

INTERACTIVE ANIMATED LEARNING OBJECTS FOR THE TEACHING OF OPTICAL MODULATION CONCEPTS

Francisco Ramos

Departamento de Comunicaciones. Universidad Politécnica de Valencia.

Camino de Vera, s/n. 46022 Valencia (Spain)

framos@upvnet.upv.es

Abstract

Optical modulation concepts are explained by means of interactive animations developed in Flash. Simulation models of a laser diode, Mach-Zehnder and electroabsorption modulators were implemented to account for the influence of different parameters: bias currents and voltages, dynamic margin with emphasis on clipping and inversion effects, extinction ratio, modulation index, as well as digital versus analogue modulations. Their effectiveness for learning was assessed by means of a much better student engagement and successful evaluation results.

Keywords

Interactive computer-based animations, telecommunication engineering, optical modulations, photonic devices, student engagement

1. INTRODUCTION

Recent advances in information and communication technologies allow the development of tools for educational purposes, promoting changes in the educational paradigm. Nowadays there are lots of digital learning objects stored on numerous repositories with the possibility of being shared among the e-learning community [1-3]. A learning object is an entity of learning content that can be used several times in different courses or in different situations [4-6]. In order to be useful, a learning object must be modular, accessible, interoperable and reusable. However, less attention is usually paid to their effectiveness for learning, which can only be assessed by means of the student engagement and the later evaluation results. Student engagement is one of most important factors that affect teaching and student motivation to learn. Computer-based animation and visualization are powerful and motivationally attractive education techniques, which can simplify the presentation of the conceptual frameworks and schematic overviews, thereby enhancing learning. Indeed the teaching of most Engineering disciplines implies the combination of visual animated objects and high interactivity. Those resources require considerable computing time and so it is not possible to access shared servers through Internet, e.g. they must be executed on the user's PC locally. To this end, several technologies such as Java and Flash are available. Java is usually employed when you need speed or have a very complex simulation. However, Flash has more advantages for e-learning applications.

In this paper, several digital learning objects for the explanation of different optical modulation concepts are shown. More specifically, simulation models for the optical response of a laser diode, Mach-Zehnder and electroabsorption modulators were implemented. The interactive Flash animations focus on the influence of the bias point (voltage or current), the dynamic margin with emphasis on clipping and inversion effects, the extinction ratio, the modulation index, as well as a comparison between digital vs. analogue modulation, and direct vs. external modulation.

2. INTERACTIVE ANIMATIONS IN ENGINEERING

Virtual laboratories, whether accessed locally or remotely, provide learning experiences similar to their in-class analogues, can facilitate deep learning in model-based knowledge domains, and can enable learning without most of the overhead inherent in traditional lab experiments [7]. Virtual labs are not actually real-world experiments in a physical laboratory but are simulations – mathematical models implemented on a computer. However, they are still very useful to complement traditional lectures, specially when explaining diverse engineering concepts. In this framework, computer-based animations are powerful and motivationally attractive education techniques. Especially attractive are

interactive animations which show variable scenarios according to key and mouse inputs by viewers. Several technologies have shown their feasibility for this purpose, such as Flash or Java applets, but each one has its own advantages and disadvantages. We decided to use Flash because it can be executed on more machines (Flash player has more than a 95% penetration among Internet users, see Fig. 1), requires a smaller plug-in, allow vector graphics and their user-friendly graphics tools provide an easier way to program 2D and 3D animations using the last version of the powerful programming language called ActionScript 3.0. This programming language allows an easy way to develop computer animations with a high degree of interactivity, which can simplify the presentation of the conceptual frameworks and schematic overviews, thereby enhancing learning.

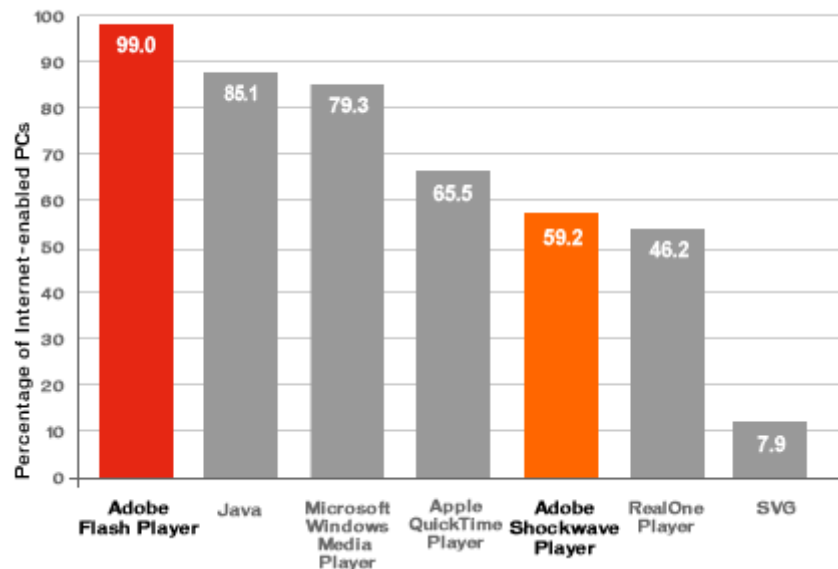


Figure 1: Flash Player penetration in mature markets (Millward Brown survey, conducted June 2008).

Some examples of Flash animations focused on different engineering disciplines can be found in the literature [8-11]. Among them, the teaching of Telecommunication Engineering is especially attractive because involves several subjects which can actually benefit from the use of computer-based animations: signal theory, antennas and propagation, fibre optics, computer networks, etc. In our case, several learning objects to explain optical modulation concepts were implemented in the framework of the 8th semester subject "Optical communication systems". More specifically, simulation models for the optical response of a laser diode, a Mach-Zehnder modulator and an electroabsorption modulator were implemented. The interactive Flash animations focus on the influence of the bias point (voltage or current), the dynamic margin with emphasis on clipping and inversion effects, the extinction ratio, the modulation index, as well as a comparison between digital vs. analogue modulation, and direct vs. external modulation. Next we explain some details about the implementation of these digital learning objects.

3. IMPLEMENTATION

Interactive animations showing the modulation process in a laser diode transmitter, a Mach-Zehnder modulator or an electroabsorption modulator were implemented using the Adobe Flash CS3 software package. These animations show the optical response of the device (output power versus input current or voltage) as well as the time varying input/output signals, providing the student the opportunity to change different parameters dynamically to see the influence on the modulated signal. The simulation models employed for each device are described in the following subsections.

3.1 Laser diode transmitter

Laser diodes are electrically pumped semiconductor lasers in which the gain is generated by an electrical current flowing through a p-n junction [12]. In this heterojunction, electrons and holes can combine, releasing the energy portions as photons. This process can be spontaneous, but can also be

stimulated by incident photons if the input current exceeds a threshold, I_{th} , in effect leading to optical amplification. Laser diodes can reach high electrical-to-optical efficiencies, typically of the order of 50%. The efficiency is usually limited by factors such as the electrical resistance, carrier leakage, scattering, absorption (particularly in doped regions), and spontaneous emission. There are very different kinds of laser diodes, operating in very different regimes of optical output power, wavelength, bandwidth, and other properties. One example is the distributed-feedback (DFB) laser which consists of a resonator based on a periodic structure, and a gain medium.

A laser diode can be modulated employing digital or analogue signals. Digital modulation is usually called on-off keying (OOK) as, in its simplest form, the presence of an optical carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero. Therefore, digital modulation is represented by a square wave. On the other hand, analogue modulation is usually done employing RF subcarriers [13]. Therefore, analogue modulation is represented by a sine wave. The bias point affects the performance of the modulation process, as several parameters such as the optical modulation index or the extinction ratio depend on it. As an example, analogue optical modulation requires a bias current well-above the threshold to avoid clipping, an undesired effect which causes high levels of nonlinear distortion [14]. By varying the bias and modulation currents, the output signal from a directly-modulated laser shows different behaviours and performance. To account for these effects from a pedagogical point of view, the modulation process should be explained by means of interactive animations. This way, the student can change the parameters dynamically and see the results in real time. Fig. 2 shows the interactive animation developed in Flash to explain the optical modulation process in a laser diode. As it can be seen, digital or analogue modulation may be chosen by means of the type of waveform. The amplitude of the bias and modulation currents can also be set. The input (modulating) and output (modulated) signals are continuously time varying to reflect the user inputs, whereas the modulation index and extinction ratio for the modulated signal are displayed as an inset. This animation is an effective way to show the student how the laser biasing around the threshold affect the performance in both analogue and digital systems.

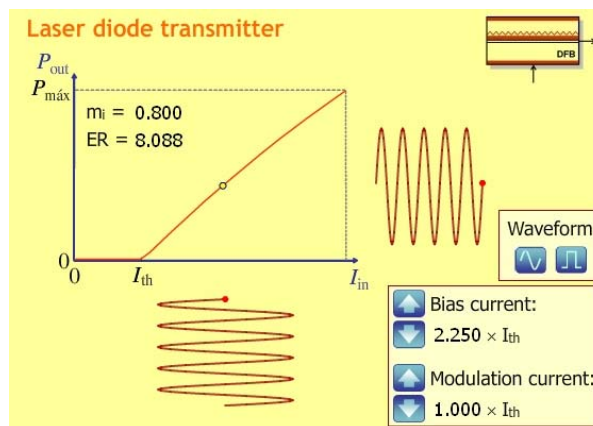


Figure 2: Interactive Flash animation of the modulation process in a directly-modulated laser diode transmitter.

3.2 Mach-Zehnder modulator

Another possibility for optical modulation is employing a Mach-Zehnder modulator. The external modulator operation is based on the linear electrooptic effect which provides a change in refractive index proportional to an applied electric field. The modulator consists of a Mach-Zehnder interferometric structure with phase modulators on each arm. The voltage applied to each arm modulates the phase of the optical carrier, so constructive and destructive interferences are obtained at the output of the modulator when this voltage is changed. The voltage-power (V-P) response for the Mach-Zehnder modulator is given by [15]:

$$P = \frac{P_{\max}}{2} \left[1 - \cos \left(\pi \frac{V}{V_{\pi}} \right) \right], \quad (1)$$

where V is the applied voltage (bias and modulation), V_π is the half-wave voltage, and P_{\max} is the maximum output power.

The optical response of a Mach-Zehnder modulator is depicted in Fig. 3. As it can be seen, it has a periodic behaviour with maxima and minima. The bias point for which no output power is obtained is called minimum transmission bias (MITB), whereas a maximum power is obtained for the maximum transmission bias (MATB) point. The optimum bias point for linear operation is called quadrature bias (QB). Therefore, analogue optical systems should be biased at $V_\pi/2$ voltage with a low dynamic range. Conversely, digital systems require high extinction ratio and so the signal excursion must achieve the MITB point. However, if the dynamic range of the input modulating signal is too high, inversion effects appear and the modulated signal exhibits distortion.

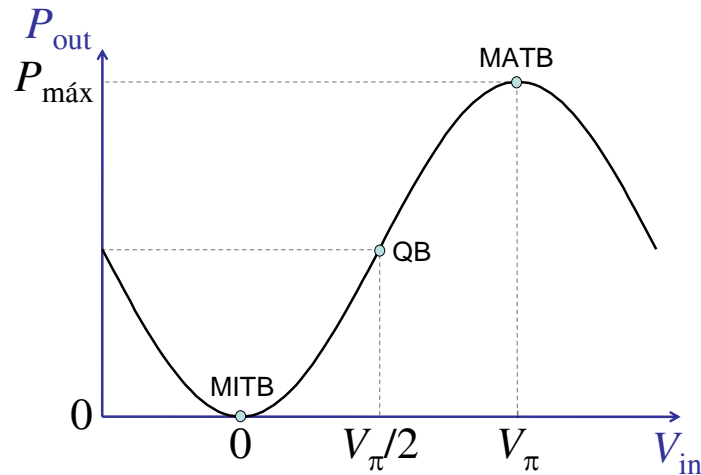


Figure 3: Modulation response of an external Mach-Zehnder modulator.

To account for these effects, a simulation model for the Mach-Zehnder modulator was implemented in Flash. Fig. 4 shows the interactive animation, very similar to the previous one for the laser diode but now with a different optical response, as well as bias and modulation voltages instead of currents. In this example, the inversion effects on the upper part of the modulated signal as a consequence of a bad biasing can be seen in the results of Fig. 4.

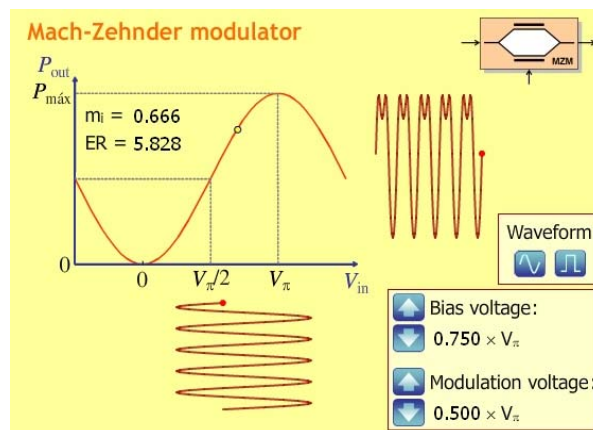


Figure 4: Interactive Flash animation of the modulation process in a Mach-Zehnder modulator.

3.3 Electroabsorption modulator

The electroabsorption modulator is a semiconductor device which can be used for modulating the intensity of a laser beam via an electrical voltage. Its principle of operation is based on the Franz–Keldysh effect (i.e., a change in the absorption spectrum caused by an applied electric field, which changes the bandgap energy). The power intensity at its output is generally expressed as [16],

$$P = P_{\max} \exp \left[- \left(\frac{V}{V_0} \right)^a \right], \quad (2)$$

where V is the applied reverse voltage, V_0 is the voltage giving an extinction ratio of P_{\max}/e and a is a parameter found to be 4-2 for multi-quantum well modulators and 2-1 for the bulk ones.

In a similar way, the electroabsorption modulator was modelled in Flash. The result is shown in Fig. 5. In this case, the optical response has an exponential decreasing behaviour. As it can be seen in Fig. 5, a bias voltage near the maximum causes signal distortion in analogue optical systems. On the other hand, digital systems require a high dynamic range to obtain good extinction ratio values.

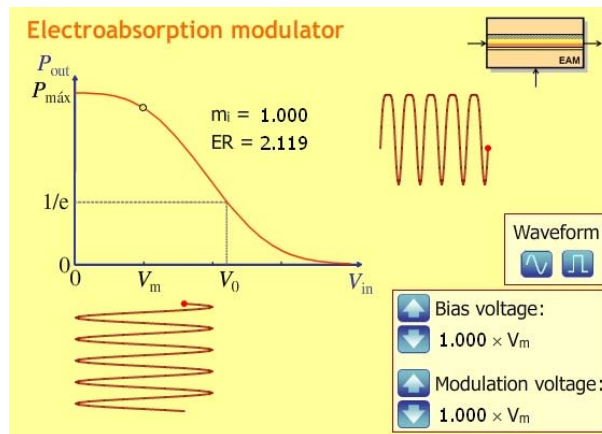


Figure 5: Interactive Flash animation of the modulation process in an electroabsorption modulator.

4. SUMMARY AND CONCLUSION

Interactive animations showing optical modulations in a laser diode transmitter, a Mach-Zehnder modulator or an electroabsorption modulator were implemented using the Adobe Flash CS3 software. These animations can be used as learning objects for the explanation of different modulation concepts, such as the influence of the bias point on the performance of analogue and digital systems, or the identification of distortion effects (clipping and inversion effects) and how to avoid them. The effectiveness of this approach has been assessed by means of the student engagement, providing a successful learning confirmed by the later evaluation results.

References

- [1] OpenCourseWare Consortium: <http://www.ocwconsortium.org/>
- [2] MERLOT - Multimedia Educational Resource for Learning and Online Teaching: <http://www.merlot.org/merlot/index.htm>
- [3] Wisc-Online - Online Learning Object Repository: <http://www.wisc-online.com/>
- [4] S. Downes, "Learning objects: resources for distance education worldwide", *Int. Review of Research in Open and Distance Learning*, vol. 2, no. 1, 2001.
- [5] P. Mohan, and C. Brooks, "Engineering a future for web-based learning objects", in *Proc. Int. Conf. on Web Engineering*, Oviedo, 2003.
- [6] M. Sosteric, and S. Hesmeier, "When is a learning object not an object: A first step towards a theory of learning objects", *Int. Review of Research in Open and Distance Learning*, 2002.
- [7] "Virtual laboratories", *Special Issue of the IEEE Trans. on Education*, vol. 51, no. 1, Feb. 2008.
- [8] C. J. Scott, "Vector animation: Web-based software training on demand", in *Proc. IEEE Aerospace Conference*, vol. 2, pp. 473-479, March 2000.
- [9] T. A. Philpot, "Using Flash animations and 3D rendering to increase the effectiveness of instructional software", *Frontiers in Education Conf.*, vol. 3, pp. S2F-S17, Oct. 2001.

- [10] E. Ferre, Wai Shan Lau, B. Ngo, E. A. Riskin, M. Soma, R. Christie, J. Harris, L. J. Collins, R. E. Lee, M. Campion, "Flash animation in introductory EE courses", *Frontiers in Education Conf.*, vol. 1, p. T1F-1, Nov. 2002.
- [11] J. M. Cho, S. I. Choi, D. K. Lee, and Y. J. Nam, "A flash-based multimedia interactive tutoring system for distance education of biomedical engineering students: new approach to teaching microcontroller-based systems", in *Proc. of 25th Int. Conf. of Engineering in Medicine and Biology*, vol. 4, pp. 3540-3543, Sept. 2003.
- [12] W. W. Chow, S. W. Koch, "Semiconductor-laser fundamentals, Springer, Berlin, 1999.
- [13] R. Olshansky, V. A. Lanzisera, and P. M. Hill, "Subcarrier multiplexed lightwave systems for broad-band distribution", *J. Lightwave Technol.*, vol. 7, no. 9, pp. 1329-1341, Sept. 1989.
- [14] N. J. Frigo, M. R. Phillips, and G. E. Bodeep, "Clipping distortion in lightwave CATV systems: Models, simulations, and measurements," *J. Lightwave Technol.*, vol. 11, pp. 138-146, Jan. 1993.
- [15] D. A. Fishman, "Design and performance of externally modulated 1.5-mm laser transmitter in the presence of chromatic dispersion", *J. Lightwave Technol.*, vol. 11, no. 4, pp. 624-632, 1993.
- [16] O. Mitomi, K. Wakita, I. Kotaka, "Chirping characteristic of electroabsorption-type optical-intensity modulator", *IEEE Photon. Technol. Lett.*, vol. 6, no. 2, pp. 205-207, 1994.