CHAPTER 1
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1.0 INTRODUCTION

Electrical systems are extensively used because of their propagation characteristics and availability of versatile devices and systems. Optical communication, computing, storage, control and signal processing are becoming more and more popular because of their immunity from electromagnetic interference, speed of operation, reduced cross talk, and higher isolation. But still the electronic communication, computing and processing continues to have its value and perhaps cannot be completely replaced by optical systems. As the frequencies of electrical signals are increasing, the gap between electrical frequencies and optical frequencies is coming down. Today electrical signals are getting into near infrared regions and optical signals are also overlapping with the electrical signals in the infrared regions. There is also a considerable effort put in, to control optical signals with electrical stimuli, and electrical signals with optical stimuli. The coexistence of optical and electrical/electronic systems is quite common and well known in the modern communication, computer and instrumentation systems because of the advantages of each system over the other. As a result, optics will be used together with electronics in a complementary manner, rather than replacing electronics. Thus, treating these two disciplines as one domain seems to be the need of the day.

1.1 RELEVANCE OF THE TOPIC AND APPLICATION AREAS

Coming to specific systems that exist, it is well known that electrical communication and optical communication are used together extensively. Optical fibers are commonly used to transmit telephone conversations and computer data from place to place. In the present optical communication systems, though the transmission is optical, but regeneration, amplification and modulation are largely electrical [1-6]. Also in optical networking, most signal processing operations, such as
switching and routing, are still performed electronically after optoelectronic (OE) conversion [7].

Communication within computing systems, has become increasingly important as the electrical interconnections connecting the components of large computers to each other have become the key factor limiting the power and speed of such systems. In silicon integrated circuit technology, electrical interconnects restrict the performance of systems even when data has to flow on and off chips or on and off boards. This is a consequence of the electrical resistance and other undesirable qualities of materials such as copper and aluminum widely used for wires. Electrical resistance and capacitance degrade the performance of electrical interconnections and slow them down. Electrical interconnections also consume more space and energy as system size increases, compared to optical interconnections. They also exhibit cross talk and due to the possibility of short-circuiting, routing of electrical interconnections is more difficult. In short, electrical interconnections consume more space and energy and contribute more delays than the devices.

For these reasons, many research groups started working on the concept of optical interconnects and optically interconnected electronic computer [8-15], where the nonlinear operations are realized by electronic transistors or logic gates, and the interconnections among these are realized optically. Such systems, also referred to as optoelectronic computers, are thought to allow optics and electronics to complement each others strengths and make up for each others weaknesses. It is important to note that, in discussing interconnects, optics is not competing against silicon, but against copper and aluminum. Optics is not trying to replace the highly successful silicon technology, which enables us to make systems of a complexity well beyond that of any other technology. The optical interconnects are used for augmenting the capabilities of silicon rather than competing with them. It is expected to
see commercial-level optical interconnect technology at the board-to-
board level and at the chip-to-chip level.

There are gadgets in the market, in which optical sensing and
electrical processing is carried out concurrently. The coexistence of optical
and electrical/electronic systems is quite common in modern gadgets like
digital cameras, scanners, optical disc readers etc.,. Thus, it may be seen
that more and more devices, circuits and gadgets which involve both
electrical and optical processes are becoming popular.

From the above discussion, it is very clear that growth of future
electronics will be around using optical and electrical systems in
conjunction to each other to obtain the best of the two worlds from the
point of faster operations, higher frequency consideration and even low
power requirements. Therefore, it is felt that there is a need for developing
the concepts, devices, circuits and systems, which can easily take signals,
either in the electrical form or/and optical form and process them
through the most efficient media (electrical or optical or both).

These hybrid circuits are of great importance, where electrical and
optical systems have to coexist namely, computing, communication,
instrumentation and control systems. One direct application of these
circuits is in developing hybrid memories where information can be stored
or accessed by both optical and electrical means. Any further expansion
of this hybrid concept for applications without really developing them is
not scientific.

Keeping the above discussion in mind, logic circuits have been
visualized which can take electrical or optical signals at the input and
produce electrical and optical signals at the output. These circuits are
named as hybrid circuits [16] by the authors who carried out a piece of
work on “Optically/Electrically (Symmetrically) Triggerable Bistable
Multivibrator”. Once these circuits and efficient devices for these circuits
are developed, it is felt that a system which can handle electrical or/and
optical signals can be visualized cutting down the barrier between these two disciplines.

1.2 FORMULATION OF THE PROBLEM

The functions that are normally encountered in communication, computing and control are generally described as digital functions, analog functions and mixed signal functions, which have a flavor of both digital as well as analog disciplines. The digital functions are generally classified as combinatorial circuits and sequential circuits. Even the sequential circuits are realized using combinatorial circuits known as logic gates. Thus, logic gates become the basic blocks for any digital system. Therefore, an attempt has been made to visualize, synthesize and characterize hybrid logic gates and hybrid sequential circuits. The description of the effort put in this direction is the subject matter of the thesis.

1.3 APPROACH TO SOLVE THE PROBLEM

One of the basic and simplest well known logic gate is the inverter and therefore a hybrid inverter has been conceived and developed to a level which could be used in cascadable circuits. After gaining confidence through the realization of this circuit, other hybrid logic gates like, NAND, NOR, AND, OR, EX-OR which could be instantiated for developing larger systems have been realized. All these hybrid logic circuits are based on optoelectronic components which respond to both electrical and optical quantities. Using hybrid logic gates as basic building blocks, several hybrid combinatorial and sequential circuits have been constructed and demonstrated which can take electrical and/or optical signals and produce both electrical and optical signals. Further the possibility of developing a new integrated optoelectronic component (light emitting hybrid phototransistor) has been visualized and discussed.

1.4 WORK CARRIED OUT IN THE THESIS

The thesis started with the description of the basic concepts of physics and electronics which are needed to visualize these hybrid
circuits. Thereafter, relevant information available in literature have been reviewed which is very close to the goals of the thesis. Later, the work connected with visualizing and demonstrating the principles of operation of hybrid logic gates and sequential circuits is given.

In the first instance, the basic logic gate namely inverter in the hybrid form has been thought of and the working of this circuit has been demonstrated by constructing this circuit and carrying out the measurements. This inverter consists of electrical transistors, phototransistors and LED’s. The LED serves as a source as well as light output devices. The phototransistors work as input active devices, which respond to both electrical and optical input signals. The conventional transistor is used as current source for the inverter. The inverter is designed in such a way that input logic levels (both electrical and optical logic levels) are the same as the output logic levels (light output from LED and electrical output across LED and resistor). This feature enables cascadability of inverters.

Even though the hybrid circuits have been developed using phototransistors, other photo sensitive three terminal devices like photo FET’s may be used. However it may be noted that photo transistors are more sensitive to light and easily available components.

The concept behind the inverter has been extended to realize hybrid NAND and NOR circuits. These circuits have been developed using well known concepts like connecting two input phototransistors in series for NAND operation and two input phototransistors in parallel for NOR operation. It has been demonstrated that it is possible to design these circuits which are cascadable. These basic hybrid logic blocks have been used in building hierarchical hybrid circuits. Implementation of higher level cascadable hybrid combinational logic circuits such as half adder, full adder and 4-bit adder have also been discussed and demonstrated.
Another important hybrid block is a memory element or a latch. The basic hybrid RS latch has been realized by cross coupling two hybrid NOR gates or hybrid NAND gates and the coupling can be either electrical or optical in nature. Later, these basic hybrid RS latches have been used in implementing other latches like, hybrid JK flip flop, master slave hybrid JK flip flop and hybrid D latch. It has been conclusively demonstrated that the sequential hybrid elements can be synthesized. The performance characteristics of these hybrid logic circuits have also been carried out to estimate the performance parameters like noise margins, propagation delays, rise time, fall time and minimum pulse width that can be applied to these circuits. Using these basic hybrid sequential building blocks, one can develop hybrid sequential systems like memories, shift registers, counters etc., in future.

1.5 ORGANISATION OF THE THESIS

The thesis is presented in 7 chapters. Organization of each chapter is given in the following.

**Chapter 1** of the thesis deals with a brief introduction explaining the relevance of the topic, formulation of the problem, approach to solve the problem and work carried out in the thesis.

**Chapter 2** is devoted to describe the relevant principles of optoelectronic p-n junction devices that are used in the realization of electro-optical hybrid logic circuits. They include light sources like Light Emitting Diodes (LED's), three terminal light detectors like phototransistors and optocouplers.

**Chapter 3** gives review of the literature carried out in the domain of optical logic gates and optical bistable devices and circuits. In the first instance, optical logic gates have been reviewed. In the end, an account of optical bistable devices and circuits are discussed.
Chapter 4 describe the electro-optical hybrid logic gates, principle of operation of the hybrid logic gates, how they are implemented to meet the requirements of cascadable logic are given. The basic hybrid building blocks like, hybrid inverter, NAND, NOR, EX-OR, AND and OR logic gates have been discussed and demonstrated in this chapter. Details of the construction of hybrid logic gates along with the results obtained are presented in this chapter. It is further demonstrated that usable and large combinational circuits can be realized by implementing combinational hybrid circuits like, hybrid half adder, hybrid full adder and hybrid 4-bit adder. These combinational hybrid circuits have been implemented using hierarchical design procedure with OrCAD Capture simulation tool.

Chapter 5 is devoted to describe hybrid sequential circuits. This chapter first explores the feasibility of developing the hybrid RS latch using hybrid NOR gates and NAND gates. After gaining confidence through the realization of these basic sequential circuits, other latches and flip flops which could be instantiated for developing larger hierarchical sequential systems have been realized and demonstrated using OrCAD Capture circuit simulation tool.

Chapter 6 is devoted to describe the work carried out to study the performance characteristics of hybrid logic circuits. The initial discussion in this chapter focuses on estimation of the performance characteristics of hybrid inverter like tolerable electrical and optical logic levels, noise margins, propagation delays, rise time, fall time and minimum pulse width. Later, the performance characteristics of other hybrid logic gates, hybrid combinational and sequential circuits have been estimated and discussed.

Chapter 7 deals with conclusions and future scope. In conclusion, the results obtained in this thesis are summarized, and the scope of future work in this area is also discussed.