

Chirp-Managed Directly-Modulated DFB Laser

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Abstract: We review recent patents on a chirp managed transmitter comprised of a DML and the subsequent optical band-pass filter. Large dispersion tolerance of this transmitter is realized by chirp control through the phase correlation between adjacent bits for the destructive interference in order to erase the power of "0" bits and enhance the extinction ratio. The reach of this transmitter without dispersion compensation is superior to the best reported DML-based and duobinary transmitters. The results show that this is a promising solution to meet the size, power, capacity and cost requirements of the optical links simultaneously in the today and tomorrow's metro and access networks.

Keywords: External modulator, directed modulated laser, dispersion compensation, distributed feedback laser, chirp, optical fiber, metro optical network, long haul optical network, single mode fiber, telecommunication, dispersion compensation fiber, wavelength, optical filter, transmitter, intensity modulation, frequency modulation.

1. INTRODUCTION

Currently, external modulation schemes, like electro-absorption modulator (EAM) or Mach Zehnder modulator (MZM) [1-4] are the dominant technologies in the existing metro and long haul optical links. However, in addition to use expensive external modulators, these systems require the dispersion compensation modules (DCMs) to overcome the dispersion limitation over standard single mode fiber (SSMF). But DCMs are expensive and bulky; for every 80-100 km of SSMF, several kilometers of DCF are required and could cost as much as the fiber for which it provides compensation [5]. Moreover, it is difficult for the telecommunication carriers to control on adding costly DCMs into the existing installed optical transport systems if they want to upgrade the metro systems from 2.5 to 10Gbit/s, build short-reach 40Gbit/s access networks or change optical path length when wavelengths are rerouted.

The three-level duobinary modulation format or dispersion supported technology (DST) may avoid using the DCMs in the optical links [6-9]. But it has not yet been widely used in commercial products. One reason for this is its weaker back-to-back performance. Additionally, it requires relatively complicated pre-coder, encoder and a high modulation drive to LiNbO₃ external modulator. In recent years, there is a growing interest in utilizing directly modulated lasers (DMLs) in cost-sensitive metropolitan and access optical links because of their potentially low cost, compact size, low power consumption and high optical output power characteristics when compared with other transmitter source using external modulation (EM) scheme. As it is well known, however, DMLs are the carrier density modulation via drive current, giving rise to inherent and highly component-specific frequency chirp, i.e., a residual phase modulation (PM) accompanying the desired intensity

modulation (IM). This results in broad spectrum that severely limits the ultimate transmission distance within twenty kilometers due to its interaction with fiber dispersion along the transmission.

One way to overcome this is to use the special fiber with a negative dispersion characteristic (MetroCor: -1.7ps/nm/km), which is a good choice to take advantage of the positive chirp characteristics of DMLs to increase the reach without the use of DCMs [10-11]. However, it is only suitable to new deployment of the optical transport system but not fit to upgrade and change of the installed base of metro SSMF links.

Hence, the cost-efficient transmitter for the transmission over SSMF in metro networks is the combination of the DML and phase-correlative modulation [12-14], which is shown in (Fig. 1). By employing DML, there is no need for the external modulator; on the other hand, by taking advantage of the phase correlation between the bits by controlling the frequency chirp, the DCMs can be avoided through the destructive interference to compensate the spread of the optical spectrum. It is a highly practical solution to meet the power consumption, size, capacity and cost simultaneously for today and tomorrow's transport networks.

In this paper, we show the recent patents related to the directly modulated transmitter with the capacity of 200km transmission over SSMF without the need of DCMs, which is a big progress in terms of cost and performance on the optical communication systems. The basic structure and operating principle of this novel chirp-managed transmitter are presented toward the commercially available products. The challenge and potential applications are also discussed.

2. RELATED PATENTS

After experiencing the winter of telecommunication industry, equipment manufacturers strive to reduce cost while at the same time adding new value, so here, replacing external modulation with directly modulated lasers and no

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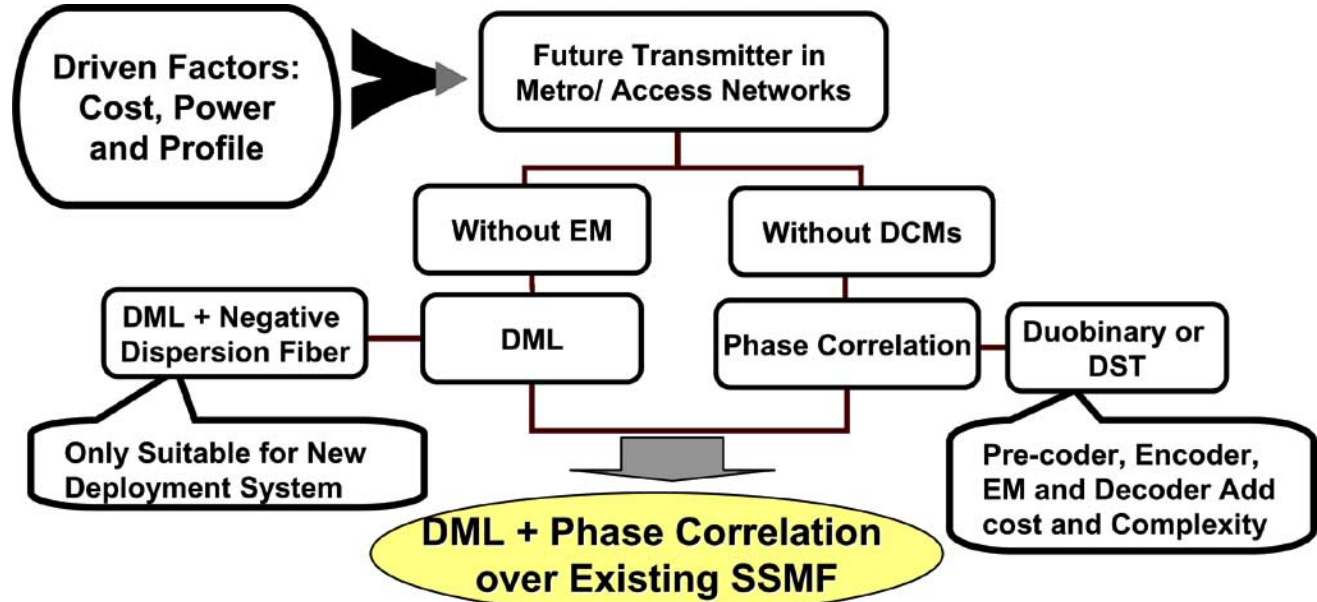


Fig. (1). Evolution of low cost, power consumption, and small profile transmitter.

dispersion compensation in optical links would substantially improve the cost basis.

AZNA LLC, founded in July, 2002, is a developer of innovative photonic components and subsystems for the communications and instrumentation industries. It is the only manufacturer to provide direct modulation transmitter based on the phase correlation between bits. Its flagship Chirp Managed Directly Modulated Lasers (CML) enable telecommunications equipment manufacturers to provide longer reach optical transmitter solutions at lower cost, better performance and less complexity compared to those based on external modulators. CML products leverage simple technology to extend the reach of high power 10G DMLs to beyond 200km and 2.5G DMLs to beyond 640km. They offer these products in butterfly packages or small footprint TOSAs for application in proprietary line cards or upcoming standardized XFP and SFP packages.

In the recent two years, AZNA published 3 international patents [15-17] and 1 U. S. patent [18] on the CML transmitter. The most comprehensive one is published on Sep. 15, 2005 by Daniel Mahgerefteh *et al.* and the title is "Optical System Comprising an FM Source and a Special Reshaping Element". It is a continuation-in-part of pending prior U.S. Patent Application Serial No. 10/289,944, filed 11/06/02; Serial No. 10/308,522, filed 12/03/02 and Serial No. 10/680,607, filed 10/06/03 by Daniel Mahgerefteh *et al.* as well [18]. This invention provides an optical spectrum reshaper (OSR) which works in tandem with a modulated optical source which, by modifying the spectral properties of the modulated signal, results in extending the optical transmission length well beyond the dispersion limit. Here, OSR is a coupled multi-cavity bandpass filter to enhance the fidelity of converting a partially frequency modulated signal into a substantially amplitude modulated signal with phase correlation between the adjacent bits. The other three patents specify the conversion between frequency modulation and amplitude modulation, the filtering effect for the adiabatic

chirp and the flat dispersion frequency discrimination by means of the bandpass multi-cavity filter respectively.

3. STRUCTURE AND OPERATING PRINCIPLE

Figure 2 shows the schematic of the CML and its operation. A CML comprises a directly modulated distributed feedback laser (DFB), followed by a multi-cavity etalon filter. The DFB is biased high above threshold (~ 5 _ threshold) to reduce transient chirp, which also leads to a low extinction ratio (ER ~ 1 -3 dB) at the DFB output. However, the laser wavelength is tuned to the transmission edge of the OSR in order to attenuate the red-shifted 0 bits relative to the blue-shifted 1 bits. In this way, the OSR increases the ER to > 10 dB and produces a clean eye. The OSR also forms a wavelength locker together with two photodiodes and a beam splitter.

The high dispersion tolerance is mainly because of the phase-correlative modulation among the adjacent bits via precisely controlling the frequency chirp from the DML modulation. The adiabatic chirp makes the "1" bits blue shifted relative to the "0" bits. Through proper controlling, the phase flip between 0 and 1 in the middle of the space bit could be realized, which leads to destructive interference between the energies on either side of the middle of the space after the dispersion-induced broad spectrum. This out of phase is the key to the dispersion tolerance. This resulting phase correlation and destructive interference along the fiber transmission is similar to that for optical duobinary modulation, but here, we don't require pre-coder, encoder, and external modulator in the transmitter side and the decoder in the receiver side.

Consider a 1 0 1 bit sequence at 10Gbit/sec where 1 bits have 5 GHz higher frequency than 0 bits. Now the phase of the carrier slips by $2 \times 5 \text{ GHz} \times 100 \text{ ps} = \pi$ during the 0 bit, making the second 1 bit out of phase with the first. Normally, dispersion closes the eye by spreading energy of the 1 bits into adjacent 0 bits. Here, the 1 bits interfere destructively in the middle 0 bit because of the phase shift,

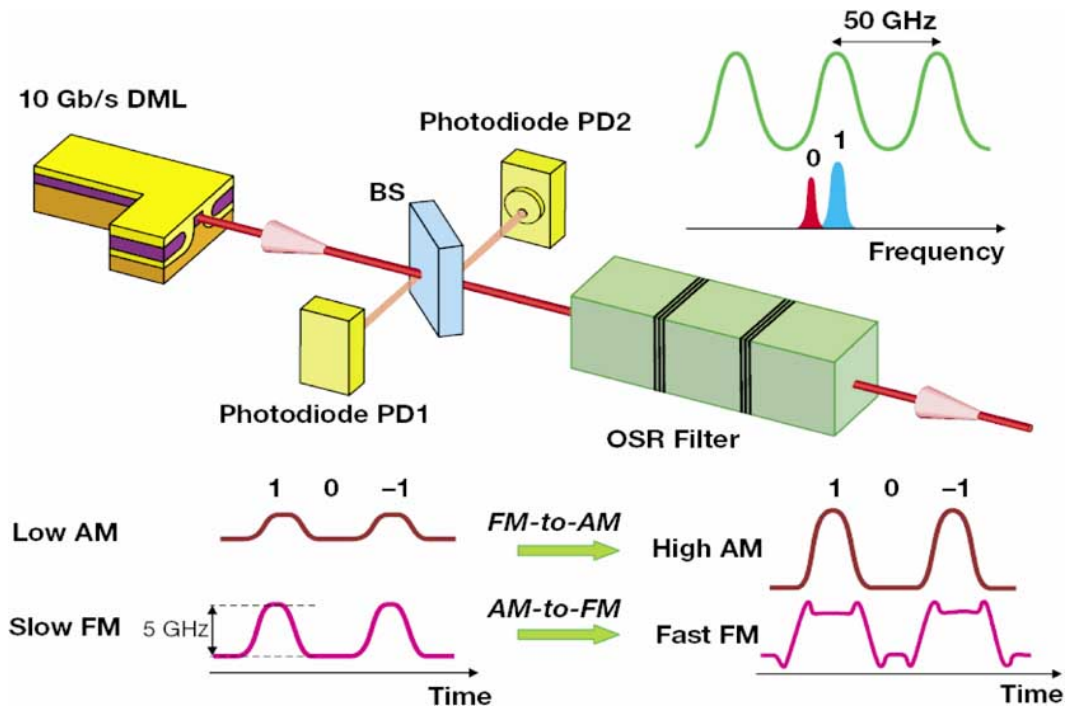


Fig. (2). Schematic of chirp-managed directly modulated DFB laser (CML).

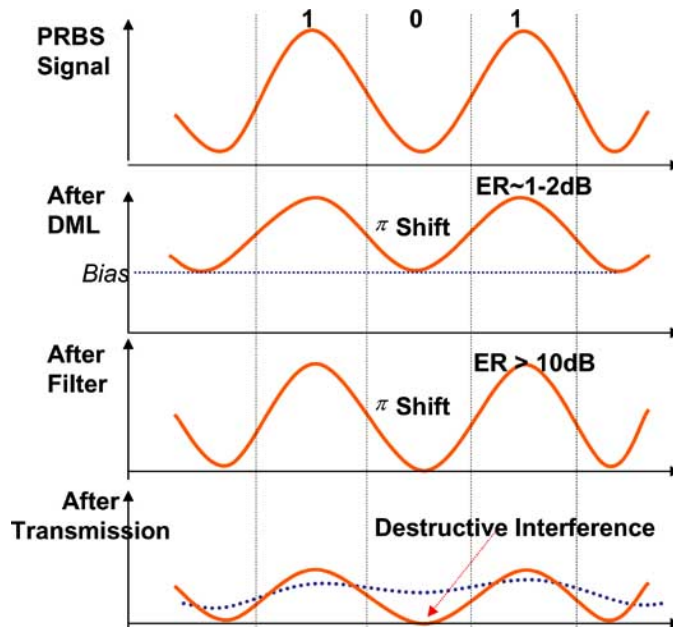


Fig. (3). Schematic of the evolution for the signal waveforms.

keeping the eye open after fiber propagation. The original binary signal, the directly modulated signal, the filtered signal and the transmitted signal are shown in Fig. 3. The change of correlative phase flips and ER are also shown here. It is clearly seen that the eye would close and the original bit could not be recognized (the dashed line in “after transmission”) without the destructive interference between the adjacent “1” bits.

4. COMMERCIAL PRODUCTS AND MARKET TRENDS

A CML is well suited for 10-Gbit/sec metro systems. No optical or electrical dispersion compensation is used. A CML can reach 250 km (4250 ps/nm) at an OSNR of 16.5 dB/0.1 nm. The performance of a CML is comparable to the best duobinary transmitters; it can also be used for reaches of 80-

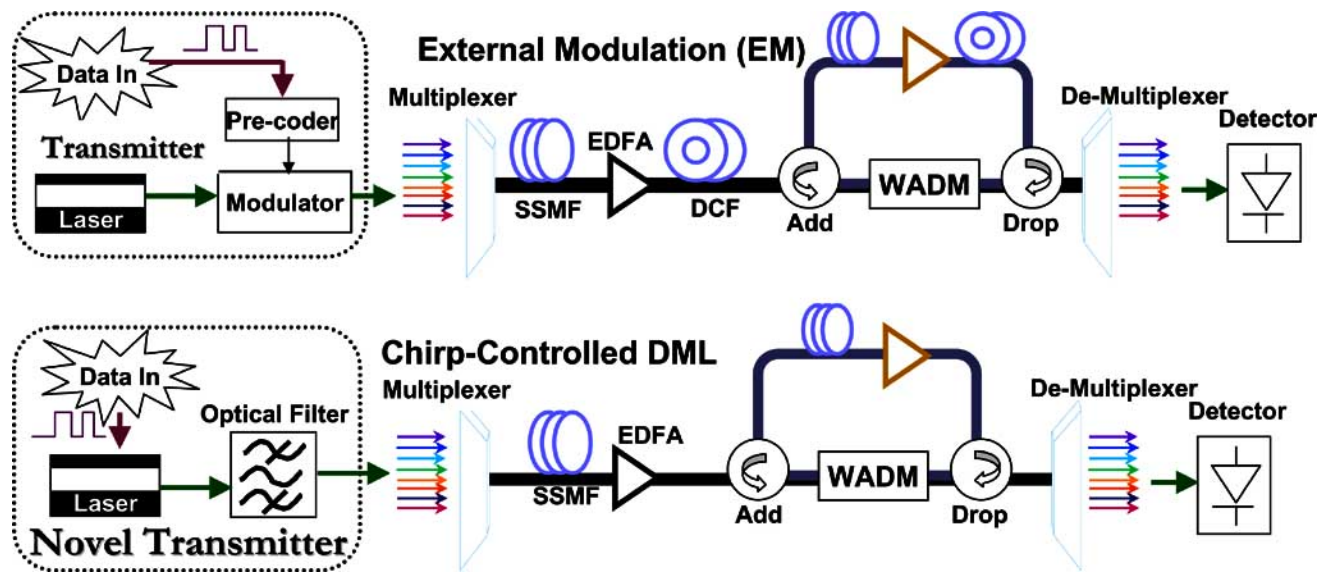


Fig. (4). Application in the current and future optical transport networks.

120 km and offers a higher optical power (4-7 dBm) and better dispersion tolerance than external modulation.

The CML laser technology from AZNA is very compelling. While to date DML laser technology can reach only 10km at 10G modulation rates, AZNA have successfully extended the no dispersion compensation reach of high power 10G DMLs to 200km and 2.5G DMLs to beyond 640km by managing various chirp properties of such DMLs. Increasing the data rates from 10Gbit/s to 40Gbit/s and wavelength tunable lasers are the future direction for the application of short-reach high-speed inter-connection between servers or routers.

In addition to offering low cost, compact size and high transmission performance, they also have big potential to increase the flexibility for current optical networks. As shown in Fig. 4, to meet the requirement of higher bandwidth, most metro optical links are needed to upgrade from 2.5Gbit/s to 10Gbit/s or re-routing the signal path while changing the existing infrastructure as few as possible in order to lower the cost. CMLs are excellent solutions to that because the carriers only need to replace transmitters with CML at the source side. They don't require caring more about the dispersion management and amplification budget for the signals.

In other scenarios, like the total dispersion is variable in metro ring optical networks if using the protected links or adding/dropping signals many times in the middle of the nodes, this dispersion-tolerant CML is ideal for avoiding this upfront cost; carriers can save the cost of installing DCMs and avoid the associated engineering costs all together.

5. CURRENT & FUTURE DEVELOPMENT

In this report, we present a novel transmitter comprised of a DML and the subsequent optical bandpass filter. The reach of this transmitter without dispersion compensation is

superior to the best reported DML-based and duobinary transmitters. The high dispersion tolerance is mainly because of the phase-correlative modulation among the adjacent bits via controlling the adiabatic chirp from the direct modulation. Future research focuses on the C+L band operation with tunable capability and TOSA packaging techniques at both 10 and 40Gbit/s in WDM systems. The results show that this is a promising solution to meet the size, power, capacity and cost requirements of the optical links simultaneously in the today and tomorrow's metro and access networks.

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