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Lens Coplanar System Application based on Lateral Refraction and Reflection of Polarized Light

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LENSCOPLANARSYSTEMAPPLICATIONBASEDONLATERALREFRACTIONANDREFLECTIONOFPOLARIZEDLIGHT

Strictly as per the compliance and regulations of:

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A linearly polarized light beam over a lens will be reflected and refracted following the lines curves resulting from the interception of a plane of polarization with the sphere lens surface, keeping the orientation of refraction and reflection inside the plane of polarization. Only looking at the lens laterally this effect is significant, and a lens behavor is like lateral analyzers if the polarization plane of the polarized light incident over the lens is rotated, and two pairs of fans on opposite edges to diameter are forming, get out to both sides of the lens. The resulting beams will take place at opposite ends to the diameter of the lens and it has the higher intensity, so that this phenomenon is noticeable only by observing the lens laterally and placing parallel to the optical axis Based in the principle that in the spherical surface of a lens fit n circles of radius r, and n is inversely proportional to r, then each circle is a lens itself. If a beam of light is projected in one of these areas, the phenomenon is expressed lateral side and the light get out diametrically opposite to the incident linearly polarized light get in, the lens acting as a waveguide for the light beam polarized. Demonstration that a polarized light over a lens will be reflected and refracted following the interception of the plane of polarization with the spherical lens surface, maintaining the orientation of refraction and reflection within the plane of polarization and it can be used for measurement of a polarized plane rotation. Now if we rotate the polarization plane of polarized light beam, not the lens, then, also changes the direction of the rays reflected and refracted as they remain within the plane of polarization of light.

Keywords: polarization, rotation, plane, lens, reflection, reflection, polarized light.

I. Background

Algebra properties of geometrical shapes are made to manifest when a linearly polarized light beam incident on a lens, such as the intersection between a plane and a spherical surface, a polarized light beam is electromagnetic waves and oscillate in planes parallel to each other in the same direction. When this planes affect orthogonally on the spherical surface of a convex lens, the light is reflected and refracted without leaving the plane which belongs at, in Figure 1 shown only the central portion of the lens for a better understanding. By rotated the polarization plane of polarized light beam, changes the direction of the rays reflected and refracted because they most remain within the plane of light polarization.

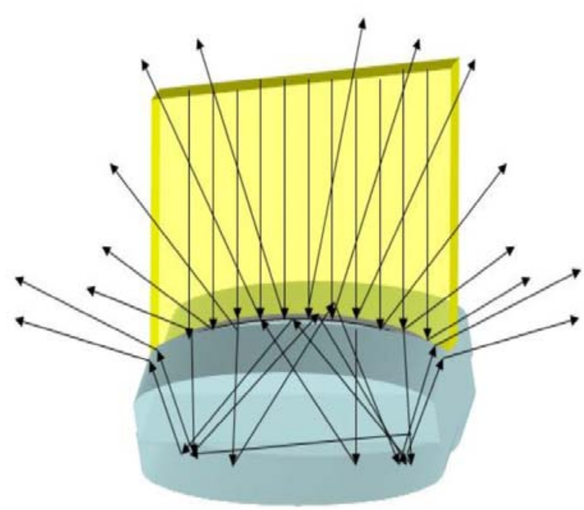

Figure 1: Refraction and reflection of polarized light in a convex lens

Now, we will put the lens over horizontal surface and a beam of polarized light incident in its geometrical centre, with the polarized plane oriented vertically to us, we can see a brightness circle inside the lens (Fig.1a), and what is that circle? It is light; light get out laterally from the lens. And why it is so brightness, because we are front of the polarized plane of the beam. With the polarized plane oriented parallel to us, the circle disappears, why, because there are two beam of light get out of the lens 90^0 from us to booths lens sides and parallel to our position, then we can not see the light. Let's consider that these two positions are *extremes positions* and between those positions, the circle change in intensity, decreasing while the polarized plane of beam is rotated up to be parallel to us.

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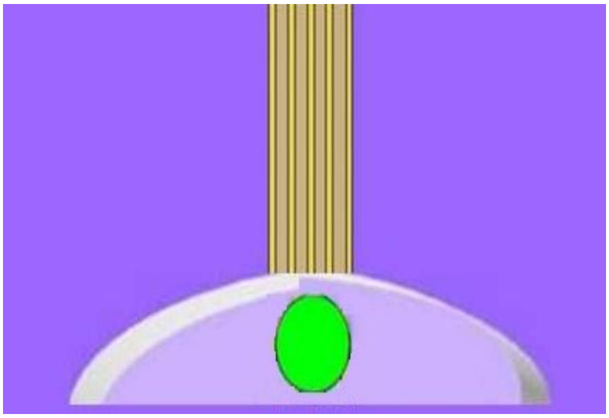

Figure 1a: Inside the lens we can see a brightness circle

This is in fact our phenomena, and it that can be used in many applications, principally in determined the polarized light positions. Using photo sensors placed to 90^0 from each other, for example, when its value been the same, the polarized light will be at 45^0 between the *extremes positions*.

a) *Concept*

Return to the photo sensors, which are showing in Fig.1a, the difference between the light intensity of each one, will be equivalent to the position of the beam polarized plane

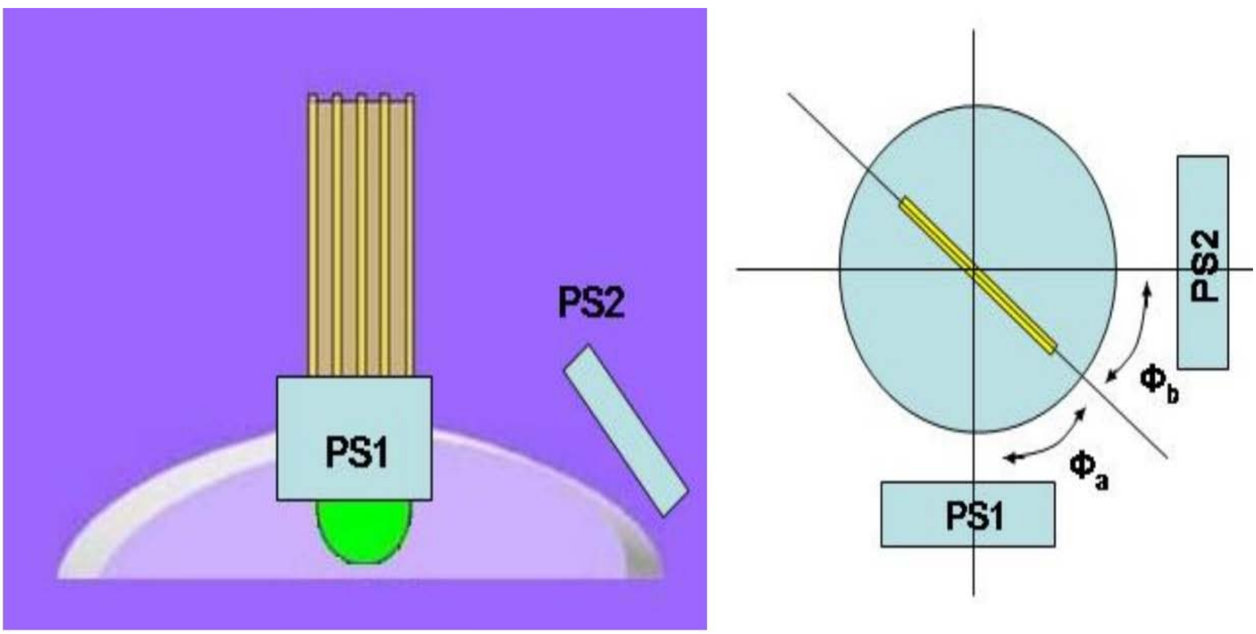

Figure 1b: Photo sensors PS1 and PS2

In the PS1:

(1) $I_a = I_0 Sin((\pi - \Phi_a)/1$

In the PS2:

(2) $I_b = I_0 Sin((\pi - \Phi_b)/180)$, $\Phi_b = 90^0 - \Phi_a$

I_0 is the incident light intensity and the difference I_a-I_b is equivalent to the rotation of the polarize plane Φ, and can be calculated:

(3) $\Phi = (0.5)*90^0 *(I_a-I_b)$

Ahead will see another concept, *coplanar lenses* and these equations will be not the same in that case, this is when only one lens has been used.

There is a way in which no matter if the light intensity has variation or not. These are an optical trigonometric system and follow trigonometric rules. The angle Φ can go between 0^0 and 90^0 how we can see in Fig. 1b, if we divided 90^0 between 3.1416, the value result is 28.64 when Φa is CERO, them Ia is equal to 3.1416, but Io in this conditions will be equal to Ia divided between Sin ($90^0/180^0$) is equal to 2(3.1416), which value is 6.28. Now can make the substitution of Io by 6.28 in the equations 1 and 2 and no matter if Io has variation or not, the result will be constant, because of the values Φa and Φb have variations, how they are subtracted, the variation will be annulated. In this way the effect of the absorption can be controlled.

Lets go used the EXCEL software, but first we will see the equations that we will use in it:

A2=K, A3=A2, A4=A3,…….
B2=Io, B3=B2, B4=B3,…….
C2=Q (Perturbación que se introduce a Φa1 y Φb1)
D2=Φa, D3=D2+1, D4=D3+1,…..
G2= Φb, G3=G2+1, G4=G3+1,……
Ia= (2,085852*3,1416/A2)*(A2*B2/B2)*SIN((90-D2)/(180))
Ib=(2,085852*3,1416/A2)*(A2*B2/B2)*SIN((90-G2)/(180))
Φ= (GRADOS((F2-I2)/180))
Φ=0.5*90*(Ia-Ib)=45*K2
Φa1=D2-C2
Φb1=G2-C2
Ia1=(2,085852*3,1416/A2)*(A2*B2/B2)*SIN((90-E2)/(180))
Ia2=(2,085852*3,1416/A2)*(A2*B2/B2)*SIN((90-H2)/(180))
Φ1=(GRADOS((O2-P2)/180))
Φ1=0.5*90*(Ia1-Ib1) =45*Q2

In the appendix is the Figure 1.1 which is Excel app.

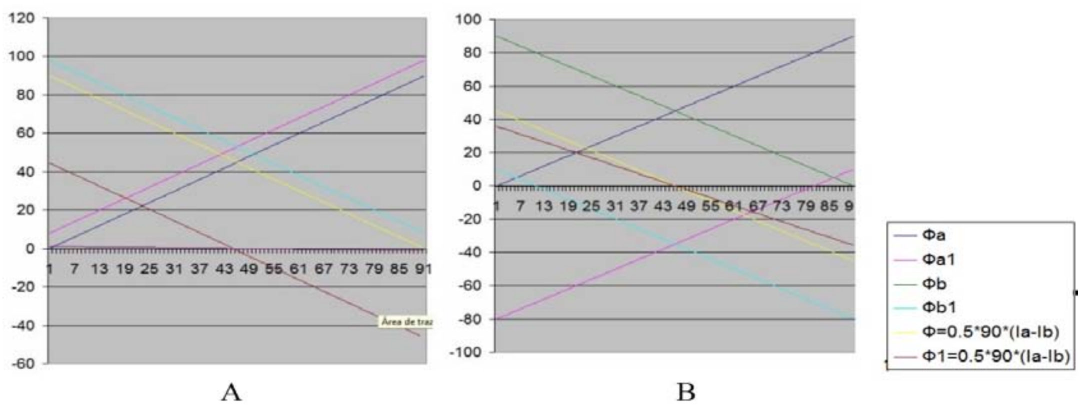

Figure 1.2: In A, Q = - 8; in B, Q= 80

When the perturbation Q is lowest than CERO, the line Φ1 is over the line Φ, that is not have perturbation. This is due to negative values are equivalent to increase the light intensity.

When the perturbation Q is upper than CERO, is equivalent to an absorption of light and pendent of Φ1 decrease respect pendent of Φ.

With these properties is possible avoid that perturbations could affect the measurements, only using an additional source or light (Q<0) nearest the lens, or the lenses in the case of coplanar lenses. The lector one can probe all this himself if build the excel table (Fig. 1.1) and change the values in columns A, B y C; but the values Φ and Φ1 remain approaches to each other.

If we desire construct an instrument to determine the value of the rotation of the plane of polarization of light using this phenomenon, it is necessary use two light sensors placed parallel to the optical axis and 90^0 spaced from each other and on the sides of the lens

This has been possible because of the physical properties when linearly polarized light impinging on a lens, the light beam is reflected and refracted following the lines curves resulting from the interception of a plane of polarization with a lens spherical surface maintaining the orientation of refraction and reflection inner the plane of polarization.

This is the physical concept obtained with our research and it permitted us understand better the phenomena and the procedure to follow in order give it a correct application.

The extension in the application of the phenomena gives us the possibility to find out the concept of *coplanar lenses* that do better than the precision of the measurements, with out loss the simplicity of the optical system used, and understood the difference between use one or two lenses and when we must use one lens or use two lenses.

If we used only one lens, when the polarized plane is rotated, there is a space between the photo sensors where the light not insides over the photo sensors areas, whereas in the system with two lenses always the light is over the photo sensors surfaces.

In conclusion we have given hear important concepts that abstract the more important things that most be remembered for a better understanding of the following matter.

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II. Researching

I in Figure 1 let go place two observers, one on the right and another one on the left of the diametric line of the lens, the observer at the right sees the left side of the light source image, the rays that reach him are the result of the refraction and reflection within of the lens from the left side of the light source. The left observer sees from his position the right side of the light source image.

When the plane of polarization is orthogonal to the plane of the paper, that means it is parallel to the two observers, both observers observed that the light intensity of the image decry completely.

In that way the lens gives information about the orientation of the plane of polarization and the lens behaviour is like an analyzer of polarized light, which, shows this effect in Figure 2.

The entire lens and the beam of polarized light are showing in Figure 2. The biggest light intensity of refraction and reflection occurred where the geometric central plane of the beam radiating on the diametric line of the circumference defined by the plane polarization of the light beam on the lens surface.

A sequence of rotation of plane polarized light beam is showing in Figure. A light spot is observed in the centre of the lens, and the light intensity varies according on the plane of polarization spatial position, in relation to the observer position. An observer, who turns around the lens at the same speed that the plane of polarization is rotated, always will see the same intensity.

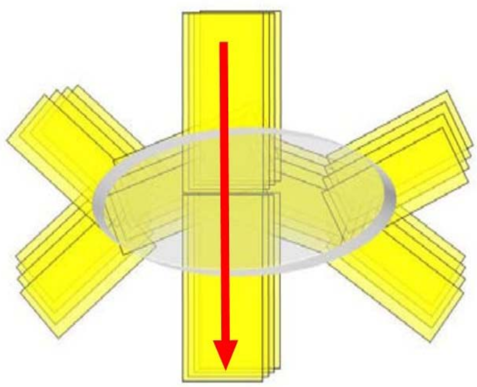


Figure 2: Inner reflection and refraction in a convex lens

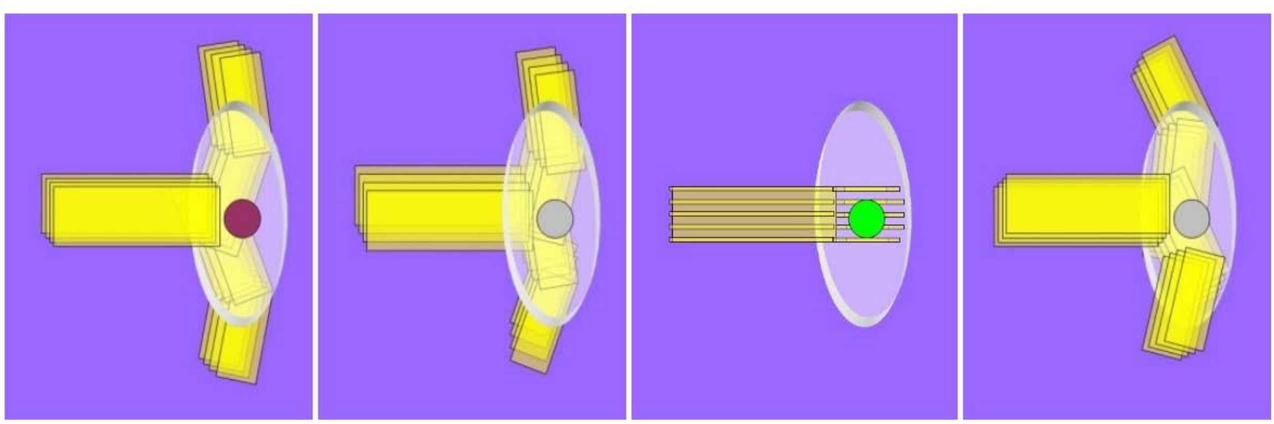
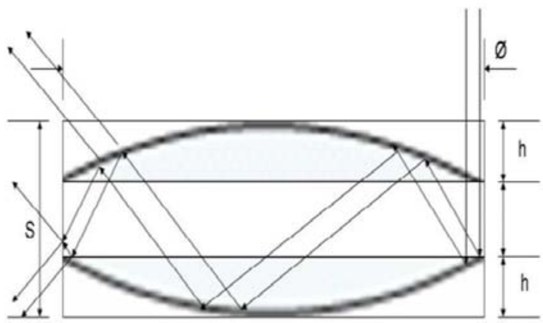


Figure 3: Sequence of the polarize plane rotation

Over the lens spherical surface can be placed perfectly **n** circles of radius **r**, the number **n** is inversely proportional to the radius **r**, whereas, while the radius will be shortest, the numbers of insert lens will be biggest. Each circle is an independent lens.

When the linearly polarized light incident chining on the lens edge, will occurred all explained before, but in the incidence region. The light travel along the lens diametric line and will exit the edge of the lens diametrically opposed to the incident beam and only at that point the image can be seen and not in any other region of the lens.

What has been explained here can be seen in Figure 4, where is including an equation in order to determine the number of reflections and selecting the appropriate lens according the lens geometry.



$$\text{Reflections} = \frac{\phi(1/S + 1/2h_{arc})}{2}$$

Figure 4: Reflections on the lens to make an impact on its edge beam perimeter

Where:
Φ: light incident angle
h: arc lens wide
S: lens wide

Let's do the beam of polarized light shinning in the lens edge, and after that the plane of polarization is rotated, when the lens diametrical line coinciding with the orientation of the polarization plane, the image of the light source, in the lens diametric opposite side, will be very bright. That bright will decrease when the polarization plane will be moved from that point.

We can be seen how change the outgoing light when the polarizing plane is rotated in the sequence shower in Figure 5.

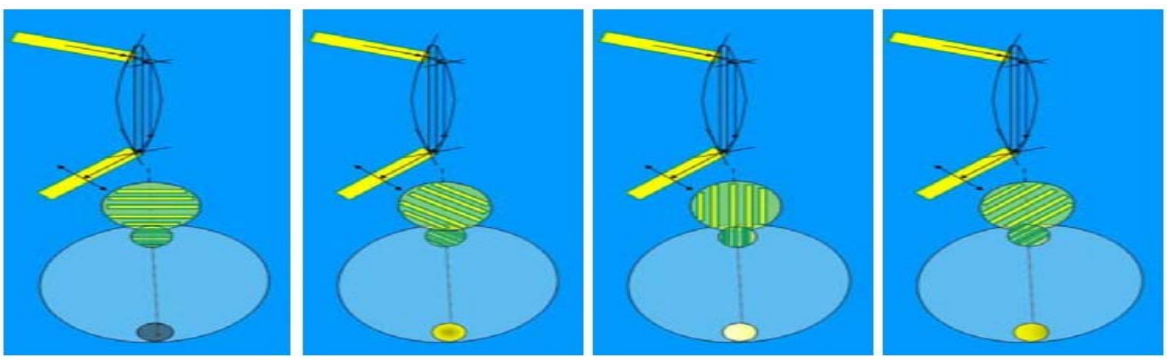


Figure 5: Sequences that shows how changes the out coming light lens

III. Coplanar Lens Systems

Placing two identical lenses in a same plane, where they join the edges lets traced between touching edges an extending line, so the intercept between this line, with another line tangent to the upper edges of the two lenses and perpendicular to the first line, will have the centre of the polarized light beam, and the light emerging in each of the lenses will be 90° to each other in two points diametrically opposite in each lens. The geometric representation of this phenomenon is represented in Figure 6.

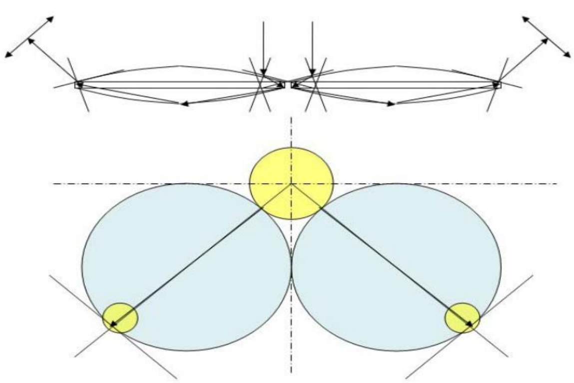


Figure 6: Coplanar lenses

If the light beam linearly polarized is rotated, when the diametrical path of one of the lens coincides with the polarization plane orientation, an image so bright of light source will be obtained in the opposite diametric position in that lens, while there be not light in the diametrically opposite position in the other lens. Rotating the plane of polarization in towards the lens with a less than intensity of light, the intensity of light in this point will grow in intensity, whereas in the other lend will decrease. The difference between the booths points is 90°.

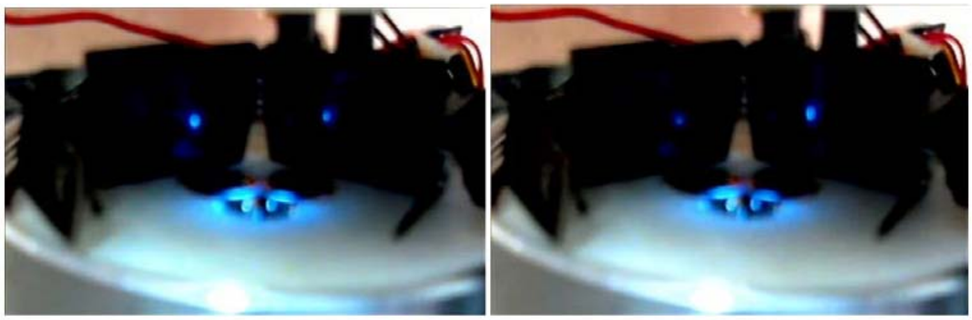


Figure 7: Scream shoots an experiment media film

The scream shoot of two still pictures taken from a media conducted in the laboratory is showing in Figure 7. In the lower part (the floor) there is a hole through which passes the polarized light beam, two lenses are positioned downwards for the back and sides of this orifice, and the bottom are projects the light emerging from the lens which are the white-bluish halos over two black screens. In the left picture the projected halo over the left black screen is brightness than the halo over the right black screen. In the left picture the spot of light of greater intensity is over the right black screen as a consequence of the polarization plane rotation.

IV. Applications

There are various applications in which this phenomenon can be used.

1. Data transmission using polarized light in which, for example 0^0 represent zeros and 90^0 represent ones in function of the variation of the polarization plane position and can be detected using a polarizer electric effect, This have the advantage in avoid the loss of information because we are only interested in the angles of the plane of polarization and it does not matter the levels of light intensity does not remain constant, and only take the information corresponding to ones and zeros and them depends of the light plane polarized position, not of the intensity.
2. Sea and air signalling guidance.
3. Rotation of the polarization plane would be proportional to body weight.
4. In polarimetry instruments.
5. In determining if a beam of light is polarized or not (astronomic).

a) One application

Stimulating a light emitter diode (LED) or a semiconductor laser with electric pulses and make passing the pulsing beam of polarize light obtained thru an optical system and the end of this system place two photodiodes spatially arranged at 90^0 to each other and their detection surfaces parallel to the transmission axis of polarized light, and its polarization plane axis oriented at 45^0 of the vertices of the edges where the photodiodes join, at output of two operational amplifiers, there will be two pulse train signals one in each one with the same shape in time, but when the polarization plane will be rotated, the radiance of the light projected onto the photodiodes change, and signals being out of phase to the outputs of the amplifiers, the difference between the fronts of the pulses in booths signals is proportional to the rotation of the plane of polarization light angle.

With a phase discriminator digital circuit, is obtained a pulse equal to the difference in time between two sides of the rise time in the output of booths amplifiers.

The value of rotation of the plane of polarization of light is directly proportional to the width of this deference, that is, the greater the rotation, the greater the pulse width.

The composition that will be used is:

1) A very simple optic system.
2) Luminous source to light emitting diode (LED).
3) Two Optic-Electronic Amplifiers sensor associated to front wave differentiating digital circuits.

This system will can be possible determined the polarized light plane rotation in form very comfortable and precise, without the necessity to use analyzers, rotational modulators, neither magnetic coil that are those more commonly employees for the polarized light plane measure. Give there that the outlined method has the advantage the mobile mechanical parts total lack and not having to use big currents densities in induction coils, its precision depending of the pulses modulation electric sign stability and the optic system alignment precision, including the photodiodes spaced to 90^0 degrees among them incidence faces.

If linearly polarized light affect in a lens, the polarized light will be reflected and refracted along the curves lines between the interceptions of a plane with a sphere, i.e. the polarized light plane on the surface of the lens, and following the orientation of the of polarization plane. Only looking at the lens side this effect is significant. Then the lens behavior is like a side analyzer when the polarization plane of polarized light that falls on it is rotated.

With this principle and adding that over the spherical surface lens we can put n circle of radius r, been n is inversely proportional to r, and each circle is a lens it self, so if we shine a beam of light in one of these areas the phenomenon of polarization is expressed lateral side and diametrically opposite to where the linearly polarized light incident.

b) *System with only one lens*

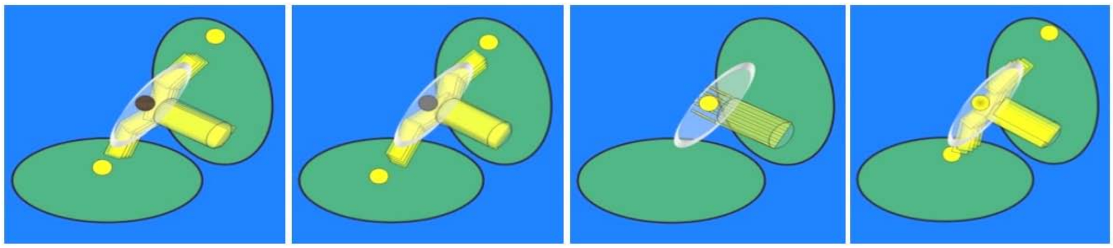


Figure 8: How two photodiodes spatially to 90 degree are illuminated when the polarize plane change

If we desire construct an instrument to determine the value of the rotation of the plane of polarization of light using this phenomenon, it is necessary use two light sensors placed parallel to the optical axis and 90^0 spaced from each other and on the sides of the lens. In Figure 8, the green color circles are the photodiodes and when the plane of polarization of light rotated, the light over photodiodes detection surface change. But this has two disadvantages, one is the light intensity is low and the other is the absorption effect of distorting information because there is a lighted space between the sensors would not touch the surface of both.

c) *System with only two lens*

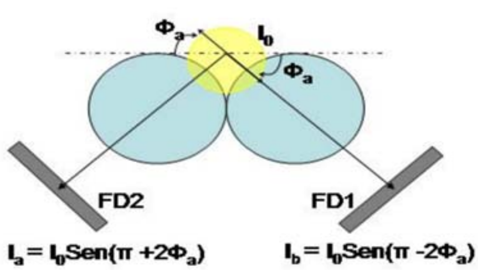


Figure 8.1: Lenses coplanar system

In this case:

(4) $I_a = I_0 Sin((\pi + 2\Phi_a)/180)$

(5) $I_b = I_0 Sin((\pi - 2\Phi_b)/180)$

(6) $\Phi = (I_a - I_b)*(0.5)*90^0$

The Eq. (6) is the same to Eq. (3) when used only one lens is; the difference is between Eq. (1) and Eq. (4) and between Eq. (2) and Eq. (5).

The problems of low light intensity and the absorption effect of distorting information because there is a lighted space between the sensors would not touch the surface of both, was fixed with a geometric study of the lenses where were find out the solution. Over the lens spherical surface can be placed perfectly **n** circles of radius **r**, the number **n** is inversely proportional to the radius **r**, whereas, while the radius will be shortest, the numbers of insert lens will be biggest. Each circle is an independent lens.

When the linearly polarized light incident chining on the lens edge, will occurred all explained before, but in the incidence region. The light travel along the lens diametric line and will exit the edge of the lens diametrically opposed to the incident beam and only at that point the image can be seen and not in any other region of the lens. In this way we will not have a cone-shaped beam on the side of the lens, but a point where we will get the whole picture and therefore with greater intensity.

In Figure 5 the sequence is showing, where the intensity of out coming light is a function of position of the polarize plane incident over the border lens surface.

But we still have a problem and we have to use two sensors to polarized light to come on as a light source. When the polarized plane is rotated, there is a space between the photo sensors where the light not insides over the photo sensors areas. The solution to this problem is to use a system of two identical lenses placed in the same plane and positioned so that they cross a line where you play two of its edges with another drawn from the edges that touch the two lenses and orthogonal to the first, is the center of the beam. This ensures that the two points of light coming out diametrically opposed in each of the lenses are at 90^0 from each other. Figure 6 is the geometric representation

By rotating the linearly polarized light beam, the lens diameter path coincides with the orientation of the polarization plane will have a very bright image of the light source, while the diametrically opposite position of the other lens will have not light. If we continue to rotate the plane of polarization in the direction of the lens with less intensity than light, it will grow in intensity and decreasing the other, when both intensities are equal will be in the place where the instrument has its zero. There will be a gap of 90^0 between the points.

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Now the light sensors are always under the light field (see Figure 9), recording exactly light variations that are proportional to the rotation of the polarization plane of light. So that by modulating the polarized light with a train of pulses of light and use as sensors photodiodes, electric current is generated in them will be directly proportional to the amount of light reaching them, there is a gap between rising fronts amplified signal pulses obtained in photodiodes if they do not receive the same amount of light and that is the value of rotation of the polarization plane.

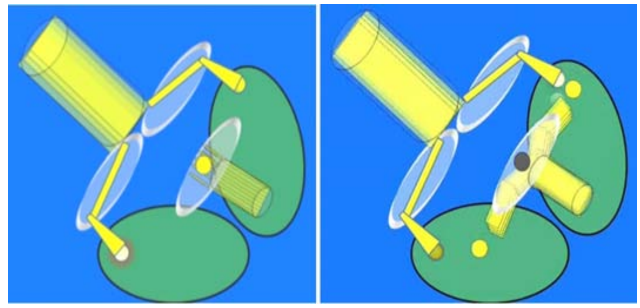

Figure 9: With two lenses the light sensors are always under the light field

d) A know methode

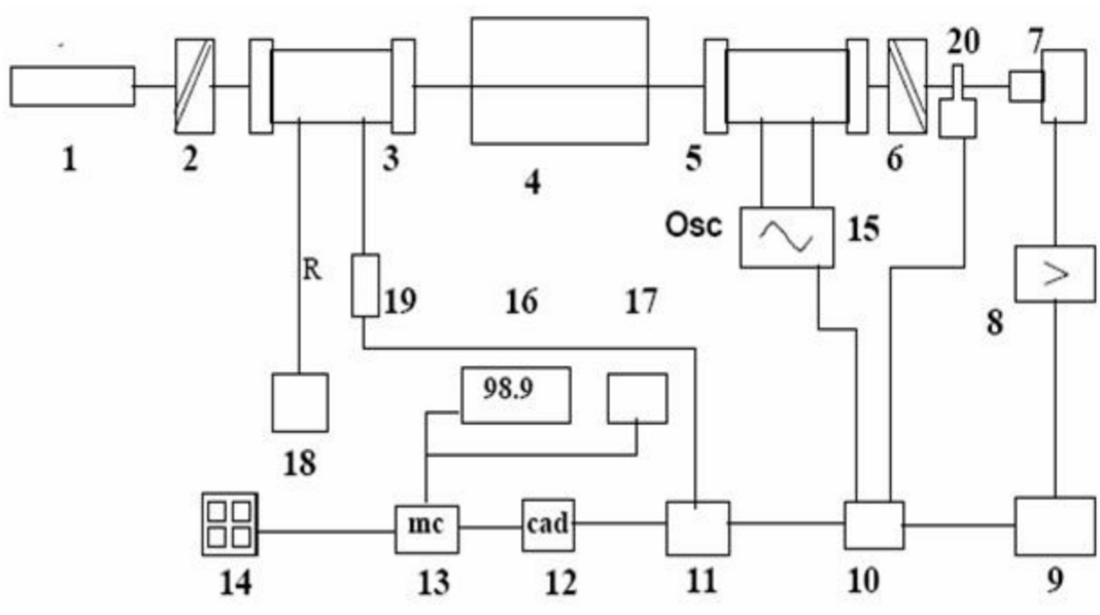

Figure 9.1: Laserpol 4

In the Fig. 9.1 we have a block diagram of the equipment LASERROL 4 [4], where:

1) He-Ne 2mW laser
2) Polarized film
3) Compensetion cell (inside de coil)
4) Sampel chamber
5) Faraday cell (modulator, inside the coil)
6) Analized film
7) Photo sensor
8) Electronic amplifier
9) Filters
10) Fase detector
11) Sampel circuit

In this case is necessary the use of two coil (3 and 5) in order compensated and modulate with a ramp electric signal the laser beam and detect the moment in which the compensation occur, and that time interval is the value of the polarized plane rotation, in our case only need a little electronic amplifier, without compensation coil nether modulation coil, ramp electric signal or scale extension mechanics because only can measurement little amount of rotation angles with this equipment.

The coils 3 and 5 are so big and its electric energy consumption is so big too and introduces errors in the measurement value.

Our method no has these problems and beside is simpler than this. See the Fig. 13 and made a comparison with Fig. 9.1.

The fundamental advantage with other methods is that the method that we are defendant hear is optic fully and uses the lens like ayes, no need process extra in order obtain the desire objective, this property reduce the errors in the measurement values, is more precision and simple than any other. It works like Laurent polarimetry [5] Fig. 9.2, in which the sensor is the human aye.

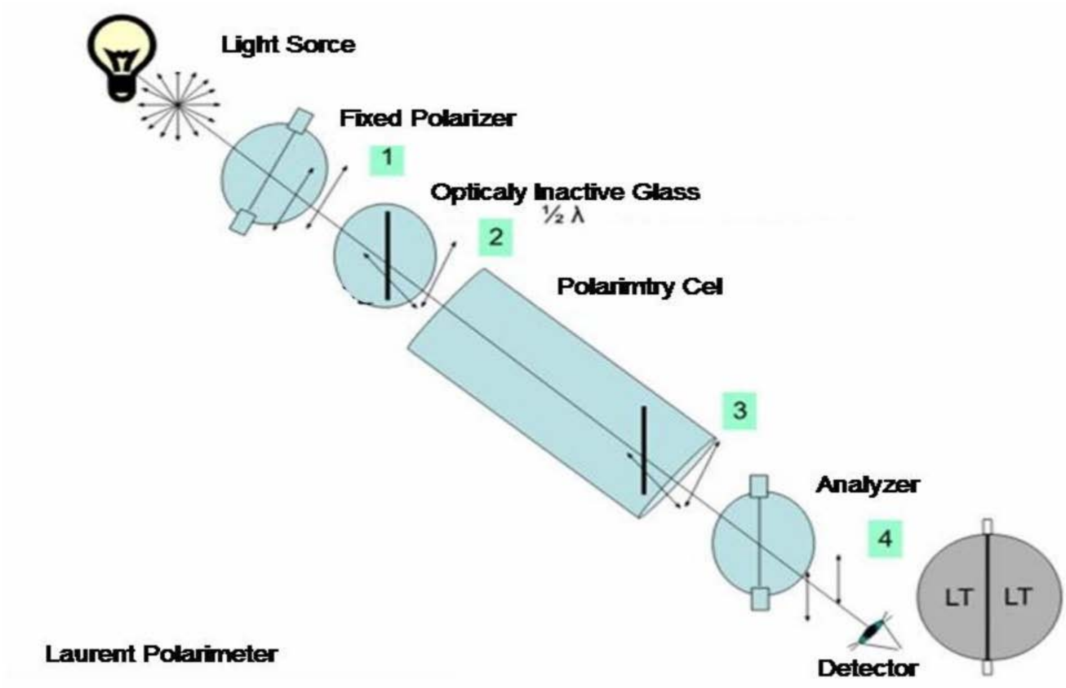

Figure 9.2: Laurent polarimetry

V. Malus ` s Low Behavior. [1, 2]

If between a pulsating light source and a radiometer we place two polarizing sheets, with their polarization axes at 90^0, the radiometer will measure zero or minimal candle power, then as broken the polarizing sheet, will go increasing the light intensity reading in the measuring instrument, until a maximum that will correspond when we have rotated it 90^0 (Malus`s low).

If now the polarizing sheet utilized as analyzer is retired and used instead of the radiometer and our amplifier is placed, its exit, view in an oscilloscope, a pulse will appear which width will go increasing until a maximum valor when going rotating the polarizing sheet in the same sense, and starting from there it will begin to diminish until a minimum and a phase shift will take place, increasing the width until a maximum, but now in opposed sense (Figure 10).

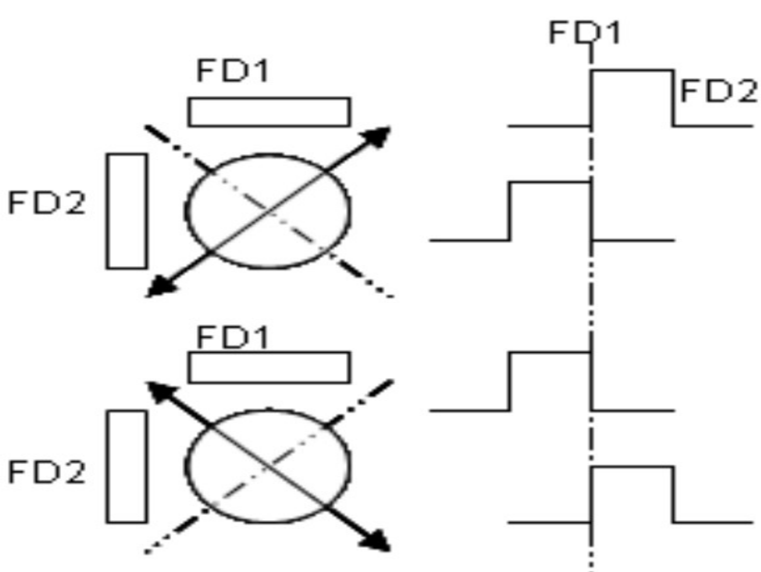

Figure 10: Operational amplifier output following the rise time of the pulse signal in each output amplifier, according to the Malus`s Low

Comparing both methods has obtained more information with our amplifier than with the radiometer. When in the oscilloscope appear a minimum, the polarized light plane will be exactly at 45^0 or -45^0 regarding the horizontal one give the paper plane and like the line with double arrow represent, that is to say that already know in the fact that the sense the polarization plane is oriented of and to identify this in the polarizing sheet.

Now then, if we place an active optic substance in that trajectory, being the plane of polarization placed at 45^0, superior image gives the drawing in Figure 10, we will have a pulse that will increase its width toward the right if the substance is levorotary, and counter-clockwise if it is not levorotary, being its magnitude in agreement with the angular quantity that the substance has rotated the plane of polarization.

If initially the plane of polarization is to -45^0, inferior image gives the drawing in Figure 8, a pulse will increase its width counter-clockwise if the substance is levorotary, and toward the right if it is not levorotary. FD1 and FD2 in the Figure 10 represent the photodiodes space disposition utilized.

The Fig. 10.1 represents how the system works.

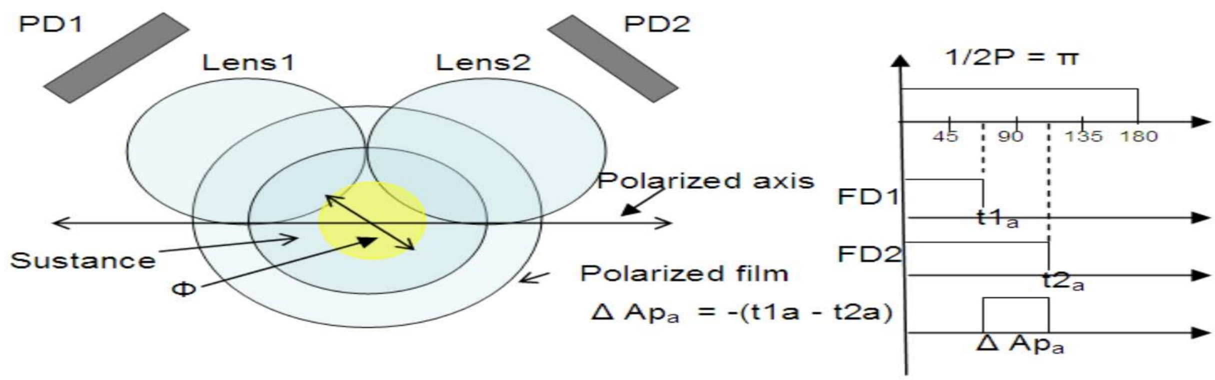

Figure 10.1: How it works

When an optical substance is put in inner measurement chamber, the polarized plane will be rotated and in one of the lents the light will be increasing and in the other the light will be decreasing, them the pulse wide in witch lents where the light increased will less than the wide where the light decreased. This deference between booths pulses will be the polarized plane rotation. If the difference is more than CERO, it means that the substance is LEVOGIRA and the wild of the pulse in FD1 will be greater than the wild pulse in FD2. Whereas, is the deference is less than CERO, it means that the substance is DEXTROGIRA and the wild of the pulse in FD1 will be less than the wild pulse in FD2.

With these is demonstrated that the system has optical behavior, no need uses others applications in order obtained the results of measurement of the polarized plane rotation.

VI. Wave Form at the Output Electronic Amplifier

In the Figure 11 the signs time letters, where we only use the rise time between the pulse signals in each output of both operational amplifiers. That difference is equivalent to the rotation of the polarize axis, this value is equal to signal pulse in the last one line.

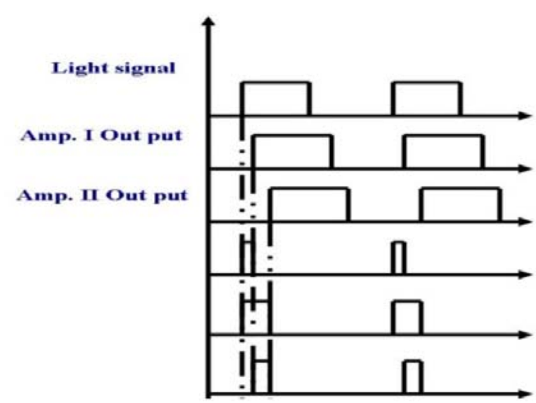

Figure 11: Letters time

In Fig.12 is represented the Equipment block diagram [3]; the first block on the left is the Electronic Light Modulator who chining the Optical System, which is represented in Fig.13. The light that thru out from the Optical System is sensed by the photodiodes FD1 y FD2 that are coupling to separately to the amplifiers I y II respectively. Each output of both amplifiers are cleaned in the Electronic Cleaner I y II by the modulator signal, and after that, that signals are compared in theirs front up, like is showed in Fig.11; and in the last block we can see the Rotation Value of the polarized light.

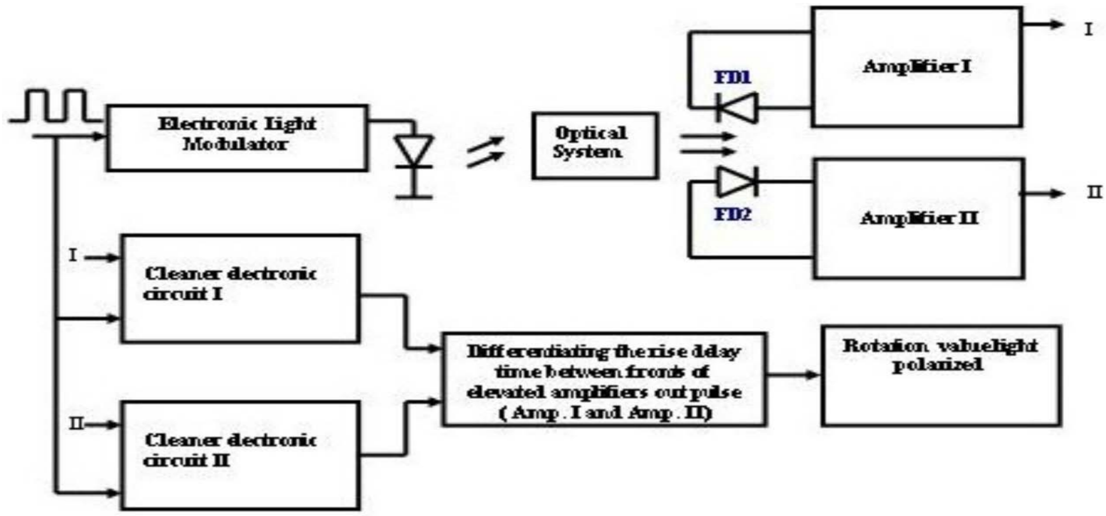

Figure 12: Equipment block diagram

The Figure 13 is the optic system utilized

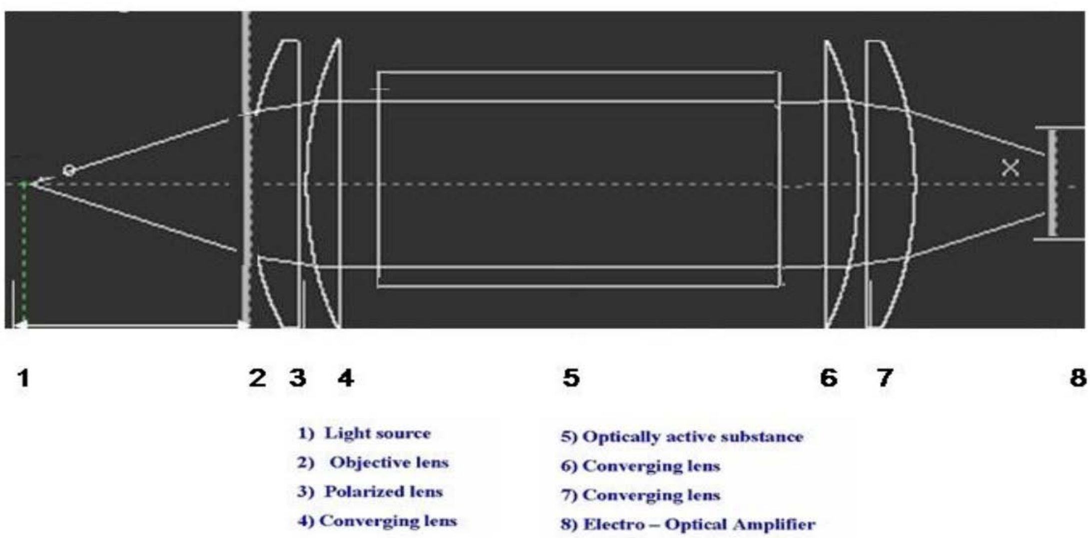

Figure 13: Optic system

VII. Conclusions

The optical system and the phenomenon which occurs therein can be used as a new polary metric detection method, in which the accuracy of alignment of the optical system is essential for accuracy of detection. It's a new polari metric detection method, based, first, the new principle of refraction and reflection of light polarized in lenses and the first time use of coplanar optical lens systems that significantly improve the use of the phenomenon analyzed.

When a bean of polarized light incident in the lens geometrical centre, with the polarized plane oriented vertically to us, we can see a brightness circle inside the lens, which is light; light get out laterally from the lens. And it is so brightness if we are front of the polarized plane of the bean. With the polarized plane oriented parallel to us, the circle disappears, because there are two bean of light get out of the lens 90^0 from us to booths lens sides and parallel to our position, then we cannot see the light. Let's consider that these two positions are *extremes positions* and between those positions, the circle change in intensity, decreasing while the polarized plane of bean is rotated up to be parallel to us.

All this has be possible because when linearly polarized light impinging on a lens, it will reflect and refract along the lines curves resulting from the interception of a plane (plane of polarization) with a sphere (lens surface) maintaining the orientation of refraction and reflection within the plane of polarization.

This is the physical concept obtained with our research and it permitted us understand better the phenomena and the procedure to follow in order give it a correct application.

Concept: The reflection and refraction when linearly polarized light impinging on a lens, it will be maintaining within the plane of polarization.

The extension in the application of the phenomena gives us the possibility to find out the concept of *coplanar lenses* that do better than the precision of the measurements, without loss the simplicity of the optical system used, and understood the difference between use one or two lenses and when we must use one lens or used two lenses.

By first time have been used a parallel lens systems and this is a new optical method for polarymetric measurement, with this, extremely simple, sure and precise measurements equipments can be built.

If we used only one lens, when the polarized plane is rotated, there is a space between the photo sensors where the light not insides over the photo sensors areas, whereas in the system with two lenses always the light is over the photo sensors surfaces.

The Constant Height and Variable Phase Electro-Optic Amplifier allow determine the beam of light polarization plane orientation. It also allows to determine the magnitude that has been rotated when introducing an active optic substance and to also know if the same one is levorotary or not.

The fundamental advantage with other methods is that the method that we are defendant hear is optic fully and uses the lens like ayes, no need process extra in order obtain the desire objective, this property reduce the errors in the measurement values, is more precision and simple than any other.

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Note References have been mentioned rather to indicate the field belonging the subject matter thereof, as the phenomenon is not reflected in the literature.

Appendix

	A	B	C	D	E	F	G	H	I	K	M	O	P	Q	R
1	K	Io	Q	Φa	Φa1	Ia	Φb	Φb1	Ib	Φ	Φ=0.5*90*(Ia-Ib)	Ia1	Ia2	Φ1	Φ1=0.5*90*(Ia-Ib)
2	6,28	1	8	0	-8	3,141633673	90	82	0	1,00001306	45,00058757	3,39403484	0,29114469	0,98768061	44,44562746
3	6,28	1	8	1	-7	3,109636901	89	81	0,03640488	0,97824013	44,02080603	3,36284117	0,32750913	0,9661762	43,47792886
4	6,28	1	8	2	-6	3,077544153	88	80	0,07280864	0,95643702	43,03966582	3,33154372	0,36386346	0,94464196	42,50888836
5	6,28	1	8	3	-5	3,045356418	87	79	0,10921015	0,93460438	42,05719724	3,30014343	0,40020656	0,92307857	41,53853586
6	6,28	1	8	4	-4	3,013074692	86	78	0,1456083	0,9127429	41,07343059	3,26864129	0,43653731	0,9014867	40,56690131
7	6,28	1	8	5	-3	2,980699969	85	77	0,18200194	0,89085325	40,08839625	3,23703827	0,47285459	0,87986699	39,59401469
8	6,28	1	8	6	-2	2,94823325	84	76	0,21838997	0,8689361	39,10212462	3,20533534	0,50915727	0,85822013	38,61990605
9	6,28	1	8	7	-1	2,915675537	83	75	0,25477126	0,84699214	38,11464614	3,17353348	0,54544424	0,83654679	37,64460543
10	6,28	1	8	8	0	2,883027833	82	74	0,29114469	0,82502203	37,12599128	3,14163367	0,58171437	0,81484762	36,66814294
11	6,28	1	8	9	1	2,850291148	81	73	0,32750913	0,80302646	36,13619056	3,1096369	0,61796655	0,79312331	35,69054873
12	6,28	1	8	10	2	2,817466491	80	72	0,36386346	0,7810061	35,14527453	3,07754415	0,65419966	0,77137451	34,71185296
13	6,28	1	8	11	3	2,784554875	79	71	0,40020656	0,75896164	34,15327377	3,04535642	0,69041257	0,74960191	33,73208584
14	6,28	1	8	12	4	2,751557316	78	70	0,43653731	0,73689375	33,1602189	3,01307469	0,72660418	0,72780617	32,7512776
15	6,28	1	8	13	5	2,718474833	77	69	0,47285459	0,71480312	32,16614057	2,98069997	0,76277336	0,70598797	31,76945853
16	6,28	1	8	14	6	2,685308447	76	68	0,50915727	0,69269043	31,17106946	2,94823325	0,798919	0,68414798	30,78665892
17	6,28	1	8	15	7	2,65205918	75	67	0,54544424	0,67055636	30,17503628	2,91567554	0,83503997	0,66228687	29,80290911
18	6,28	1	8	16	8	2,618728061	74	66	0,58171437	0,64840159	29,17807177	2,88302783	0,87113518	0,64040532	28,81823945
19	6,28	1	8	17	9	2,585316117	73	65	0,61796655	0,62622682	28,18020672	2,85029115	0,9072035	0,61850401	27,83268035
20	6,28	1	8	18	10	2,551824379	72	64	0,65419966	0,60403271	27,1814719	2,81746649	0,94324382	0,5965836	26,84626222
21	6,28	1	8	19	11	2,518253881	71	63	0,69041257	0,58181996	26,18189815	2,78455487	0,97925503	0,57464479	25,8590155
22	6,28	1	8	20	12	2,48460566	70	62	0,72660418	0,55958925	25,18151632	2,75155732	1,01523601	0,55268824	24,87097066
23	6,28	1	8	21	13	2,450880753	69	61	0,76277336	0,53734127	24,18035728	2,71847483	1,05118566	0,53071463	23,88215821
24	6,28	1	8	22	14	2,417080203	68	60	0,798919	0,51507671	23,17845194	2,68530845	1,08710287	0,50872464	22,89260865
25	6,28	1	8	23	15	2,383205051	67	59	0,83503997	0,49279625	22,17583122	2,65205918	1,12298652	0,48671895	21,90235253
26	6,28	1	8	24	16	2,349256344	66	58	0,87113518	0,47050058	21,17252606	2,61872806	1,15883551	0,46469823	20,91142042
27	6,28	1	8	25	17	2,315235129	65	57	0,9072035	0,44819039	20,16856743	2,58531612	1,19464874	0,44266318	19,91984289
28	6,28	1	8	26	18	2,281142456	64	56	0,94324382	0,42586636	19,16398631	2,55182438	1,23042509	0,42061446	18,92765055
29	6,28	1	8	27	19	2,246979378	63	55	0,97925503	0,40352919	18,15881371	2,51825388	1,26616347	0,39855276	17,93487403
30	6,28	1	8	28	20	2,212746949	62	54	1,01523601	0,38117957	17,15308066	2,48460566	1,30186277	0,37647875	16,94154397
31	6,28	1	8	29	21	2,178446225	61	53	1,05118566	0,35881818	16,14681819	2,45088075	1,33752189	0,35439313	15,94769102

Figure 1.1: Excel

32	6,28	1	8	30	22	2,144078265	60	52	1,08710287	0,33644572	15,14005737	2,4170802	1,37313973	0,33229657	14,95334585
33	6,28	1	8	31	23	2,109644131	59	51	1,12298652	0,31406287	14,13282926	2,38320505	1,40871518	0,31018976	13,95853917
34	6,28	1	8	32	24	2,075144884	58	50	1,15883551	0,29167033	13,12516495	2,34925634	1,44424716	0,28807337	12,96330167
35	6,28	1	8	33	25	2,04058159	57	49	1,19464874	0,26926879	12,11709555	2,31523513	1,47973456	0,26594809	11,96766406
36	6,28	1	8	34	26	2,005955314	56	48	1,23042509	0,24685894	11,10865216	2,28114246	1,51517629	0,2438146	10,97165709
37	6,28	1	8	35	27	1,971267127	55	47	1,26616347	0,22444146	10,09986592	2,24697938	1,55057126	0,22167359	9,975311484
38	6,28	1	8	36	28	1,936518099	54	46	1,30186277	0,20201707	9,090767949	2,21274695	1,58591837	0,19952573	8,978658
39	6,28	1	8	37	29	1,901709301	53	45	1,33752189	0,17958643	8,081389402	2,17844622	1,62121653	0,17737172	7,981727398
40	6,28	1	8	38	30	1,866841809	52	44	1,37313973	0,15715025	7,071761429	2,14407827	1,65646466	0,15521223	6,984550446
41	6,28	1	8	39	31	1,831916698	51	43	1,40871518	0,13470923	6,061915194	2,10964413	1,69166166	0,13304795	5,987157923
42	6,28	1	8	40	32	1,796935047	50	42	1,44424716	0,11226404	5,051881862	2,07514488	1,72680644	0,11087957	4,989580611
43	6,28	1	8	41	33	1,761897935	49	41	1,47973456	0,08981539	4,041692609	2,04058159	1,76189794	0,08870776	3,9918493
44	6,28	1	8	42	34	1,726806444	48	40	1,51517629	0,06736397	3,031378612	2,00595531	1,79693505	0,06653322	2,993994784
45	6,28	1	8	43	35	1,691661656	47	39	1,55057126	0,04491047	2,020971054	1,97126713	1,8319167	0,04435662	1,996047862
46	6,28	1	8	44	36	1,656464657	46	38	1,58591837	0,02245558	1,010501121	1,9365181	1,86684181	0,02217865	0,998039333
47	6,28	1	8	45	37	1,621216533	45	37	1,62121653	0	0	1,9017093	1,9017093	0	0
48	6,28	1	8	46	38	1,585918371	44	36	1,65646466	-0,02245558	-1,010501121	1,86684181	1,9365181	-0,02217865	-0,998039333
49	6,28	1	8	47	39	1,550571261	43	35	1,69166166	-0,04491047	-2,020971054	1,8319167	1,97126713	-0,04435662	-1,996047862
50	6,28	1	8	48	40	1,515176294	42	34	1,72680644	-0,06736397	-3,031378612	1,79693505	2,00595531	-0,06653322	-2,993994784
51	6,28	1	8	49	41	1,479734562	41	33	1,76189794	-0,08981539	-4,041692609	1,76189794	2,04058159	-0,08870776	-3,9918493
52	6,28	1	8	50	42	1,44424716	40	32	1,79693505	-0,11226404	-5,051881862	1,72680644	2,07514488	-0,11087957	-4,989580611
53	6,28	1	8	51	43	1,408715182	39	31	1,8319167	-0,13470923	-6,061915194	1,69166166	2,10964413	-0,13304795	-5,987157923
54	6,28	1	8	52	44	1,373139725	38	30	1,86684181	-0,15715025	-7,071761429	1,65646466	2,14407827	0,15521223	-6,984550446
55	6,28	1	8	53	45	1,337521888	37	29	1,9017093	-0,17958643	-8,081389402	1,62121653	2,17844622	-0,17737172	-7,981727398
56	6,28	1	8	54	46	1,30186277	36	28	1,9365181	-0,20201707	-9,090767949	1,58591837	2,21274695	-0,19952573	-8,978658
57	6,28	1	8	55	47	1,26616347	35	27	1,97126713	-0,22444146	-10,09986592	1,55057126	2,24697938	-0,22167359	-9,975311484
58	6,28	1	8	56	48	1,230425092	34	26	2,00595531	- 0,24685894	-11,10865216	1,51517629	2,28114246	-0,2438146	-10,97165709
59	6,28	1	8	57	49	1,194648737	33	25	2,04058159	- 0,26926879	-12,11709555	1,47973456	2,31523513	-0,26594809	-11,96766406
60	6,28	1	8	58	50	1,158835511	32	24	2,07514488	- 0,29167033	-13,12516495	1,44424716	2,34925634	-0,28807337	-12,96330167
61	6,28	1	8	59	51	1,122986518	31	23	2,10964413	- 0,31406287	-14,13282926	1,40871518	2,38320505	-0,31018976	-13,95853917
62	6,28	1	8	60	52	1,087102865	30	22	2,14407827	- 0,33644572	-15,14005737	1,37313973	2,4170802	-0,33229657	-14,95334585
63	6,28	1	8	61	53	1,05118566	29	21	2,17844622	- 0,35881818	-16,14681819	1,33752189	2,45088075	-0,35439313	-15,94769102
64	6,28	1	8	62	54	1,015236011	28	20	2,21274695	-0,38117957	-17,15308066	1,30186277	2,48460566	-0,37647875	-16,94154397
65	6,28	1	8	63	55	0,979255028	27	19	2,24697938	-0,40352919	-18,15881371	1,26616347	2,51825388	-0,39855276	-17,93487403
66	6,28	1	8	64	56	0,94324382	26	18	2,28114246	-0,42586636	-19,16398631	1,23042509	2,55182438	-0,42061446	-18,92765055
67	6,28	1	8	65	57	0,907203501	25	17	2,31523513	-0,44819039	-20,16856743	1,19464874	2,58531612	-0,44266318	-19,91984289
68	6,28	1	8	66	58	0,871135181	24	16	2,34925634	-0,47050058	-21,17252606	1,15883551	2,61872806	-0,46469823	-20,91142042
69	6,28	1	8	67	59	0,835039974	23	15	2,38320505	- 0,49279625	-22,17583122	1,12298652	2,65205918	-0,48671895	-21,90235253
70	6,28	1	8	68	60	0,798918995	22	14	2,4170802	-0,51507671	-23,17845194	1,08710287	2,68530845	-0,50872464	-22,89260865
71	6,28	1	8	69	61	0,762773358	21	13	2,45088075	-0,53734127	-24,18035728	1,05118566	2,71847483	-0,53071463	-23,88215821
72	6,28	1	8	70	62	0,726604178	20	12	2,48460566	-0,55958925	-25,18151632	1,01523601	2,75155732	-0,55268824	-24,87097066
73	6,28	1	8	71	63	0,690412573	19	11	2,51825388	-0,58181996	-26,18189815	0,97925503	2,78455487	-0,57464479	-25,8590155
74	6,28	1	8	72	64	0,654199658	18	10	2,55182438	-0,60403271	-27,1814719	0,94324382	2,81746649	-0,5965836	-26,84626222
75	6,28	1	8	73	65	0,617966552	17	9	2,58531612	-0,62622682	-28,18020672	0,9072035	2,85029115	-0,61850401	-27,83268035
76	6,28	1	8	74	66	0,581714373	16	8	2,61872806	-0,64840159	-29,17807177	0,87113518	2,88302783	-0,64040532	-28,81823945
77	6,28	1	8	75	67	0,545444241	15	7	2,65205918	-0,67055636	-30,17503628	0,83503997	2,91567554	-0,66228687	-29,80290911
78	6,28	1	8	76	68	0,509157273	14	6	2,68530845	-0,69269043	-31,17106946	0,798919	2,94823325	-0,68414798	-30,78665892
79	6,28	1	8	77	69	0,472854591	13	5	2,71847483	-0,71480312	-32,16614057	0,76277336	2,98069997	-0,70598797	-31,76945853
80	6,28	1	8	78	70	0,436537314	12	4	2,75155732	-0,73689375	-33,1602189	0,72660418	3,01307469	-0,72780617	-32,7512776
81	6,28	1	8	79	71	0,400206564	11	3	2,78455487	-0,75896164	-34,15327377	0,69041257	3,04535642	-0,74960191	-33,73208584

82	6,28	1	8	80	72	0,363863462	10	2	2,81746649	-0,7810061	-35,14527453	0,65419966	3,07754415	- 0,77137451	-34,71185296
83	6,28	1	8	81	73	0,32750913	9	1	2,85029115	-0,80302646	-36,13619056	0,61796655	3,1096369	-0,79312331	-35,69054873
84	6,28	1	8	82	74	0,29114469	8	0	2,88302783	-0,82502203	-37,12599128	0,58171437	3,14163367	- 0,81484762	-36,66814294
85	6,28	1	8	83	75	0,254771263	7	-1	2,91567554	- 0,84699214	-38,11464614	0,54544424	3,17353348	-0,83654679	-37,64460543
86	6,28	1	8	84	76	0,218389974	6	-2	2,94823325	-0,8689361	-39,10212462	0,50915727	3,20533534	-0,85822013	-38,61990605
87	6,28	1	8	85	77	0,182001943	5	-3	2,98069997	0,89085325	-40,08839625	0,47285459	3,23703827	-0,87986699	-39,59401469
88	6,28	1	8	86	78	0,145608296	4	-4	3,01307469	-0,9127429	-41,07343059	0,43653731	3,26864129	-0,9014867	-40,56690131
89	6,28	1	8	87	79	0,109210155	3	-5	3,04535642	- 0,93460438	-42,05719724	0,40020656	3,30014343	-0,92307857	-41,53853586
90	6,28	1	8	88	80	0,072808642	2	-6	3,07754415	-0,95643702	-43,03966582	0,36386346	3,33154372	- 0,94464196	-42,50888836
91	6,28	1	8	89	81	0,036404883	1	-7	3,1096369	-0,97824013	-44,02080603	0,32750913	3,36284117	-0,9661762	-43,47792886
92	6,28	1	8	90	82	0	0	-8	3,14163367	-1,00001306	-45,00058757	0,29114469	3,39403484	-0,98768061	-44,44562746