# Low-Cost 100 Gbps Transport Solution Based on DCO-CFP and G.657.A2 Fibre for Long-Haul WDM Transmission

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**ABSTRACT**
We show here that combination of "low-cost" transport solutions based on 100 Gbps DCO-CFP interface and G.657.A2 fibre is able to address long-haul (~2000 km) WDM transmission applications. A performance comparison is carried out with "premium" solutions based on 100 Gbps coherent OIF-MSA transceivers and legacy G.652.D fibre.
**Keywords**: optical fibres, coherent communications, 100 Gbps WDM interfaces.

## 1. INTRODUCTION

Silicon photonics [1] drive an incredible technological breakthrough in the field of high bit-rate coherent WDM interfaces. Integrating a coherent 100 Gbps transceiver with advanced digital signal processing and soft-decision FEC (SD-FEC) into a C-form factor pluggable (CFP) module of 5.7 × 3.2 inches is today possible [2]. This high level of miniaturization results in a drastic reduction of cost, power consumption and size of 100 Gbps WDM transceivers.

From its side, the domain of optical fibres is in a deep mutation. G.652.D fibres [3], usually deployed over regional and core transport networks, are now challenged by G.657.A2 fibres [4], that are become the standard for building wiring, connection boxes and fibre-to-the-home (FTTH) networks. Thanks to their low bending loss and compliance with G.652 fibre pigtails, G.657.A2 fibres should be of high relevance for metro/regional and long-haul (LH) transport applications, and as such, should involve significant cost savings and management simplification of fibres and cables in the field.

In this paper, we demonstrate that combination of such "low-cost" transport solutions based on 100 Gbps digital coherent CFP (DCO-CFP) transceiver [5] and G.657.A2 fibre is well-adapted to LH (~2000 km) transmission applications. For the first time, a relevant performance comparison is carried out with "premium" solutions based on 100 Gbps Optical Internetworking Forum (OIF) multi-source agreement (MSA) coherent transceivers [6] (dedicated to ultra-long-haul transport networks) and G.652.D fibres (devoted to legacy metro/core fibre infrastructure).

## 2. FIBRES AND 100 GBPS WDM TRANSCEIVERS UNDER INVESTIGATION

*Table 1: Compared features of the 100 Gbps DCO-CFP and 100 Gbps OIF-MSA WDM transceivers under test.*

| | 100G OIF-MSA interface | 100G DCO-CFP interface |
|---|---|---|
| Line Rate | 120 Gbps | 120 Gbps |
| FEC Threshold | SD-FEC (TPC) BER ~ $2\times10^{-2}$ | SD-FEC (TPC) BER ~ $1.5\times10^{-2}$ |
| CD | ~60000 ps/nm | ~40000 ps/nm |
| Distance | Up to 3500 km | Up to 2000 km |
| PMD | Up to 30 ps | Up to 25 ps |
| Sensitivity | ~ -24 dBm | ~ -28 dBm |
| Wavelength | Full C-Band | Full C-Band |
| Power Consumption | ~80 W | 28 W |
| Size (LxW) | 7” x 5” | 5.7” x 3.2” |

*Table 2: Compared features of the G.657.A2 and G.652.D fibres under test.*

| | G.652.D | G.657.A2 |
|---|---|---|
| Mode Field Diameter 1550 nm | 10.4 ± 0.5 µm | 9.7 ± 0.5 µm |
| Attenuation 1310 – 1625 nm | ≤ 0.40 dB/km | ≤ 0.40 dB/km |
| Attenuation 1550 nm | 0.20 dB/km (typ.) | 0.195 dB/km (typ.) |
| Dispersion 1550 nm | ≤ 18 ps/(nm.km) | ≤ 18 ps/(nm.km) |
| PMD Link Design Value | ≤ 0.06 ps/km$^{1/2}$ | ≤ 0.06 ps/km$^{1/2}$ |
| | Macro-Bend Loss at 1625 nm | |
| Mandrel Diameter | 60 mm | 60 / 15 mm |
| Number of turns | 100 | 100 / 1 |
| Attenuation | ≤ 0.1 dB | ≤ 0.05 / ≤ 1 dB |

The highest benefit of 100 Gbps DCO-CFP is to be three-fold cheaper than standard 100 Gbps WDM interfaces [2], while drastically reducing size (divided by four) and power consumption (divided by three when considering

OIF requirements). Its SD-FEC based on Turbo-Product-Codes (TPC) is very efficient, with a pre-FEC BER threshold of ~$1.5\times10^{-2}$, a net coding gain of ~11 dB at $10^{-15}$, an overhead of only 15%, and an OSNR (in 0.1 nm) of ~13 dB at the FEC limit [5]. Its power consumption is ~28 W when chromatic dispersion (CD) and polarization mode dispersion (PMD) compensation are at their maximum values (i.e. 40000 ps/nm for CD and 25 ps for PMD). The main features of the 100 Gbps DCO-CFP and 100 Gbps OIF-MSA (used here as a reference) transceivers are summarized in Tab. 1.

The main interest of G.657.A2 fibre resides in its high robustness to bends (see Tab. 2). The trench-assisted index-profile structure also lowers micro-bending sensitivity and thus cable-induced loss effects [7]. The other parameters are identical to those of G.652.D fibre, except the attenuation and mode field diameter which are slightly lower.

## 3. EXPERIMENTAL SET-UP

The 120 Gbps DP-QPSK wavelengths generated by the OIF-MSA interface at 1548.51 nm and the DCO-CFP module at 1547.72 nm are inserted in a 58×120 Gbps DP-QPSK 50-GHz spaced WDM multiplex. The 60 channels are then injected into an uncompensated fibre line of 20×100 km constituted of the two fibres under test (see Fig. 1). The 19.5/20-dB span losses of the G.657.A2 / G.652.D fibre spans are balanced by single-stage EDFA with 4.5-dB noise figure. Two dynamic gain equalizers (DGE) flatten the WDM multiplex at 500 km and 1500 km. At the receiver side, a 0.4-nm flat-top optical band-pass filter (OBPF) selects the right channel, while an optical switch sends the signal under measurement over the right transceiver.

The 120 Gbps coherent OIF-MSA transceiver [6] used here as a reference compensates CD up to 60000 ps/nm and PMD up to 30 ps [8]. Like the DCO-CFP module, it uses a TPC-based SD-FEC, with a pre-FEC BER of ~$2\times10^{-2}$, a net coding gain of 11.1 dB at $10^{-15}$ and an overhead of 15%. Its energy consumption is ~100 W. As shown in Fig. 3, its OSNR limit at the FEC threshold is equal to ~12.3 dB, i.e. ~0.8 dB better than the DCO-CFP. Two 100 GbE LR10 client CFP modules are plugged into the Ekinops transponder (which embeds the OIF-MSA transceiver) and the Acacia evaluation board (which hosts the DCO-CFP). Each of the two 100GbE LR10 CFP is connected to a 100 GbE tester for long-duration BER measurements. Inside the Ekinops transponder and Acacia board, the WDM transceiver and client interface communicate together thanks to a 100 Gbps attachment unit interface (CAUI).

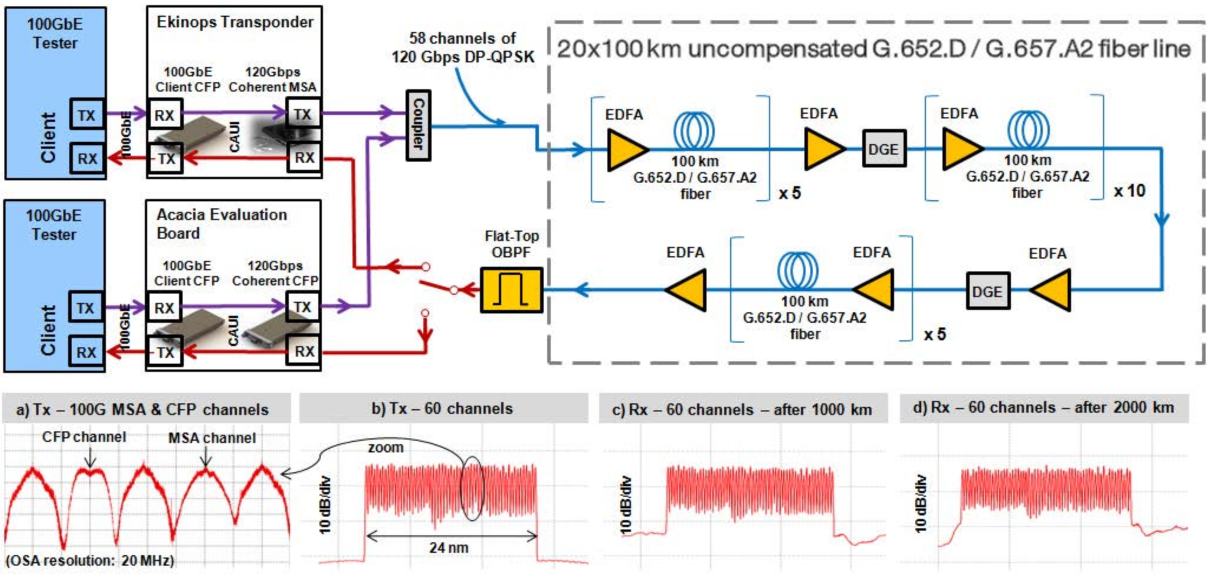


*Figure 1. Experimental setup with, in insets, the spectrum at the transmitter side (a & b), after 1000 km (c) and 2000 km (d).*

## 4. TRANSMISSION PERFORMANCE AND DISCUSSIONS

For various distances, BER versus span input power per channel ($P_{\text{in span /channel}}$) curves are plotted in Fig. 2 for each of the two fibres and each of the two interfaces under test. It can be observed first that the performances of G.657.A2 and G.652.D fibres are similar at the optimum $P_{\text{in span /channel}}$, and second, that the optimum $P_{\text{in span /channel}}$ is 1 dB lower for the G.657.A2 than for the G.652.D fibre spans. It means that G.657.A2 fibre is slightly more sensitive to nonlinear effects. Indeed, mode field diameter and effective area of G.657.A2 fibre are slightly smaller than those of G.652.D fibre (see Tab. 1). Secondly, the lower attenuation of G.657.A2 fibre slightly increases the effective length $L_{\text{eff}}$ (i.e. the length where nonlinearities are induced) of G.657.A2 fibre spans ($L_{\text{eff}}$ = 22 km for 100 km spans) with respect to G.652.D fibre spans ($L_{\text{eff}}$ = 21.5 km for 100 km spans).

Now comparing the performance of the two 100 Gbps interfaces, it can be inferred from Fig. 2 that the OIF-MSA solution works better than the DCO-CFP one. After 2000 km, the pre-FEC BER is one decade better with the OIF-MSA transceiver (BER ~ $1\times10^{-4}$) than with the DCO-CFP interface (BER ~ $1\times10^{-3}$). However, in the both cases, the optimum pre-FEC BER is far to reach the FEC threshold. In particular, for the DCO-CFP, more than one BER decade margin still exists between the BER after 2000 km and the FEC threshold (BER = $1.5\times10^{-2}$).

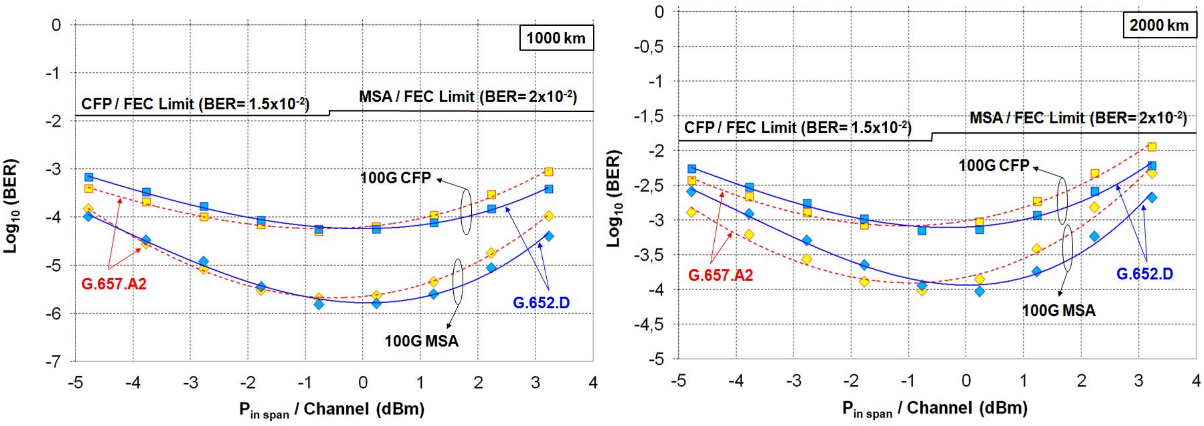


*Figure 2. BER vs. $P_{in\ span/channel}$ for the 100 Gbps OIF-MSA / DCO-CFP transceivers and the G.652.D / G.657.A2 fibres.*

Left hand side of Fig. 3 confirms these results. Whatever the distance, the performance of G.657.A2 and G.652.D fibres are equivalent, and the OIF-MSA performs better than the DCO-CFP, with large BER margins with respect to the FEC threshold. BER measurements during 24 hours with the 100 GbE testers confirm that error-free transmission is achieved after 2000 km whatever the configuration under study. In the right hand side of Fig. 3, the optimum of each BER versus $P_{in\ span\ /channel}$ curves is reported over a BER versus OSNR (in 0.1 nm) graph, where are also plotted the back-to-back (BtB) sensitivity curves of the OIF-MSA and DCO-CFP interfaces. Transmission penalties are nearly similar for the two fibres under test, and the OSNR after 2000 km is ~18.5 dB, i.e. very far from the OSNR limits measured in BtB at the FEC threshold (~12.3 dB for the OIF-MSA transceiver and ~13.1 dB for the DCO-CFP interface).

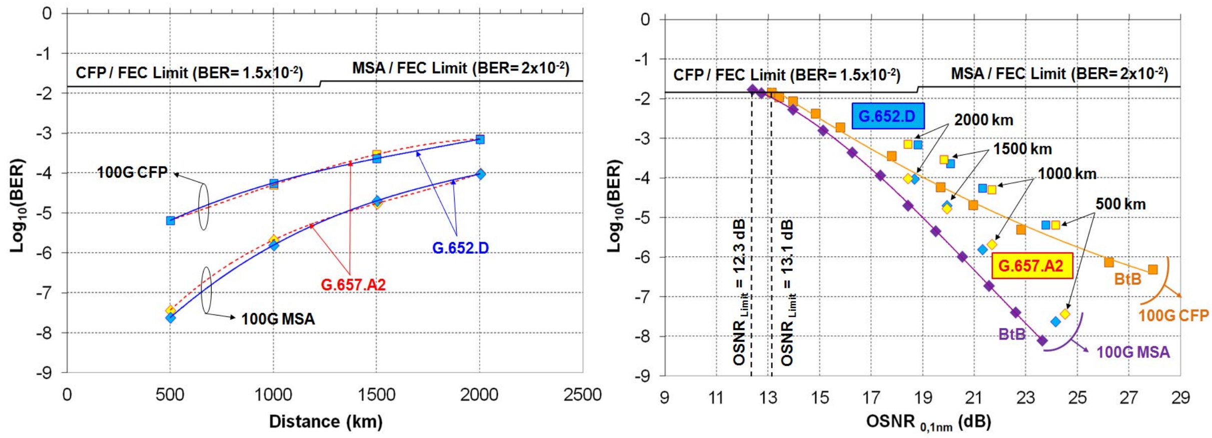


*Figure 3. BER vs. transmission distance at the optimum $P_{in\ span/channel}$ for the 100 Gbps OIF-MSA / DCO-CFP transceivers and the G.652.D / G.657.A2 fibres (Left), BER vs. OSNR in 0.1 nm in BtB for the 100 Gbps OIF-MSA and DCO-CFP transceivers. BER vs. OSNR points at the optimum $P_{in\ span/channel}$ for various distances (Right).*

## 5. CONCLUSIONS

We have shown that low-cost 100 Gbps transport solutions based on DCO-CPF module and G.657.A2 fibre can address long-haul (~ 2000 km) WDM transmission in replacement of "premium" solutions based on 100 Gbps OIF-MSA coherent transceivers and legacy G.652.D fibre. For operators facing a continuous erosion of their average revenue per user, it is critical to deploy such cheap 100 Gbps solutions well-dimensioned with respect to their transport applications.

## ACKNOWLEDGEMENTS

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