Loss and Power Budget

1 Objective

Investigate the effect of loss on optical system performance and characterize the system with the power budget equation. Use OptiSystem to optimize the fiber length of a communication system.

2 Pre-lab

Optical system performance can be limited by many physical processes for example loss, dispersion and receiver noise. If the optical signal power at the receiver is lower than the receiver sensitivity, then the signal will not be correctly detected. The power margin is the difference between the detected signal power and the receiver sensitivity.

The budget equation given by equation 1, compares the loss of system to the difference between the transmitter power and receiver sensitivity:

$$P_t - S_r = AL_f + L_c + L_a + M, \tag{1}$$

P_t = transmitter power	AL_f = fiber loss	L_a = additional loss
S_r = receiver sensitivity	L_c = coupler loss	M = power margin

Power can be measured both in linear units (Watts) or logarithmic units (dBm). The Decibel-milliwatts scale has the added benefit that losses can be easily subtracted from a signal rather than multiplied. The power budget equation above is expressed using dBm units, which can be calculated using the following relation:

$$P_{dBm} = 10\, log_{10} \frac{P_{Watts}}{1mW}, \tag{2}$$

and the dimensionless unit for loss is calculated from the ratio of input and output powers by:

$$L_{dB} = 10\, log_{10} \frac{P_{out}}{P_{in}}. \tag{3}$$

Fiber loss is then calculated by multiplying the attenuation *A* (dB/km) by the length of the fiber L_f (km).

Receiver sensitivity, also usually given in dBm, can be defined as the signal power required to achieve a certain bit error rate.

<u>Questions:</u>

2.1.1 Convert 0 dBm to Watts.

Answer: $0 = 10 \log_{10} \frac{P_{out}}{1\, mW}$

$$1 = \frac{P_{out}}{1mW}$$

$$P_{out} = 1mW$$

2.1.2 A 5 dBm signal is sent through a component and detected at its output as 0.5 mW, what is the loss of the component in dB?

Answer: $L_{dB} = 5\ dBm + 3.01\ dBm$

$$L_{dB} = 8.1\ dBm$$

2.1.3 Determine the maximum length of optical fiber that should be used in the 1 Gb/s system in Figure 1 below, to obtain a 6 dB power margin. Assume a -30 dBm receiver sensitivity.

Answer: $P_t - S_r = AL_f + L_c + L_a + M$

$$2 + 30 = 1.2L_f + 1.5 + 0.5 + 6$$

$$24 = 1.2L_f$$

$$L_f = 20\ km$$

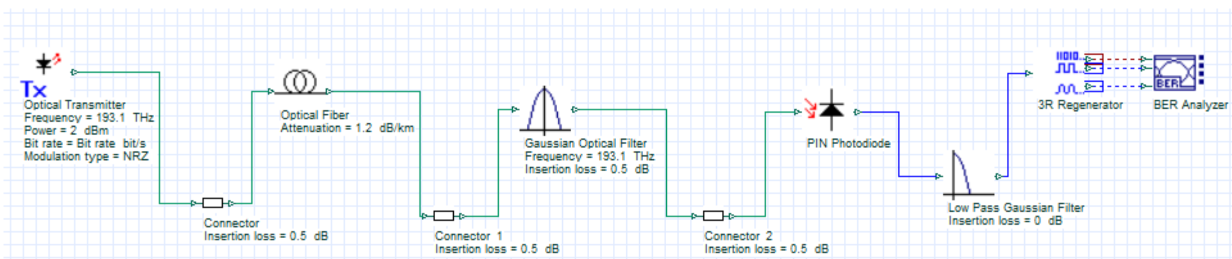


Figure 1: A loss limited system.

3 SYSTEM PERFORMANCE

Refer to the system in Figure 1 and build it in OptiSystem. Correctly set the power and bit rate of the optical transmitter to 2 dBm and 1 Gb/s respectively. To simulate a receiver with a -30 dBm sensitivity set the PIN photodiode's Thermal power density to 15e-24 W/Hz. You will need to place the following components:

• Optical Transmitter	Transmitters Library/Optical Transmitters
• Optical Fiber	Optical Fibers Library
• Connector	Passives Library/Optical/Connectors
• Gaussian Optical Filter	Filters Library/Optical
• Low Pass Gaussian Filter	Filters Library/Electrical
• PIN Photodiode	Receivers Library/Photodetectors
• 3R Regenerator	Receivers Library/Regenerators
• BER Analyzer	Visualizer Library/Electrical

Set the optical fiber length to the value calculated in question 2.1.3 and simulate the project. You should be achieving a BER less than 1e-8.

3.1 Effect of Loss on System Performance

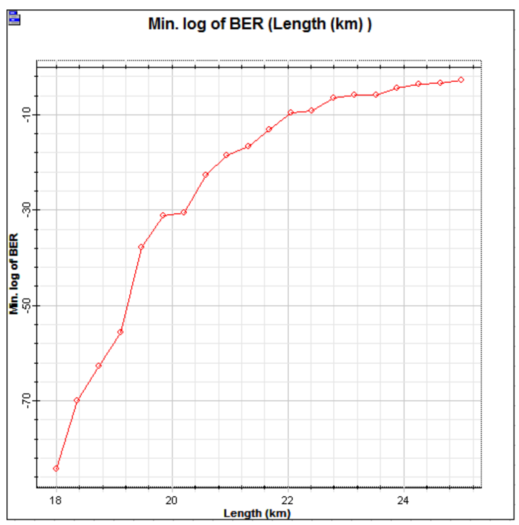
A more accurate calculation of the bit error rate can be performed if a larger sequence length is used for the simulation. In the layout properties, change the sequence length from 128 to 1024.

Create a parameter sweep of the optical fiber length and vary it from 18 km to 25 km with 10 total steps.

Questions:

3.1.1 Plot the minimum BER as a function of fiber length.

Answer:



3.1.2 Discuss the trend of the bit error rate.

Answer: The optical fiber is introducing dispersion and nonlinear effects, but loss is the limiting factor in this specific design.

3.1.3 By sweeping the fiber length and using an appropriately placed optical power meter determine the receiver sensitivity for a desired Q factor of 8.

Answer: A Q factor of approximately 8 was found for a length of 21.3 km.

3.2 OptiSystem Optimizations

OptiSystem has a built-in optimizer tool that can make designing a system simpler. In this section, the proper procedure for setting up an optimization will be demonstrated.

Starting from the same project file as used above, an optimization will be run to determine the optimal bandwidth of the Gaussian filter. First remove the parameter sweep, by changing the fiber length parameter from sweep to normal and assign it a value of 23 km and set the total number of sweep iterations to 1.

The objective of this optimization will be to determine the best cutoff frequency for the low pass electrical filter. Open the optimizations window by finding it in the Tools tab.

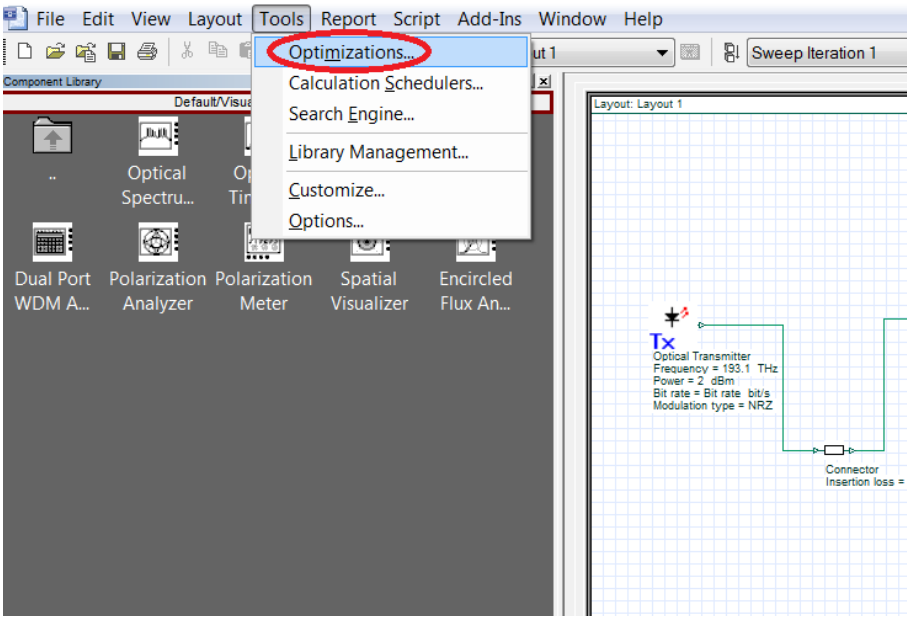


Figure 2: Opening the Optimizations window.

Choose the SPO Optimization (Single Parameter Single Result) and click Insert.

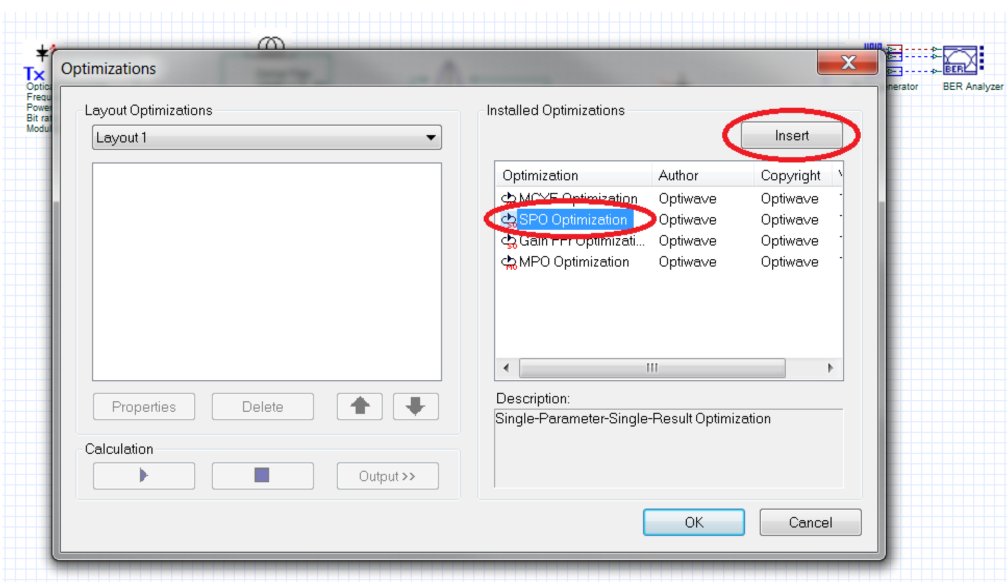


Figure 3: Selecting the SPO Optimization from the Optimizations window.

Before the optimization can be inserted, the properties have to be set. The goal for this optimization will be maximizing the Q factor result of the BER Analyzer within a 0.001 accuracy.

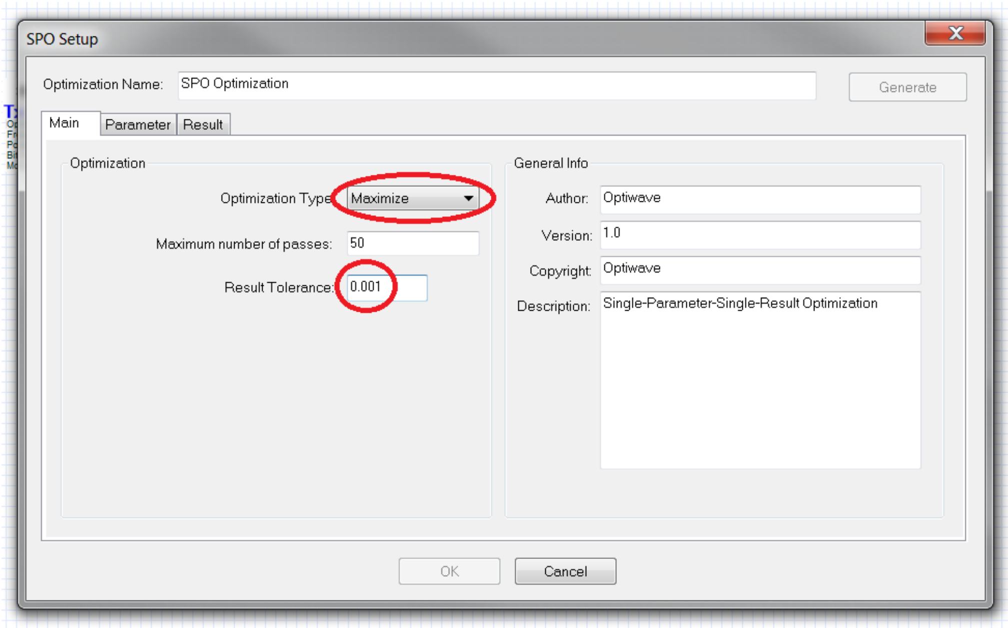


Figure 4: Setting up the optimization type.

In the Parameter tab locate the cutoff frequency in the electrical Gaussian filter and set the range from 100 MHz to 1.5 GHz.

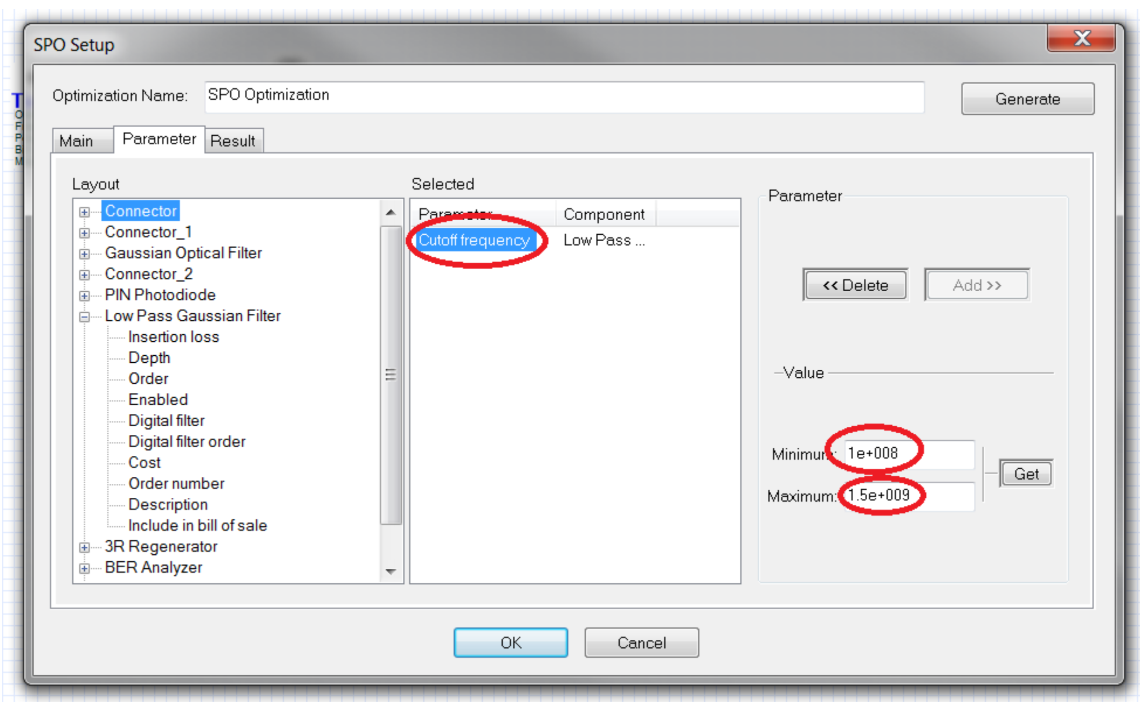


Figure 5: Selecting the parameter to optimize.

Locate the Max Q Factor result in the BER Analyzer and add it to the optimization.

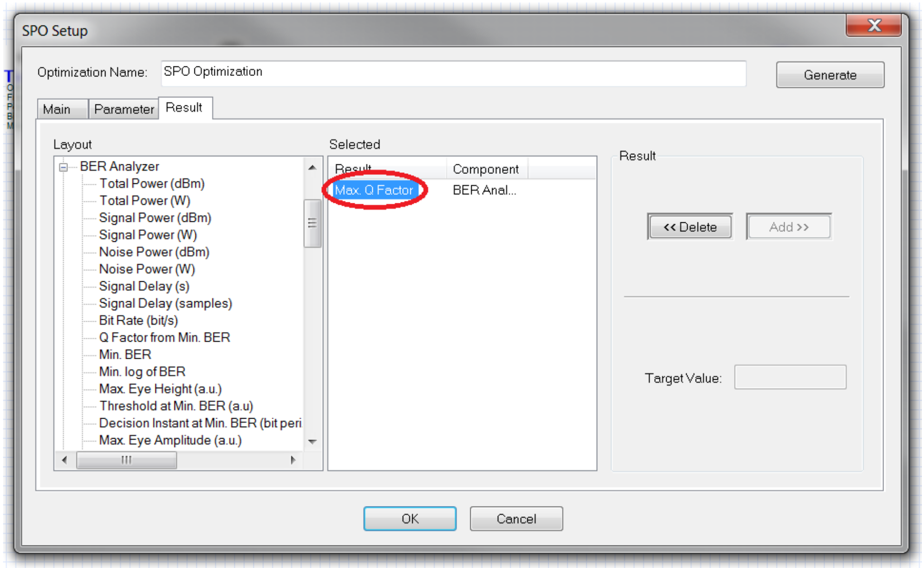


Figure 6: Choosing the result to maximize.

The simulation is ready to run. At the calculation window make sure to run all optimizations. During the simulation you can go to the optimizations tab to observe the optimization in progress.

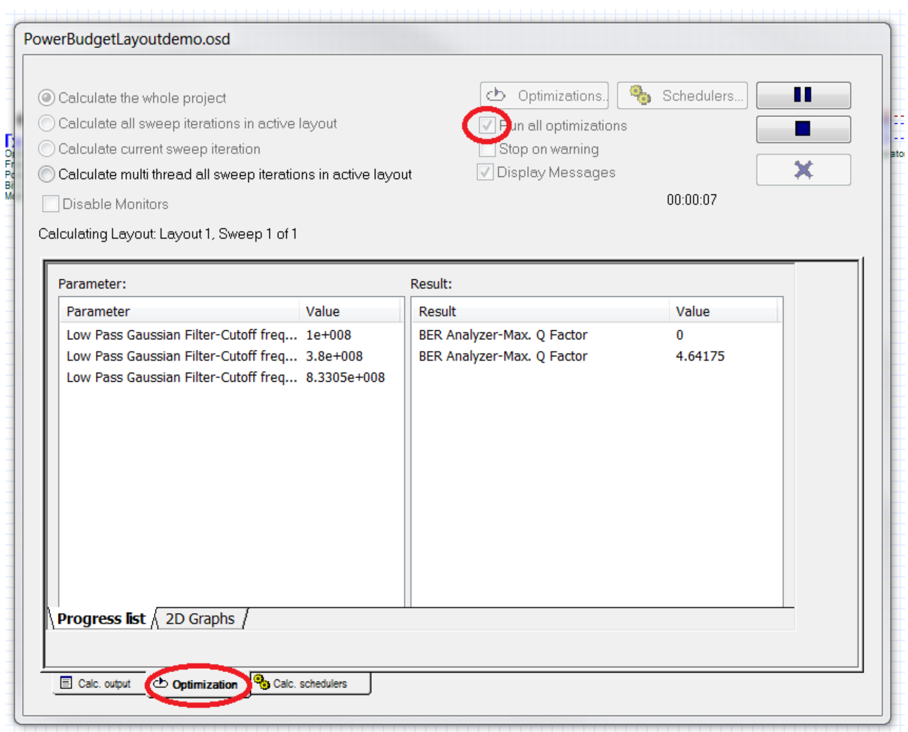


Figure 7: Running the simulation and optimizations.

The cutoff frequency should be optimized to around 505 MHz for this system.

3.3 Optimize Fiber Length

Set the cutoff frequency of the Gaussian low pass filter to 505 MHz and using the above procedure find the longest fiber length that will result in a Q factor of 10.

Questions:

3.3.1 What is the length of fiber?

Answer: 20.7 km

3.3.2 What is the associated BER of this system?

Answer: 1.02266×10^{-23}

3.3.3 What is the new Power Margin of this system? Assume a 30 dBm receiver sensitivity.

Answer: 5.16 dB

4 Report

In your lab report include the following:

- Brief overview of the background and theory.
- Answers to all pre lab questions, clearly showing your work.
- Brief description of the simulation method and setup, including screenshots.
- Final results including figures and discussion.

5 References

[1] Agrawal, G. P. *Fiber-optic Communication Systems*. New York: Wiley, 1997. Print.

[2] Saleh, Bahaa E. A., and Malvin Carl. Teich. *Fundamentals of Photonics*. New York: Wiley, 1991. Print.