

# Planning Tool of Point to Point Optical Communication Links

João Neto Cordeiro<sup>(1)</sup>

<sup>(1)</sup>IST-Universidade de Lisboa,  
Av. Rovisco Pais, 1049-001 Lisboa  
e-mail: joao.neto.cordeiro@ist.utl.pt;

**Abstract**— The use of fibre optics in long haul telecommunication systems has been growing in the last years and tends to increase given the numerous advantages that these systems present. The use of computational tools in the design and planning of such systems is essential, allowing to test the performance of the connection. In this work, a computational tool was implemented to assist or plan fibre optic systems. This tool was developed in MATLAB/Simulink, since this software has a graphical interface that facilitates the construction of systems through predefined modules. Using the graphical interface, the user can size a fibre optic connection and simulate its performance. The obtained simulator has an ability to test systems with different intricacies such as the Wavelength-Division Multiplexing (WDM) or to choose the type of optical receivers between p-i-n Photodiode (PIN) or Photodiode (APD).

**Keywords**—Simulink, Fibre Optic, Simulator of telecommunication systems, WDM

## I. INTRODUCTION

In the last 50 years, the technology of fibre optical communications has been developing very fast along with the digital processing technology. This type of advancements revolutionised the telecommunications industry with a massive increase in demand for communications bandwidth, due to increased use of the internet and other consumer services [1].

The simulation of fibre optic telecommunication systems is an important process within an optical fibre network design. The construction of fibre optic telecommunication systems can be very expensive, so before every installation, all the components must be tested together in a simulation, to assure that the connection is reliable.

The main users of fibre optic telecommunication systems simulators are companies and students of Telecommunications. The design of most fibre optic telecommunication systems simulators makes a different approach from the “Macro” level. The signal is simulated to the single photon, making the simulation very detailed but very complex, asking the user for many parameters and using many blocks to make the signal of the system. This project intends to provide a reliable tool to simulate fibre optic telecommunication systems with an easily accessible platform without the need to buy an independent software.

The developed tool Fibre Optic Telecommunication Systems Simulator (FOTSS), is can be accessed in a Simulink library. This library allows the construction of fibre optic telecommunication systems with predefined models. The

model’s parameters can be changed with a user-friendly interface.

Beyond of introduction, this paper is organized in four sections: System’s composition, Simulator’s components, Simulator’s outputs and Conclusion.

## II. SYSTEM’S COMPOSITION

The first step in a system’s simulation is the construction of the system. The FOTSS has predefined models, this models are able to simulate fibre optic systems between two points. This simulation must take in to account the constraints implied by the phenomena that occur in the system. Thus, to determine the constrains of those phenomena some parameters are required for each model. The models actually represent the components that form the fibre optic system. The construction of the fibre optic system is divided in three main blocks:

1. Optical Transmitter – The system construction requires always an optical transmitter, this component can be altered by the user. The transmitter emits a light source that needs to reach the optical receiver.
2. Communication Channel – The light source that is emitted by the optical transmitter crosses the communication channel in order to reach the optical receiver. This block can be made with a simple optical fibre or with much more complex systems with several components such as amplifiers, fibres and filters. The construction of the system of a point to point connection will differ the number of components from how complex is the communication channel.
3. Optical Receiver – A point to point optical communication needs as much a transmitter as it needs a receiver. Thus, this block is imperative for the system’s construction. The type of receiver may vary with two main types the avalanche photodiode (APD) receiver and the p-i-n photodiode (PIN) receiver.

## III. SIMULATOR’S COMPONENTS

The FOTSS has many predefined models, with this models the user is able to simulate a fibre optic telecommunication system. The theoretical analysis was made in order to construct the components and its effect on the system [2] [3] [4]. These components are organized in the following sections:

## A. Optical Transmitter

The optical transmitter is the starting block for every fibre optic telecommunication systems simulation, this block is the only one that can be connected directly to any block on the library. The parameter can be changed by simply pressing on the transmitter block, representation in Fig. 1. Also, the figure allows identifying that every parameter already has a standard value. In the regards that the user does not know the value of a specific parameter, it is recommended that the standard values remain the same.

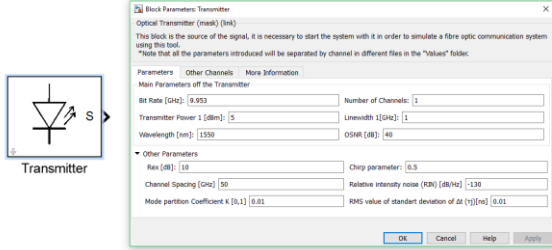


Fig. 1. Transmitter block and editing window

The main parameters of the transmitter are: the bit-rate, the signal power, the linewidth, the wavelength and the central wavelength. In order to add more than one channel, the number of channels must be inserted, note that if the number of channels surpasses 10 channels, all the channels will have the same linewidth and the same starting signal power. However, if the number of channels is between the interval ]1, 10], the values for each signal power and respectively linewidth can be inserted in the “Other Channels” tab. In addition, the value for the channel spacing must be changed in this tab. The parameters tab has a collapsible panel that appears by pressing the “Other Parameters”, as it can be observed in Fig. 1. These parameters are associated with the power penalties and sensitivity degradation, the last tab “More information” provides information about each parameter. The Table III.1 contains the standard parameters of the transmitter block.

Table III.1 Standard parameter for Transmitter block

$B$ [Ghz]	$P_e$ [dBm]	$\Delta\nu$ [GHz]	$\lambda$ [nm]	$\Delta\nu_{ch}$ [GHz]
9.953	5	1	1550	50
$R_{ex}$ [dB]	$C$	$RIN$ [dB/Hz]	$K$	$t_j$ [ns]
10	0.5	-130	0.01	0.01

## B. Optical Amplifier

The amplifier is used to amplify the signal’s power throughout the system. This block can be inserted any position between the optical transmitter and optical receiver. The amplifier parameters can be changed by pressing the amplifier block, which will open a new window where the parameters can be inserted and with some information about each parameter, an example of this is presented in Fig. 2.

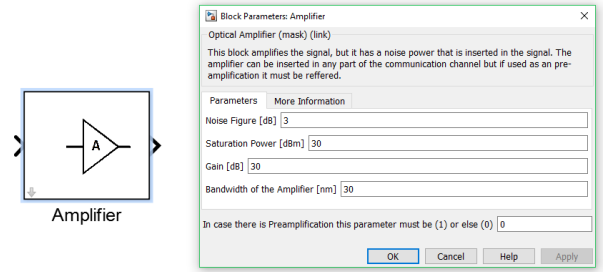


Fig. 2. Amplifier block and editing window

The use of the technic preamplification will change the formula used to calculate the average receiver sensitivity. So, in order for the program to calculate the value correctly the last parameter on the pop-up window must be inserted “1”. If the parameter is “0” the simulator will assume that there is no preamplification in the system. Table III.2 contains the standard values that are implemented in the amplifier block, this values can be altered by submitting new values and a simple explanation of each one is presented in the block window.

Table III.2 Standard parameter for Amplifier block

$F_n$ [dB]	$P_s$ [dBm]	$G$ [dB]	$B_0$ [nm]	$Pre$
3	30	30	0.3	0

## C. Optical Filter

The optical filter only works using WDM, besides the block Channel Filter 1, because it could be used to support a preamplification fibre. There are many type of blocks with optical filters, the difference between them is that they filter specific channels that the user want to analyse further. Since the number of channels is limited to 2000 channels, the number the user insets in the filter will print the graphic and in the text file for that channel. The example presented in Fig. 3 is a channel filter for two channels, this block will provide further information about that two specific channels.

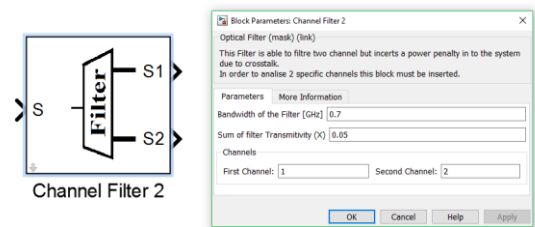


Fig. 3. Filter block for two channels and editing window

The parameter that is inserted into the optical filter block is just the specific channels that the user wants to filter, the number of channels that the filter is able to filter will depend in the type of filter. The other parameters that can be inserted in the filter block are the sum of the filter transmittivity and the filter bandwidth. This component if used is supposed to be used right before the optical receiver and there is only one use in the optical

signal simulation, every other block can be connected to it. The standard values inserted in the optical filter block are represented in Table III.3.

**Table III.3 Standard values for the Filter block**

$X$	1 <sup>st</sup> Channel	2 <sup>nd</sup> Channel	$B_{filter}[GHz]$
0,05	1	2	7

#### D. Optical Fibre

The optical fibre block can be inserted between the transmitter and the receiver, the use of this block is the basic principle in each fibre optic telecommunications systems work. However, the user can connect the transmitter directly to the receiver in order to test the losses of the system without the fibre. There are two types of fibres built in this library. However, any type of fibre should be possible to build with these blocks by simply modifying the parameters. The only difference between the block using a SMF and NZDSF is that the standard parameter is specified following an example of each type of fibre. The parameter of the fibre can be edited in the pop-up window opened when pressing the block as the example Fig. 4.

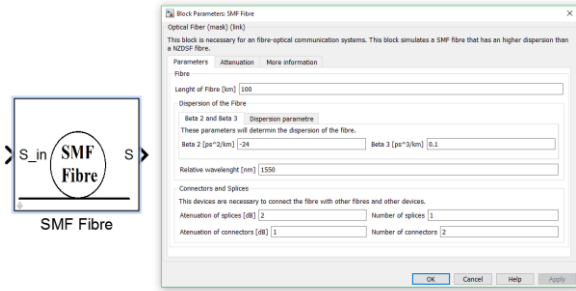


Fig. 4. SMF Fibre block and editing window

The main parameters of the optical fibre can be edited in the main window, the fibre dispersion can be presented in two ways, but if in the dispersion parameter tab is inserted a different value than 0 the program will take it into account. There is also the attenuation of splices and connectors that are asked in this block for means of simplification. The attenuation of the fibre can be inserted in three different ways, the first one is by not adding any information about the fibre attenuation and the program will assume that the values stay the same as the example G.655 or G.652, either if using a NZDSF fibre or SMF fibre. The second way is to assume that the attenuation of the fibre does not change with the frequency and it is given a constant value. The last one is giving specific values for specific intervals defined by the user as can be observed in the Fig. 5.

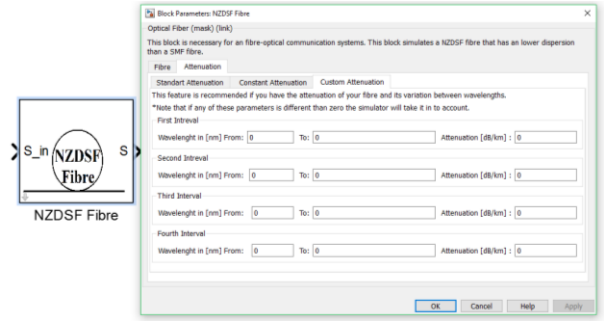


Fig. 5. NZDSF Fibre block and editing window in attenuation tab

Although, there are only two types of fibres introduced in the program, they can always be changed. This means that these types of fibres were the only ones that the standard values were already implemented following an example for each fibre. However, the user can always customise each block to replicate another type of fibre. The nonlinear effects throughout the fibre are verified in this block. The limitations of the nonlinear effects will only limit the threshold power or incident power in the fibre. Thus, if any nonlinear effect surpasses the threshold power or incident power limitations this block will print a warning message in the MATLAB® terminal and in a pop-up message Fig. 6.

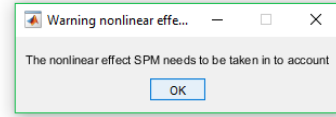


Fig. 6. Warning message received if SPM nonlinear effects needs to be taken into account

The standard values of the parameters for each type of fibre block are represented in Table III.4. Every attenuation parameter of each fibre is set as zero, this can be observed in Fig. 5. Thus, these parameters were not represented in Table III.4.

**Table III.4 Standard values for the fibre block**

Fibre	Length [km]	$\beta_2$ [ps <sup>2</sup> /km]	$\beta_3$ [ps <sup>3</sup> /km]	$\lambda_r$ [nm]	$N_s$	$A_s$ [dB]	$N_c$	$A_c$ [dB]
SMF	100	-24	0,1	1550	1	2	2	1
NZDSF	100	-2,8	0,08	1550	1	2	2	1

#### E. Optical Receiver

The optical receiver is the block that will receive the optical signal and convert it into an electrical signal. This block is supposed to be the last block of the system in this simulator, so any other block can connect to it. There are two types of receivers implemented in the simulator, PIN receiver and APD receiver instead of providing both types of block there is only one. The parameters of the receiver block can be modified in the block window, represented in Fig. 7.

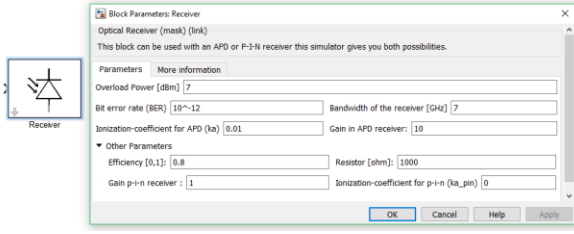


Fig. 7. Receiver block and editing window

The decision of having both types of receivers was made in order to provide the user with a comparison between both receivers by observing the difference between the SNR achieved and the system margin. The values standard values for the receiver block are represented in Table III.5. The parameters  $k_a$  and  $M$  are the only ones that will be different for both receivers.

Table III.5 Standard values for the Receiver block

BER	APD		PIN		R [ $\Omega$ ]	$\eta$	B [GHz]
	$k_a$	$M$	$k_a$	$M$			
$10^{-12}$	0,01	10	0	1	1000	0,8	7

A example of a system built with this simulation is represented in Fig. 8. This systems contains an optical transmitter and optical receiver, the otther blocks that form the communication channel consist of four NZDSF fibres and two amplifiers.

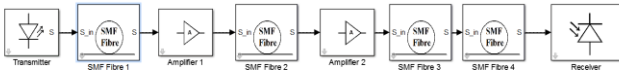


Fig. 8. Example of fibre optic system built in the simulator

#### IV. SIMULATOR'S OUTPUTS

The decision of having both types of receivers was made in order to provide the user with a comparison between both receivers by observing the difference between the SNR achieved and the system margin. The comparison between them can be observed in many ways since the information provided by the simulator has three types of sources. The information can be taken for the excel file created by the program called "Data.xlsx", this file contains the main matrix of the program, this matrix contains all the main parameters that needed to be shared for each block. The size of this matrix can go from [1 34] to [2000 200], the reason behind it is [1 34] is or the smallest systems possible with only one channel and with a transmitter and receiver. The 34 is the number of parameters that are needed to run the systems simulation, this number will rise with the number of components since each time an amplifier is added two new parameters are added to the matrix. This will depend on the number of channels since the maximum is 2000 but also on the number of amplifier blocks that can be added, the maximum number of amplifiers is  $(200-34)/2 = 83$ . The

decision for limiting the maximum size can seem arbitrary but this comes from the fact that when using Simulink, a matrix can have a variable size. However, the maximum size must be defined, which means that a maximum number of parameters must be stated. Thus, the limitation of the matrix was set to very high values usually the number of channels can go up to 300 and the number of amplifiers should not be higher than 20. Even with this limitation the program can be adapted to receive more parameters but each block and subblock have to be changed manually in the Explore option of Simulink option.

There is always another way to analyse the system by opening the "ChanelX.txt" file that corresponds to the Xth channel. This file can be found in the folder "Values" and there is one file for each channel so the user can open a specific channel and observe a simple overview of the signal propagation through the channel. The objective of this source of data is to analyse a channel independently from other channels, Fig. 9 show an example. This example is from a standard fibre optic telecommunications system consisting of six fibres five amplifiers and obviously one transmitter and one receiver.

```

ChannelX.txt - Notepad
File Edit Format View Help
[Transmitter:
Channel 1: Transmitted power:5.000 [dBm] Bit rate:9.953 [Gbit/s] Wavelength:1550 [nm]
Extinction Ratio: 10 [dB] Linewidth:1.0 [nm] Chirp Parameter:0.50
OSNR:40.00 [dB]
-----
SMF Fibre: Length:100.000 [km] Attenuation of Connectors:1.000 [dB] Attenuation of Splices:2.000 [dB]
Number of Connectors:2.000 Number of Splices:1.000
Attenuation per km:0.180 [dB/km] Dispersion:18.817*10^-6 [ps/km/nm]
Power at the end of the Fibre:-17.00 [dBm]
-----
Amplifier: Gain 29.92 [dB] Noise Figure: 3.00
Power after Amplification: 12.917 [dBm] Noise Power (Pase): -17.267 [dBm]
OSNR:29.753 [dB]
-----
SMF Fibre: Length:100.000 [km] Attenuation of Connectors:1.000 [dB] Attenuation of Splices:2.000 [dB]
Number of Connectors:2.000 Number of Splices:1.000
Attenuation per km:0.180 [dB/km] Dispersion:18.817*10^-6 [ps/km/nm]
Power at the end of the Fibre:-9.08 [dBm]
-----
Receiver: Bandwidth: 6.97 [GHz]
Received Power: -9.083
PIN Receiver: ka:0.010 M: 1
APD Receiver: ka:0.000 M: 2
OSNR:29.753 [dB]
PIN Receiver: Sensitivity:-26.318 [dBm] SNR_pin: 21 [dB]
Systems Margin: 10 [dB]
APD Receiver:

```

Fig. 9. Output text file by the receiver

Fig. 10 can be analysed and easily obtain all the important data throughout the fibre such as the OSNR of each parameter that ads noise, the attenuation of the fibre, the distortion, etc. Note that these parameters can only be an easy way to observe the parameters that were inserted by the user and correct mistakes if necessary. One of the last importante details of the data provided by this file is the gain of the amplifier since the amplifier can be saturated and the user does not notice it, so if the user inserts a gain it does not mean that the amplifier will amplify the signal with that gain.

The last kind of data source provided by the simulator are outputs of Simulink this consists of an graphical analysis of the SNR throughout the fibre weither from the first channel if a channel is not specified or from a specified channel using the filter block. The receiver will also provide a graphical analysis of the signal SNR by wavelenght if more than one channel is provided so the user can observe that each wavelenght provides an optimal SNR for the system, Fig. 11 shows an example of

such graphs. There is also a graphical analysis of the systems margin by each wavelength with equal intent to the previous one. The output sources also consist of important information being printed in the MATLAB® message box from the parameter values presented in Fig. 10. There can also be warnings if the threshold power surpasses the limitations on which the nonlinear effects will have to be taken into account, or simple warnings such as non compatible values and so forward.

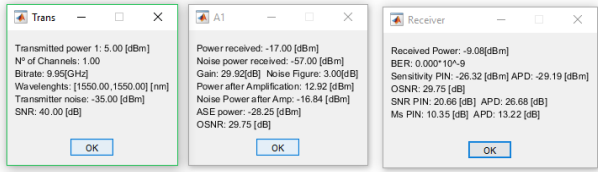


Fig. 10. Messages presented by the simulator

The receiver block also returns three graphical analysis of the system. The first one is represented in Fig. 11 This figure includes two types of graphics: the OSNR throughout the fibre and the power throughout the fibre.

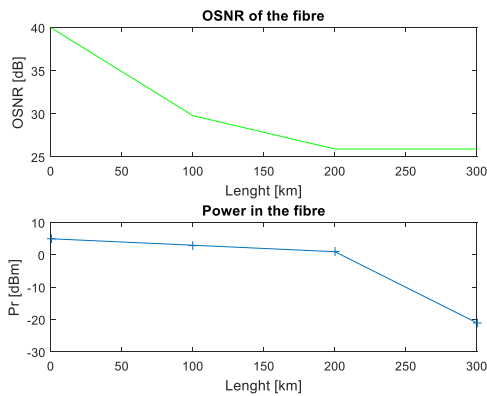


Fig. 11. Example of output graphic of OSNR and Power throughout the fibre

The second type of graphical analysis that is presented in this simulator can only be represented if more than one channel is use. The reason behind it is that Fig. 12 is a comparison between the OSNR of each channel, where the graphic is supposed to show a similar variation with the different attenuations parameters of the fibre through wavelength.

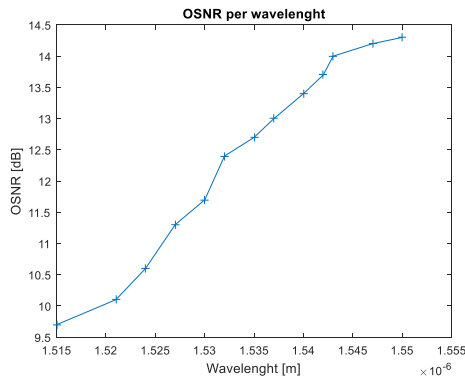


Fig. 12. Example of output graphic of OSNR changing per wavelength

The last type of graphical analysis is Fig. 13, which contains a graphical analysis of the systems margin for every channel. The graphical representation shows the minimum required systems margin represented in red. By analysing Fig. 13, it can be taken into consideration that the wavelength from 1520 [nm] to 1540[nm] are the only ones that comply with the minimum systems margin, for this example.

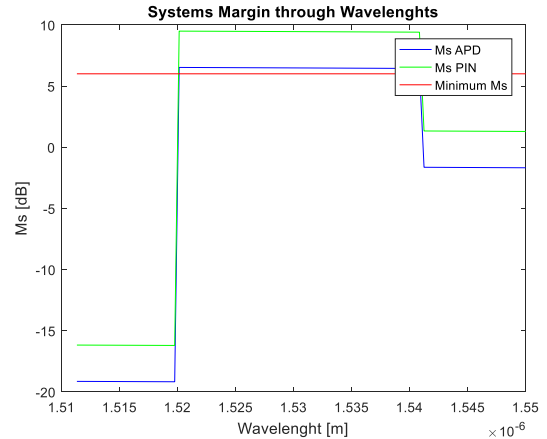


Fig. 13. Example of output graphic of system's margin per wavelength

## V. CLONCUSIONS

The project planning tool developed in this project was implemented as a library for MATLAB's Simulink. This implementation was tested against its own theoretical design and against another simulator of fibre optics communications planning tool. Those tests stated the viability of the program and its main goal that was providing a free developing tool for MATLAB's Simulink.

The simulation of the project proved the resourcefulness of the program against a real-life project and how it's simulation can be build using the provided tools. The project was also provided with a simple construction of the systems' components. Even though the simulation was not made to the signal level, the information provided by the simplification of the system was enough to provide a simple and precise conclusion about the viability of the system.

The outputs provided by the simulator are more than sufficient for a user to identify the main parameters of his system. The outputs being an excel spreadsheet with the main matrix that transmits the values throughout the fibre, a text base document with detailed information on each channel, and the Simulink outputs, which consist in a graphical analysis of the OSNR and the power throughout the system. The system also provides a comparison of the SNR of the system for the different channels, if the user is using more than one channel, and the systems margin for the different channels and receivers.

The non-linear effects that can occur in a fibre optics system were implemented in the simulator. However, the FWM was not included due to the excessive complexity of its implementation without a simulation of the communication at the signal level.

In conclusion, the simulator provides the ability to construct systems combining professional and academic

components in a free access developing tool. The use of Simulink simplifies the construction of systems by simply dragging each model and add it to the system. This tool also provides the ability for students to understand and compare their results with the results provided by this simulator, from the insertion of each component and their benefits and problems for the systems, as each parameter that is taken in to account by this program.

#### ACKNOWLEDGMENT

A special thanks to Prof. Paulo André and Prof. Pedro Pinho, for their help and availability when I had questions regarding the technical field and decision making throughout this project.

#### REFERENCES

- [1] International Telecommunications Union, "Statistics," ITU, 2016. [Online]. Available: <http://www.itu.int/ict/statistics>. [Acedido em 02 10 2016].
- [2] G. P. Agrawal, Tiber-Optic Communication Systems, John Wiley & Sons, Inc, 2002.
- [3] A. Cartaxo, Sistemas de Telecomunicações por fibra óptica, Lisboa: AEIST.
- [4] G. P. Agrawal, Lightwave Technology, John Wiley & Sons, Inc, 2005.