

Proposed Design for Optical Digital Circuits

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Abstract

Designing digital circuits has a high priority in research field in the present time; it shall also still the main concern of many researchers in the future. Many studies in this field are in progress some are published and other still confidential. This paper proposes a design for elementary digital circuits; NOT, OR, AND; using light as direct inputs. These circuits then process these optical inputs to produce optical outputs without changing the light rays to any other type of energy or wave. The proposed design depends on mirrors, lenses and properties of light to introduce new digital circuits design using infrared rays as its inputs.

Key words:

AND, Beam, Constructive Interference, Destructive Interference, Interference field, Light, Lens, mirror, NOT, Optical Digital Circuits, OR, Rays, Reflection, Refraction, Timing Analysis, Wave.

1. Introduction

Light is an amazing phenomena, in dark ages it was the only way for far communication. First, fire signals were used to send messages. Then it was used for sending signals to identify coast for ships and military signals by using lenses, mirrors and big light lamps.

Until discovery of electricity, light was the only way to transmit signals. Many studies were introduced in this field in 17th and 18th century to determine light speed, properties and components.

Light is a complicated phenomenon: in some cases, it behaves like an electromagnetic wave, but in others, it behaves like a stream of special particles (photons). The energy of a photon is equal to $n\omega$ where n Plank's constant divided by 2π and ω is the cyclic frequency of the radiation. [1,2]

Although light is recently used for optical transmission on networks by using fiber optics laser beams, infrared and ultra violet for fast transmission on networks[2] .But processing of the received optical data still depends on converting these optical inputs to electrical signals and converting electrical outputs (after processing) to optical for retransmission [10]. This makes a bottleneck for retransmission of data and video and audio signals, which leads to a delay and lost of information.

In this paper, designs for elementary digital circuits; NOT, OR, AND; using light as direct inputs was introduced. These circuits process these optical inputs to produce optical outputs without the need to change the light rays to any other type of energy or wave. The proposed design depends on mirrors, lenses and properties of light to introduce new digital circuits design using infrared rays as its inputs.

This rest of this paper is organized as follow. In section 2, a recent study in this field is introduced. Section 3 illustrates the proposed optical digital circuits design together with their operation. Timing analysis of the circuits and synchronization condition is introduced in section 4. Finally, conclusion and future trends are discussed in section 5.

2. Recent studies

Many researches are in progress in the field of optical circuits, especially in digital circuit design. NASA has started a project for inventing high-speed optical digital circuits. Its researcher publish an AND circuit operates by using laser beams in [8], figure (1) shows this circuit. NEC, Pentagon and many other organizations are working confidentially on similar projects.

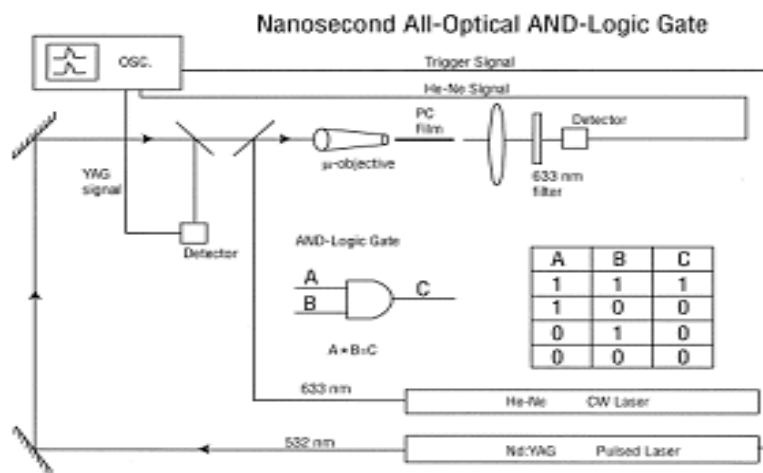


Figure 1- Structure of optical AND circuit NASA project[8]

3. Proposed Circuits Design

In this section we will describe the internal design and operation of the proposed optical digital circuits NOT, OR and AND circuits.

3.1 NOT circuit

The proposed NOT circuit design depends on two facts: First, according to reflection law of light from a flat mirror, the reflected angle of a ray is equal to the incident angle [1]. Second, a beam can be a destructive beam if its frequency is shifted by π of the interfering beam (See appendix). [1,2]

As shown in figure 2, we have two beams b_1 and b_2 . b_1 enables the circuit, it always has the logical value 1 while b_2 holds the input values. When b_2 dropped on a high polished flat mirror m_1 , m_1 reflects the beam b_2' which have the opposite angle and shifted frequency of b_2 . A lens L is used to gather the parallel beams b_1 and b_2' at its focal where they interfere together (destructive interference). The resulted value is taken at a minimum point of the interference field.

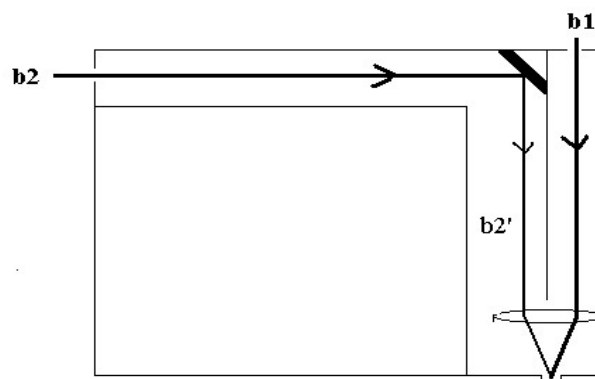


Figure 2 - Structure of the proposed optical NOT circuit

NOT operation verification:

The NOT circuit has two inputs:

- ◆ One enabled b_1 , always equal to logic 1 in order to produce logical one as output when b_2 equal to logical 0.
- ◆ One data input b_2 , which has two cases:
 - 1- $b_2 =$ logical 0: In this case, no interfering will happened, so b_1 will pass through the lens L with a value of logic 1 at L focus.
 - 2- $b_2 =$ logical 1:
 - According to distance from input port to the mirror, the phase of b_2 will be shifted by π .

- When b_2 falls on the mirror, it will reflect b_2 as b_2' towards the lens.
- The lens L gathers b_1 and b_2' at its focus, where they interfere together in a destructive interference [1], in this case the distance between interference fringes can be recognized. So we can find more than one minimum point of the interference field (dark parts) at which we can get value of logic 0.

b_2	b_1	b_2'	Interference between b_1, b_2'	Output
0	1	0	Null	1
1	1	Value = 1, phase shifted by π	<i>Destructive interference</i> [2]	0

Table 1. NOT circuit behavior

3.2 OR circuit

The proposed OR circuit uses reflection and refraction laws [2]. The circuit is shown in figure 3, it consists of three mirrors m_1 , m_2 and m_3 . m_1 and m_2 are 90% polished flat mirror while m_3 is a 70% polished concave mirror. m_1 reflects beam b_1 near the center of m_3 as b_1' , m_2 reflects b_2 near the center of m_3 as b_2' . The mirror m_3 reflects b_1' and b_2' as b_3 .

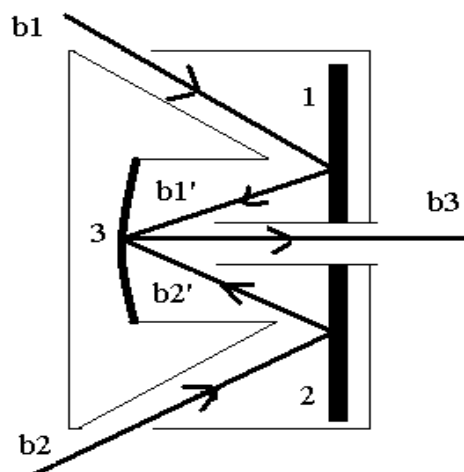


Figure 3 - Structure of the proposed optical OR circuit

The following scenario is followed in case of logical 1 input beam:

- Approximately 10% (transparency of the mirror = 10%, so 10% of the incident ray will pass through the mirror) of the beam is refracted through its corresponding mirror and lost is lost.
- The corresponding mirror about 90% (polishing ratio of the mirror surface equal to 90%, so 90% of the incident ray will be reflected from the mirror surface) of the incident beam towards the concave mirror m_3 as a new beam, and near to center of m_3 .
- The mirror m_3 refracts about 30% (transparency of the mirror = 30%,) and reflects 70% ((polishing ratio of the mirror surface equal to 70%) of the new beam, so the final beam b_3 obtain about 63% (illumination of b_1' , b_2' about 90% of b_1 and b_2 , so total illumination of $b_3 = .9 * .7 = 63%$) of the original beam. Therefore, we can recognize illumination at the output port, which gives value of logic 1.

OR operation verification:

The OR circuit has two inputs b_1 and b_2 , so its truth table has four cases:

1- $b_1=b_2=$ logical 0: Of course, no illumination at the output exists and $b_3 = 0$.

2- $b_1=$ logical 0 and $b_2=$ logical 1:

- The beam b_2 fills on the appropriate flat mirror m_2 .
- Approximately 10% of b_2 is refracted through the mirror m_2 and lost.
- The flat mirror m_2 reflects about 90% of the incident beam b_2 towards the concave mirror m_3 as b_2' , and near to center of m_3 .

- The mirror m_3 refracts about 30% and reflects 70% of the incident beam b_2' , so the final beam b_3 obtain about 63% of original beam b_2 . Therefore, we can recognize illumination at the output port, which gives value of logic 1.

3- b_1 =logical 1 and b_2 = logical 0:

- The beam b_1 fills on the appropriate flat mirror m_1 .
- Approximately 10% of b_1 is refracted through the mirror m_1 and lost.
- The flat mirror m_1 reflects about 90% of the incident beam b_1 towards the concave mirror m_3 as b_1' , and near to center of m_3 .
- The mirror m_3 refracts about 30% and reflects 70% of the incident beam b_1' , so the final beam b_3 obtain about 63% of original beam b_1 . Therefore, we can recognize illumination at the output port, which gives value of logic 1.

4- b_1 =logical 1 and b_2 = logical 1:

- The beams b_2 and b_1 acts exactly as mentioned in 2 and 3 respectively.
- Therefore, the mirror m_3 refracts about 30% and reflects 70% of both incident beams b_1' and b_2' . So the final beam b_3 have about 126% (illumination of b_1' = illumination of b_2' = 90%, illumination of b_3 = 70% of $b_1'+b_2'$ = $70% * (2*90%)$) of original beam b_1 or b_2 where we can recognize illumination at the output port, which gives value of logic 1.

b_2	b_1	b_1' after reflection from m_1	b_2' after reflection from m_2	Output (b_3)
0	0	0	0	0
0	1	illumination=90% of b_1 shifted phase by π	0	illumination = $0.9*0.7 = 63\%$ of b_1 same phase as b_1 , value =1
1	0	0	illumination=90%of b_2 shifted phase by π	illumination = $0.9*0.7 = 63\%$ of b_2 same phase as b_2 , value =1
1	1	illumination=90% of b_1 shifted phase by π	illumination=90%of b_2 shifted phase by π	illumination= $(0.9*0.7)*2=126\%$ of b_1 or b_2 same phase as b_1 and b_2 , value =1

Table 2. OR circuit behavior

3.3 AND circuit

The proposed AND circuit uses reflection and interference laws [2]. The shown circuit in figure 4 has 2 inputs beam b_1 and b_2 . Those inputs are shifted then reflected by two high polished mirrors m_1 and m_2 , as b_1' and b_2' respectively. Three Lens are used, L_1 , L_2 and L_3 . L_1 gathers b_1 and b_2' as b_3 . L_2 gathers b_2 and b_1' as b_4 . L_3 gathers b_3 and b_4 as the output of the circuit. The resulted value is taken near a minimum point of the interference field figure (4).

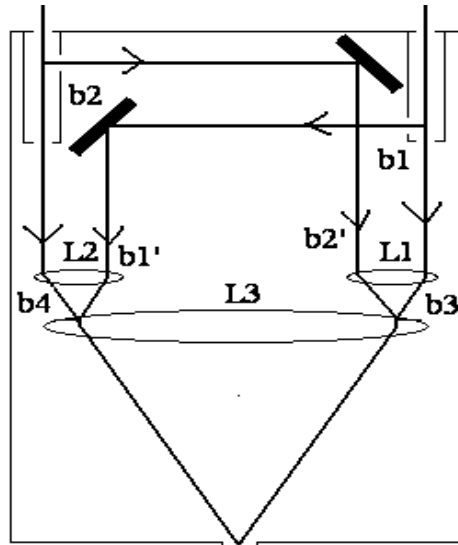


Figure 4 - Structure of the proposed optical AND circuit

The following scenario is followed in case of logical 1 input beam:

- Its phase will be shifted by π (to produce destructive interference) and then reflected from its corresponding flat mirror m_i towards its corresponding lens as a new beam'.
- The original beam moves directly to its corresponding lens and passes through its focus.
- The new beam passes through the focus of the other lens.
- L_3 gather the two beams at its focus, where they interfere together (destructive interference to ensure that the illumination of the output does not exceed the value of logical 1).

AND operation verification:

The AND circuit has two inputs b_1 and b_2 , so its truth table has four cases:

- 1- $b_1=b_2=$ logical 0: Of course, no illumination at the output exists at the output port and the resulting value =0.

2- $b_1 = \text{logical } 0$ and $b_2 = \text{logical } 1$:

- The phase of b_2 will be shifted by π and then reflected from the flat mirror m_1 towards the lens L_1 as b_2' .
- The original beam b_2 moves directly to the lens L_2 and passes through its focus as b_3 .
- b_2' passes through the focus of L_1 as b_4 .
- L_3 gather the two beams b_3 and b_4 at its focus, where they interfere together (destructive interference). Therefore, an illumination isn't recognized so the resulting value is logical 0.

3- $b_1 = \text{logical } 1$ and $b_2 = \text{logical } 0$:

- The phase of b_1 will be shifted by π and then reflected from the flat mirror m_2 towards the lens L_2 as b_1' .
- The original beam b_1 moves directly to the lens L_1 and passes through its focus as b_3 .
- b_1' passes through the focus of L_2 as b_4 .
- L_3 gather the two beams b_3 and b_4 at its focus, where they interfere together (destructive interference). Therefore, an illumination isn't recognized so the resulting value is logical 0.

4- $b_1 = \text{logical } 1$ and $b_2 = \text{logical } 1$:

- As explained before, b_1 and b_2' (which has a value of b_2 and its phase is shifted by π) interfere together, at the focus of L_1 . Also, b_2 and b_1' (which has a value of b_1 and its phase is shifted by π), interfere together, at the focus of L_2 ,
- The two beams b_3 and b_4 are collected near a minimum point of the interference field with a value about 50% of the original beam and has the same phase.
- L_3 gather b_3 and b_4 at its focus where they interfere together with a constructive interference (they have the same phase) giving the output a value about 100% (final illumination equal approximately to the sum of the incident rays in constructive

interference, where $b_3 = b_4 = 50\%$ of the original beams) of the original beams, resulting a value of logical 1.

b_2	b_1	b_1'	b_2'	b_3	b_4	Output
0	0	0	0	0	0	0
0	1	value=1 shifted phase by π	0	value=1 same phase as b_1	value=1 shifted phase by π	value =0 <i>Destructive Interference</i>
1	0	0	value=1 shifted phase by π	value=1 shifted phase by π	value=1 same phase as b_2	value =0 <i>Destructive Interference</i>
1	1	value=1 shifted phase by π	value=1 shifted phase by π	<i>Destructive Interference</i> illumination = =50% same phase as b_1 or b_2	<i>Destructive Interference</i> illumination = =50% same phase as b_1 or b_2	value=1 <i>Constructive Interference</i> illumination = =100% same phase as b_1 and b_2

Table 2. AND circuit behavior

4. Timing analysis of the circuits

Circuits timing depends on the longest path that beam travel through, so that if we want to reduce this time we must reduce these paths as possible.

The longest path of the NOT circuit is b_2b_2' . For the OR circuit, the longest paths are either $b_1b_1'b_3$ or $b_2b_2'b_3$. For the AND circuit, the longest path is either $b_1b_1'b_4$ or $b_2b_2'b_3$. To make these circuits work at $1\mu\text{s}$ these paths must be less than $(3 \times 10^8)/10^9 = 30\text{cm}$ (See appendix).

On the other hand, external interference may affect the operation of the circuits and cause undesired results, to prevent external interference (which will lead to wrong results), we must shield these circuits with black external cover.

5. Conclusion and Future Trends

In this paper, a new design for elementary optical digital circuits (NOT, OR, AND) using infrared rays was proposed. Functions of these circuits were proved theoretically. As future trend, we shall test these circuits practically. In addition, we shall study the effect of combination of these circuits when used in large-scale circuits, since they may need to be enhanced

Appendix

The following constants and properties are used in the paper:

Constants:

Light speed = 2.997×10^8 m/s [1,2].

Infrared wavelength $\geq 0.76 \mu\text{m}$ [1,2].

Visible light wavelength range (0.40 – 0.76) μm [1,2].

Frequencies of Visible light = $(0.39-0.75) \times 10^{15}$ Hz [1,2]

Properties:

Reflection laws: ¹The reflected ray lies in the same plane with the incident ray.² The angle of reflection is equal to the angle of incident [2,3,4].

Destructive interference: Two interfered waves have a destructive interference if the phase of one of them is shifted by π with the respect to the other (advancing or delaying shift) [2,4,5,6,7]

Constructive interference: Two interfering waves have a constructive interference if they have the same phase or the phase of one of them is shifted by 2π with the respect to the other (advancing or delaying shift) [2,9].

Phase Shifting: We cannot shift real time signals advancing shifting. Most of elementary circuits cannot predict future inputs. Taking this in consideration, we use delay shift. Delay shifting can be done by two ways, first decreasing the speed of signal, or, second increase the distance that the signal must travel. To make a beam a destructive beam, its phase must be shifted by π . This can be done by increasing the path that beam must travel by $(m+1/2)\lambda$, where $m = (0,1,2,\dots)$ and λ is the wavelength of the beam [1,2,3,4,5,6,7].

Interference field: It is the region in which two or more waves overlap. Within this region, there are alternating places with maximum and minimum intensity of light, which is called fringes. [2] At a minimum point there is a dark place, and light intensity increases by moving to the left or to the right side till maximum point we find high intensity of the interference field.

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