Investigation of advanced modulation formats for 40 Gbit/s optical communication systems

V. Bobrovs[1], G. Ivanovs[2]
[1]Department of Telecommunications, Riga Technical University.
Riga, LV-1010 Latvia, E-Mail: ahil@inbox.lv
[2]Department of Telecommunications, Riga Technical University.
Riga, LV-1010 Latvia, E-Mail: givanovs@rsf.rtu.lv

Abstract – Non-Return-to-Zero (NRZ), Return-to-Zero (RZ) and Dou (duobinary) modulation formats are evaluated numerically with OptSim simulation software at a bit rate of 10 and 40 Gbit/s for single channel and wavelength-division-multiplexing (WDM) systems using long fiber spans and dispersion compensation technique. For the single channel systems, conventional RZ modulation format is found to be optimum. For the WDM systems, especially for 40 Gbit/s, duobinary modulation turns out to be a much better choice in this case since it is more resilient to dispersion, nonlinear-optical-effects (NOE) and is also reasonably simple to implement.
Keywords: Non-Return-to-Zero (NRZ), Return-to-Zero (RZ), duobinary, wavelength-division-multiplexing (WDM).

I. INTRODUCTION.

The format used to modulate the carrier light wave in optical communication systems is vital to achieving good system performance. Some modulation formats are more suitable to modern, ultra-high speed, long-haul optical communication systems than others. A currently operating typical 10 Gbit/s system uses NRZ coding formats to create a 10 Gbit/s signal, most often using a distributed feed-back (DFB) laser and an external modulator to encode the signal. This has worked well up to 10 Gbit/s, but could potentially limit the potential distance of a 40 Gbit/s signal because of the impact of nonlinearity effects in the fiber [2].
RZ modulation format has become a popular solution for 10 Gbit/s systems in the later systems, because it has a higher peak power, a higher signal-to-noise ratio, and lower bit error rate that NRZ encoding. It also offers better immunity to fiber NOE [2].
Duobinary modulation turns out to be a much better choice for 40 Gbit/s WDM since it is more resilient to dispersion, NOE and is also reasonably simple to implement. In this paper the simulations are presented that clearly show its superiority to NRZ or RZ modulations for the optical fiber channels.

II. PROPOSAL OF COMPUTATION METHOD.

Our research is based on evaluating such system parameter as optical signal-to-noise ratio (OSNR) and bit error rate (BER) using powerful techniques, which are incorporated in OptSim 4.6 simulation software [1]. The method of calculation is based on solving a complex set of differential equations, taking into account optical and electrical noise, linear and nonlinear effects. We used model where signals are propagating as time domain samples over a selectable bandwidth (in our case, a bandwidth that contains all channels). The Time Domain Split Step (TDSS) method is used to simulate linear and nonlinear behavior for both optical and electrical components. The Split Step method is used in all commercial simulation tools to perform the integration of the fiber propagation equation:

$$\frac{\partial A(t,z)}{\partial z} = \{L + N\} A(t,z) \tag{1}$$

In equation (1) $A(t,z)$ is the optical field, L – linear operator that stands for dispersion and other linear effects, N – operator that is responsible for all nonlinear effects. The idea is to calculate the equation over small spans of fiber Δz by including either linear or nonlinear operator. For instance, on the first span Δz only linear effects are considered, on the second – only nonlinear, on the third – again only linear and so on [4].

III. SIMULATION SCHEME.

The main idea of our simulation is to demonstrate the influence of NOE optical effects to the NRZ, RZ and Duo modulation formats in WDM systems, respectively, self phase modulation, cross phase modulation and four waves mixing [4].
The transmitter block consists of 8 multiplexed channels, each of them consist of data source: NRZ, RZ or Dou driver, and continuous wavelength laser source and external Mach-Zehnder modulator. The data source produces a 10 Gbit/s or 40 Gbit/s bit streams, which represents the information we want to transmit via fiber optical link. Then we need a driver, which forms NRZ, RZ or Duo pulses from incoming bits. The pulses are then modulated with continuous wave laser radiation to obtain optical pulses.
After transmission block the signal is sent directly to a single mode fiber (SMF), where optical pulses are propagating via 100 km length. The used fiber has a large core effective area 80 μm^2, attenuation α = 0.2 dB/km, and nonlinear refractive coefficient $n_k = 2.5 \cdot 10^{-20}$ cm/W at the reference wavelength λ = 1550 nm. The idea is to compare system performance when using different dispersion values, laser powers, and frequency intervals between the channels. At the end of the fiber channels are demultiplexed, each channel could be analyzed separately. After that, each channel is optically filtered, converted to electrical and then electrically filtered. To evaluate system performance we are interested in observing optical spectrum at the end of optical link [3].

IV. RESULTS AND DISCUSSION.

The SPM and other nonlinear effects such as XPM and four wave mixing, occur simultaneously inside optical fibers. Fiber nonlinearity can also couple two fields through XPM without inducing any energy transfer between them. XPM is always accompanied by SPM and occurs because the effective refractive index seen by an optical beam in a nonlinear medium depends not only on the intensity of that beam but also on the intensity of other co propagating beams. Similar to the case of SPM, XPM effect develops a spectrum multipeak structure, like FWM effect in WDM systems. Therefore it is difficult to detect each of those effects separately.

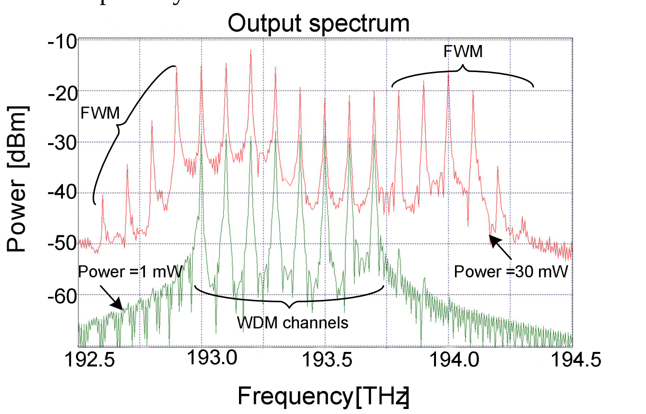

Fig. 1. Superimposed spectrum on output. 10 Gbit/s NRZ signal, 100 GHz channels interval, zero dispersion value, and different input power levels.

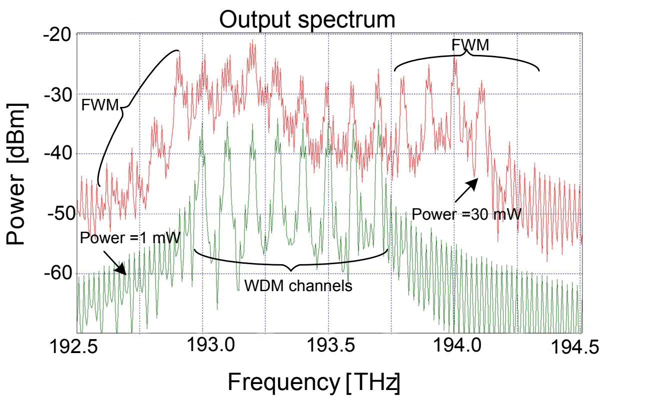

Fig. 2. Superimposed spectrum on output. 10 Gbit/s RZ signal, 100 GHz channels interval, zero dispersion value, and different input power levels.

It has been already mentioned that FWM effect develops a spectrum negative multipeak structure. Let us present that structure with different modulation methods and power levels. Numerical simulation for a 8-channel WDM system displays superimposed spectrum on output in “Fig. 1”, “Fig. 2” and “Fig. 3”.

From “Fig. 1”, “Fig. 2” and “Fig. 3” we can see a new harmonics generation in complex 10 Gbit/s WDM system. The power level of these harmonics is enough for new channels detection at output in NRZ and RZ modulations case. For duobinary modulation format the level difference between useful and negative adjacent channels enough for system good profile.

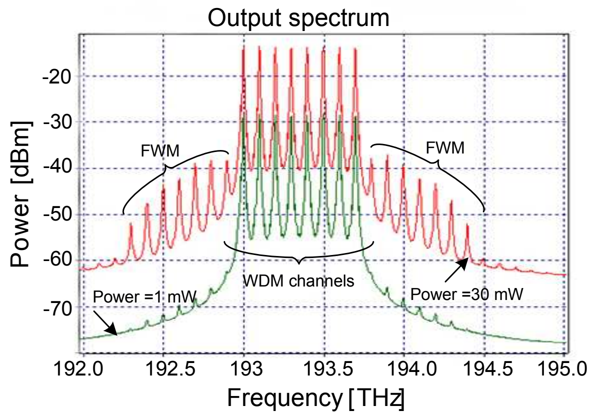

Fig. 3. Superimposed spectrum on output. 10 Gbit/s Duo signal, 100 GHz channels interval, zero dispersion value, and different input power levels.

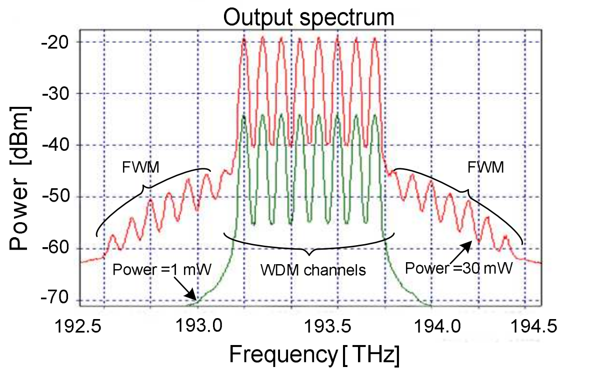

Fig. 4. Superimposed spectrum on output. 40 Gbit/s Duo signal, 100 GHz channels interval, zero dispersion value, and different input power levels.

Duobinary modulation is a much more resilient modulation scheme compared with NRZ or RZ modulations in the presence of chromatic dispersion and NOE. It is possible to increase the bit rate of complex 10 Gbit/s WDM system up to 40 Gbit/s for each channel “Fig. 4”.

V. CONCLUSIONS.

In this work we have been presented the influence of nonlinear optical effects on the NRZ, RZ and Duo modulation signals. The results show the nonlinear changes in WDM systems.

For the single channel systems, conventional RZ modulation format is found to be optimum. For the WDM systems, especially for 40 Gbit/s, duobinary modulation turns out to be a much better choice in this case since it is more resilient to dispersion and NOE, and is also reasonably simple to implement.

REFERENCES

[1] J. Leibrich, W. Rosenkranz, "Efficient numerical simulation of Multichannel WDM Transmission Systems Limited by XPM," IEEE Photon. Techno. Lett., May 2002.

[2] G. Agrawal, Nonlinear Fiber Optics, 3rd ed., Academic Press., 2002, pp. 40-73.

[3] H. Renxiang, Simulation and Experimental Study of WDM Optical Systems, 2001, pp. 28-44.

[4] V. Bobrovs, J. Porins, G. Ivanovs, "Influence of Nonlinear Optical Effects on the NRZ and RZ Modulation signals in WDM systems," Electronics and Electrical Engineering, vol. 4, pp. 31-34, 2007.