Optical Communications-2013/14

Simulation Lab on: **Optical Transmitters and Receivers**

In this test on optical transmitters and receivers, we will study:

- The optical spectrum and time evolution of CW FP laser output, the time evolution of carrier density in the FP laser
- The optical spectrum and time evolution of CW DFB laser output, the time evolution of carrier density in the DFB laser
- The line width of CW DFB laser output
- Directly modulated DFB lasers
- Externally modulated DFB lasers
- Compare sensitivity of PIN diode and APD

Exercise 1: Build Up of a FP Cavity Laser

First, we build up a Fabry-Perot (FP) cavity laser instead of using a laser module directly. Open setup Tx1_1. In the schematic: Two isolators, *IsolatorNonIdeal*, are used as reflectors in the laser cavity; The *AmpSysOpt* modules provides gain; Noise generated from *NoiseWhiteGaussOpt* is added into the cavity to simulate the spontaneous emission of the laser; The *Attenuator* simulates the loss of the laser; The gain profile of the laser is simulated by the *FilterOpt* module.

- **Question 1.0**: When the gain value of the optical amplifier is at least as large as the loss in the cavity (set by the *Attenuator*) plus the loss caused by the reflector (or *IsolatorNonIdeal*), the laser starts lasing. Plot the optical spectrum and the temporal waveform of the laser output. Reduce the gain of the optical amplifier (or increase the cavity loss) and run the simulation again. How do the optical spectrum and waveform of the laser output look like now? Explain why.

- **Question 1.1**: Increase the gain of the optical amplifier and run the simulation again. How do the optical spectrum and waveform of the laser output look like? Explain why. Why this phenomenon doesn't occur in semiconductor lasers?

Exercise 2: Fabry-Perot Laser

In this lab, we investigate the characteristics of continuous wavelength (CW) FP lasers. Open setup Tx1_2. For this study, the module *Laser_TLM* has been configured to model a Bulk FP laser. For this, the parameter *Laser_TLM* ***FacetReflectivity*** is set to 0.32. The laser is driven by DC current provided by *DCSource*. The optical spectrum of the laser output is visualized by the *SignalAnalyzer* **(OSA)**.

- **Question 2.1:** Plot the optical spectrum of the FP laser output. Describe the structure of the obtained spectrum. What is the bandwidth of the laser modes? Which limitation to the transmission capacity (in terms of bit rate times length) one obtains when using such a laser in a transmission fiber with a dispersion D=17 ps/(nm.km)?
- **Question 2.1:** Measure the longitudinal mode separation; the group refractive index of the laser material is 3.7. Calculate the laser cavity length and check if the result is the same as given by the parameter *Laser_TLM* ***DeviceSectionLength***.

Exercise 3: L-I Curve of Laser Output

In this exercise, we look at the relationship between optical output power and FP laser diode drive current. Open the setup Tx1_3. The output power of the laser is measured by the *FreqPowerMeter* module.

- **Question 3.1:** Sweep the drive current from 0 up to 60 mA (at intervals of 5 mA); in the scheme, the *Const* ***level*** is equal to the drive current. Using the *NumericalAnalyzer2D,* plot the optical output power versus FP laser diode drive current. Describe what is observed at low diode currents. How to obtain the lasing threshold from the L-I curve?

- **Question 3.2**: The external differential quantum efficiency h is defined as the number of photons emitted per radiative electron-hole pair recombination above threshold. It is proportional to dP/dI. Change the parameter *Laser_TLM* ***InterfaceReflectionCoefficient*** For example, to 0.2 and 0.5) and run the simulation again. Which is the relationship between the threshold current I_{th} and facet reflectivity and between dP/dI and the facet reflectivity?

Exercise 4: Temporal Dynamics of FP Laser

In this exercise, the dynamics of FP laser diodes can be simulated by the setup Tx1_4.

- **Question 4.1:** Using *SignalAnalyzer* **(Scope),** plot the carrier density and waveform of laser output. Run Tx1_4. Carrier density and output laser power waveform after the current is put into the laser are shown in the right top and bottom figure, respectively. Divide the total observation time (800 ps) in four time intervals, separated by the points in time when the carrier density has either a local maximum or a minimum. Describe and provide a physical justification for the observed coupled time dynamics of carrier density and output laser power in each individual temporal sub-interval.

Exercise 5: Resonant Frequency and Drive Current

In this lab setup, Tx1_5, we investigate the relationship between the resonant frequency and drive current of the laser. The waveform of the laser output is visualized by the *SignalAnalyzer* **(Scope)**.

- **Question 5.1:** Sweep the drive current between 0 A and 0.06 A. In this simulation, the L-I curve of the laser is shown in the *NumericalAnalyzer2D.* Plot the waveform and the L-I curve of laser output. The resonant frequency f_r is 1/Dt, where Δt is the period of the first oscillation of the laser output waveform. Measure the resonant frequency at different drive current I. Plot f_r^2 versus $(I/I_{th}-1)$.

Exercise 6: DFB Laser

Although FP laser are cheap, the multimode output of FP lasers limits their application in optical communication. Single mode lasers are needed to overcome the drawback of multimode lasers. Distributed feedback (DFB) can generate signal mode lasers by using a grating in the laser cavity. Open the setup Tx1_6. Now, the module *LaserTLM* is configured to model a bulk DFB laser with quarter-wave-shifted grating. For this, the following parameters have been set: *LaserTLM*

InterfaceReflectionCoefficient = 1.0e-12; *LaserTLM GratingModel* = Coupling; *LaserTLM GratingPhaseShift* = 90

- **Question 6.1:** Run the setup with default parameters, and plot the optical spectrum of the DFB laser output. How many cavity modes are present in the spectrum? What is the signal mode bandwidth? How this compares with the previous case of a FP laser? What are the consequences of the DFB laser bandwidth for its applications to WDM transmission systems? What happens to the laser spectrum if the grating phase shift is changed to zero? And to 180 degrees? Explain your observations.
- **Question 6.2:** To investigate, why the mode of the DFB laser has such a small line width, open and run (with default parameters) the schematic Tx1_7. The output of the DFB laser is visualized both in time domain by *SignalAnalyzer* **(Scope)** and frequency domain by *SignalAnalyzer* **(OSA)**. Plot the temporal waveform and relative frequency of the DFB laser output, and describe your observations. In particular, discuss the relationship between the time-domain and spectral measurements in question 6.1.

Exercise 7: Directly Modulated DFB Laser

Data can be added by simply directly modulating the DFB laser. Open the setup Tx1_8. The electrical NRZ signal provided by *PRBS* and *CoderNRZEI* is injected into DFB laser *LaserTLM* through the module *LaserDriver*. Then the electrical NRZ signal is turned into an optical NRZ signal at the DFB laser output by direct modulation.

- **Question 7.1:** Plot the optical spectrum of the directly modulated DFB laser output with the NRS signal set to *One* or *PRBS*. Compare and discuss the difference of the optical spectrum of CW DFB laser output in the two cases.
- **Question 7.2:** In the PRBS case, plot the power waveform and chirp of the directly modulated DFB laser. What is observed in the power waveform at the leading edge of the pulses? What is the chirp at the pulse leading edge and its trailing edge? Change the drive current from 0 to 90 mA (in intervals of 20 mA) by changing *LaserDriver* ***DriveAmplitude*** and measure the peak power (P) and the amplitude of the laser noise-induced chirp fluctuation ΔC (or adiabatic chirp) of the DFB laser output. Plot ΔC as a function of 1/P.
- **Question 7.3:** For the a 60 mA drive current, plot the time evolution of the carrier density in the DFB laser, and describe what is observed.

Exercise 8: External Modulation & Direct Modulation

Data can be added to the optical signal through external modulation, where an additional modulator is needed. Open the setup Tx1_9. In this simulation, we will compare the optical signal after external modulation and direct modulation. An electro-absorption (EA) modulator is used to externally modulate the laser output

- **Question 8.1:** Plot the power waveform and chirp of the directly modulated DFB laser and describe what is observed in both leading edge and trailing edge of the pulses.
- **Question 8.2:** Plot the power waveform and chirp of the externally modulated DFB laser and describe what is observed in both leading edge and trailing edge of the pulses. Compare with the previous case.

Exercise 9: Responsivity of PIN & APD

In this part of Lab (open the setup Rx1_1), we will show the relationship between the photocurrent generated from PIN or APD photodiode and input optical power. The optical input light of PIN and APD photodiode is generated from CW laser *LaserCW*. The power of input light is measure by power meter *PowerMeter*. The photocurrent generated by PIN photodetector or APD is averaged by *PowerMeterEI*. The averaged photocurrent generated from PIN photodetector and APD versus input power of the photodetector is visualized through NumericalAnalyzer (2D).

- **Question 9.1:** Sweep the input optical power of photodetector by controlling the attenuator value (decrease the attenuation from 20 to 0 dB, with steps of 2 dB). Plot the averaged photocurrent generated from both the PIN and APD photodiode versus input optical power. What type of relationship is obtained between the photocurrent generated from photo-detector and the input optical power? Estimate the responsivity of the PIN and the APD photodiode, and compare with the corresponding parameter values. Is the measured value the same as the parameter value? In case they are different, explain why.