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Design and Evaluation of an 1.25 Tbit/s 60 Ghz Optical Injection Locking Generator (OILG) Over Standard Single Mode Fiber (SSMF) Employing an External Modulation

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Abstract In this article, the design of an ultra-high speed generator in millimeter band is presented. It is designed according to Optical Injection Locking (OIL) principle with external modulation. It delivers 1.25 Tbit/s 60 Ghz. In our proposal paper, OIL consists of a correlation of two slave lasers controlled by a master laser modulated with a LiNb Mach Zehnder. This generator will serve in Radio over Fiber (RoF) technology several base stations to connect the rural areas and to allow them to benefit broadband ICT needed very high bit rate. These base stations can be those of new generation wireless networks such as global interoperability for microwave access (WiMax), wireless loyalty (WiFi), long-term evolution (LTE), technologies 5G, etc.

Keywords Radio over Fiber (RoF), Optical Injection Locking Generator (OILG), ultra-high-speed, millimeters waves

1. Introduction

Broadband multimedia services demand for wireless users are increasing exponentially even in rural areas. Broadband means short transmission range. The next generation cellular wireless networks is hailed to provide higher data rate, lower end-to-end latency, improved spectrum/energy efficiency, and reduced cost per bit. In general, addressing these requirements will require significantly larger amount of spectrum, more aggressive frequency reuse, extreme densification of small cells, and the wide use of several enabling technologies (e.g., full-duplex, massive MIMO, C-RAN, and wireless virtualization) [1]. Low loss, low cost and wide bandwidth makes fiber optic the ideal medium for millimeter wave transmission. Radio over Fiber (ROF) technology is welcome to meet with such demands [2-10].

RoF consists of using an optical infrastructure to connect different radio access points. RoF technology enables the centralization of RF signal processing functions such as frequency conversion, modulation and multiplexing at a central station [11]. It allows base stations to be moved to rural areas in order to deploy broadband ICTs on a massive scale. These base stations are driven from the central station where broadband is generated. These base stations can be those of Worldwide Interoperability for Microwave Access (WiMax), Wireless Fidelity (WiFi), Long Term Evolution (LTE), 5G technologies [3, 7], in short for new generation wireless network.

Remote Heterodyne Detection (RHD) is one of the methods for generating millimeter signals over optical fiber. It is a technique for generating a microwave signal by detecting an optical beat based on photodetection of the mixture of two optical waves whose frequency interval is equal to the desired millimeter frequency. Heterodyne detection allows generation of very high frequency signals without using components having large bandwidths. Indeed, it's just the frequency difference between the two lasers that gives the carrier frequency. The stability problem of the heterodyning method stems from the independence between the two lasers used. In order to solve this problem, it is therefore necessary to correlate the two lasers. Phase coherence of the two lasers can be obtained by optical injection called Optical Injection Locking (OIL).

In this paper, we focus on an ultra-high-speed generator at millimeter frequencies of the Optical Injection Locking (OIL) type. Therefore, our proposal introduction will be followed by a related work in section 2 and a general presentation of the proposal OIL Generator in section 3. Before the presentation of the performances obtained through our simulations in 6, we have described in section 4 the transmission block and in section 5 the reception system. Conclusion and future work will complete this study in section 7.

2. Related works

In OIL concept, the master laser injects its output light into one or two slave lasers, locking it or them in phase and frequency to itself [12]. Researchers have shown that this technique can generate microwave signals equal to an integer number of times the modulating signal [11]. Optical transmission is limited by chromatic dispersion and phase noise. OIL guarantees signal purity by neglecting these two scourges .

NG'OMA et al [9], Devang Parekh [12] demonstrated a directly modulated multi-Gb/s 60 GHz RoF system using an injection-locked low-bandwidth VCSEL. One slave laser was used. 3Gb/s and 4Gb/s of ASK-modulated data, and 2 Gb/s of QPSK-modulated data were transported over up to 20 km of standard single mode fiber.

S. Chaudhary et al [13] demonstrated an external modulated 10 Gb/s 60 GHz RoF transmission system over 60 km optical fiber for 5G Applications.

An in-depth study of the latest work shows the use of the OIL technique in Radio over Fiber (RoF) for connecting the most distant customers, especially those of the rural population. On the other hand, it is strong to note that these prototypes are complex and expensive for the operators by their technique of modulations like ASK, QPSK and even OFDM. They are also limited in terms of bandwidth and their range does not exceed 50km. Here OIL method consists to apply correlated system technique of two slave lasers controlled by a master laser [5, 6, 14]. We propose a performant and low cost generator with an external modulated 1.25 Tbit/s 60 GHz system. To reduce the complexity of our generator, we use the NRZ encoder. Modulated data are transported over standard single mode fiber up to 100 km.

3. General presentation of the OIL Generator

Optical Injection Locking Generator (OILG) that we have designed is an optoelectronic device making it possible to generate ultra-high-speed at millimeter frequencies to serve rural areas with broadband ICT Figure 1.

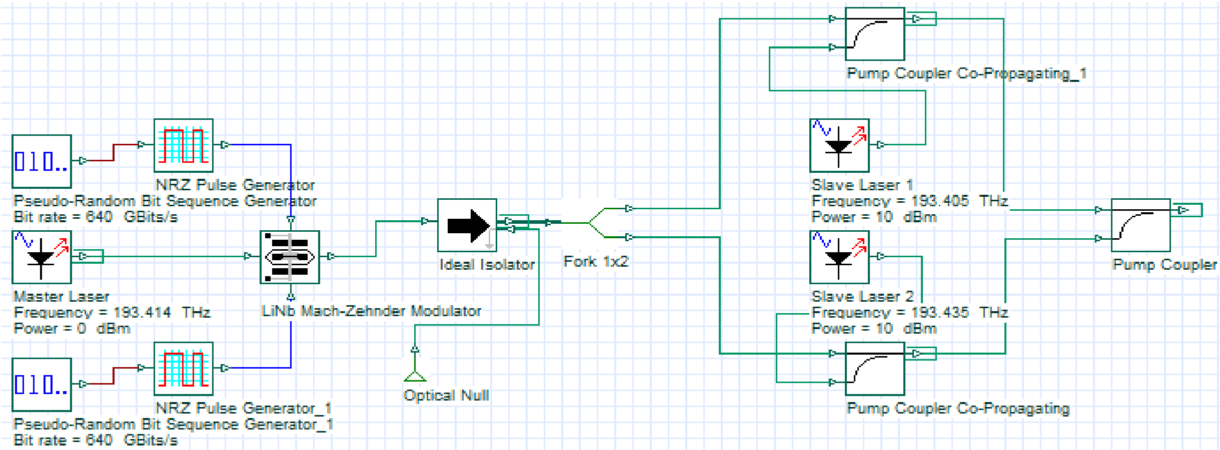

Figure 1: Proposed OIL Generator (OILG)

In the rest of the article, OILG is materialized by a box called subsystem in the jargon of the Optisystem software as illustrated in Figure 2.

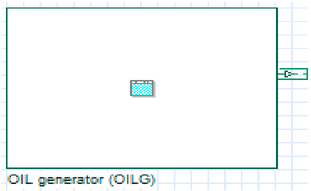

Figure 2: OILG

The designed OIL Generator includes a master laser (ML), a Pseudo-Random Bit Sequence Generator (PRBSG), an Non Return to Zero (NRZ) encoder, an external LiNb Mach Zehnder Modulator (MZM), an ideal isolator, two correlated slave lasers (SL) controlled by the master laser.

The master laser controls the slave lasers by injecting its modulated signal with the NRZ data through the external LiNb Mach Zehnder modulator. The two slave lasers are attached one to the lower harmonic and the other to the upper harmonic of the master laser modulated to have a difference equal to 60 GHz [11]. The master laser no longer participates in terms of power to the heterodyne beat and we can take advantage of the whole of the power delivered by slave lasers [11].

The ideal isolator between master laser and slave lasers allows one-way light propagation to reduce optical feedback. The PRBSG sends the bit sequence to the NRZ Pulse Generator.

The NRZ pulse generator shapes the input digital signal to a NRZ electrical signal [15]. .For the NRZ format, the signal transmitted in each bit time is continuous and if two '1' symbols follow each other, the signal remains at its high level [15].

The simulations context of our OIL Generator components settings are recorded in Table 1 below.

Table 1: OILG component settings

Components	**Settings**	**Value**
PRBSG	Bite rate	640 Gbit/s
NRZ Pulse Generator	Rise time	0.05 bit
	Fall time	0.05 bit
Master Laser	Frequency	193.414 Thz
	Power	0 dBm
	Linewidth	0.005 Mhz
	Initial phase	0 deg
	polarization	0 deg
	Noise bandwidth	125 Thz
	Noise threshold	-100 dB
	Noise dynamic	3 dB
LiNb MZM	Extinction ratio	20 dB
	Switching bias voltage	4V
	Switching RF voltage	4V
	Insertion loss	5dB
	Normalize electrical signal	ok
	Modulation voltage1	2
	Modulation voltage2	-2
	Bias voltage1	0
	Bias voltage2	2
Ideal isolator	Insertion loss	40 dB
Slave Lasers	Frequency	193.405/435 Thz
	Power	10 dBm
	Linewidth	0.005 Mhz
	Initial phase	0 deg
	polarization	0 deg
	Noise bandwidth	0 Thz
	Noise threshold	-100 dB
	Noise dynamic	3 dB

NB: Frequency SL1 = 193.405 Thz Frequency SL2 = 193.435 Thz; PRBSG: Pseudo-Random Bit Sequence Generator

4. Transmission block

The transmission block is composed of an Standard Single Mode Fiber (SSMF) in a first series of simulations. In a second series of simulations, it consists of an SSMF and a 5m EDFA amplifier Figure 3. SSMF settings are in Table 2 below.

Table 2: SSMF settings

Settings	Value
Dispersion	16.75 ps/nm/km
Dispersion Slope	0.075 ps/nm^2/km
PMD Coefficient	0.5 ps/km
Effective area	80 um^2
Nonlinearity Coefficient	2.6×10^{-20}
Attenuation	0.2 dB/km

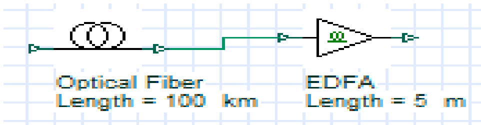

Figure 3: Transmission block

5. Reception block

This block includes a photodetector, a low pass Bessel filter, a 3R regenerator, an analyzer (eye diagram or BER) Figure 4. The Photodetector converts the optical flow to an electrical current, which can then be amplified and processed [16]. The Low Pass Bessel Filter filters the electrical signal. BER Analyzer measures the performance of the system based on the signal before and after the propagation [17]. The Eye Diagram Analyser displays multiple traces of a modulated signal to produce an eye diagram [17].

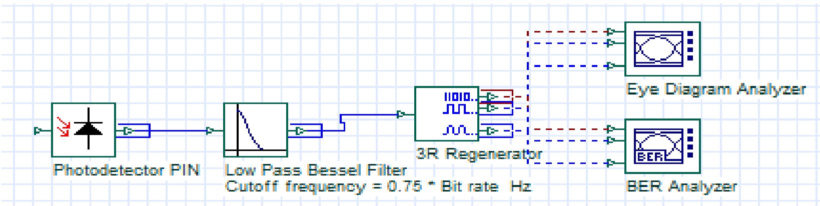

Figure 4: Reception block

The reception block settings are listed in the Table 3 below.

Table 3: Reception block settings

Components	Settings	Value
PPIN	Responsivity	1A/W
	Dark current	5 nA
	Center frequency	193.1 Thz
	Sample rate	5*(sample rate) Hz
	Noise calculation type	numerical
	Add signal-ASE noise	ok
	Add ASE-ASE noise	ok
	Thermal noise	1e-022 W/Hz
	Add shot noise	ok
	Shot noise distribution	Gaussian
LPBF	Cutoff frequency	0.75*Bit rate Hz
	Insertion loss	0 dB
	Depth	100 dB
	Order	4
3RRegenerator	Reference bit rate	60 Gbit/s
EDA	Time window	1.5 Bit period
	Threshold mode	relative
	Relative threshold	50%
	Decision instant	0.5 Bit period

NB: LPBF: Low Pass Bessel Filter; PPIN: Photodetector PIN; EDA: Eye Diagram Analyzer

6. Simulation and results

The evaluation of our architecture is carried out with the performance indicators of the quality of an optical network. Usually, these are three transmission quality criteria, which are evaluated after detection of the signal: the eye diagram, The Bit Error Rate (BER) and the quality factor Q. We evaluated the performance of three systems: the back to back link, a system without amplifier and system with an amplifier.

6.1. Back to back link

The back to back link consists in connecting the generator directly to the reception block as shown in Figure 5 below.

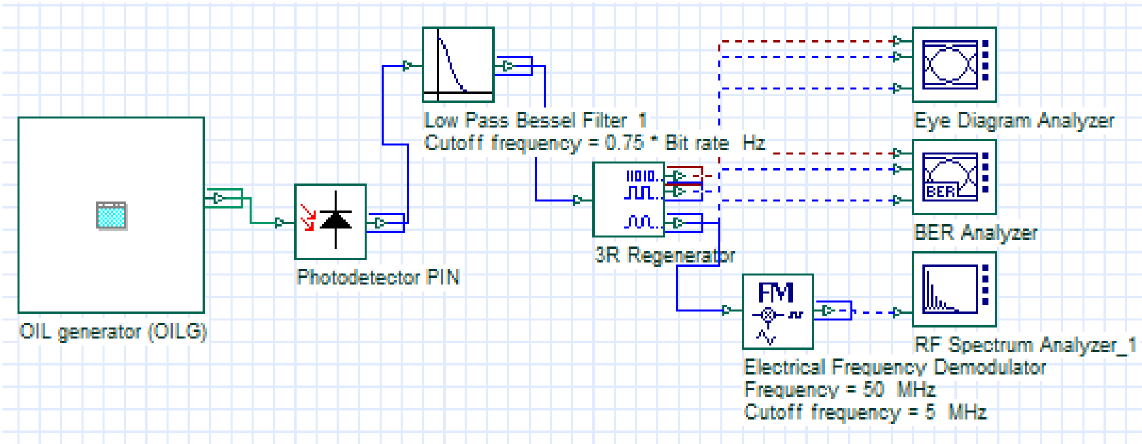

Figure 5: Back to back link

The results obtained on the back to back give on the one hand, a 60 GHz radio frequency visualized by the spectrum analyzer connected to the output of the frequency demodulator, Figure 6. The latter illustrates the OIL method used to generate a millimeter wave signal of 60 GHz. On the other hand the link quality is given by the eye diagram in Figure 7. This figure shows also good performance with a Q-factor equals to 21.7649 corresponding to a BER of 2.49288e-105.

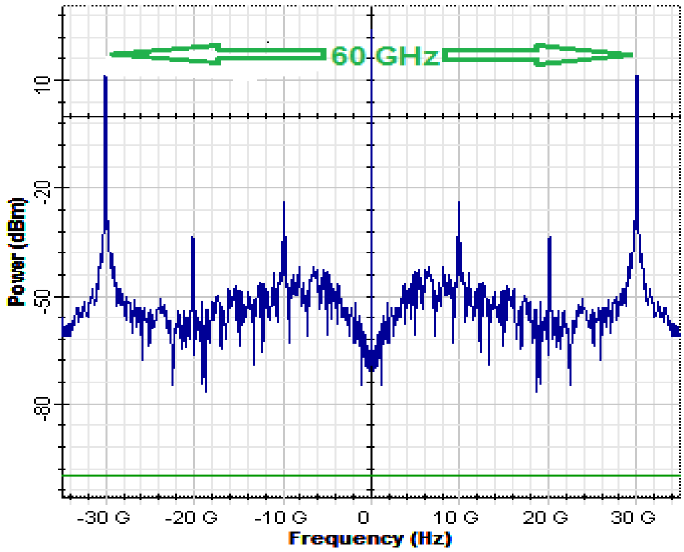

Figure 6: 60 GHz radio frequency

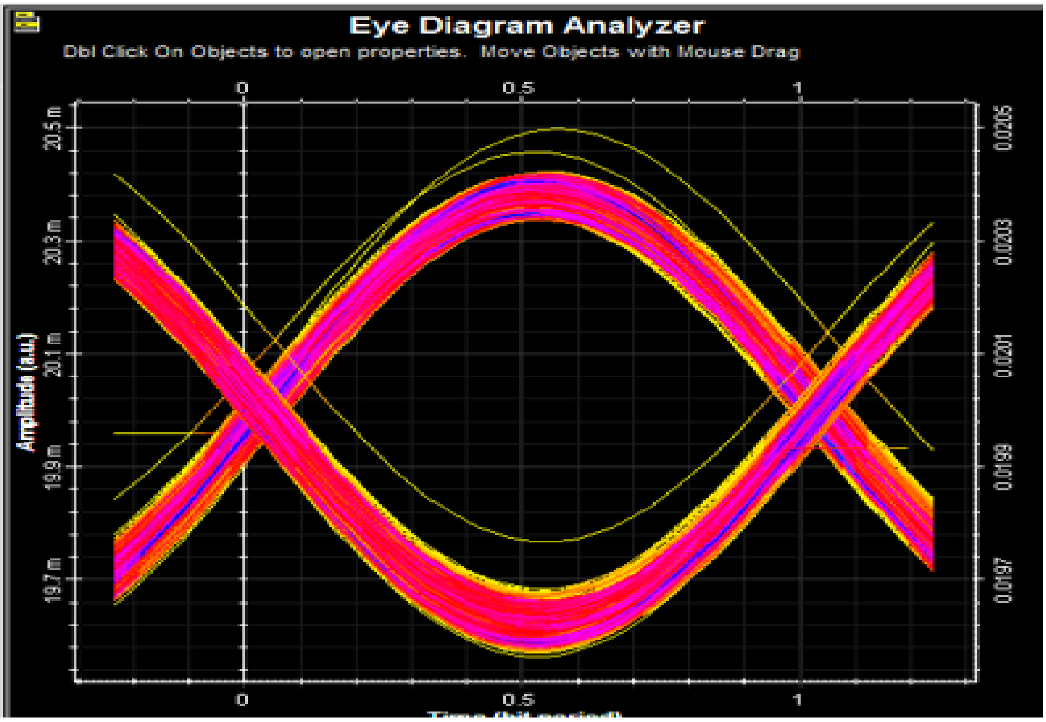

Figure 7: Eye diagram of back to back link

6.2. Simulation without amplifier

In this paragraph we introduce the standard single mode fiber between the generator and the reception block without using an amplifier to see up to what length of fiber the transmission quality is maintained. The simulation link is illustrated in Figure 8.

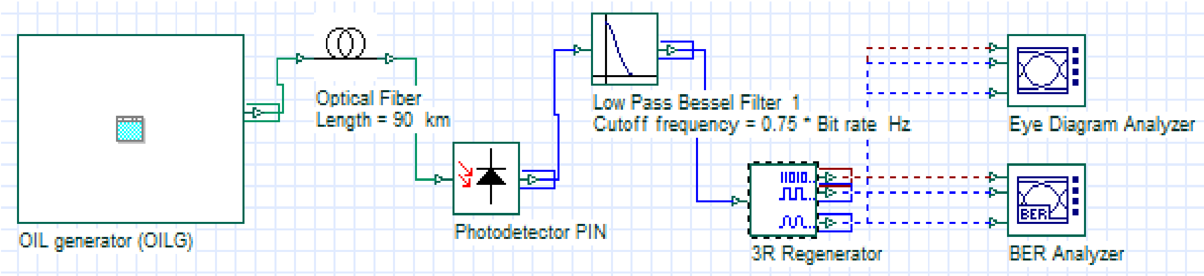

Figure 8: 1.25Tbit/s 60 Ghz transmission link without amplifier

For the evaluation of our proposal link, we look at this quality with the Q -factor and the BER for different values of the fiber length. The simulation results obtained are recorded in Table 4.

Table 4: Simulation results

Fiber length (km)	Q factor	BER
0	21.7649	2.49288e-105
10	19.1613	3.88711e-082
20	19.0303	4.78264e-081
30	14.6719	4.87684e-049
40	12.0356	1.15412e-033
50	10.7789	2.16381e-027
60	8.51193	8.55206e-018
70	6.97604	1.51804e-012
80	5.21136	9.37323e-008
90	3.54714	1.9472e-004
100	0	1

Figure 9 shows the evolution of the quality factor as a function of the fiber length. We naturally note a decrease in quality with the increasement of the fiber length. This phenomenon is undoubtedly linked to the fiber limits such as attenuation, chromatic dispersion, non-linear effects etc.

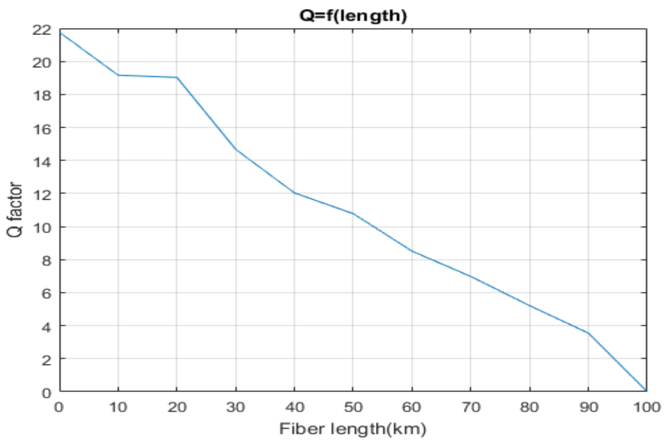

Figure 9: Q factor versus length

The simulations results of our link where we don't use an amplification in the transmission bloc provide that the quality is maintained up to 70 km with Q=6.97604>=6 and BER=1.51804e-012 which is lower than 10^{-9}. Beyond 70 km, we note a detrition of the signal quality. The Figure 10 and the Figure 11 give the eye-diagram at 70 km and 80 km respectively.

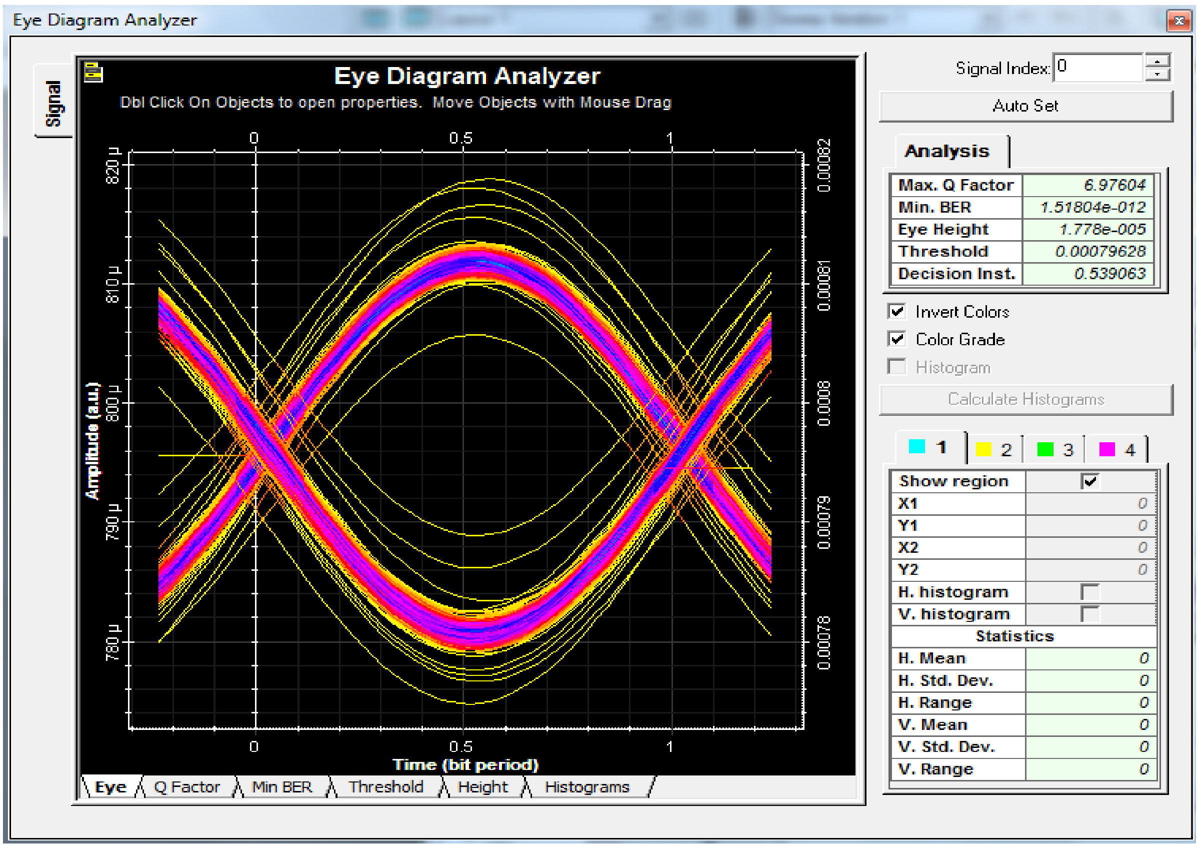

Figure 10: Eye diagram at 70 km

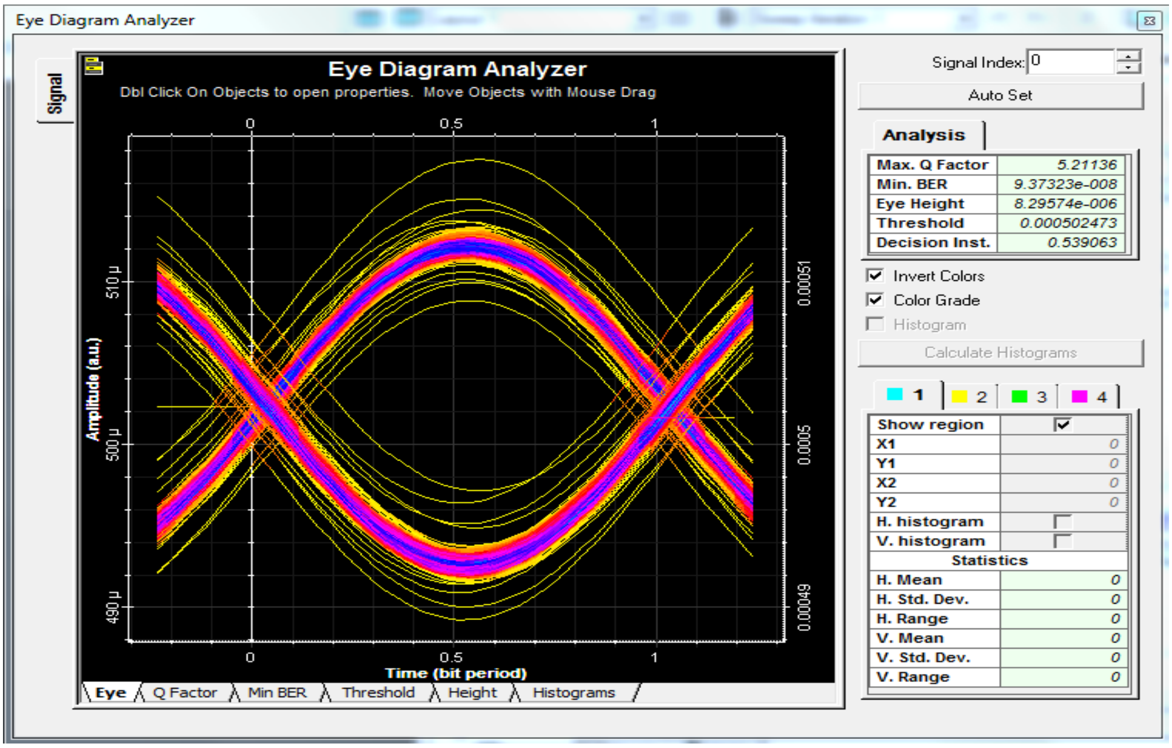

Figure 11: Eye diagram at 80 km

6.3. Simulation with amplifier

In order to maintain the transmission quality over a long reach, we propose to introduce an amplifier at 70 km. We use the Figure 12 below to continue our investigation. In this link where we introduce the optical amplifier in the transmission bloc, we try to obtain a 1.25 Tbit/s 60 GHz transmission link.

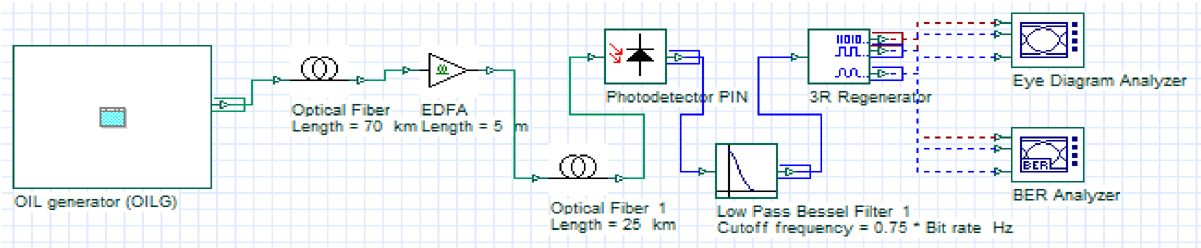

Figure 12: 1.25Tbit/s 60 Ghz transmission link with amplifier

We varied the fiber length from 70 km to 100 km and obtained the results recorded in Table 5. Q factor versus length is shown in Figure 13.

Table 5: Simulation results

Fiber length (km)	Q factor	BER
0	21.7649	2.49288e-105
10	19.1613	3.88711e-082
20	19.0303	4.78264e-081
30	14.6719	4.87684e-049
40	12.0356	1.15412e-033
50	10.7789	2.16381e-027
60	8.51193	8.55206e-018
70	7.52382	2.65972e-014
80	6.99675	1.30974e-012
90	7.4519	4.61804e-014
95	6.24001	2.18743e-010
100	6.3184	1.32086e-010

As we said, we also find in Figure13 a decrease in quality with the length of the fiber due to the fiber limits. But the amplifier help us to reach long range for connecting the rural users.

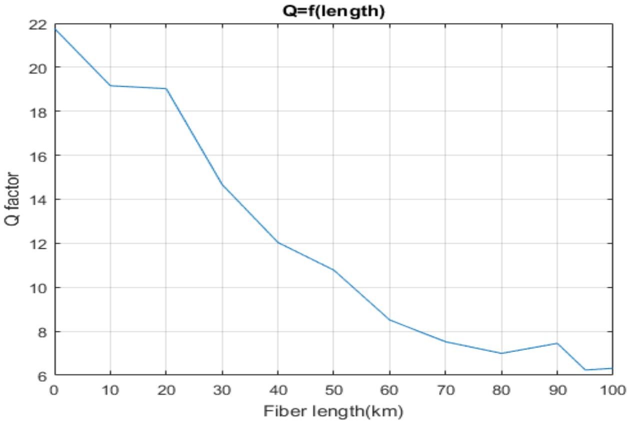

Figure 13: Q factor versus length

With amplification at 70km, the transmission quality is maintained up to 100km with Q=6.3184 upper than Q=6 and BER=1.32086e-010 lower than 10^{-9}. Figure 14 shows eye-diagram at 100 km. At 101km, Q=5.8882 lower than Q=6 for BER=1.9511e-009 upper than 10^{-9}.

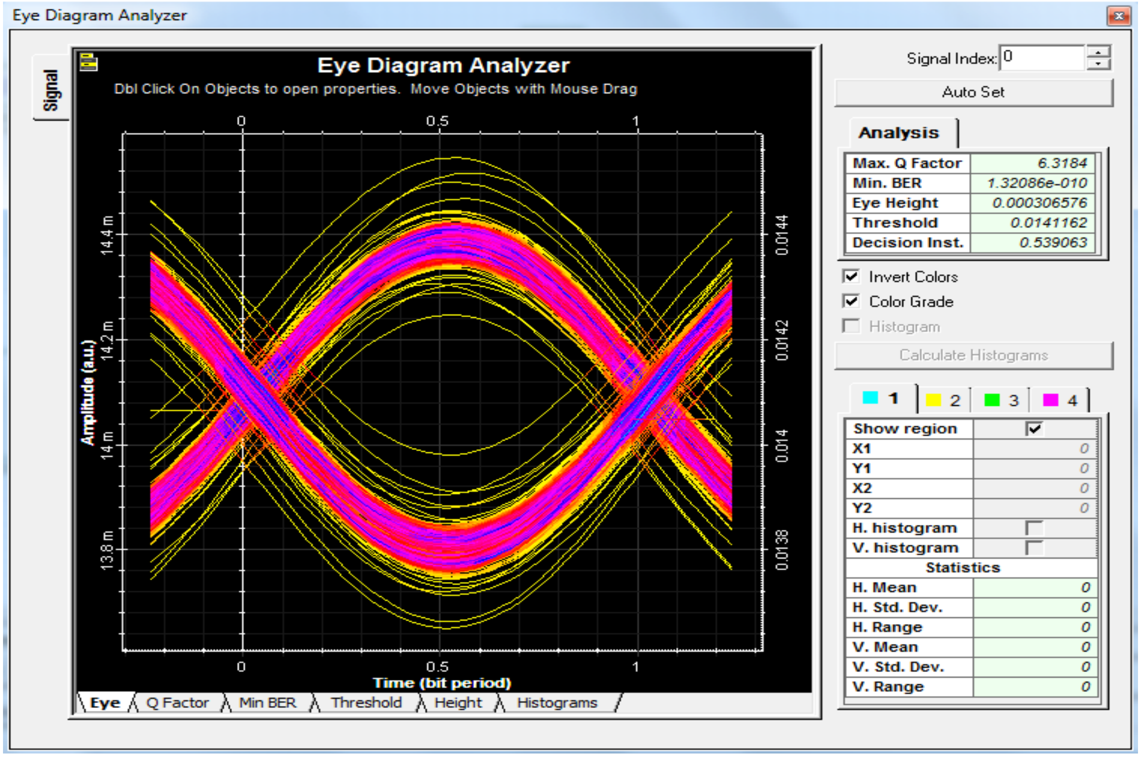

Figure 14: Eye diagram at 100km

7. Conclusion and future work

We designed a 1.25Tbit/s 60 GHz OIL Generator for a high bit rate in a Radio over Fiber architecture with millimeters waves signal. In this proposal the presentation and the simulations context which presented components setting of our OIL Generator, the transmission and reception blocks were given. Simulation step was done at three scenarios. The first one consisted of simulating the back to back link which shows and gives our method to generate radio signal at 60 GHz with the OIL technique. The second one consisted of simulating a link without amplifier in the transmission bloc over 100 km. The quality was maintained up to 70 km with Q=6.97604 corresponding a BER quality equals to 1.51804e-012. In the third one of our simulation we put an amplifier in the transmission bloc. We obtained satisfactory quality up to 100 km with Q=6.3184 and BER=1.32086e-010. This type of generator is well suited to serve rural areas that need multiple broadband ICT speeds. To increase the capacity of your architecture to connect a large number of clients, it is possible to associate it with multiplexing techniques such as Time Division Multiplexing (TDM) and WDM (Wavelength Division Multiplexing).

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