Concepts for teaching optoelectronic circuits and systems

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CONCEPTS FOR TEACHING OPTOELECTRONIC CIRCUITS AND SYSTEMS

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Abstract : We introduce an attractive approach for the teaching of optical circuits and systems. This approach avoids to the students and teachers the use of complex physics to understand the optical communication circuits and systems. It is based on the use of standard software and can be integrated into the student program as an extension of electronics and microelectronics lectures.

1 Introduction

Development and design of optical communication and optoelectronic systems is now necessary for the engineers in electronics and microelectronics [1]. While such design is mainly based on the physical understanding of the optics and optoelectronic phenomena, it cannot be efficiently achieved without using the design and optimization tools. Computer Aided Design (CAD) tools are now widely used in the field of electronic and communication systems. For the development of optoelectronic systems, such tools are thus of great importance. At the INPG/ESISAR we developed a teaching approach for optical/optoelectronic circuits and systems for optical communication applications. Such approach is based the use of the available software at universities. We introduced two complementary techniques. The first one is system oriented and is based on the use of the SIMULINK simulator (within the MATLAB software) frequently used in signal processing. One of the experiment objectives is thus to teach to the student how to adapt a conventional system simulator for the design of an optical or optoelectronic system. The second one is mainly dedicated for guided waves optical circuits and is based on the use the SERENADE suite and more specifically the Harmonica module for the linear and non linear simulation of RF circuits. In both cases, the students have to develop their own model describing the optical properties of the considered devices. Then the simulation capabilities of the software are used to get the optical response and to study complex optical circuits and systems.

2 System Approach

In this approach we introduce the domain of simulation and computer aided design to the student using a wide spectrum simulator which is the SIMULINK simulator within the MATLAB software. The first direction of this approach is to develop different model of optoelectronic components and obtain their responses as single elements. Let's consider the example of laser diode. The model of the laser diode is based on the electrical, optical and geometrical parameters. This model is expressed in

the form of rate equations describing the static and dynamic behavior of carriers and photons inside the active region of the laser diode. Once the equations obtained and normalized, the laser diode is represented by a block diagram as shown fig.1. All the black boxes in the previous diagram are available as defined functions into the Simulink module. As example of simulation result, fig. 1 gives the static and dynamic optical response (photon density) of the laser diode. Such results are thus used to extract the overall parameters of the source.
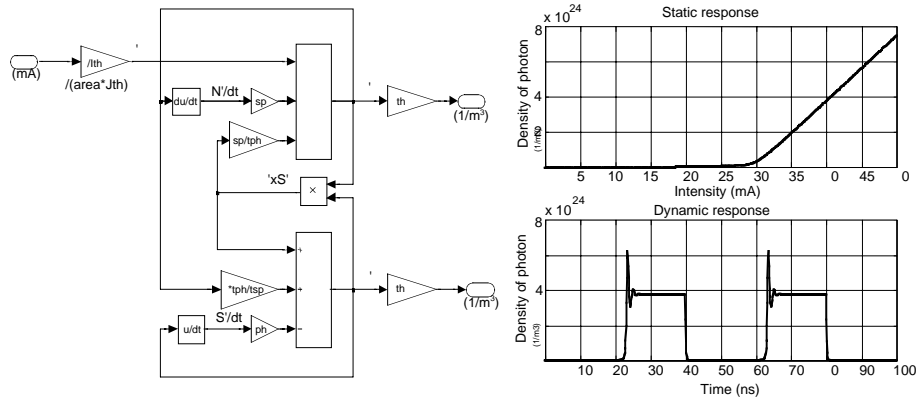

Figure 1. Model of the laser diode and simulated responses.

The second direction is to simulate a more complete, but simplified, optical communication system. To do so, we have developed a library which is composed of a several single elements: a Gaussian pulse generator, a laser diode module, a single mode fiber module and a photodetector module. All the modules have different adjustable parameters, that can be modified by the user into a specific dialogue window. A typical communication system is shown fig. 2, in which we added several scope probes. An example of the system response is shown fig.3.

NB: The time axis of the scope 3 and 4 do not correspond with the time axis of the scope 1 and 2, due to time delay
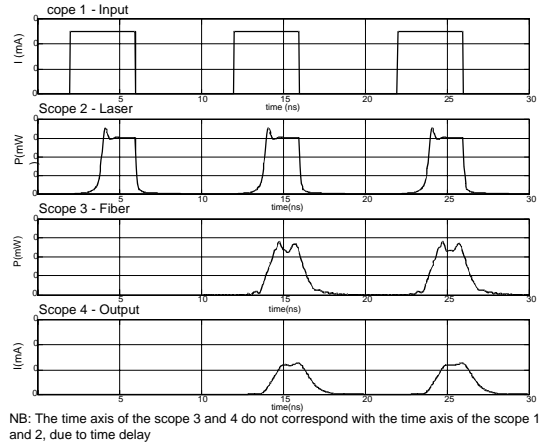
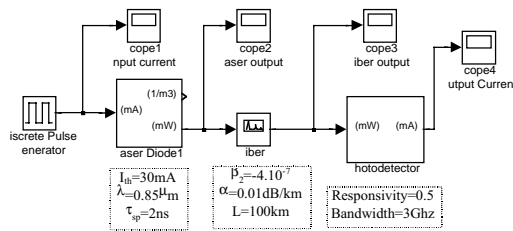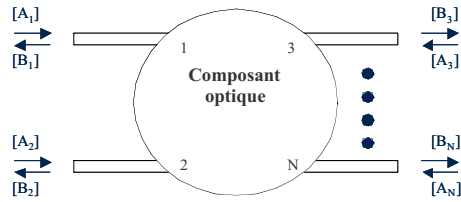Figure 2. Responses of the communication system at different points of the optical link.

Figure 3. Block diagram of the optical communication system.

3 Circuit Approach

A second approach consists in the use of circuit oriented tools. The main advantage of such approach is its capability to take into account the interference between the basic elements into the studied circuit. Indeed, due to the propagation phenomena, the optical elements have reflection and transmission properties. In frequency domain the reflection will lead to filtering effect, and in the time domain re-circulating loops will be generated. On the other hand, optical signals are in general polarized. To meet these requirements in terms of signal polarization and bi-directional behavior we considered RF/microwave simulators [2,3]. We used the Harmonica module of the SERENADE suite in which we extended the concept of S-parameters to the optical devices.

For each optical basic element we associated an extended scattering matrix that includes the polarization, reflection and transmission properties. Then a library of optical elements has been integrated into the software as a User Defined Library.

As a basic example of User Defined Element, let's consider an optical waveguide. The waveguide is a two-port passive component. Ideally, it should be loss less and matched. Thus, the S-matrix of a perfect waveguide is unitary and symmetric. In addition, the polarization of the optical signals must be described which leads to a four-port model (two for each polarization). The S-matrix of an ideal waveguide has the following form. :

$$[S] = \exp(j.\alpha). \begin{bmatrix} 0 & 0 & \exp(j.\phi).\cos(\theta) & j.\sin(\theta) \\ 0 & 0 & j.\sin(\theta) & \exp(-j.\phi).\cos(\theta) \\ \exp(j.\phi).\cos(\theta) & j.\sin(\theta) & 0 & 0 \\ j.\sin(\theta) & \exp(-j.\phi).\cos(\theta) & 0 & 0 \end{bmatrix}, \text{ where } \begin{cases} \theta = polarisation \\ \alpha + \phi = \dfrac{2.\pi.L.n_x.\nu}{c} \\ \alpha - \phi = \dfrac{2.\pi.L.n_y.\nu}{c} \end{cases}$$

Finally, the dispersion and losses effects can be considered by integrating closed form expressions into the defined optical S-matrix.
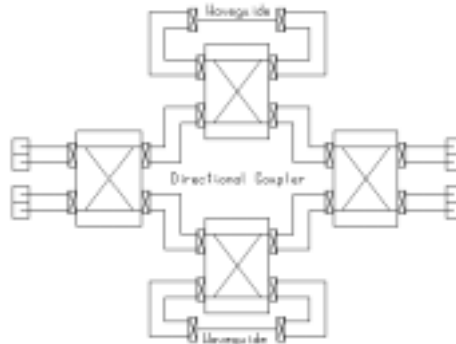

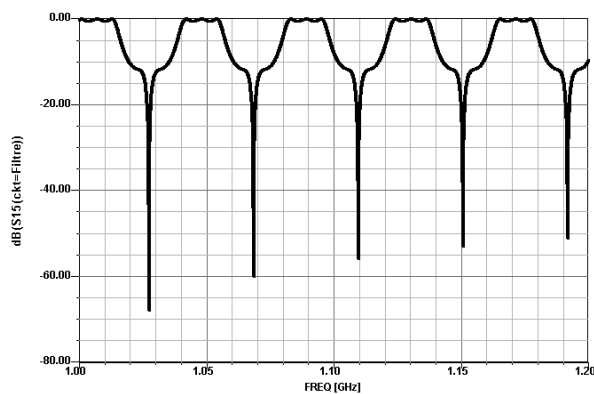Figure 4. A Mach-Zehnder filter designed on SERENADE

Figure 5. A Mach-Zehnder filter frequency response.

We developed models for several optical elements usually used to design optical circuits. The fig.4 is an example of an optical fiber circuit. This is a modified Mach-Zehnder filter based on the use of single mode fibers and couplers. Four directional couplers are used (two with α=0.5 and two with α=0.9) and two single mode optical fibers: 10 and 15m length. This is a linear circuit and its simulated frequency response is given fig.5. The response of the circuit can be optimized using the capabilities of Harmonica module. More complex circuits, including integrated optics, can be studied using the same procedure [4].

4 Conclusion

The optical technologies based on the use of optical fibers and integrated optic/optoelecronic devices is a fast growing filed. In the last decade several theoretical and technological advances have been accomplished and allow today very sophisticated applications both for ultra large bandwidth transmission and the processing of high-speed signals. Nowadays, the optical technology allow more and more complex applications using a large number of components integrated on the same substrate or connected by optical fibers or waveguides. The teaching of these aspects to electronics and microelectronics engineers become urgent and must be integrated as an extension of electronics lectures. We developed an attractive approach that introduces the simulation of optical circuits and systems based on commonly used and widely available software for education. One of the main advantages of this approach is its potential to allow to the students the understanding of optics and optoelectronics applications without need of complex physics. The conducted experience at the INPG/ESISAR is very encouraging and well appreciated by the students.

5 References

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