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From TEM pulse switching to computing with light

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Abstract

Exploiting light-matter interactions for computing has become a new paradigm in this field for efficient and high-speed computing systems. In this communication we will present an overview of our recent and ongoing efforts in exploiting electromagnetic waves for computing processes.

1. Introduction

The introduction of semiconductor-based switching elements was key for the development of the field of computing as we know it. A fundamental example in this context is the MOS-FET (metal oxide field-effect transistor) which became the pilar to create the logic gates and then opened new avenues in the development of digital electronics. However, while such switching devices for computing are used worldwide, there is a challenge in terms of speed of computations and in energy consumption when using a large amount of these elements[1].

In this context, there is a growing interest in creating new paradigms for routing and switching of signals as they are fundamental processes in computing. In recent years different approaches for computing have been proposed and demonstrated in different research fields including quantum computing[2], solitons[3] and beam splitting for optical networks[4]. Additionally, metamaterials and metasurfaces (artificially engineered structures that enable the manipulation of electromagnetic waves both in space and time [5]–[12]) have also been implemented in the field of computing with some ground-breaking examples for analogue computing[13]–[15].

Motivated by the infinite opportunities that the manipulation of light-matter interactions can offer and the need of new paradigms for future computing technologies, in this invited talk we will present the different efforts we are carrying out in our group exploiting electromagnetic waves for computing. We will present our ongoing research in switching and routing of transverse electromagnetic (TEM) pulses[16], [17] showing how this technique can also be exploited for decision making processes (such as *if…then…else*) and potential logic gate designs[18]. Additionally, we will discuss how such switching processes can be efficiently modelled using graphical modelling techniques such as Petri-nets[19] (an important modelling technique used in different areas such as in industrial engineering, asynchronous circuit designs and chemical engineering, to name a few). Finally, we will discuss our ongoing studies for analogue computing to calculate the first and second order derivatives of temporal signals using arrays of transmission lines (TLs) along with neural network techniques[20].

2. Results and discussion

2.1 TEM pulse switching and routing

One of the fundamental processes for computing is the switching and routing of signals within a network. Here we will show how interconnected parallel plate waveguides as TLs[21] can be exploited to achieve such processes. We will discuss how multiple incident pulses from different ports can be redirected to a desired TL output when properly engineering both the polarities of the pulses (+/-) and the number of interconnected TLs in the network [16], [17](see example in Figure 1).

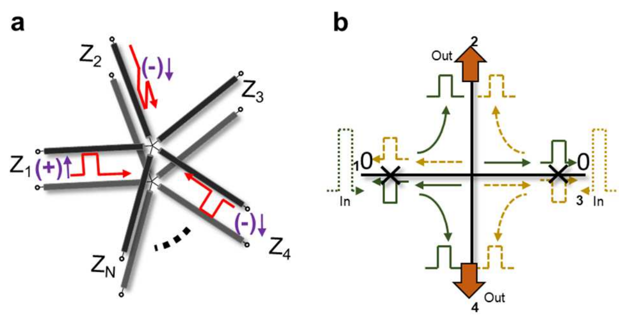

Figure 1. (a) schematic representation of *N* interconntected transmission lines in series and (b) schematic representation of the interaction of two square pulses of different polarities excited from ports 1 and 3 within a 4-interconnected transmission lines in a parallel configuration.

2.2 Amplitude controlled switching: decision making processes with light

It will be presented how TEM square pulses traveling within interconnected TLs in series or parallel configurations, as those from section 2.1, can be used for decision making processes (such as *if… then… else*) when both the amplitude and polarity of the TEM pulses are correctly engineered. Applications such as a *comparator* between two numbers and pulse *director* will be discussed[18].

2.3 Petri-nets and TEM pulse switching

Petri-nets are a graphical modeling technique used in areas such as circuit design and industrial processes, among others. Here we will introduce our recent works in modelling TEM pulse switching in interconnected TLs (as in sections 2.1-2.2) using such graphical modelling technique. In this context, this is a fundamental step towards enabling experts from multiple research fields to interact and share their knowledge in the design of future computing systems using electromagnetic waves[19].

2.4 Derivatives with electromagnetic wave-based structures

We will discuss our ongoing efforts exploiting TL concepts along with multilayered structures and Neural Networks to achieve the derivative of incident sinusoidally-modulated temporal signals[20].

During the conference we will discuss in detail our recent and ongoing findings and we will propose potential future research avenues of each of these studies.

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