IRACST - International Journal of Computer Science and Information Technology & Security (IJCSITS), ISSN: 2249-9555
Vol.7, No.2, Mar-April 2017

Comparative Study of Chirp in Direct and External Optical Modulation

Paul O. Idowu[1], Oluwarotimi W. Samuel[2*], Mojisola G. Asogbon[3], Wahab B. Wajeed[1], Toluwalope M. Akinmoladun[4]
[1]University of Hertfordshire, United Kingdom, England.
[2]Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China
[3]Department of Computer Science, Federal University of Technology, P.M.B. 704, Akure, Nigeria
[4]Department of Computing, Sheffield Hallam University, Sheffield, UK, England

***Abstract*— The paper investigates the effect of chirp and bit error rate (BER) on the performance of a directly modulated DFB (distribution feedback) laser operating at 1550 nm and the external modulation using Mach-Zehnder (MZ) modulator. The characteristics are obtained from the simulation using Optisystem 10 on both experimental setup. The parameter known as alpha factor (α) is used to characterize the chirp behavior and the effects of extension ratio (ER) on BER. This investigation confirmed that the frequency chirping can be reduced by controlling α factor and the ER where the amount of chirp is eliminated by controlling the parameter k, known as symmetry factor.**

Keywords- Chirp; Direct modulation; DFB; External modulation; MZ; Bit error rate.

I. Introduction

Optical modulation is the process of applying information to a light wave which may be sent through a transparent medium as a laser beam or contained within a fiber optic cable [1]. The simplest and the most widely used modulation scheme is the on-off keying (OOK), where the light stream is turned on or off depending on whether the data bit is a 1 or 0. The two ways to generate a modulated optical signal are: direct modulation, this is realized when the laser is turned on and off by modulating its current or external modulation, when the laser is on at all times and the light beam is modulated with a modulator such as Mach-Zehnder [2][3] .

Direct modulation has the advantages of simplicity, compactness, and cost effectiveness, whereas external modulation can produce higher-quality optical pulses, permitting extended reach and higher bit rates [4]. A directly modulated Distributed – feedback (DFB) lasers are single-mode lasers containing an integrated grating structure) laser is used in this experiment because it is designed to generate a single line spectrum at the output under a high data rates of modulation. Figure 1 of the DFB laser shows a grating etched along the cavity length on the surface of a cladding layer. The grating leads to an effective spatial modulation of the refractive index which contributes to the device feedback mechanism so that single mode is produced and undesirable mode is suppressed.

The dynamic line width broadening under the direct modulation of the injection current in semiconductor laser is called chirping [5] as shown in Figure 2. Frequency chirping occurs due to a gain induced variations in laser refractive index as a results of strong coupling between the flux carrier density and the index of refraction. The temperature in the cavity also increases which changes the refractive index of the material in the active region within the cavity. The changes in the refractive index of the cavity produce a rapid change in the centre wavelength of the signal produced which results in broadening of line width referred to as frequency chirping. Frequency chirping is not a problem in short distance single channel transmissions but in long distance applications, chirp is a very serious problem. Frequency chirping broadens the spectral width of the signal and produce distortion.

The frequency chirping due to the direct modulation of a semiconductor laser limits the transmission bandwidth of a single-mode fiber system [6]. An external modulation technique is considered to be an alternative in order to eliminate this problem.

The two most widely used external modulators are Electro-absorption modulators (EAM) and Electro optic modulators (EOM). The EAM are usually built based on FranzKeldysh-effect or Stark effect. The principle of operation is the change in the absorption characteristics of the material in the presence of electric field. However, the EOM are built on Pockels effect (a linear electro-optic effect, where the refractive index of a medium is modified in proportion to the applied electric field strength). And also finds application in implementing phase modulator, long distance optical Communications and amplitude modulation. As a result, Frequency chirp is lower on EOM but high in EAM [7].

Mach-Zehnder (MZ) modulator is a planar waveguide structure deposited on the substrate, as shown in Figure 2. It consists of two optical couplers, one each at input and output of the device, which are connected together via two waveguides. Generally, MZ modulator can control the phase shift better than all other implementation and so they have better ER. Similar to direct modulation, MZ modulators also suffers chirping, where the chirp-like spectral broadening occurs in an external modulation technique. One possible cause is the wavelength shift of the

semiconductor laser due to an external reflection outside of the external modulator. This is because the coupled power of the externally reflected light to the laser cavity is varied with intensity modulation, which changes the laser wavelength. Another possible cause is the phase modulation due to the refractive index change of medium inside an external modulator [8]. The alpha factor, α is used to characterize the chirp behavior using the parameter symmetry factor, k.

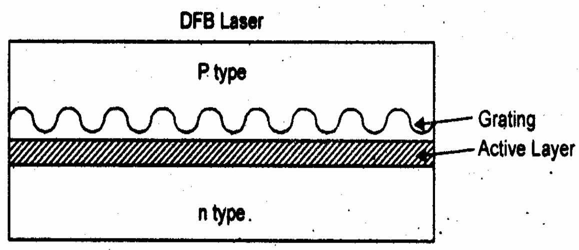


Figure 1. A DFB Laser [3]

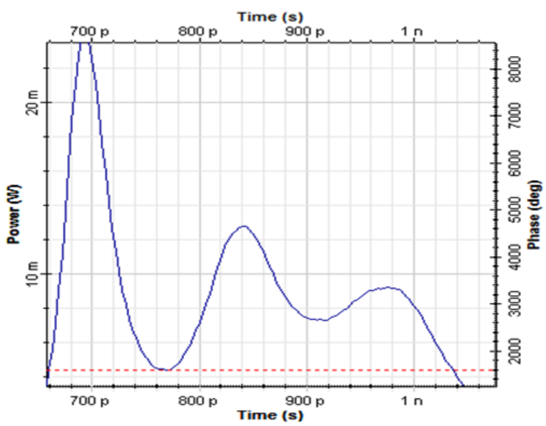


Figure 2. Appearance of chirp in signal

II. THEORY

The general form of chirp equation is given as;

$\Delta f(t) = \alpha$ transient $(dP(t)/dt)$+a adiabatic $P(t)$………….(3)

The estimated chirp equation of a direct modulated DFB laser is given by;

$\Delta f(t) \approx \alpha/4\pi(dP(t)/dt + K_1 P - K_2/P)$ ……………….(4)

The first term is transient term while the second and the third terms are referred to as adiabatic. In the transient chirp limited regions such as the rising and falling edges, alpha can be calculated using the equation below;

α=2P(d□/dt)/(dP/dt) = 4πPΔf(t)/(dp/dt)… ……………..(5)

alpha factor (α) is commonly called the linewidth enhancement factor and is used to predict the frequency behaviour of a laser. To characterize the chirp behavior of the MZ, the parameter symmetry factor k is used. Typical values of k may vary from -1 (modulation without any chirp) to 1 (≤1 actually). In special cases, k is defined as follows [1][6].

TABLE 1. CHIRP BEHAVIOUR OF THE MZ MODULATOR WITH K

K	Chirp behaviour of MZ modulator
-1	Zero chirp
0	Considerable amount of of chirp
≥1	Only the phase of light wave is modulated

$$K = \frac{\alpha - 1.\,\mathrm{Sign}(\alpha)}{\alpha + 1.\,\mathrm{Sign}(\alpha)}$$

The above cases were investigated in order to better understand the effect of chirp on the optical communication link. The evaluations were based on the simulation experiment using OptiSystem simulation software.

III. OBJECTIVES

In this experiment, a simulation approach is used to perform various measurements on an optical communication setup based on DFB laser and a range of different components, and the spectrum and eye diagrams of the transmitted signals is observed in order to compare the quality of data transmission using the different configurations.

IV. SIMULATION

Simulation Setup of Direct Modulation

This setup is based on Figure3. It is performed with Optiwave simulation software. In this setup the DFB operating at 1550nm is used. A Non Return Zero (NRZ) pulse generator which operates as a laser driver is modulated by a pseudo-random bit sequence (PRBS) generator. The output of the NRZ generator is connected to a low-pass filter which limits the bandwidth to 0.75*bit rate before applying the filter output to the bias input of the DFB laser. The laser is then been connected to the SMF (single mode fiber is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier and is used for long-distance signal transmission). The fibre output is connected to an optical attenuator whose output is fed to an optical receiver (PIN Photodiode). A data recovery module is connected at the end of the link, in order to observe and measure the quality of the link through its eye diagram and bit-error rate (BER) characteristics. The binary signal input of the data recovery module is connected to the PRBS (a pseudo random binary sequence is used as a model data to test a high-speed serial interface device for emulating a mission mode) output and the electrical signal input is connected to the sequence generator. This is to enable the data recovery module to compare the transmitted and received signal for BER analysis. The optical power meter is connected to the attenuator output to measure the received optical power (known as sensitivity as BER = 10^{-9}). An optical spectrum analyzer (OSA) and optical time domain visualizer (OTDV) were also connected to the laser output to observe the emitted optical signal.

A. Experimental Procedures

The simulation was conducted in three different stages. The first stage is to investigate the receiver sensitivity. The Second stage is to investigate the effect of chirp as the bit rate is varied.

The optical time domain visualizer is used to measure the amount of chirp in the optical modulated signal. The maximum chirp is measured and recorded in Table 1. The next step is to decrease the attenuation value by 3dB to 27dB and the bit rate is increased by 1 Gbit/s steps. This procedure is repeated until the BER reached 10^{-9} again.

The third stage is used to investigate the effect of increasing the fibre length as the chirp contributes to signal spectrum broadening, and as the chromatic dispersion will limits the distance of the transmission. The first step is to set the simulation bit rates and attenuation to its initial condition (2.5 Gbit/s and 30 dB respectively). The length is set to 20km and simulation is repeated by varying the attenuation value in order to achieve the BER of 10^{-9}. The procedure is repeated by increasing the fibre length by the step of 20km.

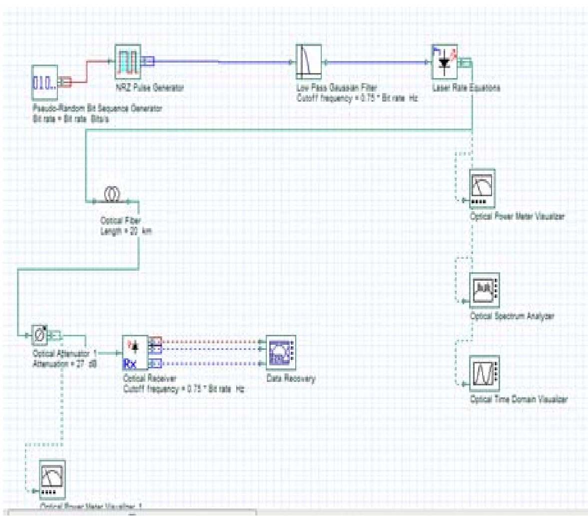


Figure 3. Direct modulation set up

B. Results and Analysis

The results for this simulation are discussed as follows:

i. Receiver Sensitivity

The attenuation value used to obtain minimum BER of 10^{-9} is 30dB. The power measured from the optical receiver at this BER is known as sensitivity. This is the minimum power at the receiver in order to have an error free transmission. The sensitivity measured is -26.982dBm. The resulting eye diagram is shown in Figure 4.

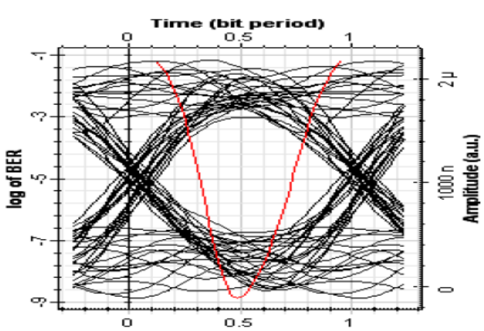


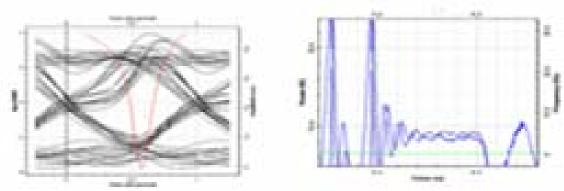
Figure 4. Eye diagram at BER of 10-9

ii. Chirp against Bit rate measurements

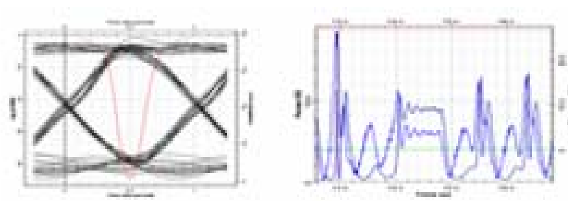
TABLE 2: CHIRP AGAINST BIT RATE MEASUREMENT

	Fiber length = 20km			
	Bit rate (Gbit/s)			
	Att. 30dB	Attenuation 27dB		
Bit rate (Gb/s)	2.5	3.5	4.5	5.1
Sensitivity(dBm)	-29.9	-24.9	-24.9	-24.9
Chirp (Ghz)	35.5	27	34	38
BER	1.4E-9	1.8E-51	1.3E-34	3.7E-9

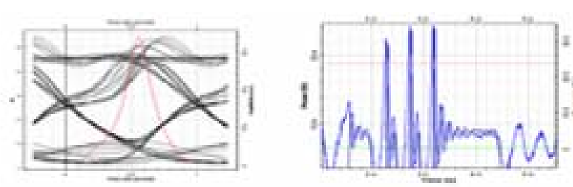
From Table 2, it can be concluded that the amount of chirp measured is increased as the bit rate is increasing with the same receiver sensitivity. Figure 5 shows the eye diagrams for various bit rates. The power at the receiver does not give any impact on the changes of bit rate. The value of the attenuation is decreased by 3 dB to allow for loss in signal strength or light power that occurs as light pulses propagate through the fibre. Thus, by using approximately -24.9 dB receiver sensitivity, only 5.1 Gbit/s signal can be transmitted in order to have minimum error (BER 10^{-9} in this case). Unfortunately, the amount of chirp detected is too high.



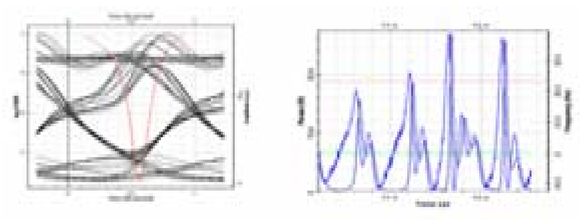
2.5Gbps 35.5GHZ



3.5Gbps 27 GHZ



4.5Gbps 34 GHZ



5.1 Gbps 38 GHZ

Figure 5: Eye diagram & chirp measurement for various bit rate

iii. Chirp against Fibre Length

From the results in Table 3 and the eye diagram in Figure 6, it shows that as the fibre length is increasing, the attenuation and receiver sensitivity is also decreasing. This experiment proved that the attenuation limits the transmission distance. The power penalty is the difference in receiver sensitivity in dB, used to measure signal degradations. Higher receiver input power were required as the quality of the signal degraded.

TABLE 3. PENALTY MEASUREMENTS FOR DIFFERENT FIBER LENGTH FOR DIRECT MODULATION

		Bit Rate = 2.5 Gbit/s	
		BER = 10^{-9}	
SMF length (km)	**Attenuation(dB)**	**Sensitivity (dBm)**	**Penalty (dB)**
20	30	-29.890	-
40	26	-29.690	0.6
60	22	-29.600	0.09
80	18	-28.600	1.0
100	14	-27.600	1.0
120	10	-21.600	6.0

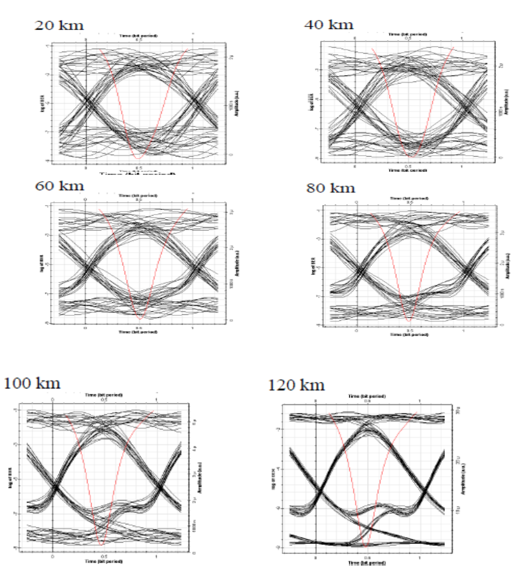


Figure 6. Eye diagram for various transmission distance

Simulation Setup of External Modulation

This setup is based on Figure7, it is performed with Optiwave simulation software. In this setup radio frequency input of a MZ modulator were connected to the PRBS, NRZ pulse generator and low pass filter modules. A laser is also applied to the other input of the MZ modulator. BER performance is measured using a variable attenuator. While the power of the optical signal at input to the receiver is measured by using an optical power meter. Data recovery module is used to observe the eye diagram and BER for the various chirp and ER values.

A. *Experimental Procedures*

The initial condition for the simulation is set to ER = 30 dB and the symmetry factor, k is set to -1 corresponding to an alpha factor, a of -1. Then, the simulation was run and maximum chirp measured were recorded in Table 4. The procedures were repeated by changing the symmetric factor, which can be obtained by changing the alpha factor 1 and 0.5 in equation (6). To investigating the ER measurement, the same setup is used and the symmetry factor is reset to -1 and ER to 30 dB. Then simulation is run by changing the ER value to 30, 20, 10 and 5 dB. The data measured were recorded in Table5. From the results obtained, a semi-logarithmic graph was produced in Figure 9.

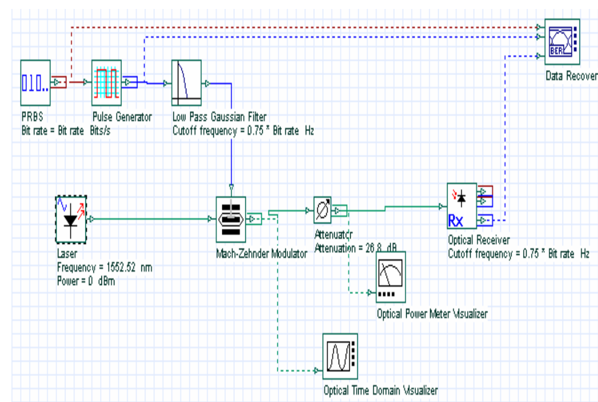


Figure 7. External modulation setup

B. Results and Analysis

i. *Chirp Measurement*:

TABLE 4. EXTERNAL MODULATION CHIRP MEASUREMENT

		Bit Rate = 2.5Gb/s	
		ER = 30dB	
α	K	Chirp (Hz)	BER
-1	-1	1.6m	$4.458*10^{-11}$
0	0	5.3G	$4.458*10^{-11}$
0.5	-0.333333	2.6G	$4.458*10^{-11}$

From Table 4, it can be concluded that when k = -1, the amount of chirp is very small. This is an ideal intensity modulation with small amount of chirp. When the Symmetry factor, k is set to zero (k= 0), it shows the highest chirp were measured. This results into intensity modulation with chirp as only one arm was being driven by the input signal. Thus, the amount of chirp can be reduced by decreasing the value of k (the smaller the k, the less chirp). In addition, varying α is important as its interaction with chromatic dispersion will limits the transmission distance without regenerating the signal.

α =-1 α = 0.5

α = 0

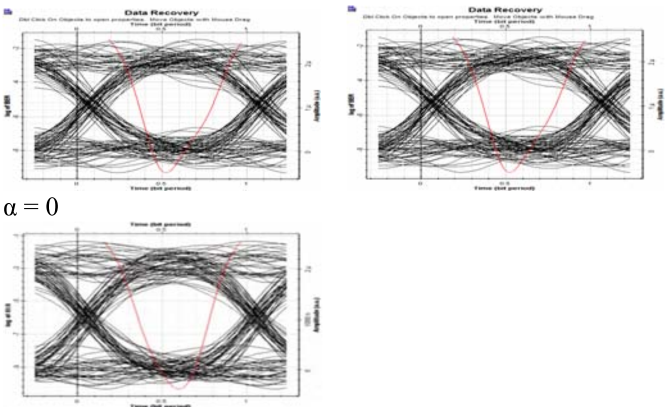


Figure 8. Eye diagram for different α factor

ii. ER Measurement:

From the results in Table 5 and the semi-logarithmic graph plotted in Figure 9, ER is proportionally increased as BER increases. The figure gives visual representation of the effects of ER on the quality of the link. The graph clearly shows that the BER rises each time ER increases.

Furthermore, only small changes in ER are required to relatively make large differences in the power in order to maintain a constant bit error rate (BER).

TABLE 5: ER MEASUREMENT

	Bit Rate = 2.5 Gbit/s
	K = -1
ER(dB)	BER
30	$4.7241*10^{-10}$
20	$1.4187*10^{-9}$
10	$6.4536*10^{-7}$
5	$1.2040*10^{-3}$

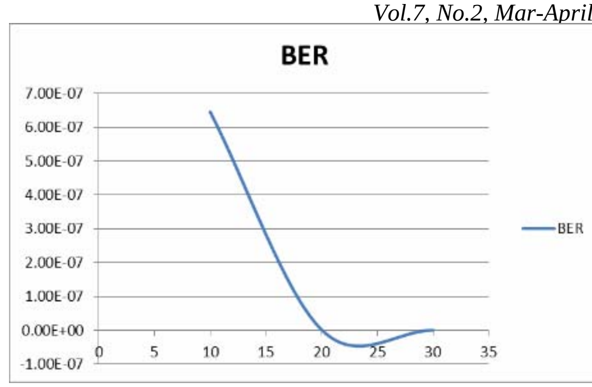


Figure 9: Graph ER against BER

C. MZ Operating point

The figure 10 below shows the symmetry graph at the iteration 5.The bias voltage to operate the MZ modulator is equivalent to 2.2volts

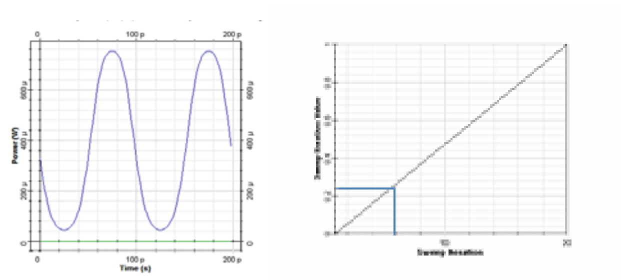


Figure 10: symmetry of bias voltage versus iteration number

D. Modulation Bandwidth

This experiment is to compare the modulation bandwidth between direct modulation and external modulation. The attenuator is decreased to 27dB when bit rate is set to 5 GHz. The bit rate is furthermore increased by the step of 5 GHz until the BER reach 10^{-9}.

TABLE 6: BIT RATE AGAINST BER

Bit rate(GHz)	BER
5	$2.4*10^{-27}$.
10	$1.3*10^{-22}$
15	$6.08*10^{-16}$
20	$9.8*10^{-16}$
25	0.00376

From the data in Table 6 above, it can be found that the bit rate achieved minimum BER at about 20GHz, which is larger than that of direct modulation (5GHz). At this bit rate, the optical power of receiver is $3.555*10^{-6}$w.

Thus, it can be concluded here that external modulation has a larger bandwidth than direct modulation at the same BER.

E. The effect of chirp on network fibre length

This study was conducted to observe the effect of chirp on a network across varying fiber length. The bit rate is set back to 2.5 GHz and the fiber length is increased by the step of 40km until 160km as shown in table 7 below.

TABLE 7. PENALTY MEASUREMENTS FOR DIFFERENT FIBER LENGTH FOR EXTERNAL MODULATION

SMF length(km)	sensitivity	penalty	Attenuator(dB)
20	-30.388	-	28.1
40	-30.28	0.1	23.991
80	-29.74	0.54	15.451
120	-29.64	0.1	7.351
160	-	-	-

To compare the sensitivity at 120km between direct modulation and external modulation, it can be found that the sensitivity of direct modulation at 120km is much less than that of external modulation and its' minimum BER cannot reach 10^{-9}. In other words, external modulation has a longer available SMF length than direct modulation.

When SMF is 160 km, the minimum BER cannot reach 10^{-9}, which means this length has exceeded the range of this system.

V. CONCLUSSION

The completion of the simulation experiment enables detailed investigation on the influence of chirp in direct and external modulation as a result of instability of the center wavelength of the laser. Also a difference in the refractive index of the laser output can cause charp. Although the method provided in this study does allow faster modulation in principle but does not totally eliminate the effect of chirp. Further possible ways of eliminating chirp is by pumping current, pumping effective carrier temperature and suppressing wavelength chirping at high modulation frequencies [6].

REFERENCES

[1] Breed, G. (2007, May). A Tutorial to Optical Modulation Techniques. *High Frequency Electronics Magazine.*

[2] Optical Society of America, Fiber Optics Handbook: Fiber, Devices, and Systems for Optical Communications, McGraw-Hill Professional,2001

[3] zaiton Binti A.M,"frequency chirp characteristics on WDM Direct modulation", international conference on computer engineering and Application,no.2,2010.

[4] zaiton Binti A.M,"frequency chirp characteristics on WDM External modulation", international conference on computer engineering and Application,no.2,2010

[5]J M Senior, Optical Fibre communications: principles & practise, 2nd edition, Prentice Hall

[6] Vera B. Gorfinkel(1993), High-frequency modulation and suppression of chirp in semiconductor lasers,Germany.

[7]Shreyas S S, Guruprasad B,Sheethal S Prabhu,"External modulators and, Electro-optic Mach-Zehnder modulator - modelling and analysis using Matlab",International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682 Vol.5, No.2, February 2016.

[8]Sanjeev Kumar Raghuwanshi, Ritesh Kumar, Akash Srivastava, and Nimish Kumar Srivasta,"Dual-chirp Arbitrary Microwave Waveform Generation by Using a Dual Parallel Mach-Zehnder Modulator Feeding with RF Chirp Signal", Progress In Electromagnetics Research C, Vol. 65, 79–92, 2016