From photonic components to optical network : an online simulation of a spectral CDMA system

G. Pille[1,2], Y. Moreau[1], K. Kribich[1], J. Jabbour[1], S. Gatti[1] and J. Galy[2]

[1] *Centre d'Electronique et de Micro-Optoélectronique, Courrier 084*
Université Montpellier II - 34 095 - Montpellier cedex 5
[2] *Laboratoire d'Informatique Robotique et Microélectronique de Montpellier*
161, Rue ADA - 34392 - Montpellier cedex 5

Email: *pille@cem2.univ-montp2.fr*

ABSTRACT

The presented work is focused on a set of linked applications from the component level to the system level: namely mode computation, mode propagation, beam propagation and spectral Code Division Multiple Access (CDMA) system simulator. These applications, partly available online through Internet, constitute a powerful teaching tool and a complete design flow for systems such as Wavelength Division Multiple Access (WDMA) or even Optical Spectral CDMA.

1 SOFTWARE ENVIRONMENT

We have developed a simulation package made of five Java applets for optics. Since we are interested here in a particular device we detail here three of them: jWDM, jBPM and jCDMA. Other applets developed are jModes [1] (it computes the optical modes in a section of a guide for instance for integrated optical circuits), and jGrating which computes the reflectance of index modulation in Bragg grating.

The choice of Java is justified by the portability of the language and its good overall performance [3], as shown in table 1.

Code	Pentium III 1.3GHz (s)	Athlon 1 GHz (s)
Java - Interpreted	5.83	5.18
Java - Client Hotspot JIT	0.897	0.541
Java - Server Hotspot JIT	0.921	0.574
C++	0.800	0.402
FORTRAN	0.820	0.572

Table 1: Execution times for a test program depending on the source language (after J.C. Schatzman [3]).

Java is an object oriented language compiled into bytecodes which are instructions for a virtual machine. Java has performance close to C++, particularly since the Just-In-Time (JIT) compiling technique is used. Moreover it has interesting advantages:

- Easy code writing: Java is relatively recent and incorporates modern simplification of language writing.
- Standard built-in library of user-friendly interfaces (windows, menus, mouse events, etc. . .).
- Same code can be used with personal computers under Windows, Linux or Mac OS through the use of a Java Virtual Machine which interprets locally the code.
- Free, since Sun Microsystems does not ask fees. This is interesting in an education or opened context.
- It can be used directly on Internet without explicit installation, just through a browser like Internet Explorer, Netscape or Mozilla: the code is loaded (a few tens of kBytes) from the server and interpreted on the client side (locally) by the Virtual Machine of the browser in a transparent way. Owing of this, it can be embedded in presentations, it can be used as illustration in education and is well accepted by young generations accustomed to Internet.

2 PROPAGATION IN PHASARS WITH JWDM

The jWDM applet [4] is a multi-purpose program based on modal approach. Basically it computes modes in rectangular section of guides and is able to compute the propagation of a beam considered as a sum of weighted modes. The simulation is thus very fast even for a complex structure.

An associated script reader has been developed to concatenate the basic operations corresponding to menus and dialogs. The script a user can write is a listing of successive menu actions and values edited. Figure 1 shows an simple example of operations which can be linked and described as a sequence of commands: computations, propagation of modes in guide A, injection of the resulting beam in a large guide B, propagation in B, then grabbing of light in specific zones to feed small guides, etc…

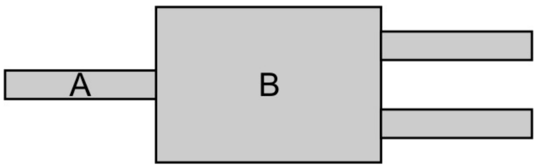

Figure 1: Simple example of optical circuit jWDM can handle as a sequence of linked operations.

Moreover the script can control a sequence of computations with a series of values for a parameter (for instance wavelength) to evaluate the impact. For instance, this scripting facility has allowed the spectral study of PHASAR WDM consisting of two star-couplers joined by an array of forty arms (Array Waveguide Grating).

It also enables evaluation of loss in bent waveguides, diffraction of light, phases with MultiMode Interference devices, generation of a description file and a drawing for an Array Waveguide Grating…

3 BEAM PROPAGATION WITH jBPM

Optical integrated circuits like WDMs can be also studied and simulated with the Beam Propagation Method (jBPM is also available through Internet [5]) in a more accurate and more versatile way (shapes can be arcs, tapers, etc…). The circuit is entered with mouse or with a description file and the propagation is simulated slice after slice by solving a system of algebraic equations derived from the Helmholtz equation through a finite difference scheme. A scripting facility allows automatic successive simulations in order to evaluate impact of parameters. Simulations of realistic integrated PHASARs have been performed. If the interpretation through modal approach (as with jWDM) is easier and the simulation fast, geometric diversity can be taken into account and evaluation of performance like crosstalk in an optical multiplexer is more accurate with BPM.

4 SIMULATION OF CDMA TRANSMISSION (jCDMA)

CDMA (Code Division Multiple Access) is a multiplexing technique based on orthogonal or quasi-orthogonal codes attributed to each user to prepare their messages which are

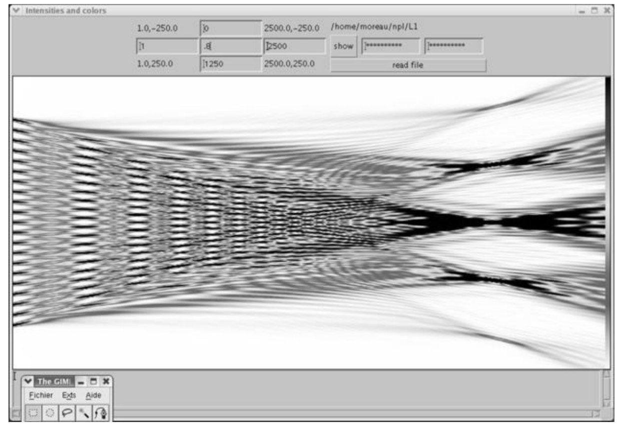

Figure 2: jBPM simulation, convergence of the beams according to the wavelength in the final star-coupler of an AWG.

mixed together. At the other end correlators are capable to extract each message because of the mathematical properties of the codes.

The jCDMA applet is a didactic approach of the principles of CDMA. By choosing a spreading sequence among the most commonly used (Hadamar-Walsh, m-sequence, gold codes…), one can create several transmitters owning each a specific code and simulate the coding and the decoding operations in CDMA. Simulations are relevant for Direct-Sequence CDMA (the code is a pseudo-random sequence of bits called “chips” at a higher rate than message bits) and spectral CDMA (the code is a spectrum) , and is not dedicated to optical transmissions only. jCDMA can handle codes defined as spectra (set of amplitude peaks for specific wavelengths). We designed an Optical CDMA system based on optical devices to generate such spectra.

For Direct-Sequence CDMA, the applet shows the signal generated with all the mixed chips, its frequency distribution and its spectrum: as long as the number of users increases, the signal should resemble a white Gaussian noise according to theory, in the used frequency band. The amplitude distribution is shown to be Gaussian soon, while the white spectrum needs a consequent number of users.

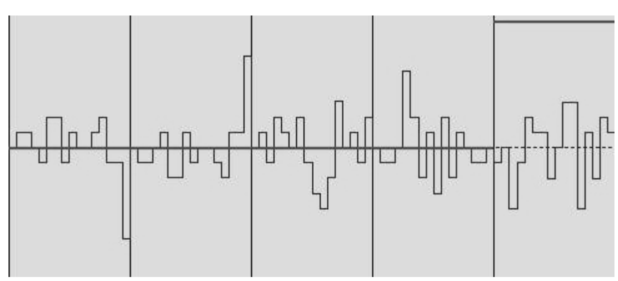

Figure 3: jCDMA simulation, signal generated with 16 users.

5 SIMULATION OF A SPECTRAL AMPLITUDE CODING CDMA

The three applets considered earlier constitute a design flow available for our Spectral Amplitude Coding CDMA (SAC-CDMA).

In the optical spectral CDMA [6], each user sends a signal with a specific spectrum (the code) for the “1” or the complementary spectrum for a “0”. The advantage of this solution is its possible use with low cost emitting source (like super LED), it does not require a synchronization between the users, also it can feed along with the signal all the wavelengths needed by the receiver to build an answer using the same medium.

Our device is based on the generation of codes (spectrum) with the use of an AWG. The spectrum is made by mixing half of the outputs to generate one spectrum and the other half to generate the complementary spectrum [7]. Figure 4 shows our version of a SAC-CDMA encoder.

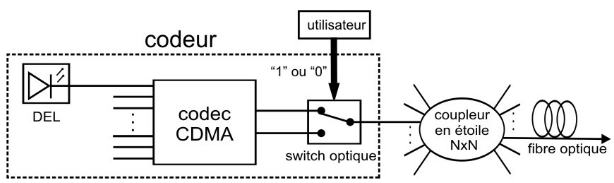

Figure 4: Coder of our SAC-CDMA system.

The bit of the user selects the spectrum (code to be sent). Changing the codes can be made by changing the input used thanks to the properties of the m-sequence codes we use, and of the cyclic property of distribution of light in the outputs of AWG.

This part is a circuit very similar to those used for conventional WDMA. The performance is evaluated with jWDM and jBPM (component simulation).Once the spectra are known, it can feed the system simulation (jCDMA) in order to take into account the particularity of the spectrum codes. Figure 5 shows the simulation blocks for CDMA analysis of performance.

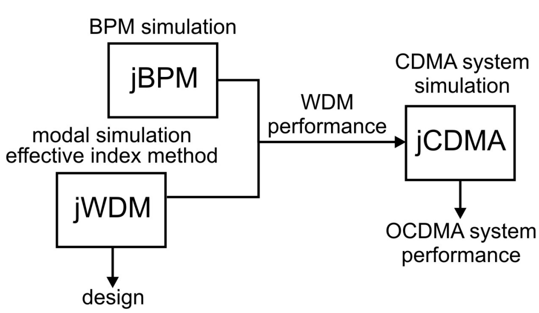

Figure 5: Software conception flow of SAC-CDMA

The receiver is based of similar WDM devices, the outputs are also mixed half by half. Each half feeds a photodiode. Because of the properties of the codes, all the codes but one (the one of the user to be decoded) feed both photodiodes so that the balanced photodiodes receive the same amount. The tuned code on the other hand feeds only one of the two photodiodes.

Figure 6 shows the differential photocurrent evaluated after a simulation of 7 transmitters using a code with 7 available wavelengths. In this case, the spectrum “1” of a user is created by summing 4 Gaussian-like profiles centered on a particular wavelength, whereas the spectrum “0” is created starting from the three remaining wavelengths. All the 7 codes are generated similarly, in accordance with a 7 symbols m-sequence. Space between wavelength rays and width of the ray is 1 nm (the spectrum simulation allows the definition of ray of gaussian shape with adjustable amplitude and width). The detection threshold has to be clearly taken between the values for a “1” or a “0” to be detected. The curves are clearly separate for a linewidth less than 3 nm. Beyond this value, the detection is no more possible. In our case, 3 nm corresponds to a bit rate around 25 GHz.

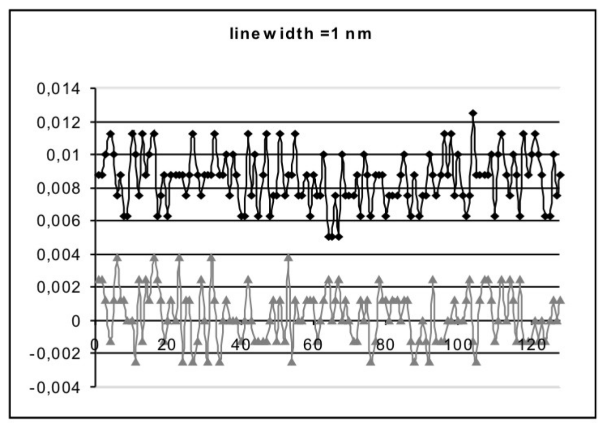

Figure 6: Photocurrent on the balanced receiver for 7 users and linewidth of 1 nm for each wavelength. The upper curve corresponds to a “1”, the lower curve to “0”. The threshold can be simply defined.

It is also possible to feed this simulation with output files from a BPM simulation of our coder and even with results from the characterization of a real component.

CONCLUSION

The package described here covers optical components as well as system simulation. Optical simulations are shown here to be valid for AWG, but they can be used for many other optical circuits. The system simulation covers a large field of CDMA systems, even if it is applied here as a tool for a Spectral Amplitude Coding CDMA designed in the laboratory. The overall system allows evaluation of up to the bit rate based on realistic components. Let us mention also that part of these simulations are available directly (without install) on the internet (Java applets), with all the operating systems. Also they are fast with user-friendly interfaces based on common concepts like windows, menus, dialogs, but they integrate also scripting facilities for routine simulations with varying parameters.

REFERENCES

[1] Y.Moreau, G. Pille and J. Galy, "Guides optiques à section transversale quelconque : un calcul scalaire et vectoriel en ligne", Proc. JNMO 2004, pp. 161-162, La Grande Motte, France (2004).

[2] Y. Moreau, P. Arguel, P. Coudray, J. Porque and P. Etienne, "Index modulation gratings directly imprinted on sol-gel layers", Proc.of International Conference SPIE, vol 3278, pp. 179, San Jose, USA (1998)

[3] J. C. Schatzman, "Writing High Performance Java Code Which Runs as Fast as Fortran, C or C++" Proc. SPIE, vol. 4521 p.106, Denver, USA (2001)

[4] `http://www.cem2.univ-montp2.fr/~moreau/jWDM`

[5] `http://www.cem2.univ-montp2.fr/~moreau/jBPM`

[6] D. Zaccarin and M. Kavehrad, "An optical CDMA system based on the spectral encoding of LED", IEEE Photonics Technology letters, 4(4), pp.479-482 (1993)

[7] G. Pille, Y. Moreau and J. Galy, "WDM PHASAR pour la génération de m-séquences dans un système OCDMA spectral", Proc. JNOG 2004, pp 176-178, Paris, France (2004).