# Transmission of 1550nm 10Gb/s directly modulated signal over 100km of negative dispersion fiber without any dispersion compensation

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***Abstract***: We demonstrate the largest transmission distance (100km) ever reported for a 10Gb/s 1.55μm directly modulated signal over a single fiber link without using any dispersion compensation. The fiber is optimised for operation with directly modulated lasers and has negative dispersion.

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## 1. Introduction

Cost-effective directly modulated distributed feedback lasers (DMLs) have attracted much attention recently for 2.5Gb/s operation at both 1.3μm and 1.55μm wavelength bands for applications in metropolitan area systems [1]. Recently, there has also been a rapidly growing interest in 10Gb/s Ethernet transmission for high-speed data networking where DMLs are a possible transmitter choice.

DMLs have the advantages of small-size, low-cost, low driving voltage and high output power, so they can exploit the loss margin that single mode fibers can provide at 1.55μm. The output power of DMLs can provide for a power budget that allows for amplifier/regenerator spacing of 80-100km. However, the chirp characteristics of DMLs significantly limit the maximum achievable transmission distance over conventional single-mode fibers [2]. At 2.5Gb/s the 2-dB power penalty dispersion-limited distance of commercially available 1.55μm DMLs as specified by their manufactures is typically 100km. At 10Gb/s the dispersion-limited distance of 1.55μm DMLs is much lower (usually less than 10km). In fact, for a chirp-free 10Gb/s signal the theoretical 2dB dispersion-induced power penalty limit is just 75km over standard fiber. Therefore, 10Gb/s DMLs were developed initially for the 1.3μm wavelength band, where the dispersion of conventional single mode fibers is very small [3]. It is only recently that 10Gb/s DMLs were developed for the 1.55μm wavelength band.

Electro-absorption modulator integrated distributed feedback lasers (EA-DFBs) are another possible solution as 10Gb/s 1.55μm sources [4]. Commercially available EA-DFBs are specified for a dispersion tolerance of 1440-1600ps/nm (about 80km of standard fiber). However, their output power is small (~5-10dB lower than that of DMLs) and the use of optical amplification is needed for successful detection at such distances.

The absence of optical amplification results in reduced system cost and complexity. For such amplification-free designs DMLs appear as a more attractive solution if the dispersion penalty is not significant. Dispersion compensation techniques can be used as an effective solution to avoid the distortion in a linear system. However, their use adds cost, complexity and loss to the system. Therefore, an optical fiber that will increase the dispersion-limited distance to 80-100km when using high power DMLs is of significant importance.

Previous studies have tried to increase the dispersion-limited distance of DMLs over standard fibers [5]. However, these solutions have several drawbacks in terms of increased system costs and/or complexity. We believe that the use of a negative dispersion fiber that will take advantage of the positive transient chirp of DMLs will dramatically enhance the capabilities of 10Gb/s directly modulated lasers. The use of negative dispersion fiber (i.e. MetroCor™ fiber) has been demonstrated for successful transmission of 2.5Gb/s directly modulated signals [6]. It was shown in a 32-channel system that the negative dispersion fiber works well across the EDFA bands and transmission without dispersion compensation over 300km is easily achieved with a BER $< 10^{-15}$.

In this work we investigated the transmission performance of a commercially available 1.55μm 10Gb/s DML over negative dispersion fiber for different bias and driving conditions. The performance is compared to that of SMF-28™ fiber. A transmission distance of 100km is achieved for a directly modulated signal with an extinction ratio of 5dB without using any dispersion compensation. This is the largest distance reported for this kind of sources. We also demonstrate error-free (BER < $10^{-15}$) transmission over 75km without dispersion compensation and without pre-amplification for a directly modulated signal with an extinction ratio of 8dB. Based on our previous experiments with 2.5Gb/s signals we believe that similar performance can be achieved for channels across the EDFA C-and L- bands.

## 2. Results and discussion

A 1.55μm commercially available 10Gb/s DML (NLK-1551-SSC) was used in our experiments. The laser wavelength was 1541.81nm and its threshold current 15.3mA. At a bias current of 50mA, the output power was ~6dBm and the 3-dB modulation bandwidth ~20GHz. The power and chirp waveforms were measured for various driving conditions and it was found that the laser presented strong transient chirp. The DML was also characterised using the experimental procedures described in Ref. [7] and the rate equation parameters associated with this specific laser were determined. Transmission simulations were then performed using the modelled DML and the characteristics of MetroCor fiber. MetroCor fiber, has a zero dispersion wavelength beyond L-band and negative dispersion in the entire usable bandwidth (1280-1620 nm). The other fiber characteristics (attenuation, dispersion slope, effective area, etc.) are typical for non zero dispersion shifted fibers (G.655 compliant fiber). The simulations indicated that transmission over 100km was possible with less than 2-dB dispersion-induced power-penalty. A transmission experiment was then performed to validate the simulation predictions.

A $2^{31}$-1 PRBS signal, provided by the signal generator of a bit error rate test-set (BERT), was used to drive the DML at 10Gb/s. By varying the amplitude of this signal we could achieve different extinction ratios (ER) for the modulated optical signal. An electrical amplifier was used in the cases where the modulation voltage needed for high ER was larger than the maximum available peak-to-peak voltage from the BERT. The directly modulated 10Gb/s optical signal was then transmitted over various lengths of either SMF-28 or MetroCor fiber. An optical amplifier was used in some cases to provide the necessary power into the receiver. No dispersion compensation was used in any point of the transmission link. The performance of the detected signal was determined by measuring the Q-factor ($Q_{dB}=10\log Q_{linear}$).

Two different driving conditions were used in our experiments. In the first case the laser bias current was 55mA and the modulation voltage provided by the BERT was $2V_{p-p}$. These conditions resulted in a dynamic extinction ratio of 5dB. In the second case the bias current was 70mA and using an amplified electrical drive signal we could achieve an ER of 8dB. For the first bias and driving conditions the measured peak-to-peak transient chirp was ~19GHz, while for the second set of conditions the peak-to-peak transient chirp was ~39GHz.

In a first set of experiments, the performance was measured by using an optical pre-amplifier before the receiver. A transmission distance of 100km over MetroCor fiber was achieved with a Q-factor of 9.4dB (BER<$10^{-15}$) for a directly modulated signal with an extinction ratio of 5dB. In the case of 8dB ER a Q-factor of 9.3dB was measured for a transmission distance of 75 km over MetroCor fiber.

Since the main advantage of DMLs in comparison with EA-DFBs (and more generally with external modulation schemes) is the higher available output power, we measured the transmission performance of the system without amplification at any point. In this second set of experiments, we observed that in the case of a directly modulated signal with an ER of 8dB we could achieve a Q-factor of 9.5dB after a transmission distance of 75km of MetroCor fiber. For the same conditions we measured the performance over SMF-28 fiber. A Q-factor of 8.8dB was achieved after 10km. It is evident that a significant improvement in the transmission performance is possible when using a negative dispersion fiber.

In Fig. 1 we present the measured received eye-patterns for the cases of (a) transmission over 100km of MetroCor fiber of a signal with an ER of 5dB, (b) transmission over 75km of MetroCor fiber of a signal with an ER of 8dB and (c) transmission over 10km of SMF-28 fiber of a signal with an ER of 8dB. The simulation predictions using the extracted parameters for the specific 10Gb/s DML [7] and for the same conditions with the experiment are also shown. The simulations show very good agreement with the experiment.

Fig. 2 summarizes the Q-factor measurements over different lengths of SMF-28 and MetroCor fibers for various driving conditions. We should note that in the case of an ER of 5dB, a Q-factor improvement relative to the back-to-back case is evident for a distance up to 75km of MetroCor fiber. Also for an ER of 8dB a Q-factor improvement is observed for a distance up to 30km. These results demonstrate clearly the advantages resulting from the use of a negative dispersion fiber for transmission of directly modulated signals.

## 3. Conclusions

We demonstrated error-free (Q > 9.5dB, BER< $10^{-15}$) transmission over 100km of negative dispersion fiber for a 10Gb/s 1.55μm directly modulated signal over a single fiber link without using any dispersion compensation. To our knowledge, this is the largest distance ever reported for this kind of laser sources.

## 4. References

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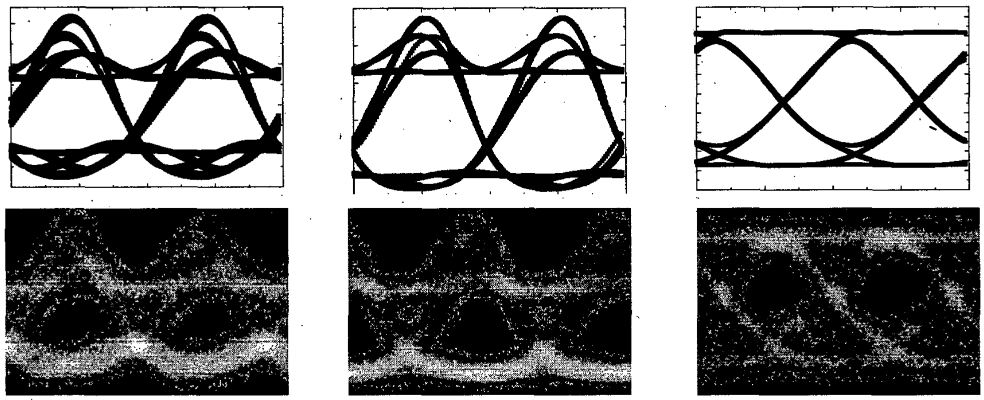

(a) (b) (c)

Fig. 1 – Simulated (top row) and measured (bottom row) eye-diagrams for (a) 100km MetroCor, ER=5dB, (b) 75km MetroCor, ER=8dB, and (c) 10km SMF-28, ER=8dB.

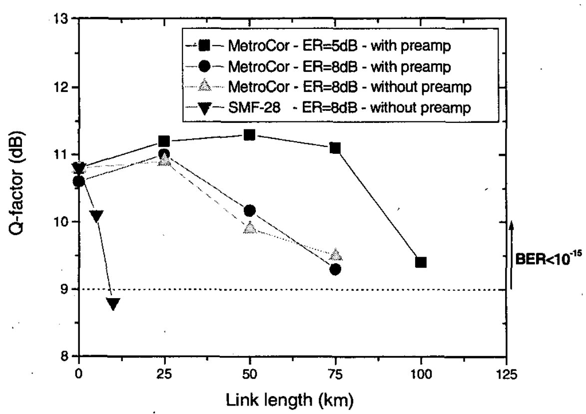


Fig. 2 – Q-factor measurements after transmission over various lengths of MetroCor and SMF-28 fibers for two different bias conditions, with or without the use of pre-amplification in front of the receiver.