laser is not integrated in this work. And the femtosecond laser currently still faces significant challenges in on-chip integration, which we believe limits the system's overall integration level. Therefore, we emphasize a highly integrated transmitter light source, and we apologize for any confusion caused by our original wording. In the revised manuscript, we have replaced 'integrated' with 'on-chip' for clarity.

(Result, page 14) As far as we are aware, this represents the highest rate realized with an ~~integrated~~ on-chip light source over the entire C-band, significantly simplifying the cumulative device requirements while avoiding saturation of the erbium-doped fiber amplifier (EDFA).

Comment 5: *"The manuscript, including methods and supplementary material, does not provide detailed description of: microresonator used (although I assume is the one from Ref 22), the soliton state, all equipment used, DSP, etc. The lack of details prevents properly evaluating the veracity of their results and questions its reproducibility. "*

Our reply: In the revised manuscript, we have provided more comprehensive descriptions of the microcomb and the DSP (digital signal processing) procedures, including the specific models of key components such as the EDFA, modulator, and AWG used in the experiments.

(Materials and Methods, page 23) The fabricated microresonator exhibits a free spectral range of 100 GHz (aligned with the DWDM ITU grid spacing standard), a Q-factor of approximately 1.7×10^7 , and a coupling loss of ≤ 2.5 dB/facet @ 1550 nm. The microring resonator adopts a racetrack configuration, with Euler bends on both curved sections. The coupling gap is 1 μ m, and the coupling length is 110 μ m, forming an overall over-coupled structure for high conversion efficiency.

(Materials and Methods, page 24) By fine-tuning the position of the six-axis stage, the generation of dark pulse microcombs can be observed on the optical spectrum analyzer (as shown in Fig. 2(d)). Stable microcomb generation is sustained for over 1000 minutes.

(Materials and Methods, page 28) A 256-GSa/s real-time oscilloscope (KEYSIGHT UXR0594AP) with 59-GHz bandwidth captures waveforms from four channels and sends them to a computer for DSP. In the context of DSP, at the transmitter side, we initially generate a PRBS sequence for QAM mapping, followed by 0.01 Root Raised Cosine pulse shaping, and then resample the signal before sending it to the AWG. On the receiver side, the captured signal undergoes sequential processing including resampling, frame synchronization, dispersion compensation, carrier frequency offset estimation using the fourth-power algorithm, adaptive MIMO equalization, carrier phase recovery through a two-stage blind phase search algorithm (with filter lengths of 32 and 8 for the first and second stages, respectively), demodulation, and BER calculation. It is noteworthy that during the verification of the relationship between OCNr and linewidth versus maximum net rate,

DSP section utilized an 81-tap adaptive MIMO equalizer. In other experimental scenarios, the use of a 41-tap MIMO equalizer with reduced compensation capability and the decreased received OSNR per combine caused by WDM collectively lead to a degradation in achievable symbol rate compared to the former configuration.

The specifications/model numbers of all equipment used are provided.

(Materials and Methods, page 27) The experimental results presented in Fig. 2(e) were obtained using multiple light sources with varying linewidth characteristics: NKT Photonics (1 Hz), Comb0 (25 Hz), Comb1 (81.64 Hz), Comb5 (220 Hz), SANTEC TSL-510 (1.576 kHz), RIO ORION-1550-30-15-M (5 kHz), KEYSIGHT N7714A ECL (10.4 kHz), ALNAIR TLT-200 (20 kHz), APEX AP3350A (238 kHz), and CONQUER CUSTOMIZED (628 kHz), along with two cases that failed demodulation - an InP DFB (3 MHz) and BOXOPTRONICS CUSTOMIZED (8.8 MHz). Throughout the transmission experiments, the KEYSIGHT N7714A ECL served as the LO to maintain phase reference stability.

(Materials and Methods, page 27) The WSS (Finisar Waveshaper 4000s) (with 5 dB insertion loss) splits these channels into odd/even paths while performing power equalization.

(Materials and Methods, page 27) Subsequently, the light source carrying 16 wavelengths is amplified by an amplifier to boost the power of each channel, with the aggregate power reaching approximately 13 dBm prior to entering two 35-GHz 3dB bandwidth IQ modulators (Sumicem T.SBXH1.5PL-35PD-ADC). Both paths are simultaneously modulated by data generated from a 128-GSa/s Arbitrary Waveform Generator (AWG-M9505A).

(Materials and Methods, page 27) The transmission link consists of an EDFA (KEOPSYS) for signal amplification, multiplexers/demultiplexers, and multidimensional multiplexing fiber to validate the optical comb's transmission performance.

(Materials and Methods, page 28) A 256-GSa/s real-time oscilloscope (KEYSIGHT UXR0594AP) with 59-GHz bandwidth captures waveforms from four channels and sends them to a computer for DSP.

(Supplementary Note 4) Fig. S3 Detailed Schematic Diagram of the Communication System; OC: Optical Coupler. PD: Photodetector. WSS: Wavelength Selective Switch. AWG: Arbitrary Waveform Generator. LO: Local Oscillator. EDFA: Erbium-Doped Fiber Amplifier. PC: Polarization Controller. VOA: Variable Optical Attenuator (CETC AV6381B). BPD: Balanced Photodetector (Finisar BPDV3120RQ). Mixer (Optolex).

Comment 6: "The authors highlight the power conversion efficiency, but what about the wall-plug efficiency? How does it compare to other similar approaches?"

Our reply: Our InP-DFB laser operates with a laser voltage of 1.564 V and current of 300 mA, delivering an output power of 18 dBm (63.1 mW). The wall-plug efficiency (WPE) is calculated as: $63.1/469.2 = 13.45\%$.

This performance falls within a relatively ideal range (9-16%) [*Opt. Express* 30, 27983-27992 (2022)]. The primary limitations come from the laser's intrinsic quantum efficiency as well as optical losses caused by reflection and absorption. Compared to existing literature, our WPE does not show significant advantages. However, when considering the product of WPE and power conversion efficiency [*Journal of Lightwave Technology* 38, 5517-5525 (2020)], our design demonstrates a clear superiority (inferred ~18 dB). We have now included this information in the main text.

(Result, page 9) A laser diode chip, which exhibits a wall-plug efficiency of 13.45%, is directly coupled with the designed silicon nitride (SiN) microresonator chip.

Comment 7: "The authors performed several transmission demonstrators with different symbol rates, modulation formats, with SMF, MCF, FMF, RCF. They could consider having a simple way to indicate them, e.g, table or in the respective figures."

Our reply: Thanks for the valuable suggestions from the reviewers. We have provided all the experimental tables to clarify the overall context of all the experiments, in the SI.

(Supplementary Note 6) To better present the experimental results and conceptual framework, we have tabulated the obtained data. Experiments 1 and 2 primarily demonstrate transmission in short-range campus/edge networks and metropolitan area networks. Experiments 3–5 employ SDM to showcase multi-node aggregated data transmission.

Experiment 6 achieves more integrated lightweight transmission through the use of highly integrated components such as SOA and IWC.

Table S3. Tabulation of experimental results.

	Symbol rate [Gbaud]	Signal format	Raw capacity [Tbps]	Summation Net rate [Tbps]	Net rate/ λ /core [Gbps]	Multiplexing scheme	Local oscillator
1	110	DP-32QAM	838	8.064	1008	1 km-SMF	SIL-Comb
2	70	DP-16QAM	8.96	8.37	523	160 km-SMF	ECL
3	70	DP-16QAM	215.04	200.97	523	2 km-24MCF	ECL
4	40	DP-16QAM	10.24	9.57	598	25 km-FMF	ECL
5	70	SP-16QAM	8.96	8.37	523.	50 m-RCF	ECL
6	40	DP-16QAM	5.12	5.015	313	10 km-SMF	ECL

Comment 8: "Some typos:

-line 140: "combines"

- line 247 : "include"

- Line 293 "perabit"

- Line 252

Fig. 5 : this should be just for comb-based transmission experiments. "

Our reply: We have meticulously examined all technical details and implemented corresponding revisions. We sincerely appreciate the reviewers' rigorous scientific approach.

(Result, page 5) For adequate OCNr, we select the central 16 **comblines** with power exceeding -10 dBm as parallel optical carriers.

(Result, page 15) Besides, we show the first proof-of-concept mode-division multiplexed (MDM) multi-dimensional transmissions **includes** LP modes in few-mode fiber (FMF) and OAM modes in ring-core fiber (RCF) driven by integrated photonic light source.

(Result, page 21) Despite the total capacity is below the **petabit-per-second** scale compared to state-of-the-art demonstrations, a higher channel capacity and streamlined nature of this light source would significantly reduce the footprint and overhead associated with channel scaling, making it well-suited for compact edge infrastructure.

(Results, page 12) Compared with a high-performance tunable ECL1 with a ~10 kHz linewidth (gray dots), the self-injection locking scheme (~~gray dots~~ **purple dots**) exhibits a 3 dB lower OSNR requirement at the same EVM level due to the parallel high coherence.

(Discussion, page 22) Fig. 6 Review of **comb-based** coherent transmission systems.

Comment 9: "In summary, the authors would need to position their work a bit more fairly and more clearly with respect to the state of the art in a meaningful way before the manuscript can be accepted."

Our reply: We sincerely appreciate the time and effort the reviewers dedicated to providing such valuable feedback. The core innovation of our work lies in lightweight transmission, which encompasses two key aspects: power consumption/energy efficiency and size/cost reduction. Overall, we have supplemented three additional experiments to support our claims, as shown in above discussion and concluded below.

- (1) We have supplemented experiments **investigating the relationship between transmission rate and noise-OCNR** (Fig. 2(e)). These were conducted to further demonstrate the advantages of our light source in coherent systems, and to provide clearer guidance for subsequent experiments.
- (2) We have achieved a transmission capacity of **1 Tbps/ λ across all carrier wavelengths** (Fig. 3(b)), demonstrating the superior parallel transmission capability of our light source.
- (3) We demonstrate **the system using chip-level components** (Fig. 5(e)), with **80 times smaller** compared with our previous demonstrations and confirm that our light source exhibits significantly higher tolerance to both OSNR degradation and coherence impairment.

We greatly appreciate the reviewer's suggestions, which have significantly contributed to the revision of the manuscript.

Response to the report from the Referee #3

General comments: *"This manuscript reports technically work demonstrating high-speed multidimensional optical communication utilizing a self-injection-locked (SIL) dark-pulse microcomb. The authors ascribe the achieved high baud rate and 1 Tbps per-channel performance to the noise suppression facilitated by injection locking. However, in comparison with existing literature, this study does not introduce a fundamentally novel device architecture or a system-level innovation of transformative significance. Rather, the primary contribution appears to be the enhancement of single-carrier transmission rates, achieved at the cost of a reduced number of utilized channels, without providing substantial forward-looking perspectives. Consequently, I believe the scope and impact of this work might be more appropriately aligned with the focus of specialized journals in photonics or communications. The reasons I'm not entirely convinced by this work are listed below."*

Our reply: We sincerely appreciate the reviewers' valuable comments. Here, we would like to further elaborate on the significance and innovative aspects of our work. We have provided a detailed, point-by-point response to clarify the technical aspects and address all raised concerns. We also conducted additional experiments to further support our claims.

First of all, we would like to clarify that our work specifically addresses **the communication and aggregation challenges among distributed edge computing nodes** [1]. In such scenarios, an excessive number of wavelength channels imposes significant pressure on hardware components. Our primary goal is to develop a **lightweight parallel transmission system, with reduced volume, power consumption and cost**, to meet the growing high-capacity demands of network edges and modular data centers in **space-constrained scenarios**.

We understand the reviewer's concerns mainly focus on three aspects:

- (1) First, the reason why such a comb source could support superior transmission lacked quantitative support, and the differences from previous work were not specified in detail.
- (2) Second, our emphasized single-carrier rate transmission capability comes at the cost of reduced channel count. The presentation of parallelism is insufficient.
- (3) Third, the system is not "lightweight" enough, as some components such as WSS and EDFA cannot be modularized, which contradicts the lightweight architecture.

For (1): We conducted additional **experiments to quantify the relationship between the maximum transmission rate and OCNR and linewidth of the laser carrier**. The results demonstrate that the high coherence and high conversion efficiency of our light source strongly support such high-speed transmission. (**Response to Comment 1**). In the revised main text, newly added Fig. 2(e) presents such relationship. Moreover, **the superior coherence and OCNR provide strong resilience against amplification-induced degradation**, allowing the system to tolerate the additional noise introduced by SOAs when replacing bulky EDFAs, thereby enabling a more compact configuration. Supplementary experiments are also performed as in newly added Fig. 5 for analysis on such impact.

In comparison, **none of the currently available integrated optical frequency combs (typically featuring around 10 kHz linewidth and 40 dB OCNR) could reach such performance while remaining compact**. Also, compared to previous work (e.g., Ref. 22), our design achieves significantly improved integration simplicity. In terms of device architecture, we reduced components by removing additional LDs and TEC controllers, as we require only a single DFB pump. Regarding power efficiency, our design achieves higher conversion efficiency compared to prior solutions. Most importantly, Ref. 22 primarily aimed to realize an integrated ultra-low-noise parallel source, which required ultra-low-loss integrated photonic circuits (thin SiN). Such platforms are costly and difficult to obtain commercially. At the system level, we obtained remarkable transmission results - achieving 200 Tbps using just 16 comb lines. This demonstration breaks the conventional paradigm by scaling up the capacity of each channel in a micro-parallelism system with low system overhead, rather than scaling up channel numbers with relatively low per-channel data rates.

For (2): We firmly believe that enhancing single-carrier rates holds significant value - indeed, this represents a critical performance metric where integrated optical frequency combs currently lag behind bulk laser systems [2,3]. As mentioned before, an excessive number of comb lines does not necessarily translate to practical advantages, especially in resource-constrained scenarios. Through innovative microring resonator design, we achieve more concentrated energy distribution

within targeted spectral regions (as elaborated in the Supplementary Information). While our initial single-carrier 1 Tbps transmission is indeed lack of convincement, in the revised manuscript, we have substantiated our approach by demonstrating **uniform 1 Tbps transmission (110 Gbaud DP-32QAM) across all 16-comblines** (Fig. 3(b)) (**Response to Comment 1-c**). Implemented via our self-homodyne architecture, this solution unlocks the potential of ultrahigh per-channel rate parallel transmission, making it well-suited for short-reach campus and edge network environments with stringent bandwidth demands.

For (3): We performed a **proof-of-concept lightweight transmission link, by replacing the bulk WSSs and EDFAs with integrated waveshaping chips and semiconductor optical amplifiers**, in the revised manuscript. By leveraging integrated photonic devices, **the system volume is reduced by 80-fold**. We find that such replacement degrades both the carrier linewidth and the received OSNR. However, thanks to its high carrier power and narrow linewidth, the SIL microcomb exhibits significantly high tolerance to both OSNR degradation and coherence impairment. Comparative experiments are also conducted with EO combs, which further confirm that the proposed SIL microcomb source can withstand such degradation (**Response to Comment 2**).

In conclusion, this work introduces both the concept and the first practical demonstration of a chip-level lightweight optical transmission system. It represents a paradigm shift toward greener, higher-density compute-and-transport architectures, with broad potential impact across fields such as high-performance computing and intelligent manufacturing. To address the novelty concerns raised by reviewers, we have substantially revised the manuscript and added three compelling new experiments. We hope that the responses provided below fully address the reviewer's concerns. We sincerely thank the reviewer for their thorough and thoughtful review.

1. Xing, S., Sun, A., Wang, C. et al. Seamless optical cloud computing across edge-metro network for generative AI. *Nat Commun* 16, 6097 (2025).
2. R. Rios-Müller et al., "1-Terabit/s net data-rate transceiver based on single-carrier Nyquist-shaped 124 GBaud PDM-32QAM," *Optical Fiber Communications Conference and Exhibition (OFC)*, Los Angeles, CA, USA, pp. 1-3, (2015).
3. H. Mardoyan et al., "First Single-Carrier Transmission at Net Data Rates of 1.6 Tb/s over 9075 km and 2.4 Tb/s over 1210 km Using 300 GBd Dual-Polarization Signals and Probabilistic Constellation Shaping," *European Conference on Optical Communication (ECOC)*, Frankfurt, Germany, pp. 1805-1808, (2024).

Comment 1: *"The authors attribute the high baud rate and 1 Tbps/channel performance to noise suppression via injection locking, but this claim lacks quantitative support."*

Our reply: We sincerely appreciate the reviewers' questions. In response to the request for quantitative support evidence, we have conducted additional experiments.

To systematically investigate the relationship between OCNR, linewidth and baud rate, we conducted extensive experiments utilizing dozens of optical sources with varying linewidths, with the OCNR also varies with the change of laser output power. All transmission systems employed DP-16QAM modulation with homodyne detection, maintaining consistency with our previous experimental configuration. The corresponding results are presented in Fig. 2(e), clearly shows that high OCNRs (high powers) and narrow linewidths are the basis for high transmission rates.

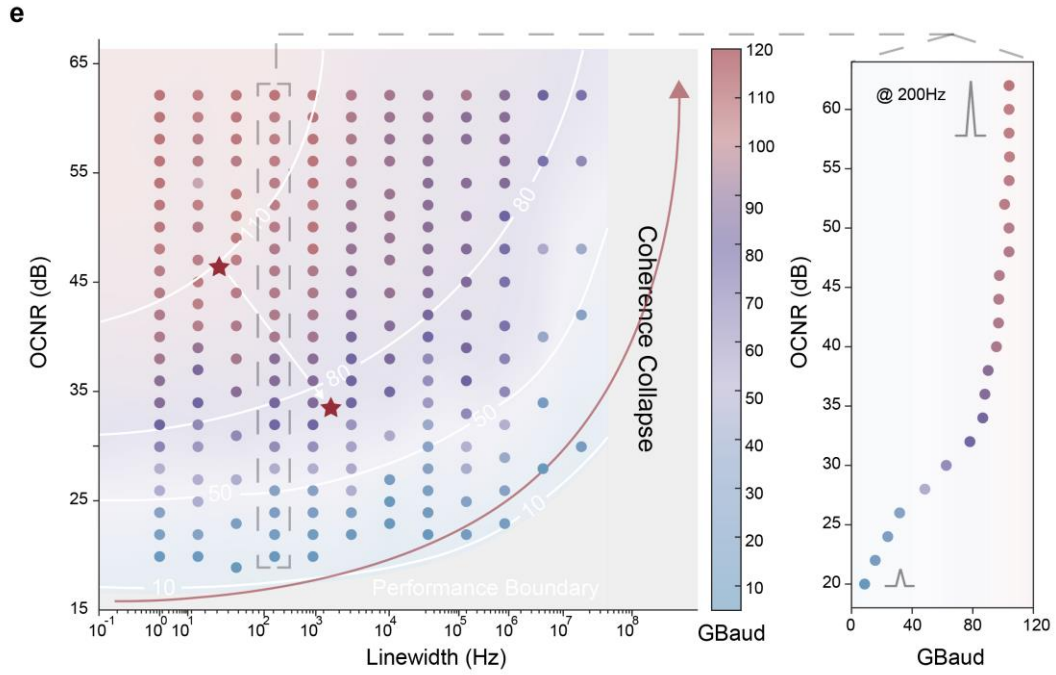


Fig. 2 Integrated coherent comb source generation and the effect of light source on transmission. (e) The influence of OCNR and linewidth on the maximum net symbol rate is evaluated under the error-free condition. The red pentagrams in the figure trace the degradation path of the light source in the communication system.

"(a) Please provide comparative data (OCNR, linewidth/phase noise, combine power) between the SIL and non-SIL combs. How do these differences translate to single-wavelength capacity?"

Our reply: (a) Figures 2(a) and (d) show the OCNR of all combines under non-SIL conditions. The OCNR at the pump position remains approximately 72.86 dB before and after SIL. After completing the SIL process, energy is redistributed to other combines through four-wave mixing, resulting in an OCNR of about 67.45 dB for comb0. Considering the lowest comb line, the OCNR is approximately 50 dB. The linewidth is approximately 3 MHz for InP-DFB without SIL but narrows to 25 Hz after SIL implementation, as shown in Fig. 5(d) and (f).

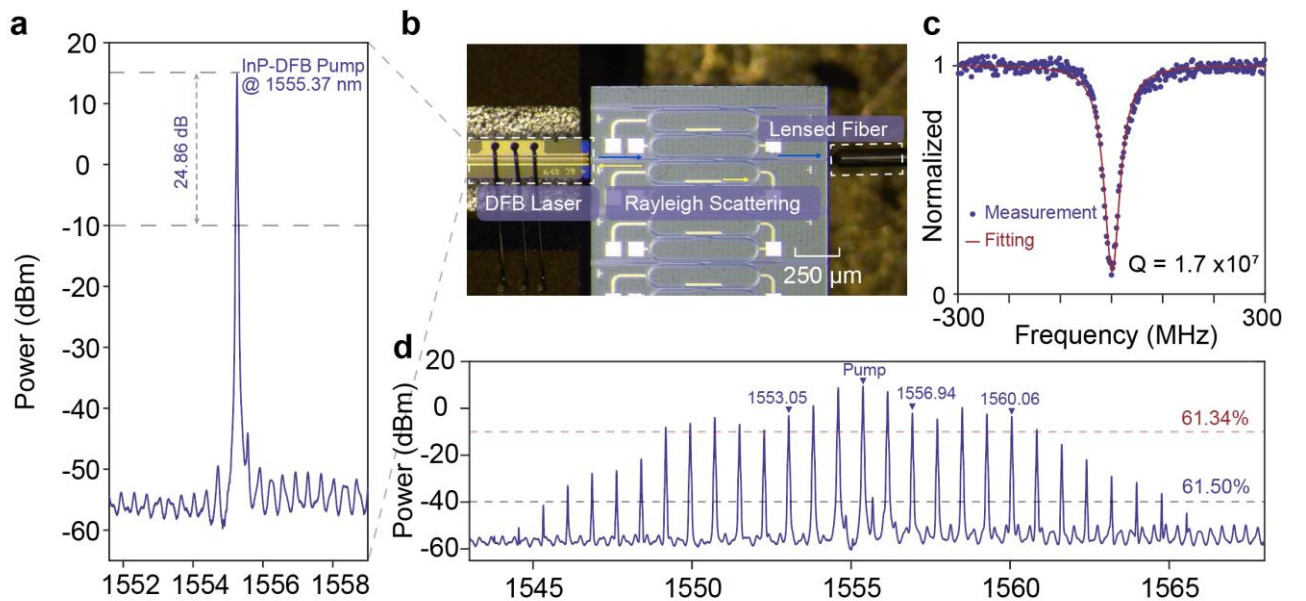


Fig. 2 Integrated coherent comb source generation and the effect of light source on transmission. (a) The pump light source input (including insertion loss), at 1555.37 nm. (b) Physical image of microcomb generation. (c) Normalized coupling diagram. (d) SIL combines generate with 16 channels (over -10 dBm) ranging from 1549.17 nm to 1560.84 nm.

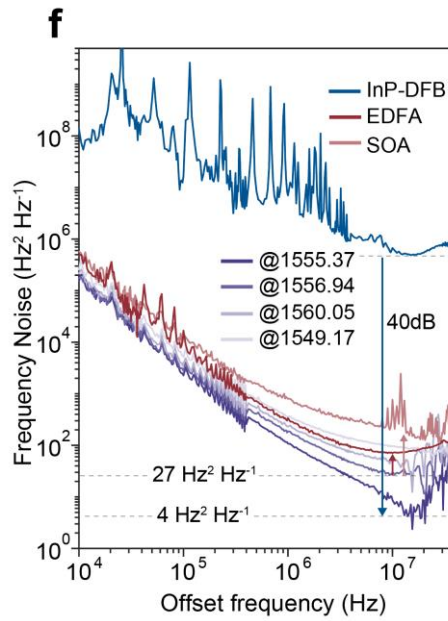


Fig. 5 Highly integrated transmitter demonstration. (f) Power spectral density of frequency noise, including components from comb lines (0, 2, 6, and -8), as well as noise levels when the InP-DFB and comb2 (1556.94 nm) are amplified to 10 dBm by an SOA and EDFA respectively.

For clear and concise comparison, we have listed several representative works in the field. Our work demonstrates significant advantages in both linewidth performance and OCNR characteristics. Because of that, we have achieved multi-fold improvement in single-carrier capacity, and it accords with the quantified analysis shown in Fig. 2(e) above.

	OCNR	linewidth/phase noise	single comb line power
<i>Nature</i> 546, 274–279 (2017).	~40 dB	<100 kHz	-20 dB
<i>Nature Photon</i> 12, 469–473 (2018).	~20 dB	40 kHz	-20 dB
<i>Nat Commun</i> 9, 1598 (2018).	~45 dB	<10 kHz	-15 dB
<i>Nat Commun</i> 11, 2568 (2020).	~30 dB	—	<-40 dB
<i>Photonics Research</i> 12, 2573-2580 (2024).	~32 dB	107~1.2k Hz (ultra-narrow linewidth fiber laser pump)	-28 dB
<i>Nat Commun</i> 16, 6387 (2025).	~40 dB	—	-6 dB
This work	>50 dB	25~600 Hz (DFB pump)	-10 dB

The "—" indicates that no specific value is explicitly stated in the text. However, the soliton generation method described in the aforementioned literature results in comb line linewidth characteristics that are correlated with the pump source, and are therefore dependent on the performance of the laser used.

"(b) The explanation for setting the baud rate based on OCNR (lines 186-187) is unclear. What is the precise relationship between OCNR and maximum baud rate per channel? Why does the SIL comb achieve higher baud rates than other sources? Supporting analysis is required."

Our reply: (b) Thanks for identifying these issues. We acknowledge the lack of clarity in our original presentation and have accordingly revised the manuscript to address these concerns. The symbol rate was set to 70 Gbaud after considering the combined impact of all optical components (including modulator, optical amplifier, and WSS), and the degraded coherence of the edge comb lines.

(Result, page 12) The symbol rate is limited to 70 Gbaud due to constraints from the power level and linewidth characteristics of the edge combines, while simultaneously satisfying requirements for fiber transmission loss and component insertion losses. A DP-16QAM signal is then modulated onto the parallel carriers, which are subsequently combined and transmitted through a 160-km standard SMF.

To further investigate the impact of source noise on the transmission system performance, we conducted experimental verification using laser sources with dozens of different noise levels. The experimental results, as detailed in Fig. 2(e), demonstrate that the narrow linewidth achieved through self-injection locking significantly improves the performance of homodyne communication systems. Detailed analysis has been included in the revised manuscript. Additional comparative experiments with other comb sources in Fig. 5(d, e) further validate the feasibility of our approach.

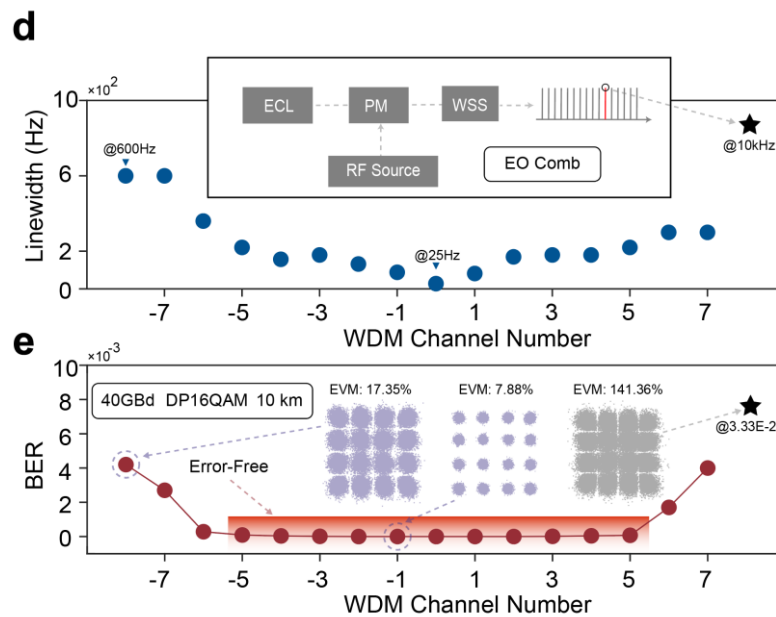


Fig. 5 Highly integrated transmitter demonstration. (d) Intrinsic linewidth characteristics of individual combline. The black pentagrams in the figure denote the combline generated by the microwave-driven electro-optic frequency comb. (e) Transmission with a symbol rate of 40 Gbaud and DP-16QAM modulation format. Partial constellation diagrams and corresponding EVM values are provided. Eleven channels are considered to achieve error-free transmission.

(Result, page 9) To quantitatively verify the necessity of such high-performance sources for high-capacity transmission, we conduct a systematic investigation of the impact of linewidth and OCNR on optical communication systems under back-to-back (BTB) conditions. The experimental link transmits DP-16QAM signals as described in the Methods, wherein a Keysight N7714A external cavity laser (ECL) with 10-kHz linewidth serves as the local oscillator (LO). Optical carrier linewidths are varied from 1 Hz to 10 MHz, provided by different commercial lasers and comblines of the SIL microcomb. The OCNR is adjusted by controlling the laser intensity via a variable optical attenuator. Intuitively, high-speed transmission systems require coordinated optimization of both OCNR and laser linewidth characteristics. While the degradation of OCNR critically impacts transmission, light sources with superior coherence properties, could partially alleviate such degradation. With narrow linewidth (200 Hz for example), an OCNR of ~ 45 dB suffices to achieve transmission rate exceeding 100 Gbaud, where a higher OCNR provides negligible improvement. Importantly, maintaining a linewidth < 1 kHz is essential to achieve 1 Tbps in our system, as coherent receivers exhibit heightened sensitivity to phase noise under high-speed signal conditions. As coherence progressively deteriorates, the accumulated phase noise not only elevates the BER at the receiver but also disrupts frequency offset estimation in the offline digital signal processing. This impairment leads to failed carrier phase recovery, loss of phase synchronization, and ultimately complete system failure.

(Results, page 18) For comparison, we implement a reference system using a 45-GHz-spacing electro-optic frequency comb pumped by an N7714A ECL (Fig. 5(d)). Under identical conditions, severely degraded constellation diagrams are obtained due to its poor original coherence (Fig. 5(e) black pentagrams).

"(c) The 1 Tbps record relies on a single high-power comb line. This does not represent the system's parallel performance and weakens the claim of a system-level breakthrough based on the microcomb."

Our reply: (c) We acknowledge the reviewer's keen insight. To enhance parallelism, we have demonstrated all combines achieving 1 Tbps transmission rates. The modifications have been incorporated into the manuscript.

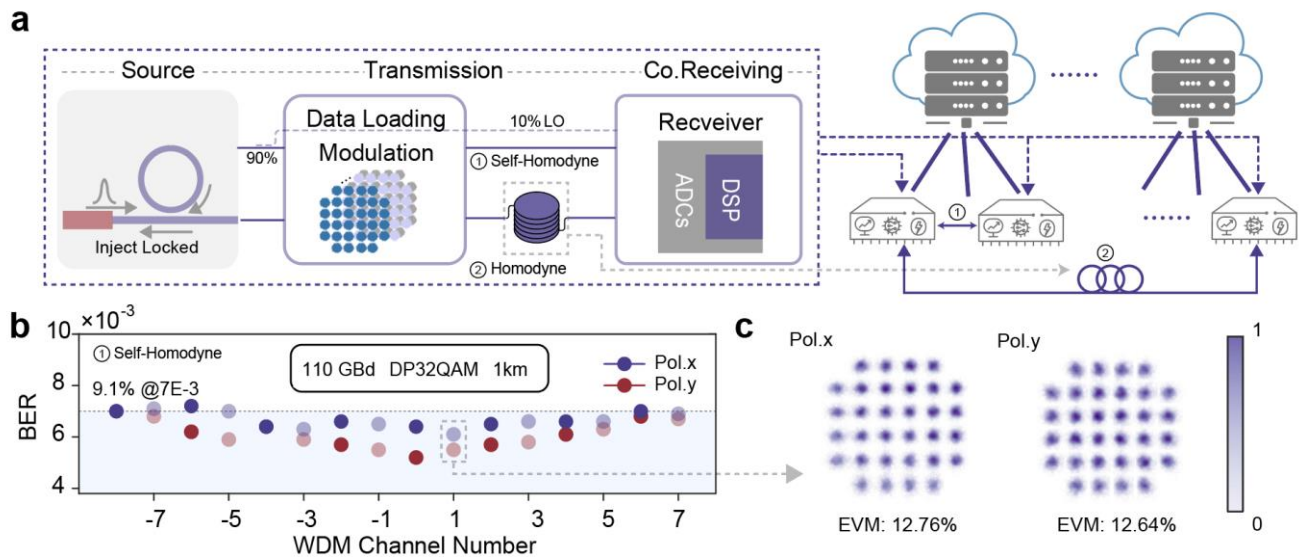


Fig. 3 SMF transmission system. (a) Schematic diagram of the high-speed node-to-node transmission system for short-reach campus/edge networks and metropolitan-scale optical transmission. (b) The self-homodyne-based campus/edge interconnect system achieves per-channel transmission rates exceeding 1 Tbps across all wavelength channels. (c) Constellation diagram of DP-32QAM.

(Result, page 11) First, we build up a 1 km self-hemodyne coherent transmission system to explore the maximum capacity of the comelines. Limited by the channel spacing of 100 GHz, we artificially doubled the spectral interval through WSS, as shown in Fig. 3(b), and distinguish by transparency. Thanks to the high OCNR with power levels above -10 dBm, all channels can support 110 GBaud DP-32QAM signal transmissions in the WDM configuration, indicating single-channel rate of 1.1 (net 1.008) Tbps.

Comment 2: "The authors frequently emphasize the "lightweight" nature of the system, attributed to the compactness and conversion efficiency of the SIL comb."

Our reply: Thanks for these insightful questions regarding the lightweight aspects. We consider both the high efficiency and coherence properties of the SIL comb to be the critical enablers for lightweight transmission systems. We have conducted extensive supplementary experiments to address these concerns and provide point-by-point clarifications below:

"(a)However, reliance on external EDFA amplification and WSSs for spectral shaping/equalization (Supplementary Note 4) contradicts the compactness claim. The authors should propose mitigation strategies or quantify the hardware overhead."

Our reply: (a) The reviewer is correct that EDFAs and WSS would compromise the system's lightweight nature. To better demonstrate system-level lightweight transmission, we replaced EDFAs with more integrated SOA chips and substituted bulky WSS with compact silicon photonic waveshaping chips (IWC), achieving over 5 Tbps WDM transmission while reducing overall size to 100 cm²*3cm, as shown in Fig. 5. The trade-off for lightweight design is higher insertion loss and degraded coherence performance introduced by integrated devices. Nevertheless, it is the high conversion efficiency and high output power characteristics that help this comb source tolerate the additional insertion loss from IWC and the severely degraded ASE noise and linewidth broadening induced by SOA.

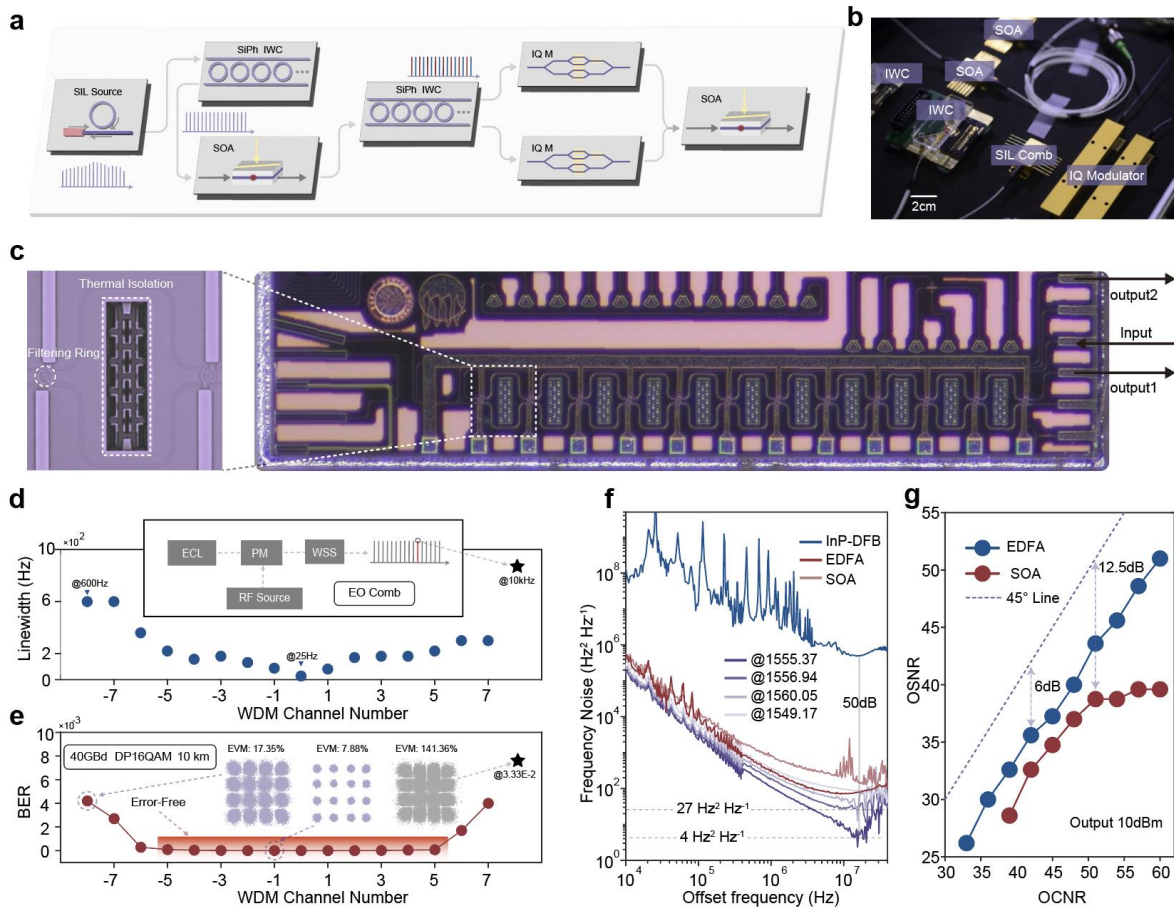


Fig. 5 Highly integrated transmitter demonstration. (a) Lightweight Transmitter Scheme. (b) Physical Diagram of the Transmitter Module. (c) Microphotograph of the SiPh integrated waveshaping chip. (d) Intrinsic linewidth characteristics of individual combline. The black pentagrams in the figure denote the combline generated by the microwave-driven electro-optic frequency comb. (e) Transmission with a symbol rate of 40 Gbaud and DP-16QAM modulation format. Partial constellation diagrams and corresponding EVM values are provided. Eleven channels are considered to achieve error-free transmission. (f) Power spectral density of frequency noise, including components from comb lines (0, 2, 6, and -8), as well as noise levels when the InP-DFB and comb6 are amplified to 10 dBm by an SOA and EDFA respectively. (g) OCNr degradation induced by SOA and EDFA at 10dBm output power.

(Result, page 17) A highly integrated system is essential for realizing lightweight transmission in distributed edge nodes, especially under stringent cost and footprint constraints. In this section, beyond integrated light sources, we present a chip-level parallel carrier generator where bulky WSSs and EDFAs are replaced by SOAs and silicon photonic IWCs. Figure 5(a) illustrates the architecture of the chip-level transmitter module, with photographs of all modules provided in Fig. 5(b). The IWC is fabricated using mature silicon photonics technology, featuring cascaded microring resonators with a free spectral range (FSR) of approximately 1.3 THz. Microheaters placed above the microrings allow tuning of resonant frequencies to adjust the output spectrum, as detailed in Supplementary Information Note 5. To suppress thermal crosstalk, adjacent microrings are physically separated by etched trenches, as illustrated in Fig. 5(c). Since not all combines require power equalization, we achieve uniform power distribution across all spectral lines using only 12 microrings. After the IWC, all 16 combines are equalized to -18 dBm, accounting for an 8 dB insertion loss. The carriers are then amplified by an SOA and routed through another IWC for odd-even channel separation. Separated carriers are modulated by 35-GHz-bandwidth IQ modulators, combined, and then amplified through an SOA before transmission. As demonstrated in Fig. 5(e), a 10-km transmission at 5.12 Tbps (net 5.015 Tbps) is achieved using 40-Gbaud DP-16QAM modulation. The BER trend per channel aligns consistently with the linewidth values as shown in Fig. 5(d), with combines below 300 Hz linewidth achieving error-free operation.

It is noteworthy that the capacity of the present chip-level transmitter is lower than that of systems based on bulky devices. This primarily stems from carrier performance degradation caused by integrated components, which featuring higher noise figures and insertion losses than their benchtop counterparts. Specifically, the IWC contributes an additional 3 dB insertion loss compared to benchtop WSS. SOAs, while far more compact than EDFAs, introduce excessive amplified spontaneous emission (ASE) noise. Meanwhile, their high α -factor and nonlinear effects (notably XPM) further induce cumulative phase noise and waveform distortion in high-speed systems^{46,47}. Figure 5(f) and (g) present the corresponding noise and OSNR degradation after amplification. When amplified to 10 dBm, the linewidth of channel 6 increases of approximately threefold and tenfold via EDFA and SOA respectively. In addition, the OCNr decreases by 6 dB and 12.5 dB respectively. Despite these impairments, the SIL light source still enables >5 Tbps transmission within the chip-level lightweight system, due to its original superior coherence and OCNr. For comparison, we implement a reference system using a 45-GHz-spacing electro-optic frequency comb pumped by an N7714A ECL (Fig. 5(d)). Under identical conditions, severely degraded constellation diagrams are obtained due to its poor original coherence (Fig. 5(e) black pentagrams).

"(b) Furthermore, the use of EDFAs and WSSs may negate the noise benefits of SIL combs. How does ASE noise impact OCNr, linewidth, and BER? Is the performance comparable or inferior to simpler pump-plus-filter approaches? This trade-off needs clarification."

Our reply: The reviewer's concerns are justified, and we carefully evaluate this. The ASE noise from optical amplifiers (EDFA or SOA) and the insertion loss of spectral shapers (WSS or IWC) will inevitably affect OCNr. The insertion loss of WSS (IWC) is approximately 5 dB (8 dB), and the OCNr degradation caused by EDFA (SOA) has been shown in Fig. 5(g). When the combine power is -10 dBm (OCNr=48), the insertion loss of WSS (IWC) will reduce the OCNr to 43 dB (40 dB). After amplification by EDFA (SOA), the OSNR will decrease by 6 dB (10 dB).

Moreover, the amplifiers' inherent linewidth enhancement will broaden the linewidth. Figure 5(f) shows the test results: SOA exhibits higher noise degradation than EDFA, increasing the 170 Hz linewidth by approximately threefold and tenfold, respectively. The measurements in Fig. 2(e) demonstrate that lower OCNr and broader linewidth will affect the maximum transmission rate, and the same applies to BER.

(Result, page 18) Figure 5(f) and (g) present the corresponding noise and OSNR degradation after amplification. When amplified to 10 dBm, the linewidth of channel 6 increases of approximately threefold and tenfold via EDFA and SOA respectively. In addition, the OCNr decreases by 6 dB and 12.5 dB respectively.

We infer that the mentioned "pump-plus-filter" approach refers to the conventional microcomb generation approach, where the pump laser is amplified and ASE noise is suppressed with a narrow bandpass filter. However, this configuration requires a complex tuning process with precise alignment between the pump frequency and the resonator peak, and the coherence of the generated combines is ultimately limited by the pump laser. Pump lasers that simultaneously offer high power and narrow linewidth are costly and challenging to integrate. In contrast, the SIL scheme, achieved via hybrid integration, is inherently more suitable for lightweight transmission. Additionally, benefiting from linewidth narrowing enabled by the high-Q microresonator, we can achieve combines with sub-1 kHz linewidth.

"(c) While a 61.5% conversion efficiency for 15 lines is reported, power distribution is uneven. Spectral flattening for power equalization introduces additional insertion loss. The authors should recalculate an "effective" conversion efficiency considering usable lines post-equalization."

Our reply: We sincerely appreciate the reviewer's insightful comments. As noted, conversion efficiency can be defined in multiple ways. In the main text, we give the conversion efficiency as the ratio between the total power of the 15 generated combines to the pump laser power. We understand the reviewer's concern, since practical transmission systems require consistent power levels across channels. Considering the 18 dBm LD power is converted to 16 >-10 dBm carriers, the "effective" conversion efficiency can be calculated as $16 \times 10^{-1} / 10^{1.8} = 2.5\%$. After including the additional insertion loss of the WSS (IWC), the post-equalization conversion efficiency falls to 0.8% (0.4%).

Following the wall-plug efficiency definition, we also provide the electro-optic conversion efficiency, which accounts for the generated optical power relative to the electrical power driving the optical sources. Considering the electrical consumption

of 0.469 W ($0.3 \text{ A} \times 1.564 \text{ V}$) for the laser diode, 0.587 W ($0.38 \text{ A} \times 1.545 \text{ V}$) for the SOA and the output optical power of 0.031 W (15 dBm), the overall electric-optic conversion efficiency is $\sim 3.0\%$. This is lower than typical wall-plug efficiency ($9\% \sim 16\%$) of DFB laser diodes. However, we emphasize that the strength of microcomb sources lies in their parallel transmission capability, which fundamentally distinguishes them from laser arrays. In WDM systems, the wavelengths of individual laser diodes must be carefully controlled, requiring multiple controllers and added power consumption. In contrast, the optical frequency comb provides intrinsically stable channel spacing, since the microcomb is mode-locked. This property dramatically reduces system complexity: in our demonstrated system, only two temperature controllers are required, whereas a 16-channel laser array would require 16 independent controllers.

The reviewer may concern that the post-equalization conversion efficiency is comparable to the other types of mode-locked microcombs, bright soliton microcombs, which feature flatter spectra. However, even in those cases, the central combline powers are not perfectly uniform. For example, combline power variations of $\sim 4 \text{ dB}$ and $\sim 10 \text{ dB}$ among the central 16 lines were observed in [Science 373, 99–103 (2021)] and [Nature Photonics 18, 294–299 (2024)], which also necessitate power equalization. Soliton crystal-based optical frequency combs, despite achieving conversion efficiencies $>40\%$, suffer from spectral non-uniformity that necessitates equalization exceeding 20 dB for individual combines [Nat Commun 11, 2568 (2020)].

(Supplementary Note 1) In the main text, we give the conversion efficiency as the ratio between the total power of the 15 generated combines to the pump laser power. Considering the 18 dBm LD power is converted to 16 $>-10 \text{ dBm}$ carriers, the “effective” conversion efficiency can be calculated as $16 \times 10^{-1} / 101.8 = 2.5\%$. After including the additional insertion loss of the WSS (IWC), the post-equalization conversion efficiency falls to 0.8% (0.4%).

Following the wall-plug efficiency definition, we also provide the electro-optic conversion efficiency, which accounts for the generated optical power relative to the electrical power driving the optical sources. Considering the electric consumption of 0.469 W ($0.3 \text{ A} \times 1.564 \text{ V}$) for the laser diode, 0.587 W ($0.38 \text{ A} \times 1.545 \text{ V}$) for the SOA and the output optical power of 0.031 W (15 dBm), the overall electric-optic conversion efficiency is $\sim 3.0\%$. This is lower than the typical wall-plug efficiency ($9\% \sim 16\%$) of DFB laser diodes, but unlike DFB arrays, it requires no individual LD or TEC control for each laser unit.

Comment 3: *“The manuscript mentions injection-locked amplification as a future improvement but this contradicts earlier claims that such techniques are less suitable for lightweight systems. Furthermore, prior work (e.g., Ref. [22]) has already demonstrated injection-locked amplification of SIL microcombs with comparable or better performance. The authors should re-evaluate their novelty claim and clarify the meaningful differences of their implementation compared to these prior studies.”*

Our reply: We sincerely appreciate the reviewer's rigorous scientific attitude. Relatively low combline power is a significant constraint of microcombs in high capacity transmission. Ref. 22 presents a feasible solution. However, the proposed SIL-plus-IL (injection locking) scheme relies on multiple laser diodes along with controllers for temperature and other parameters, leading to high power consumption and large volume, contrary to the goals of a lightweight system. In contrast, the revised manuscript presents a much more practical solution for lightweight transmission, employing four types of integrated chips: a laser diode, a SiN microresonator, a silicon photonic waveshaper, and a III–V semiconductor amplifier. All components are chip-level and commercially available, enabling a system with high integration, low power consumption, and significantly reduced cost.

We also note that integrated rare-earth-doped optical amplifiers with high output power (W-level) and low noise figures ($<5 \text{ dB}$) have already been demonstrated, and their combination with microcombs has been experimentally validated in transmission links. Such high-performance amplifiers are highly promising for compensating the low combline power and further strengthening the practicality of microcomb-based lightweight systems.

(Discussion, page 21) Additionally, despite high conversion efficiency, the comb power is still constrained by the limited pump power, making it challenging to adopt higher-order modulation formats, which can be mitigated by further optimization in coupling loss^{36,37} and integrated optical amplifier with high output power and low noise figure⁵⁰.

Comment 4: "Minor issues and editorial errors:

(a) Line 202: "gray dots" should be "purple dots".

(b) Supplementary Note 4, line 65: "Fig.1(e)" reference is unclear."

Our reply: We are grateful for the reviewer's meticulous evaluation and have thoroughly addressed all raised concerns through comprehensive revisions in our updated submission.

(Results, page 12) Compared with a high-performance tunable ECL1 with a ~10 kHz linewidth (gray dots), the self-injection locking scheme (~~gray dots~~ purple dots) exhibits a 3 dB lower OSNR requirement at the same EVM level due to the parallel high coherence.

(Supplementary Note 4) The local oscillator at the receiver is ~~of the same model as the ECL1 laser shown in Fig. 1(e).~~ KEYSIGHT N7714A ECL.

Thanks again for the valuable comments and helpful suggestions.

Dear Editor and Reviewers of Nature Communications,

We sincerely appreciate the careful review by the reviewers and have modified the manuscript in accordance with their suggestions. Here, we present a point-by-point reply (in blue) to the reviewers' comments (in black). All the changes have been highlighted (in red) with corresponding original text provided for comparison (in orange).

Response to the report from the Referee #1

General comments: *"I would like to acknowledge the authors for addressing my comments in a careful and thorough manner. The additions to the text are reasonable and fairly convincing. I would be happy to see this paper published after these requests and other reviewer comments are fully addressed."*

Our reply: We sincerely appreciate the reviewer's favorable comments and the considerable time and effort dedicated to evaluating our work. In the revised manuscript, we have incorporated a more detailed description and refined the analysis of the system footprint. Please find our point-by-point response attached.

Comment 1: *"In rebuttal comment 2: The authors state a simulated transmission; however, I believe they show an experimental result. Please clarify if these 1 Tbps results are experimental or simulation."*

Our reply: We sincerely thank you for this comment. We would like to clarify that our results are based on experimental demonstrations, not simulations. Corresponding clarifications have been added to the manuscript.

(Introduction, page 6 line 111) We ~~simulated~~ experimentally demonstrated short-reach campus/edge networks and metropolitan area network transmission separately. In the campus/edge networks, we achieved a transmission capacity of 1 Tbps/λ across all carriers using a self-homodyne system.

Comment 2: *"Please specify in text what FEC each raw (net) transmission result is using as some plots use the 7% HD-FEC, while other use a 9.1% overhead. "*

Our reply: We sincerely thank the reviewer for this valuable feedback. We have now provided clarification regarding all FEC overheads mentioned in the manuscript.

(Results, page 12, line 218-219) Thanks to the high OCNR with power levels above -10 dBm, all channels can support 110 GBaud DP-32QAM signal transmissions in the WDM configuration, indicating a single-channel rate of 1.1 (net 1.008) Tbps below the 9.1% forward error correction (FEC) threshold with a BER of 7×10^{-3} .

(Results, page 12, line 231-232) Overall, this 16-channel WDM scheme achieves a raw (net) aggregated rate of 8.96 (8.37) Tbps below the 7% HD (hard decision)-FEC.

(Results, page 15, line 278) In this case, we achieve a raw (net) transmission rate of 215.04 (200.97) Tbps below the 7% HD-FEC BER threshold by loading 70 Gbaud DP-16QAM signals, with only 16 wavelength channels, as shown in Fig. 4(c).

(Results, page 18, line 334) As demonstrated in Fig. 5(e), a 10-km transmission at 5.12 Tbps (net 5.015 Tbps, 5 channels under 7% HD-FEC threshold condition) is achieved using 40-GBaud DP-16QAM signals.

(Results, Fig. 4, line 312) (f) LP and OAM MDM transmission under 7% HD-FEC threshold.

Comment 3: *" In rebuttal comment 4: The authors show a on-chip size comparison for multiple components; however, they still emulate a real system by using an even/odd modulation scheme which only requires 2 DP-IQMs. It would be more useful*

to know the size and performance of the full system using on chip MUX/DEMUX pairs and individual modulators instead of an IWC."

Our reply: We are grateful to the reviewer for their valuable comments. We acknowledge the necessity of employing independent modulators for each wavelength channel in a practical deployment scenario, which underscores the importance of a more comprehensive statistical evaluation. In response, we have updated the relevant table and provided a detailed explanation in the manuscript to enhance the robustness of our discussion.

Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
EDFA	2	32*25*10
WSS	1	31*24*12
DP-IQM	16	8.8*1.4*1
2x1 Optical Coupler	1	0.7*5*0.4 0.3*6*0.3

In a practical deployment scenario using commercially available EDFAs and WSSs, the overall footprint is 2546 cm² with a height of 12 cm. By adopting a more lightweight SOA system and on-chip DEMUX/MUX components, the overall required footprint is further reduced to 208 cm² with a height of 1 cm. This results in a volume reduction by a factor of approximately 150 (2546*12/208/1 = 147). Furthermore, the use of on-chip IQ modulators holds the promise of achieving a volume reduction of more than a thousandfold [*Nature Communications* 15, 7892 (2024)].

Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
SOA	2	3*1.27*1
AWG (DEMUX/MUX) [<i>IEEE Photonics Technology Letters</i> , 35(7), 369-372, 2023]	2	~0.11*0.07
DP-IQM	16	8.8*1.4*1

(SI, Supplementary Note 7) We present the volume and quantity of all components in the transmitter. For our long-haul, high-speed demonstration, the transmitter assembly features a footprint of 2374 cm² and a height of 12 cm. In the more lightweight transmitter demonstration, our system occupies an area of 89 cm² with a height of 3 cm. This results in a volume reduction of more than a hundred-fold (2374*12/89/3 = 106).

It is noteworthy that in our experiment, two DP-IQ modulators were used to separate the odd and even channels to simulate a real world transmission system. In an actual communication node deployment, each carrier channel requires an individual modulator for signal loading. Consequently, we have re-evaluated the size here in table S5. In a practical deployment scenario using commercially available EDFAs and WSSs, the overall footprint is 2546 cm² with a height of 12 cm. By adopting a more lightweight SOA system and on-chip DEMUX/MUX components¹, the overall required footprint is further reduced to 208 cm² with a height of 1 cm. This results in a volume reduction by a factor of approximately 150 (2546*12/208/1 = 147). Furthermore, the use of on-chip IQ modulators holds the promise of achieving a volume reduction of more than a thousand-fold.

Table S4. Experimental system component sizes.

EDFA-WSS-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
EDFA	2	32*25*10

WSS	1	31*24*12
DP-IQM	2	8.8*1.4*1
2x1 Optical Coupler	1	0.3*6*0.3
SOA-IWC-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
SOA	2	3*1.27*1
IWC	2	5.2*4.8*3
DP-IQM	2	8.8*1.4*1
2x1 Optical Coupler	1	0.3*6*0.3

Table S5. Real deployment system component sizes.

EDFA-WSS-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
EDFA	2	32*25*10
WSS	1	31*24*12
DP-IQM	16	8.8*1.4*1
16x1 Optical Coupler	1	0.7*5*0.4
SOA-AWG-based		
Component	Number	Volume (cm*cm*cm)
SIL Comb	1	2.8*1.2*1
SOA	2	3*1.27*1
AWG (DEMUX/MUX)	2	~0.11*0.07
DP-IQM	16	8.8*1.4*1

In summary, we thank the reviewers for the thorough review, which has been invaluable in strengthening our paper. We have carefully revised the manuscript.

Response to the report from the Referee #2

General comments: *"The reviewed manuscript now adds additional experimental data: impact of linewidth and OCNR, the BER achieved with all the comb lines and comparison with ECL, and data transmission replacing EDFA and AWG by SOA and IWC, respectively. These experiments and the associated data clarify some of the concerns raised from the prior manuscript. In addition, the authors have increased the details of their experimental investigations with the added Methods and Supplementary information. I believe the paper contains enough results, however, it does have some issues associated mostly with the new extensive new content."*

Our reply: We sincerely appreciate the reviewer's meticulous review and rigorous assessment. We have provided further elaboration and refinements to the newly added experimental content. Please find our point-by-point response attached.

Comment 1: *"The paper includes multiple experiments with different settings, e.g., 70 GBd or 110 GBd, ECL or comb lines or a single line, SOA or EDFAs, and so on. The authors did include two setups in the supplementary document, however it is still not clear if, e.g., the same LO and receiver configuration is used. If so, do the authors observe or expect to observe penalties due to the 10 kHz linewidth of the LO? (I short sentence here would suffice)"*

Our reply: We thank the reviewer for their careful review of our manuscript. We apologize for the lack of clarity. However, to clarify, the local oscillator and receiver configuration were identical across both experimental architectures. We did not conduct experimental validation regarding the impact of LO laser linewidth. However, based on established understanding, we believe that an increase in LO linewidth would primarily place a greater computational burden on the DSP and consequently degrade the BER [*Journal of Lightwave Technology*, 38(6), 1138-1147 (2020)]. However, since the LO does not traverse the transmission channel, its impact is relatively "pure" and direct compared to the transmitter laser. Switching to an LO with a better linewidth would certainly achieve better transmission performance. In practical deployment, it may lower the economic benefit.

(SI, Supplementary Note 4) After generating the frequency comb, it is split into odd and even channels and decorrelated. Each channel undergoes I/Q modulation, and the signals are then coupled and transmitted through the fiber. The local oscillator at the receiver in both the EDFA-based and the SOA-based configurations is the KEYSIGHT N7714A ECL.

Comment 2: *"The authors use 2 SOAs. They mention the output power of the first one (10 dBm) but that of the second one is missing."*

Our reply: We are grateful to the reviewer for this comment. In our setup, the first SOA initially delivers an output power of 18 dBm. This signal subsequently experiences an 8 dB attenuation from the IWC, entering the modulators at 10 dBm. The modulators then introduce an inherent 20 dB insertion loss. After the signals are combined, they are finally amplified by a subsequent SOA to 2 dBm for transmission. This has been addressed by adding a clearer description in the manuscript.

(Results, page 18, line 327-333) After the IWC, all 16 comb lines are equalized to -18 dBm per carrier, accounting for an 8 dB insertion loss. All carriers are then amplified by an SOA to a total output power of 18 dBm and routed through another IWC for odd-even channel separation. The separated carriers are modulated by 35-GHz-bandwidth DP-IQ modulators (which introduce 20 dB of insertion loss), combined, and then amplified by an SOA to an output power of 2 dBm before transmission.

Comment 3: *"The authors continuously refer to OCNR and OSNR values. How are these quantities measured? Are the authors using the optical spectrum analyzer? If so, which resolution bandwidth they consider? Importantly, where are they measured? I believe the authors should clearly indicate everytime where the OCNR and OSNRs are measured. If the authors consider a resolution bandwidth of 12.5 GHz, I can't understand how they measured an OSNR of 40 dB (Fig. 5g) if the power of the comb line before the first SOA is already -18 dBm. I would expect a much lower OSNR if that is measured after the second SOA. The authors should clarify this as it questions the validity of this analysis."*

Our reply: We sincerely thank the reviewer for pointing out the lack of clarity in our experimental description. We have revised the corresponding section to provide a more explicit explanation and have supplemented it with additional experimental data to resolve the ambiguity.

"The authors continuously refer to OCNR and OSNR values. How are these quantities measured? Are the authors using the optical spectrum analyzer? If so, which resolution bandwidth they consider? "

- We confirm that both the OCNR and OSNR were indeed measured using an optical spectrum analyzer (OSA), with the resolution bandwidth set to **6.25 GHz**. The measurement method is primarily determined by the power ratio (in dB) between the peak of the optical carrier and the ASE noise floor.

(Materials and Methods, page 27, line 504-506) It must be emphasized that all OCNR measurements were performed with the optical spectrum analyzer's resolution bandwidth set to 6.25 GHz.

"Importantly, where are they measured? I believe the authors should clearly indicate everytime where the OCNR and OSNRs are measured. "

- The measurement location has been explicitly specified at all points where OCNR and OSNR data is presented.

(Results, Fig. 2) (e) The influence of OCNR and linewidth on the maximum net symbol rate is evaluated under the error-free condition in single carrier condition. This OCNR is measured at the output of the first-stage EDFA and is primarily determined by the intrinsic property of the optical source itself.

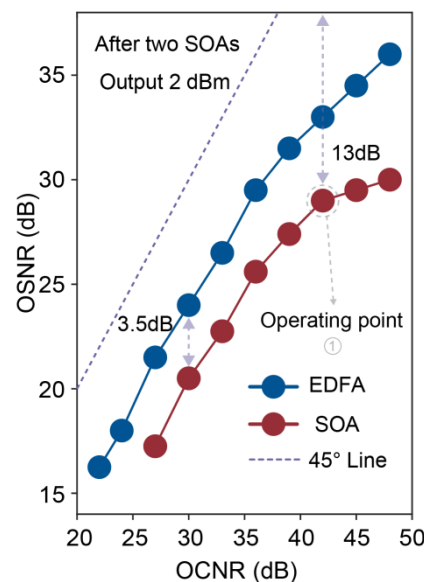
(Results, Fig. 3) (f) OSNR penalty process. The OSNR measurement is performed after the first EDFA at the receiver. The left and right panels show BTB and 160-km transmission, respectively.

(Results, page 19, line 349-353) After two SOAs, IWC and modulators, the OCNR decreases by 13 dB at the 2 dBm output operating point, as shown in Fig. 5(g). We find that when the input optical carrier has an OCNR < 25 dB, the ASE noise from the dual SOAs completely overwhelms the carrier, rendering it incapable of supporting signal transmission.

(Results, Fig. 5) (g) OCNR-OSNR degradation induced by two SOAs or EDFAs at 2dBm output power.

"If the authors consider a resolution bandwidth of 12.5 GHz, I can't understand how they measured an OSNR of 40 dB (Fig. 5g) if the power of the comb line before the first SOA is already -18 dBm. I would expect a much lower OSNR if that is measured after the second SOA. The authors should clarify this as it questions the validity of this analysis. "

- We are grateful to the reviewer for their meticulous attention to detail in identifying this discrepancy. The original figure 5g was measured after the first stage amplification using a single wavelength laser as the input, and was presented to qualitatively explain the OCNR degradation during the amplification process. Additionally, the vertical axis in the initial version of Fig. 5g, labeled as OSNR, may be misleading. As the measurement was taken after amplification by a single SOA and without any signal transmission, it actually shows the OCNR variation. The label has been corrected accordingly. To address the reviewer's concern, we have supplemented the analysis with an investigation of the OCNR to the exact OSNR degradation under WDM conditions, following the signal path through two SOAs, an IWC and a modulator, which is same as the one in data transmission experiment.



(g) OCNR-OSNR degradation induced by two SOAs (EDFAs) at 2dBm output power.

We have re-measured the OCNR variation under the experimental conditions. With an input power of -18 dBm (corresponding to an OCNR of 42 dB), the final achieved OSNR was only 29 dB. To better elucidate the system's operating point, we have created a schematic diagram to show the power budget at each connection points.

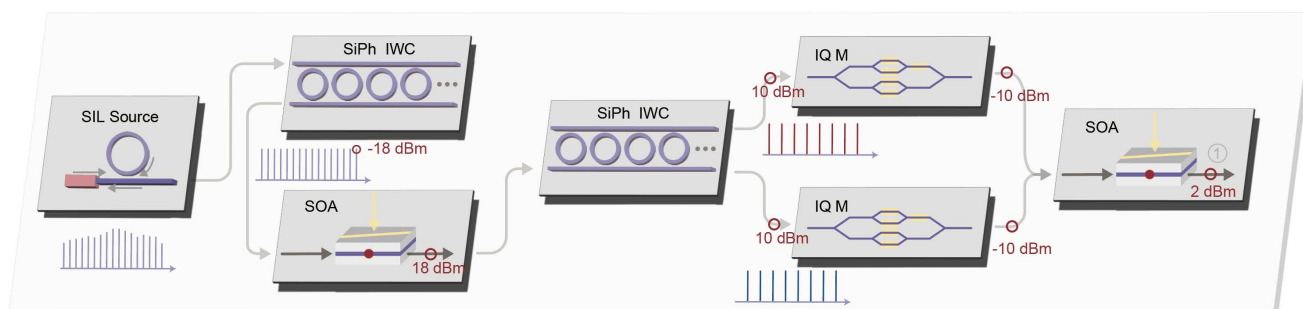


Fig. Operating point optical power

Meanwhile, we put the original Fig. 5g into the updated version in the SI, with corrected labels.

(SI, Supplementary Note 6) We present the degradation of the input OCNR by a single SOA at an output power of 10 dBm using a single wavelength laser, which is caused by the introduction of ASE noise. In comparison, EDFAs introduce lower ASE noise, which results in a 4 dB higher final OCNR output. Additionally, EDFAs offer superior linearity, broader span range, higher saturation power, and lower input power requirements.

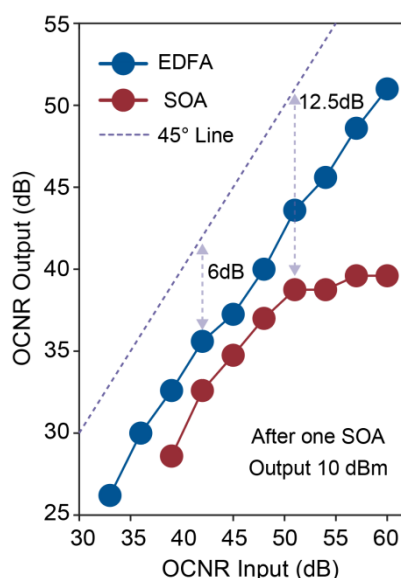


Fig. S6 OCNR degradation. The blue curve represents the EDFA, and the red curve represents the SOA, both at an output power of 10 dBm. The EDFA shows a degradation of approximately 6 dB, while the SOA exhibits about 10 dB.

Comment 4: "The manuscript seems to have lost the well organized structure from the first version. The authors may want to revise the content for smooth reading and clear transitions between experiments."

Our reply: We sincerely thank the reviewers for their valuable suggestions. We have added more transitional sentences to make the logical connections between experiments smoother and more coherent.

(Introduction, page 5, line 98-99) Such a source is essential to maximize single-channel capacity, enable multi-dimensional multiplexing for even higher aggregate rates, and tolerate the performance degradation inherent in lightweight systems.

(Introduction, page 5, line 105-108) To establish an overarching framework for our study, we perform a detailed investigation of the constraints among OCNR, linewidth, and achievable transmission rate.

(Introduction, page 6, line 122) Finally, for more compact deployment scenarios, a chip-level multicarrier generator is demonstrated, replacing bulky erbium-doped fiber amplifiers (EDFAs) and wavelength-selective switches (WSS) with integrated semiconductor optical amplifiers and silicon photonic waveshapers.

(Results, page 18, line 314-316) Under stringent cost and footprint constraints, bulky equipment impedes system integration, particularly for achieving lightweight transmission in distributed edge nodes.

Comment 5: *"In addition, there quite some grammatical error, e.g., lines 213-215 have some of them. The authors may want to also revise this thoroughly."*

Our reply: We sincerely thank the reviewer for this reminder. We have thoroughly re-examined the entire manuscript and made corrections to grammatical and spelling errors throughout the text.

(Introduction, page 3, line 62) Despite the achievement of ultra-high capacity integrated parallel transmission systems, conventional schemes still struggle to deliver the required data throughput while maintaining compact structure and energy efficient efficiency in space-limited and power-constrained scenarios.

(Introduction, page 5, line 101-102) The highly integrated source provides both high coherence with approximately 40 dB frequency noise suppression and high ~~pre-channel~~ per-channel power with >60% on-chip conversion efficiency.

(Results, page 8, line 142-143) To fulfill the demand for a compact, highly coherent source, the SIL microcomb scheme is implemented for frequency noise compression and carrier-to-noise enhancement in this work, as shown in Fig. 2(b).

(Results, page 11, line 214) Limited by the channel spacing of 100 GHz, we artificially doubled the spectral interval through WSS, as shown in Fig. 3(b), and distinguish the channels by their transparency.

(Results, page 11, line 216) Thanks to the high OCNR with power levels above -10 dBm, all channels can support 110 GBaud DP-32QAM signal transmissions in the WDM configuration, indicating a single-channel rate of 1.1 (net 1.008) Tbps below the 9.1% FEC (forward error correction) threshold with a BER of 7×10^{-3} .

(Results, page 12, line 226-229) DP-16QAM signals are then modulated onto the parallel carriers, which are subsequently combined and transmitted through a 160-km standard single mode fiber (SMF). At the receiver end, the LO source and transmitted comb lines are detected and mixed by a coherent receiver.

(Results, page 15, line 282-285) Besides, we show the first proof-of-concept mode-division multiplexed (MDM) multi-dimensional transmissions includes LP modes in a few-mode fiber (FMF) and OAM modes in a ring-core fiber (RCF) driven by the integrated photonic light source.

(Results, page 19, line 340) This primarily stems from carrier performance degradation caused by integrated components, which feature higher noise figures and insertion losses than their benchtop counterparts.

(Results, page 19, line 346-348) Figure 5(f) presents the corresponding noise degradation after an SOA amplification. When amplified to 10 dBm, the linewidth of channel 6 increases ~~of~~ by approximately threefold and tenfold via EDFA and SOA respectively.

(Results, page 19, line 355) For ~~comparation~~ comparison, we implement a reference system using a 45-GHz-spacing electro-optic frequency comb pumped by an N7714A ECL (Fig. 5(d)).

(Discussion, page 22, line 398) ~~Despite~~ Although the total capacity is below the petabit-per-second scale compared to state-of-the-art demonstrations, a higher channel capacity and streamlined nature of this architecture would significantly reduce the footprint and overhead associated with channel scaling, making it well-suited for compact edge infrastructure.

(Materials and Methods, page 27, line 501) along with two cases that failed demodulation - an InP DFB laser (3 MHz)

Response to the report from the Referee #3

General comments: " *The authors have made significant improvements to the manuscript, particularly by providing a more compact DFB-laser pumping scheme for the frequency comb. This alternative is a valuable addition. However, it is also clear that this new scheme comes at the cost of substantially worse performance parameters compared to the original EDFA-based approach. While this trade-off between compactness and performance is an important discussion point, the manuscript has been improved enough through the added comparisons to be acceptable for publication. I recommend acceptance.*"

Our reply: We thank the reviewer for carefully reviewing our manuscript and for providing valuable comments

Thanks again for the valuable comments and helpful suggestions!