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SUMMARY

This communication introduces the modelling of optical and optoelectronic components and the simulation of optical circuits and links using a Computer aided design (CAD) tool. A specific library describing several optical components and devices has been established and integrated as User-Defined-Models into the simulator. Then, the simulation facilities of our tool are used to study an integrated optical circuit: an integrated interferometer sensor.

KEYWORD

Optical circuit, simulation tool, modelling, S-matrix.

ABSTRACT

INTRODUCTION

The optical technologies based on the use of optical fibres and integrated optic/optoelectronic devices are a fast growing field. 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 for the processing of high-speed signals. Nowadays, the technology allows more and more complex applications using a large number of components integrated on the same substrate or connected by optical link.
At the origin, the optical fibres have been used for long distance transmission thanks to their large bandwidth and low loss properties. The transmitted signals were simply intensity modulated lasers and direct or envelope detection were used for the regeneration and the reception. To achieve such a solution the engineers have to optimize a limited number of independent parameters.
Today, multiplexed architectures TDM, WDM and OCDM have replaced the original simple transmission for increase the capability of communication. The architecture of the transmission networks includes large numbers of new elements like optical filters or other optical devices. Due to this complexity, the number of parameters to be optimized by the designers becomes large and generally, they are not independent. Concerning the integrated devices they were developed at the origin to be compatible with optical fibres in order to replace classical optical elements. The technological advances allow today the design and the realization of full optical function on the same substrate [1].
So, for both optical links and integrated optical circuits, design and simulation tools are needed in order to improve the characteristics, to optimize the performances and more generally to simplify the definition and the realization of optical applications.

DIFFERENT FAMILY OF SIMULATOR

The proliferation of optical communications has created a need for efficient and accurate CAD tools for the design of optical and optoelectronic (fibre-based or integrated) circuits and systems. In the electronic domain, highly advanced CAD tools exist for the design, analysis, and simulation of nearly every aspect of integration, ranging from process to component to circuit to system. The state of optoelectronic circuit and system design today parallels that of the electronic domain over a decade. As in the early days of electronic design, optoelectronic circuit and subsystem design, as well as system integration tends to take place in a trial-and-error

manner. Now, in electronic circuit and system design, CAD tools are used to reduce the design cycle and the number of required iterations. So like in the electronic domain, the optoelectronic domain need efficient and accurate CAD tools.
The simulation of optical and optoelectronic devices can be performed at various stages of integration [2]. In fact, in general, a system is composed by many circuits, a circuit is composed by many devices and a device is composed by many layers constituting its structure. This is shown figure 1.
For doing this, different tools exist:

- Oriented device,
- Oriented circuit,
- Oriented system.

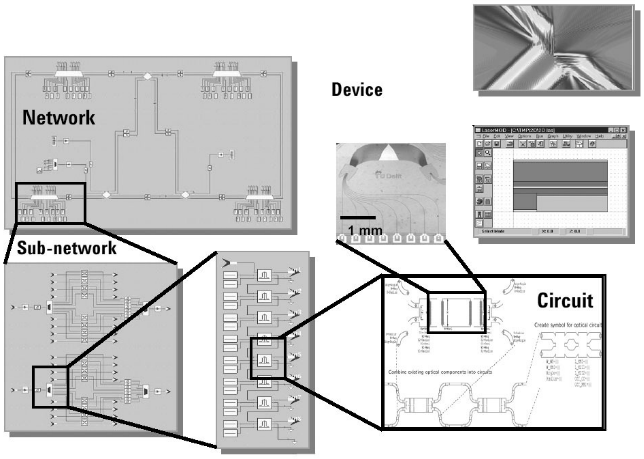

Fig. 1 DIFFERENT LEVEL OF SIMULATION

At the device level, the component electromagnetic equations (Maxwell) are solved for a given set of materials, device geometries, index profiles, everywhere on the component. This kind of simulation is not adapted for a circuit and less for a system simulation.
At the circuit level, the simulation is based on the electrical model. This model uses the electrical characteristic of a component like reflection and transmission coefficient. In the electrical domain, and most particularly in microwave domain, the concept of S-Matrix (Scattering matrix) is used for it. This kind of simulator takes into account the reflection and transmission parameters on each access of the component, and so permits designer to study the interference phenomena.
At the system level, the simulation is based on the behavioural model. In fact, this kind of simulator uses the transfer function of each component or sub-circuit to calculate a global transfer function of the simulate system. This kind of simulator is the fastest but it is probably the less efficient because it is not take into account the interference phenomena due to the unidirectionality of the system model.
Like in electrical domain, each kind of simulator had a place. But at this time, just the device and the system simulator had been developed. Our work is so to develop the alternative level call circuit level for the optic and optoelectronic system.

MODELLING PRINCIPLE

At the circuit level, we have seen in previous paper [3] that the model is based on the S-matrix of the device. Here, we regard the device as black box, isolated from the rest of the system except for a few designated ports that are accessible for external connection. For circuit analysis purpose, a component is completely characterized by the relations between the signals at these ports called scattering parameters. These parameters make up the S-matrix. However, due to the fact that in the optical waveguides there are two guided modes (represented by Jones vectors [4]), each physical port of an optical component is actually equivalent to two strictly single-mode ports. Consider the situation described in figure.2. It's an N-port optical component.

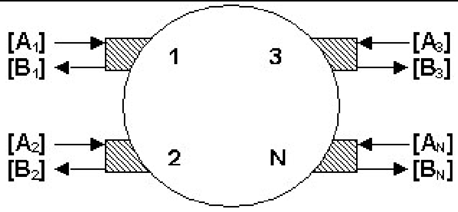

Fig. 2 A SCHEME OF AN N-PORT COMPONENT

The Jones vectors $\vec{A}_1, \vec{A}_2$, ..., $\vec{A}_N$ are incident upon an N-port component, so that $\vec{A}_k$ is the Jones vector incident upon port k. These Jones vectors give rise to another set of Jones $\vec{B}_1, \vec{B}_2$, ..., $\vec{B}_N$, so that $\vec{B}_k$ emerges from the port k. We should use two vectors $\vec{A}$ and $\vec{B}$ held the different vector $\vec{A}_k$ and $\vec{B}_k$. Or each vector $\vec{A}_k$ and $\vec{B}_k$ is a two components vectors. So the dimension of $\vec{A}$ and $\vec{B}$ is 2N. So for a time independent, linear component, the vectors $\vec{A}$ and $\vec{B}$ are related by:

$$\vec{B} = S \times \vec{A} + \vec{C}$$

Where S is a complex $2n \times 2n$ matrix and $\vec{C}$ is a complex 2n elements vector both independent of $\vec{A}$. The matrix S is called the scattering matrix of the component and $\vec{C}$ represent the different outer source in the component.
This relation may be regarded as a general definition of the S-matrix S of an N-port optical component.

CIRCUIT SIMULATION: APPLICATION TO DISTANCE SENSOR INTERFEROMETER

Once the models of each basic device are described in our CAD software, we can simulate any circuits based on these components. As an example, let us consider the circuit represented figure.3. This circuit represent a distance sensor interferometer integrated on glass.

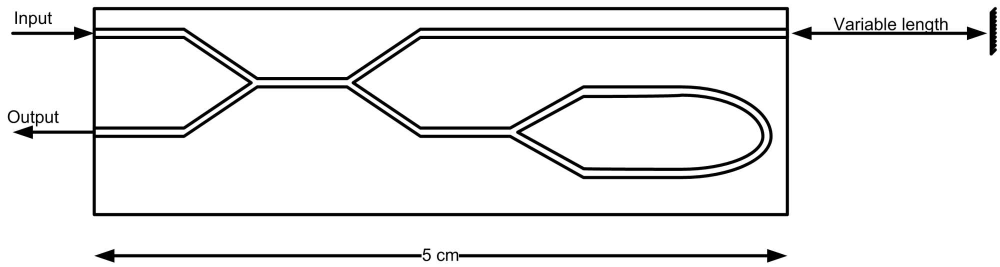

Fig. 3 SCHEMATIC VIEW OF INTEGRATED INTERFEROMETER DISTANCE SENSOR

Some models, dedicated to integrated optic device diffused on glass had been developed. To do this, a tool based on WKB's method had been realized [5][6]. This tool, shown figure.4, determine the effective index of our guide for each mode.

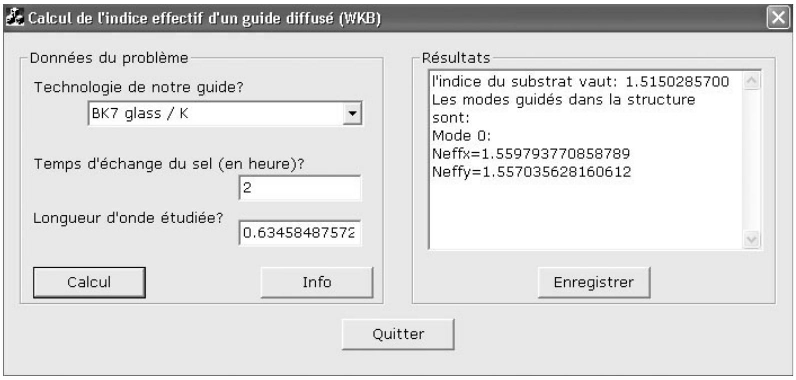

Fig. 4 EFFECTIVE INDEX CALCULATION TOOL

In this circuit, the light coming from the laser is coupled into the optical device using single-mode fibre by the input arm. Then the signal is divided into two arms: the reference and the sensing ones by Y-junction. The reference mirror is simply a loop waveguide. The loop's Y-junction splits the beam into two equal parts which propagate in opposite directions. Then the light is collimated to the out of the sensing waveguide onto the moving reflecting mirror. After reflection, the beam is focussed and coupled into the waveguide. The reference and the sensing beams are combined by another Y-junction and interfere together at the sensor's output waveguide.
The representation on our CAD tools and the simulation responses of this circuit, for different length between sensor and moving mirror (5cm, 10cm and 25cm) are represented figure.5.

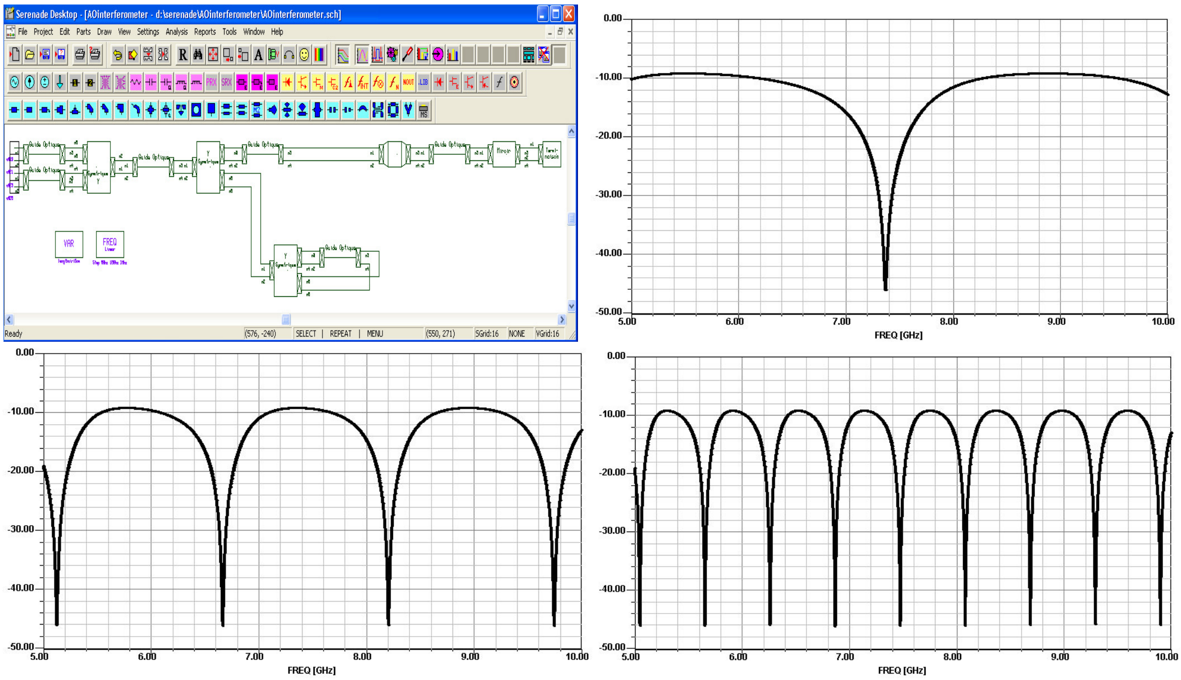

Fig. 5 REPRESENTATION AND FREQUENCY RESPONSES OF STUDIED CIRCUIT DIFFERENT LENGTH OF AIR GAP BETWEEN SENSOR AND MOVING MIRROR (5 CM, 10 CM AND 25CM)

We saw on these results some frequency rejection with particular step function of the length of air gap between the sensor and the moving mirror. So with the step measure, we should deduce the distance between sensor and the mirror. The simulation delay for this circuit is less than 10s on a P4-1.6GHz.

CONCLUSION

In this study, after having briefly presented the various types of optical simulators, and presented the modelling principle, we shown a simulation example used our model. The example application is an integrated interferometer distance sensor. On this example, we saw different frequency responses corresponding to different length of the air gap between the sensor and the moving mirror. The simulation length corresponding to this application is less than 10s. This shown the usefulness of this type of simulator to simulate some optical circuit.

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