

Use of Optical Masers in Displays and Printers

Quarterly Progress Report

7 January through 6 April 1963

Contract No. DA36-039-AMC-00118 (E)

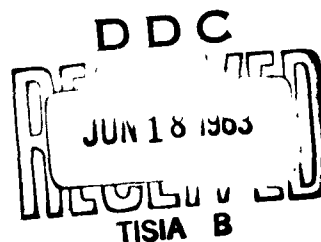
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Fort Monmouth, New Jersey



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Report No. 1

FIRST QUARTERLY REPORT
7 January 1963 to 6 April 1963

on

USE OF OPTICAL MASERS IN DISPLAYS AND PRINTERS

Technical Requirement SCL-4396, 6 June 1962
Contract No. DA-36-039-AMC-00118(E)
Order No. 5389-PM-63-91; PR & C No. 63-ELN/R-6505

to

U. S. Army Signal Research and Development Laboratory
Fort Monmouth, New Jersey

The objective of this study and investigation is a significant improvement in the state of the art among electro-optical input/output devices using the Laser as an electro-optic tool.

Report prepared by Dr. H. Fleisher and Dr. W. Kulcke
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PURPOSE

Speed and storage capabilities of data processing systems have increased steadily in the past decade. The display of results and information produced by computers handling problems of such high speeds must be accomplished by similarly sophisticated approaches.

In addition to the display and hard copy production of alpha-numeric material, we must consider two-dimensional and multidimensional display of graphic and analog type information. The display must be compatible with the human in terms of matching his frequency range of sensitivity, resolving power, and image retention.

The immediate purpose of this study is to develop laser technology for computer input-output devices, and to prepare a laboratory-type demonstration to indicate the ability to modulate electronically and deflect a light beam. This task is preparatory to further development of a complete laser display system.

ABSTRACT

We investigated the deflection of laser beams using digital light deflectors and conical refraction, and the focusing of laser beams with a Fresnel zone lens. The results indicate that laser beams can be accurately deflected by means of a digital light deflector.

Conical refraction shows promise for analog deflection of the beam and the Fresnel zone plate lens when constructed with proper electrodes is suitable for focus/defocus control.

The conclusion indicates that digital electro-optic deflection of intense light beams is feasible and could lead to the realization of practical laser display and printing apparatus.

NEXT QUARTER PLANS

DIGITAL LIGHT DEFLECTOR

We will receive and assemble the parts for the 8 position, one-dimensional light deflector. Using this model, we will work with collimated light beams and use semitransparent electrodes on the electro-optic crystals. Since semitransparent electrodes give rise to considerable light absorption if the deflector comprises many stages, we will investigate other possible electrodes. These include slit electrodes, gratings, or meshes, as well as improved semitransparent electrodes. The use of convergent light beams requires further investigations of compensation of zero field birefringence of off-axis rays.

CONICAL REFRACTION

We plan to obtain crystals of sufficient optical quality, cut perpendicular to their optical axis, and large enough to show an output circle for quantitative investigations. These crystals could be naphthalene or anthracene or an inorganic mineral such as aragonite. We plan to measure quantitatively the intensity distribution around the output circle for different polarization directions of the incoming light to help resolve discrepancies.

FRESNEL LENS

We will continue in our endeavors to obtain the Fresnel zone plate electrodes configuration of the proper resolution.

DISCUSSION

INTRODUCTION

Light propagates through an isotropic medium in a straight line, independent of polarization. The direction of the light is changed only by changing the medium or by introducing anisotropy.

In the past, control of light deflection was mainly performed by mechanically changing the boundary conditions, e. g., changing the angle of incidence at the surface of a mirror. The mechanical inertia involved in this process of deflection limits the deflection speed to frequency responses in the range of some 10,000 cps.

The electrically controlled light deflectors described in this report are based on the principle of generation of anisotropy in the medium. The generated anisotropy is without inertia up to microwave frequencies. Three concepts are described in this report. One of them is of a digital nature, where a light beam can be switched discontinuously to a sequence of discrete positions by applying one fixed electrical voltage to properly selected electro-optic switches. Another concept is of analog nature, where a light beam can be directed to a continuous sequence of positions by changing the voltage applied to one electro-optic active crystal. This deflector is based on the phenomenon of internal conical refraction. The third concept refers to a Fresnel lens structure which allows focusing/defocusing action under the influence of an electric field. Depending on the application, it could be operated under digital or analog conditions.

DIGITAL LIGHT DEFLECTOR

General

Unpolarized light, passing through a birefringent crystal such as calcite, splits into an ordinary and an extraordinary ray which propagate through the suitably oriented crystal in different directions. In the digital light deflector, linearly polarized light can be controlled by electro-optic switches to pass through calcite crystals as either the ordinary or the extraordinary ray. The principle is shown in Figure 1, where a linearly polarized collimated light beam of small diameter passes through an arrangement of

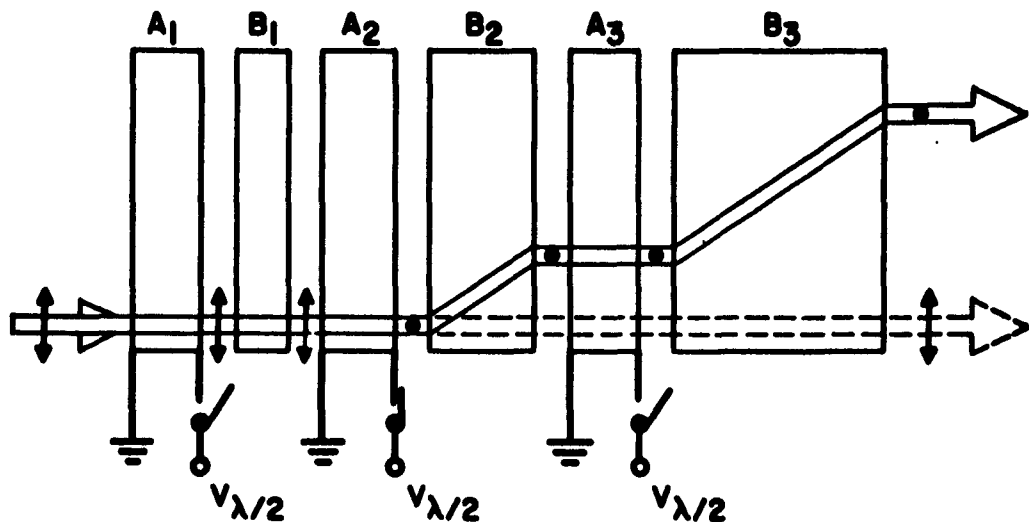


Figure 1. Digital light deflector for collimated beams.

electro-optic switches A and calcite crystals B. The original polarization direction is assumed to be vertical. The electro-optic switches, A, change the direction of polarization from vertical to horizontal or vice versa after application of the half-wave length voltage $V_{\lambda/2}$. For the switch positions

shown in Figure 1, no voltage is applied to A_1 , and the polarization direction of the incident light beam remains vertical traversing this switch. The light passes through the first calcite crystals, B_1 , as the ordinary ray. Since $V_{\lambda/2}$ is applied to the second switch, A_2 , the light leaves this switch horizontally polarized and passes through calcite crystal B_2 as the extraordinary ray. No voltage is applied to A_3 , and therefore, the polarization direction of the beam remains horizontal, the beam also traversing calcite crystal B_3 as the extraordinary ray.

In this way, with several switches and calcite crystals arranged as shown in Figure 1, a multiplicity of different output loci can be switched digitally. The thickness of the calcite crystals can be changed from stage to stage in a binary sequence. In this case, a maximum of different output loci can be switched by a minimum of switches.

We are considering two versions of the digital light deflector — collimated beam and converging beam. The deflector (Figure 1) for a collimated beam is the simpler of the two, but it has some limitations with regard to intensity and resolution of the deflected beam. In our effort to achieve higher resolution and higher intensity, we are also studying a second version of the digital light deflector (Figure 2) which involves sending a converging beam through the device and focusing on the other side. In this way, we can make full use of the aperture, a , of the device and obtain smaller useable spots of light, thus increasing the number of deflection positions for a given crystal size. For demonstration, referring to Figure 2, another

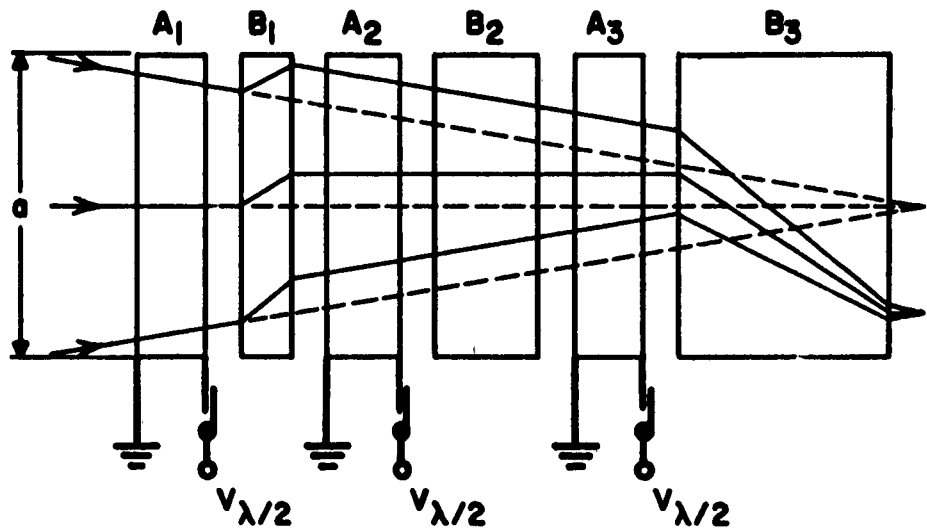


Figure 2. Digital light deflector for convergent beams. (For symmetrical deflection, calcite crystal B₃ is arranged upside down.)

selection of electro-optic switches is chosen by which the beam is deviated in the calcite crystals B₁ and B₃.

In view of the design problems associated with the converging beam deflector, we have decided to work initially on a model of the deflector utilizing the narrow collimated beam. We note that this device possesses potential for displays, production of hard copy, and interrogation of optical read-only memories.

Accomplishments

During this reporting period we:

- (1) started the design of a bread-board model of a linear digital light deflector for 8 positions, utilizing a collimated beam of about 1 mm diam. This model is equipped with calcite crystals of 5 by 12 mm aperture and it

will be about 20 cm long. The bread-board model will be delivered to USASRDL after completion.

(2) measured the half-wave length voltages $V_{\lambda/2}$ of the electro-optic active materials ammonium dihydrogen phosphate $\text{NH}_4\text{H}_2\text{PO}_4$ (ADP), potassium dihydrogen phosphate KH_2PO_4 (KDP) and potassium dideuterium phosphate KD_2PO_4 (heavy water KDP). $V_{\lambda/2}$ is the voltage necessary for a 90° rotation of the plane of polarization. Figure 3 shows the results, according to which $V_{\lambda/2}$ assumes the smallest values in heavy water KDP. The half-wave length voltage depends almost linearly on the wave length, being smaller in the blue than in the red. At the wave length $\lambda = 546.1 \text{ m}\mu$, $V_{\lambda/2}$ is:

ADP	9.4 kv
KDP	7.7 kv
KDP (heavy water)	3.4 kv

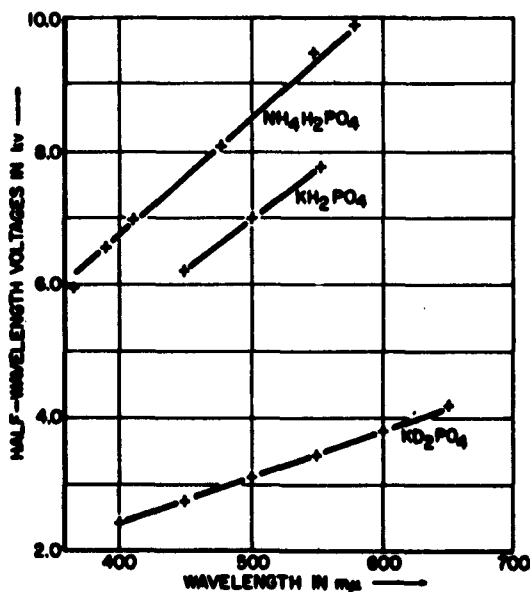


Figure 3. Half-wave length voltages $V_{\lambda/2}$ of $\text{NH}_4\text{H}_2\text{PO}_4$, KH_2PO_4 , and KD_2PO_4 as a function of wave length.

(3) determined the cutting direction for optimum separation of the ordinary and extraordinary rays in calcite as shown in Figure 4. The angle between the rays, $\epsilon_{\max}$, for calcite is approximately 6° . This angular separation indicates that calcite is a satisfactory birefringent crystal for use in the digital light deflector.

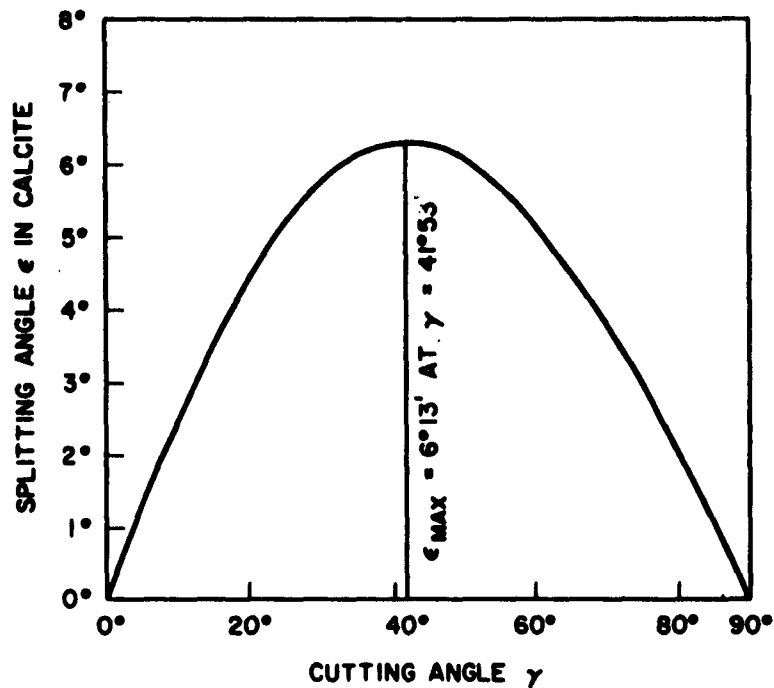


Figure 4. Orientation of calcite crystals for maximum splitting of ordinary and extraordinary rays.

Looking forward to a deflector utilizing convergent light beams we:

(4) calculated the relation between the maximum number of resolvable positions and aperture of the deflector due to diffraction as shown in Figure 5. This calculation indicates that a 1000 position linear digital light deflector is feasible without requiring too large crystals.

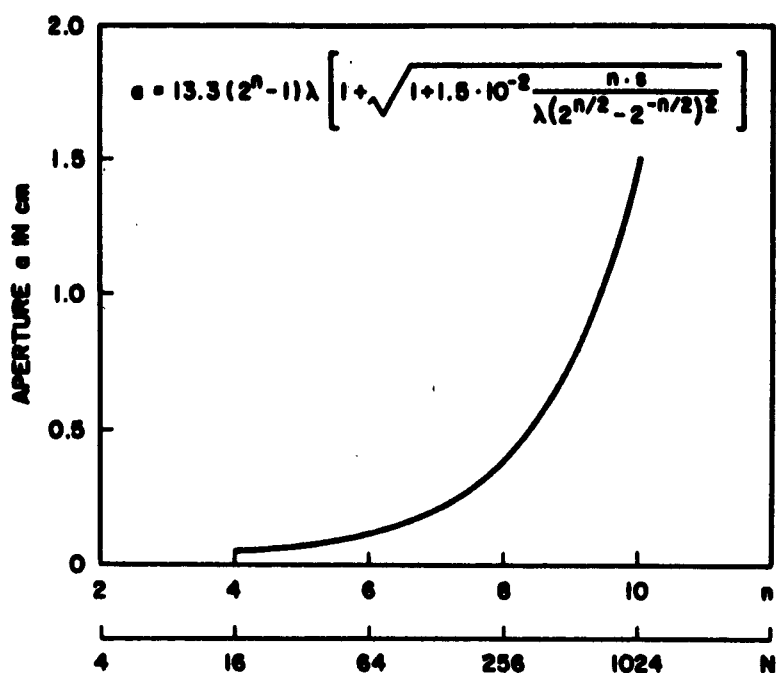


Figure 5. Minimum aperture, a , of the convergent beam deflector for N resolvable spots.

(5) calculated the minimum spot size δ with relation to the number of resolvable spots (Figure 6) for a convergent beam deflector of aperture, $a = 1.2$ cm. Due to diffraction at the aperture, the spot size will be approximately 30μ for a field of 256 resolvable spots.

(6) investigated compensation of angular birefringence in KDP crystals employing a 90° rotation quartz crystal arranged between two properly oriented KDP crystals.¹ Figure 7 shows the zero field transmission of the compensated electro-optic switch as a function of incidence angle of light. Compensation is essential in deflectors utilizing convergent beams since, without compensation, only collimated beams directed parallel to the optic axis find no birefringence in unswitched KDP crystals.

1. Wiley, C. A., U. S. Patent 2, 780, 958, December 1950.

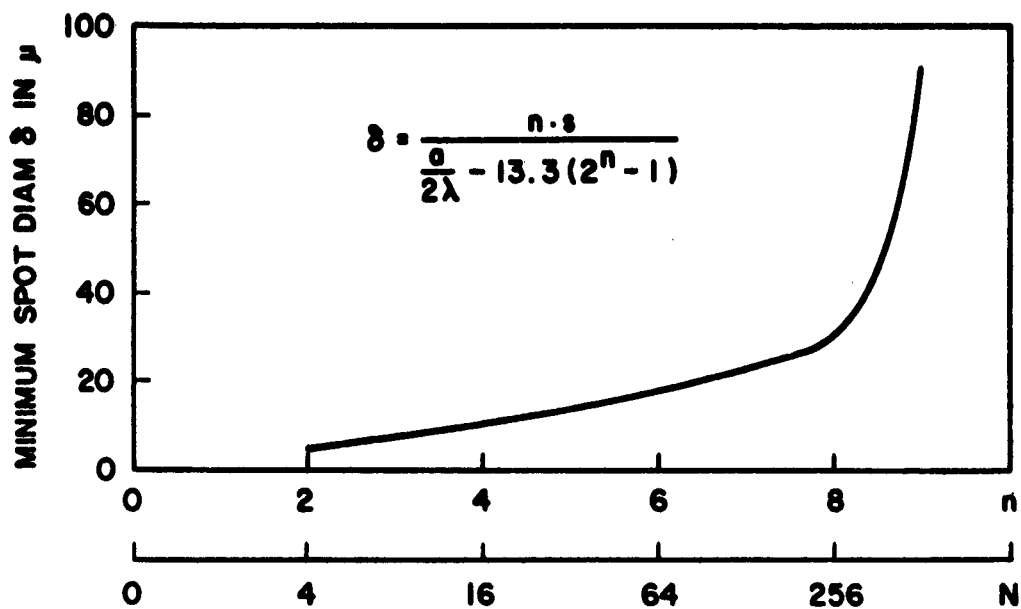


Figure 6. Minimum spot size of a convergent beam deflector having a 1.2 cm aperture.

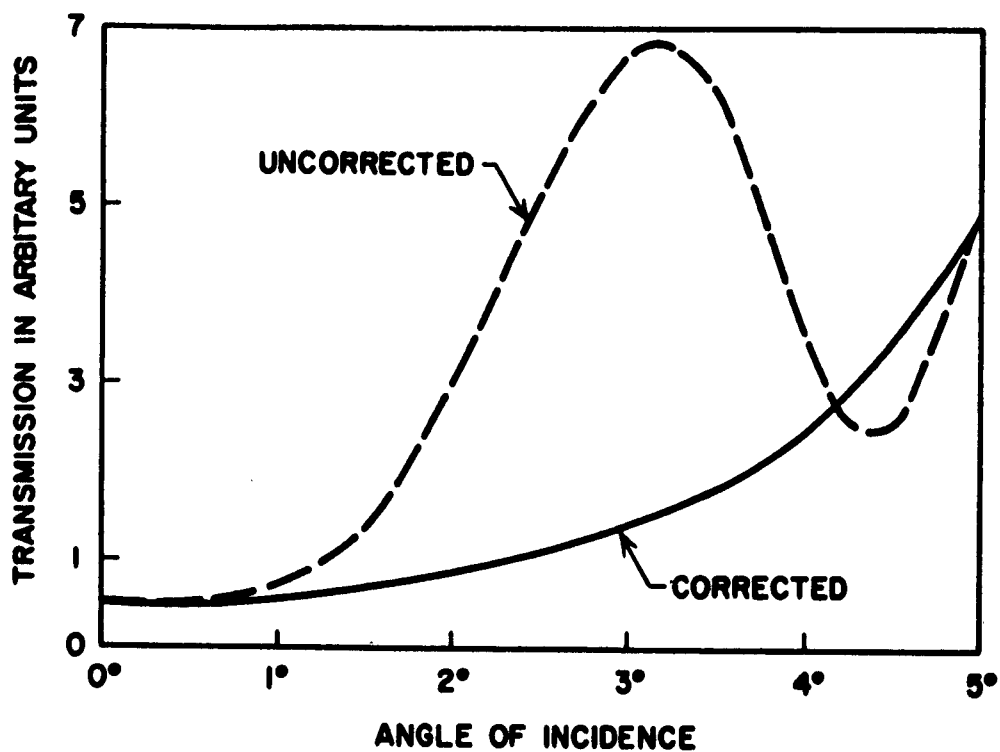


Figure 7. Compensation of angular birefringence.

Calculation of maximum splitting angle in an optically birefringent crystal

The following symbols apply to Figure 8.

- IE principal section (X-Z plane) through the index ellipsoid of a birefringent crystal
- λ angle between the normal on the crystal and the Z axis of the index ellipsoid
- LO light beam - normally incident on the surface of the crystal
- OA path of the ordinary ray within the crystal
- OE path of the extraordinary ray within the crystal, which according to theory of crystal optics is parallel to T
- ϵ angle between OA and OE which is to be calculated
- ON direction of oscillation of the D vector of the extraordinary ray. The length of O-N is equal to the index of the refraction n' of the extraordinary ray. Due to the normal incidence of LO, ON lies in the surface of the crystal
- T Tangent on IE at N

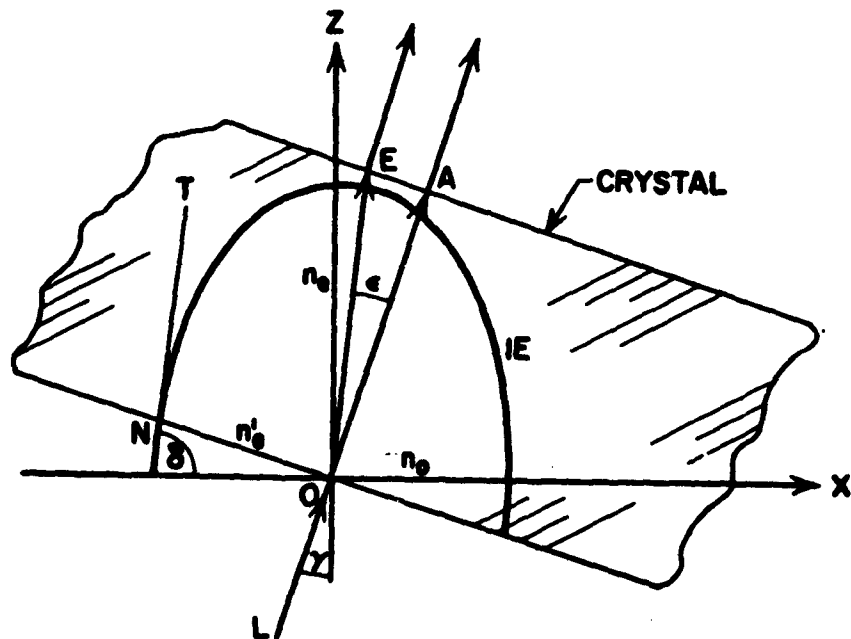


Figure 8. Calculation of maximum splitting angle.

The equation of the index ellipsoid is $\frac{x^2}{n_o^2} + \frac{z^2}{n_e^2} = 1$

It yields for T

$$\tan \delta = - \left(\frac{n_e}{n_o} \right)^2 \frac{x}{z} = \left(\frac{n_e}{n_o} \right)^2 \frac{1}{\tan \gamma}$$

Therefore

$$\epsilon = \gamma + \delta - \frac{\pi}{2} = \gamma + \arctan \left[\left(\frac{n_e}{n_o} \right)^2 \frac{1}{\tan \gamma} \right] - \frac{\pi}{2}$$

The maximum condition $\frac{\partial \epsilon}{\partial \gamma} = 0$ yields for $\epsilon_{\max}$

$$\epsilon_{\max} = \arcsin \frac{n_e}{\sqrt{n_e^2 + n_o^2}} + \arctan \left(\frac{n_e}{n_o} \right) - \frac{\pi}{2}$$

Calculation of the relation between the numbers of positions and the aperture of a digital deflector, for convergent beams

In Figure 9, the following symbols are used:

- a input aperture of the deflector
- s space necessary for each electro-optic rotator
- Δ thickness of the first calcite crystal
- $n\Delta$ thickness of the nth calcite crystal
- δ diameter of the first order diffraction ring
- α diffraction angle
- L total length of the deflector
- n number of stages
- N number of resolvable spots

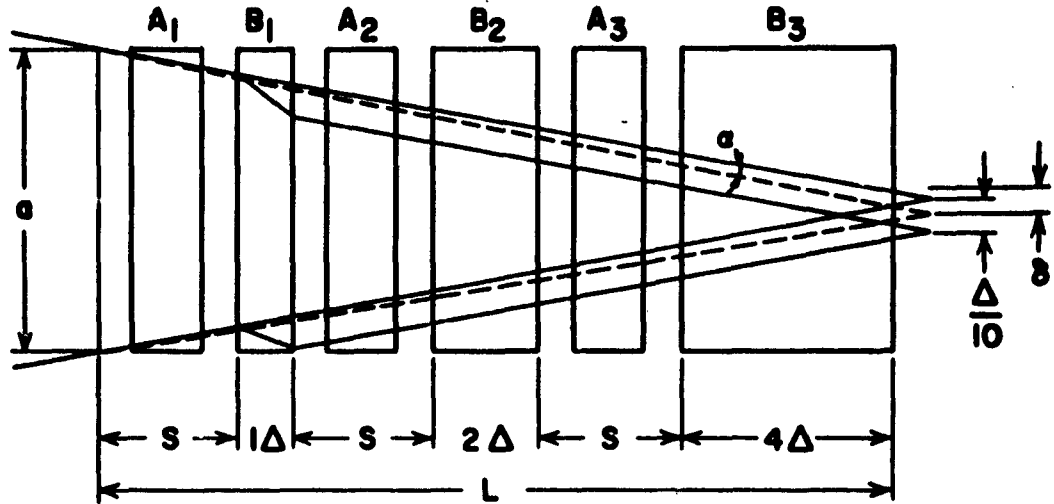


Figure 9. Diffraction problem in the digital deflector.

In calcite crystals, the splitting angle between the two rays is $\approx 6^\circ$. The separation of outputs therefore is $\Delta \cdot \frac{\pi}{180} \cdot 6 \approx \frac{\Delta}{10}$. For a good resolution of neighboring spots, it is assumed $\frac{\Delta}{10} = 1.33 \delta$.

Starting with

$$L = n \cdot s + \sum_{v=1}^n 2^{v-1} \Delta = n \cdot s + (2^n - 1) \Delta$$

and the relation for the first order diffraction minimum

$$L = \frac{\delta}{2 \sin \alpha} \approx \frac{\delta a}{2 \lambda}$$

one finds the minimum spot size is:

$$\delta = \frac{n \cdot s}{\frac{a}{2 \lambda} - 13.3(2^n - 1)}$$

The curve of Figure 6 is calculated for $s = 3$ cm space for each electro-optic switch, an aperture $a = 1.2$ cm and a wave length $\lambda = 546.1$ mμ.

The minimum aperture, a , for N resolvable spots can be calculated from the above equation by setting the aperture, a , equal to the space needed for the N resolved spots:

$$1.33 \delta \cdot 2^n = a$$

This yields

$$a = 13.3 (2^n - 1) \lambda \left[1 + \sqrt{1 + 1.5 \cdot 10^{-2} \cdot \frac{s \cdot n}{\lambda (2^{n/2} - 2^{-n/2})^2}} \right]$$

The curve of Figure 5 is calculated for $s = 3$ cm and $\lambda = 546.1$ m μ

CONICAL REFRACTION

General

Conical refraction was originally predicted theoretically in 1832 in Hamilton² and experimentally confirmed by Lloyd² in 1833. An infinite number of possible propagation directions of irradiated light exists in conical refraction. These directions form a cone in the crystal. Incident polarized light leaves the crystal with a $\cos^2$ distribution of intensity on the periphery of a cylinder. The locus of maximum light intensity depends on the polarization direction of incoming light and therefore can be controlled electrically by the aid of an electro-optic rotator (Figure 10). The relatively low resolution of this deflectable $\cos^2$ distribution can be improved to a $\cos^4$ distribution by the aid of a second identical electro-optic rotator (Figure 11 and Appendix I). Additional improvement can be obtained by the combination with other analog deflectors of higher resolution which need some predeflection

² Szivessy, G: Kristalloptik, In Geiger and Scheel's Handbuch d. Physik, Vol. 20, pp. 635-904 Berlin, Springer 1928

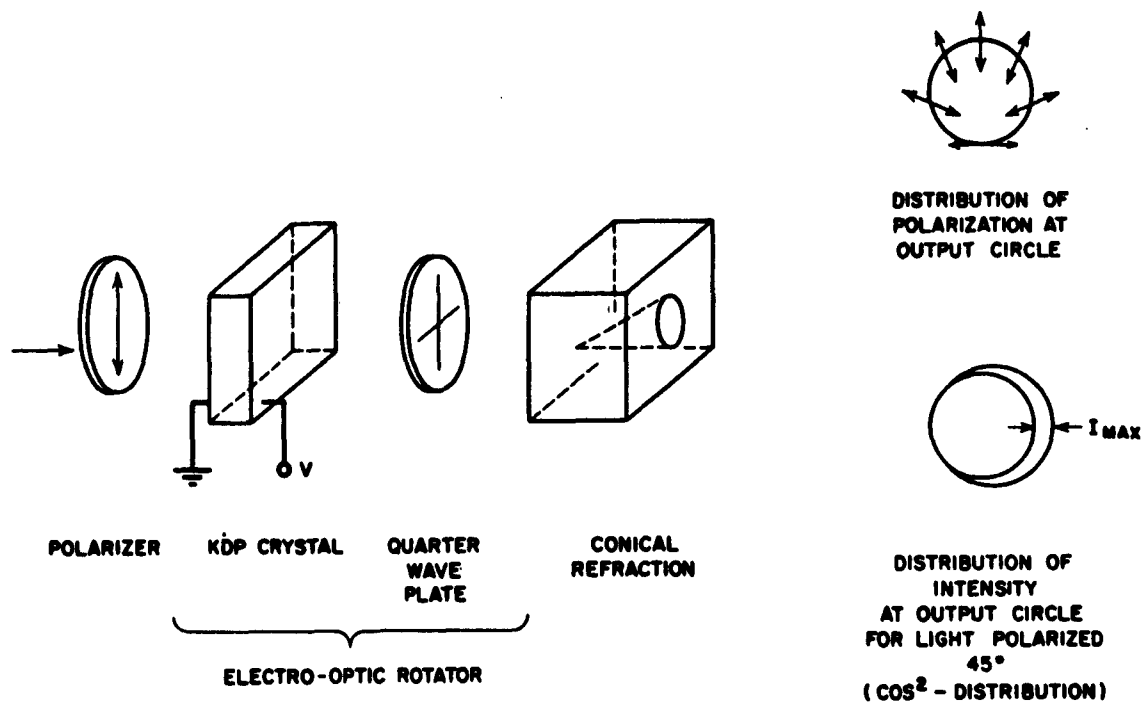


Figure 10. Light deflection by conical refraction.

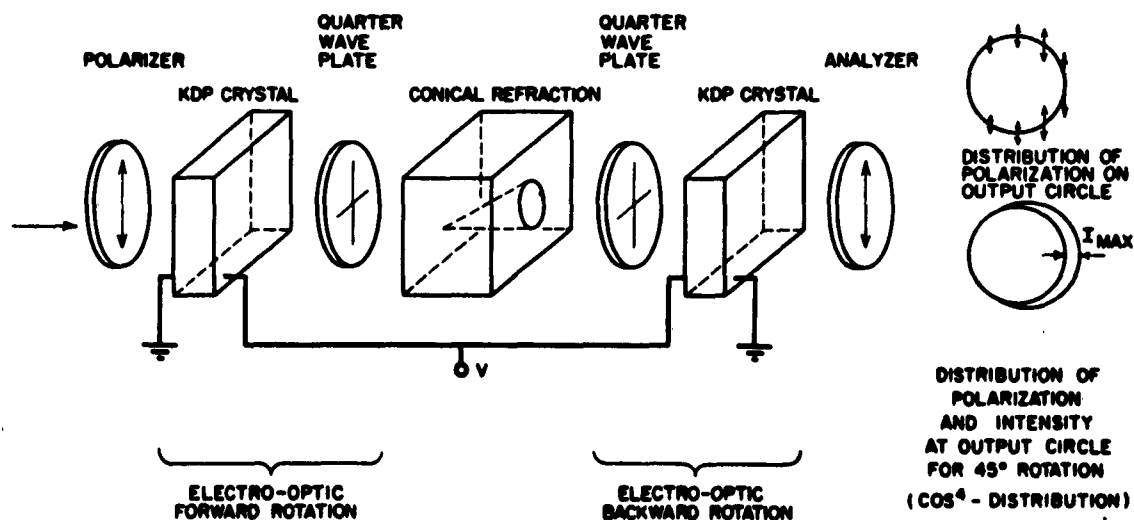


Figure 11. Improved light deflection by conical refraction.

of the beam to yield a useful light intensity. Our prime motivation for investigating conical refraction is to explore its usefulness in an analog light deflection system, but in addition there are uncertainties related to a basic understanding of the phenomenon.

Accomplishments

As part of our work in the first quarter reporting period on conical refraction, we calculated (Appendix II) the cone angle ϵ of several materials:

Anthracene	$18^{\circ}30'$
Naphthalene	$13^{\circ}42'$
Hydrocarbostyryl	$10^{\circ}56'$
Naphthalene disulfonic acid	$10^{\circ}17'$
Stilbene	$3^{\circ}49'$
Aragonite	$1^{\circ}48'$
Turquoise	$1^{\circ}9'$
Topaz	$0^{\circ}11'$

On the basis of the table, and availability of materials, we are investigating anthracene, naphthalene, and aragonite.

We contacted Harshaw Chemical Co., Isomet Corp. and Semielements, Inc. for single crystals of suitable materials. Although we succeeded in getting naphthalene crystals, these crystals exhibited some unfavorable properties such as unsatisfactory optical quality and high vapor pressure.

The major part of this quarter's effort on conical refraction was devoted to:

- a) surface protection
- b) cutting, grinding, and polishing naphthalene crystals
- c) orienting naphthalene crystals for optic axis determination
- d) calculating an improved electro-optic analog light deflector wiring conical refraction

We succeeded in finding the optic axes and obtaining conical refraction in crystal slices approximately 0.3 mm thick. Pin hole diaphragms had to be used to detect the output circle at this thickness. These diaphragms did not permit collimation of the input beam. We have not, as yet, succeeded in obtaining conical refraction with thicker naphthalene plates. Since this is partly due to the unsatisfactory optical quality of these crystals, we have begun a review of other possible materials.

ELECTRICALLY CONTROLLED FRESNEL ZONE LENS

If normal light is passed through a grating the periodicity of which is in the order of some hundreds of millimeters, the light will be diffracted at this grating. In certain directions, the light will interfere constructively, in other directions destructively so that the light leaves the grating diffracted in certain directions.

A Fresnel zone lens is a concentric grating the periodicity of which varies with the distance from the center. The boundaries between lines and slits are called zones. If the radius of the m -th zone is

$$r_m = \sqrt{m f \lambda}$$

(where λ is the wave length of light), the collimated light passing through the plate is focussed to a point at the axis at a distance, f , from the plate. This action of a Fresnel zone lens is described in more detail by others.^{3,4} The basic idea of the Fresnel zone lens of this contract is shown in Figure 12. An electro-optic active crystal (e. g. a KDP crystal) is oriented so that the

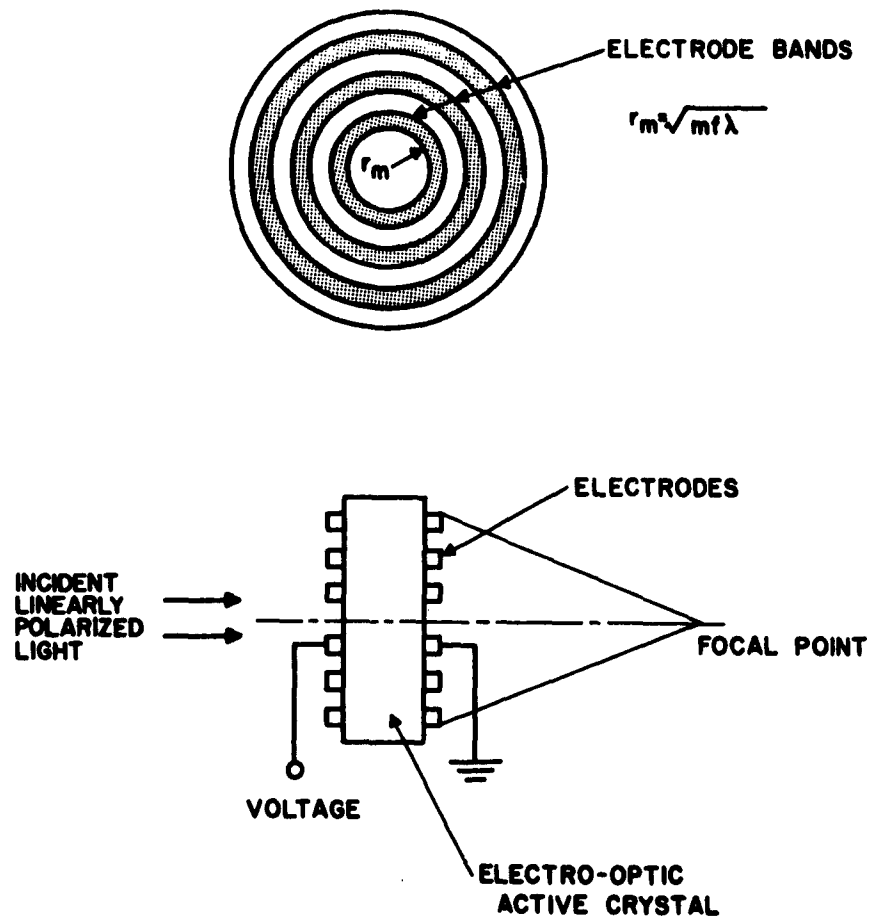


Figure 12. Electrically controlled Fresnel zone lens.

³ R. S. Longhurst, Geometrical and Physical Optics, Wiley, 1962, p. 261 ff.

⁴ Rome Air Dev. Center (contract AF 30(602) - 2457)

incident collimated light - which is also linearly polarized - passes through this crystal in the direction of its optic axis. To the front and back surface of the crystal are attached bands of transparent electrodes the spacing of which is according to that of Fresnel zones. An electric voltage $V_{\lambda/2}$ can be applied to these electrodes. This effects the crystal to become birefringent in the areas between opposite electrodes so that the plane of polarization of the light passing through this area is rotated for 90° .

The action of the Fresnel zone plate is the following: If no voltage is applied to the electrodes the incident light finds an isotropic plate through which it passes unaffected. After application of the voltage $V_{\lambda/2}$ the light which passes through the electrode areas experiences 90° rotation of its plane of polarization. Therefore this light no longer is capable of interfering with the light which has passed through areas not covered by the electrodes. Thus, the rotated and the not rotated parts of the light beam each act as the light in a normal Fresnel lens: they are focussed to the focal point.

A variation of this principal idea comprises the use of opaque electrodes. In a similar arrangement like that of Figure 12, either no light is transmitted or the light is focussed. Other variations comprise effects arising if the applied voltage is varied continuously.

During this quarterly reporting period we:

(1) tried to get a pattern of five opaque electrode bands. Photo-etched copper plates were used as masks for vacuum deposition. The evaporated electrode pattern, however, was too blurred at the edges to be useful.

(2) we calculated the zone radii for the first 100 zones for $f = 30$ cm and $f = 50$ cm focal length. For exact values this work was done by our computer dept. The results are shown in Table I and II and indicate the minute work to be spent for the electrodes.

(3) we are now examining the feasibility of photo-etching glass substrates to produce the fine resolution electrode structure required for a 50 zone-electrode Fresnel lens.

As is evident from the description of our activity on the Fresnel lens, our major problem is to obtain an electrode structure with sufficient precision to produce a good focusing action.

Table I. Zone radii of Fresnel lens for $f = 30$ cm at $\lambda = 546.1$ m μ .

Zone Number	Radius (cm)	Zone Number	Radius (cm)	Zone Number	Radius (cm)
1	0.0404759	36	0.2428555	71	0.3410562
2	0.0572416	37	0.2462054	72	0.3434496
3	0.0701063	38	0.2495103	73	0.3458264
4	0.0809518	39	0.2527720	74	0.3481870
5	0.0905069	40	0.2559922	75	0.3505317
6	0.0991453	41	0.2591723	76	0.3528609
7	0.1070892	42	0.2623139	77	0.3551747
8	0.1144832	43	0.2654183	78	0.3574736
9	0.1214278	44	0.2684869	79	0.3597578
10	0.1279961	45	0.2715207	80	0.3620276
11	0.1342434	46	0.2745210	81	0.3642833
12	0.1402127	47	0.2774889	82	0.3665250
13	0.1459380	48	0.2804254	83	0.3687532
14	0.1514470	49	0.2833314	84	0.3709679
15	0.1567626	50	0.2862080	85	0.3731695
16	0.1619037	51	0.2890559	86	0.3753582
17	0.1668865	52	0.2918760	87	0.3775342
18	0.1717248	53	0.2946691	88	0.3796978
19	0.1764304	54	0.2974360	89	0.3818491
20	0.1810138	55	0.3001774	90	0.3839883
21	0.1854840	56	0.3028940	91	0.3861157
22	0.1898489	57	0.3055865	92	0.3882314
23	0.1941157	58	0.3082554	93	0.3903356
24	0.1982907	59	0.3109014	94	0.3924286
25	0.2023796	60	0.3135251	95	0.3945105
26	0.2063875	61	0.3161270	96	0.3965814
27	0.2103190	62	0.3187077	97	0.3986416
28	0.2141784	63	0.3212676	98	0.4006912
29	0.2179695	64	0.3238073	99	0.4027303
30	0.2216957	65	0.3263273	100	0.4047592
31	0.2253604	66	0.3288279		
32	0.2289664	67	0.3313097		
33	0.2325164	68	0.3337730		
34	0.2360131	69	0.3362182		
35	0.2394588	70	0.3386458		

Table II. Zone radii of Fresnel lens for $f = 30$ cm at $\lambda = 546.1$ m μ .

Zone Number	Radius (cm)	Zone Number	Radius (cm)	Zone Number	Radius (cm)
1	0.0522542	36	0.3135251	71	0.4403016
2	0.0738986	37	0.3178498	72	0.4433915
3	0.0905069	38	0.3221164	73	0.4464600
4	0.1045084	39	0.3263273	74	0.4495075
5	0.1168439	40	0.3304845	75	0.4525345
6	0.1279961	41	0.3345900	76	0.4555414
7	0.1382516	42	0.3386458	77	0.4585286
8	0.1477972	43	0.3426536	78	0.4614965
9	0.1567626	44	0.3466151	79	0.4644454
10	0.1652422	45	0.3505317	80	0.4673757
11	0.1733075	46	0.3544051	81	0.4702877
12	0.1810138	47	0.3582366	82	0.4731818
13	0.1884051	48	0.3620276	83	0.4760583
14	0.1955173	49	0.3657793	84	0.4789175
15	0.2023796	50	0.3694929	85	0.4817598
16	0.2090167	51	0.3731695	86	0.4845854
17	0.2154495	52	0.3768103	87	0.4873946
18	0.2216957	53	0.3804162	88	0.4901877
19	0.2277707	54	0.3839883	89	0.4929650
20	0.2336878	55	0.3875274	90	0.4957267
21	0.2394588	56	0.3910345	91	0.4984732
22	0.2450939	57	0.3945105	92	0.5012045
23	0.2506023	58	0.3979560	93	0.5039211
24	0.2559922	59	0.4013720	94	0.5066231
25	0.2612709	60	0.4047592	95	0.5093108
26	0.2664451	61	0.4081182	96	0.5119844
27	0.2715207	62	0.4114499	97	0.5146440
28	0.2765032	63	0.4147547	98	0.5172900
29	0.2813974	64	0.4180335	99	0.5199226
30	0.2862080	65	0.4212867	100	0.5225419
31	0.2909390	66	0.4245150		
32	0.2955943	67	0.4277189		
33	0.3001774	68	0.4308991		
34	0.3046916	69	0.4340559		
35	0.3091399	70	0.4371899		

CONCLUSIONS

On the basis of our work during this quarterly reporting period, we have arrived at the following conclusions:

a. Digital light deflection by means of a combination of electro-optic switches and passive birefringent crystals has shown promise of meeting our performance expectations for practical display and printing apparatus using optical masers as the high-intensity light source.

b. Conical refraction is a difficult phenomenon to work with, but nevertheless shows promise for those applications requiring analog control of deflections.

c. An electrically controlled focus/defocus lens employing the Fresnel zone plate principle requires fine detail in its electrode construction, but is promising as an amplitudemodulation device for optical masers.

d. We have decided to devote our major efforts to the design and construction of the digital light deflector during the next quarter of the contract.

PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

CONFERENCES

A conference was held 25 January 1963 at Fort Monmouth, New Jersey between Messrs. W. Huber, and D. Bonda at Fort Monmouth and Messrs. J. Ballance, D. A. Raunick and H. Fleisher of IBM to review the work to date and discuss future plans on the Laser study. Dr. Fleisher indicated, and Messrs. Huber and Bonda agreed that at a later date it may be desirable to change direction -- especially in the deflections study.

A conference was held on February 6, 1963 at IBM, Poughkeepsie, New York between Mr. Bonda at Fort Monmouth and Messrs H. Fleisher and D. Raunick of IBM. Mr. Bonda reviewed the monthly letter report format and met the personnel assigned to work on this contract. Dr. Fleisher conducted a tour of the laser laboratories and demonstrated two basic experiments which have been set up under the contract.

PATENTS REDUCED TO PRACTICE

Docket No: 7662

Title: "A Digital Index Electro-Optic Light Beam Deflection System"

Inventors: W. Kulcke and T. J. Harris

KEY PERSONNEL

The following key personnel are directly assigned to this contract:

Name	Title	Approximate Man-hours worked on this contract
Dr. Harold Fleisher	Senior Physicist	130
Dr. Werner Kulcke	Physicist	240
Kurt Kosanke	Physicist	240
William Robinson, Jr.	Senior Associate Engineer	16
Werner Schneider	Technician	240

Resume data for each of the key personnel follows.

HAROLD FLEISHER

Dr. Fleisher is the manager of IBM's Electro-Optics Laboratory, Poughkeepsie, New York. This contract is under his immediate direction and supervision. He has been a research physicist and senior engineer at various academic institutions and industrial companies. He has managed many technical and administrative groups at IBM, has written many technical articles, and has contributed chapters to scientific and technical books. He holds several patents and many disclosures. In list form, Dr. Fleisher's wide technical and scientific background and accomplishments are:

1. Research Assistant in Physics Department and Institute of Optics during 1942-1943, University of Rochester.

2. Staff Member, Radiation Laboratory, Massachusetts Institute of Technology, during 1943-1946.
3. Senior Engineer, Rauland Corporation, Chicago, Illinois, during 1946.
4. Instructor at the Case Institute of Technology during 1946-1950.
5. Physicist at International Business Machines Corporation (Engineering Laboratories), Poughkeepsie, New York. Worked on transistor research and development, 1950-1956.
6. Manager of Research Communications 1956-1958, IBM Research Laboratory.
7. Manager, Theory of Machine Organization, IBM Research Laboratory, 1959 to September 1961.
8. Manager, Exploratory Electro-Optics (present).

Education

BA (Physics) University of Rochester (1942)

MS (Physics) University of Rochester (1943)

PhD (Physics) Case Institute of Technology (1951)

Papers

1. Chapter 10 in Volume 18, "Vacuum Tube Amplifiers" Radiation Laboratory Series.
2. Two chapters in Handbook of Semi-Conductor Electronics.
3. Articles on graphical analysis of transistor, published in Proceedings of IRE; and on Information Theory, published in Library Quarterly.

4. Currently working on book on Logic and Switching.

5. Internal Technical Reports.

Patents and Disclosures

Four patents on switching circuits and 21 disclosures.

Societies (Member)

American Physical Society, Sigma X₁ and RESA; Institute of Radio Engineers; Institute of Symbolic Logic; American Mathematical Society.

Honors

Turnbull Fellowship at Case Institute of Technology.

Listed in American Men of Science; Industrial Who's Who.

WERNER KULCKE

Dr. W. Kulcke does theoretical and experimental work for the control of light. Previously, Dr. Kulcke was manager of the Electro-Optics project at the German IBM Laboratories in Boeblingen. At the German Laboratory he worked on problems of polarization optical logic, electro-optic measurements in ferroelectric crystals, and he supervised the construction of the feasibility model of a very high speed electro-optic character generator.

Before joining IBM he worked on X-ray investigations of the structures of amorphous selenium at the T. H. Stuttgart/Germany and he developed a radio-sonde for measurement of the ozone content of the upper atmosphere at the Max-Planck Institute for Physics of the Stratosphere. The latter work was done for the International Geophysical Year 1956-57 and the apparatus is now used by the U. S. Weather Bureau.

Education

Diploma in Physics T. H. Stuttgart/Germany

Thesis - Max-Planck Institute for Physics of the Stratosphere

Weissenau/Germany

Dr. ver. nat. T. H. Stuttgart/Germany

Patents and Disclosures

One patent and 11 disclosures.

Papers

Two papers on Physics of the upper atmosphere and X-ray analysis, published in German Journals.

Three technical reports and 5 laboratory reports on different electro-optic subjects.

Memberships

Member of the Germany Physical Society.

KURT KOSANKE

Mr. Kosanke, received a thorough training in the design and fabrication of optical instruments while working for the I. D. Moeller Company in Germany before returning to school. After graduating with an Engineer of Physics degree from the Physics Techn. Lehranstalt, Luebeck, Mr. Kosank joined IBM, Germany. There he first attended a training course on IBM machines and was subsequently assigned to working on the electro-optic effect in crystals in the IBM Laboratories in Germany.

Mr. Kosanke recently transferred to the IBM Data Systems Laboratory in the United States to continue working in electro-optics effects and devices.

Education

Engineer of Physics, Physics Techn. Lehranstalt, Luebeck, Germany.

Patent Disclosures

2

Papers

2 IBM reports pertaining to electro-optic effects and devices.

Memberships

VDI (Verein Deutscher Ingenieure) Germany

WILLIAM J. ROBINSON, JR.

Mr. Robinson work in the IBM Data Systems Division Optics Laboratory involves the specifications and alignment of all optics equipment. He sets up and assists in the optics experiments for the study of laser output and laser application. Mr. Robinson has had extensive experience in optics. As Optical Engineer for Autometric Corporation he was engaged in the alignment of optics in Zenith Star camera, Uniscale Matcher Photogrammetric apparatus and preliminary "mock-ups" of optical radar restitutor and other photogrammetric instruments.

At the Perkin-Elmer Corporation he conducted the alignment of Optical Reference for missile firing system in nuclear submarines; conducted studies of human cornea plotter for the research department; planned over-all optical testing facilities and photographic darkrooms for a new engineering

building. He aligned the optical readout system for ROTI missile tracking telescope at White Sands Missile Range; and conducted distortion measurements of "Geocon" aerial camera lenses.

He was the Resident Engineer for Cape Canaveral Optics, handling problems concerned with all optical and photographic equipment at Cape Canaveral and outlying camera stations. Cared for all optical engineering problems relating to cameras, lenses, tracking mounts and allied facilities.

At Patrick Air Force Base (Cape Canaveral), Mr. Robinson was in the Quality Analysis group for the investigation of optical tracking data and the study of optical instrumentation errors.

At Arma Corporation, he was engaged in optical engineering on problems relating to the manufacturing of the T-41 stereoscope range finder for medium tanks. He worked on the development and design of test equipment through test-to-production stage of program.

At the Zoomar Corporation, Mr. Robinson was engaged in the development and field engineering of special effects lenses and related devices for motion picture and television cameras.

At Western Union, he was in charge of applications investigations for the Western Union Concentrated Arc Lamp (Zirconium Arc) and other by-products of Western Union Research.

While in the Army, Mr. Robinson served as Research Assistant in Instrumentation, interpretation of data and the development of theory on the tropical environments studies staff of laboratory, and was in charge of statistical group.

As Development Engineer for Westinghouse, he was engaged in research and development in problems relating to manufacture of incandescent, fluorescent and vapor lamps, quality control problems, instrumentation and adaption to manufacture. Conducted special investigation on lamps for the armed forces.

Also, Mr. Robinson has served as a consultant in Optical Instrumentation for Sloan-Kettering Institute for Cancer Research, Edmund Scientific Corporation, and Star-Fuse Company, Inc.

Education

AB (Physics) Washington Missionary College (1942)

Electronics, Columbia University (1943-3)

Graduate Research Management, New York University (1949-50)

Papers

Rough Service Electrical Device -- U. S. Patent #2, 398, 595

Publications in: New York Times; Popular Science; Scientific American; Time; Life; Graphic Arts.

Lectures

"On Zirconium Arc"

To: New York Section, Technical Division, Photographic Society of America; Biological Photographers Association, National Convention; Alpha Chi Sigma Fraternity (Chemists), New York Chapter.

Professional Societies

Optical Society of America (member)

Technical Division, Photographic Society of America (Member and Chairman)

National Scholarship Committee (Member)

Honors

Certificate of Honor - New York Section, Technical Division, Photographic Society of American (1952)

WERNER SCHNEIDER

Mr. Schneider is presently engaged in the IBM Data Systems Division Optics Laboratory. According to his experiences he works on design and construction of the needed apparatus suggested in this project and he assists in the conduction of experiments.

Before joining IBM Mr. Schneider worked in the Daimler Benz AG, Sindelfingen, Germany on electronic control of machines for automobile manufacture. He joined IBM December 1960 and has worked since then on CdSe photo conductors, parts for the electronic control of the electro-optic high-speed printer, and on the growth of water soluble electro-optic active crystals (KDP, ADP).

Education

Technician Techn. Lehrinstitut, Weil/Rhein, Germany.

APPENDIX I.

Calculation of Improved Electro-Optic Light Deflector Utilizing Conical Refraction

The elements of the improved light deflector are shown in Figure 13.

The electric vector for incoming light from the left of the diagram is split into components as shown. Changes of components of the light as they occur in the elements of the deflector are calculated. The status of polarization with respect to the selected coordinates is also shown. The components of the electric vector E of the light are described below as the light leaves the element:

(1) Polarizer

$$E_x = 0 \text{ and } E_y = E_0 \sin \omega t$$

(2) KDP Crystal

(ψ = phase retardation produced by voltage v)

$$E_{x'} = -1/2 \sqrt{2} E_0 \sin(\omega t + \psi) \text{ and } E_{y'} = 1/2 \sqrt{2} E_0 \sin \omega t$$

Therefore elliptically polarized light is obtained.

(3) Quarter Wave Plate

$$E_x = \sqrt{1/2 (1 - \cos \psi)} E_0 \sin(\omega t + \psi/2) \text{ and } E_y = \sqrt{1/2 (1 + \cos \psi)} E_0 \sin(\omega t + \psi/2)$$

Linearly polarized light, direction of polarization rotated for $\varphi = \psi/2 =$

$$\frac{\pi}{2} \quad \frac{v}{v_{\lambda/2}}$$

(4) Crystal with conical refraction

$$E(\varphi, \theta) = E_0' \cos(\theta - \varphi) \sin(\omega t + \varphi)$$

Therefore, the intensity $I(\varphi, \theta) = I_0' \cos^2(\theta - \varphi) \sin^2(\omega t + \varphi)$ which is the $\cos^2$ distribution.

(5) Quarter Wave Plate

$$E_x(\varphi, \theta) = E_0' \sin \theta \cos(\theta - \varphi) \cos(\omega t + \varphi)$$

$$E_y(\varphi, \theta) = E_0' \cos \theta \cos(\theta - \varphi) \cos(\omega t + \varphi)$$

(6) KDP Crystal

$$E_x'(\varphi, \theta) = -1/2 \sqrt{2} E_0' \cos(\theta - \varphi) \sin[\omega t - (\theta - \varphi)]$$

$$E_y'(\varphi, \theta) = 1/2 \sqrt{2} E_0' \cos(\theta - \varphi) \sin[\omega t + (\theta - \varphi)]$$

(7) Polarizer

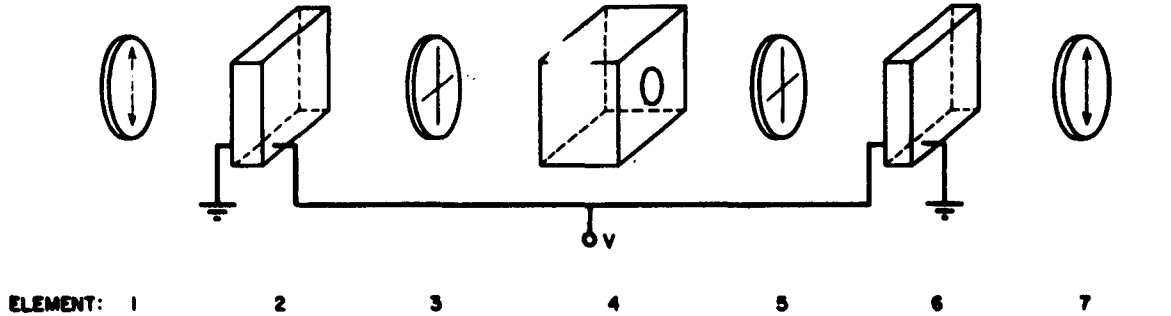
$$E_x = 0$$

$$E_y = E_0' \cos^2(\theta - \varphi) \sin \omega t$$

or the intensity

$$I(\varphi, \theta) = I_0' \cos^4(\theta - \varphi) \sin^2 \omega t$$

The light leaving the deflector has a distribution of intensity as $\cos^4(\theta, \varphi)$, with the maximum intensity at $\theta = \varphi$.



COORDINATES:

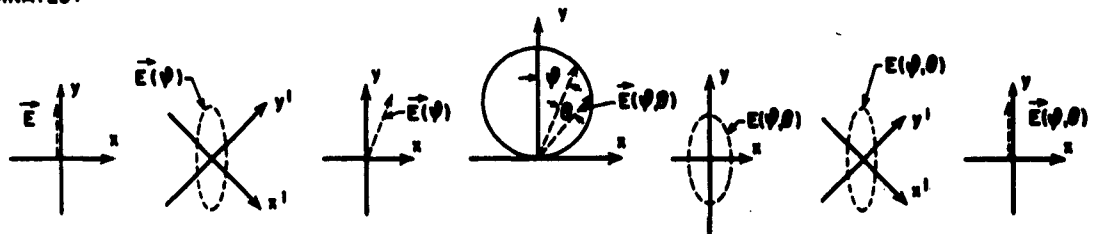


Figure 13. Calculation of improved electro-optic light deflector.

APPENDIX II

Calculation of the Cone Angle ξ of Conical Refraction

Referring to Figure 14, the cone angle, ξ , is found in the X-Z plane of the index ellipsoid. It is the angle between the optic axis OA and the line OP; therefore

$$\xi = V - W$$

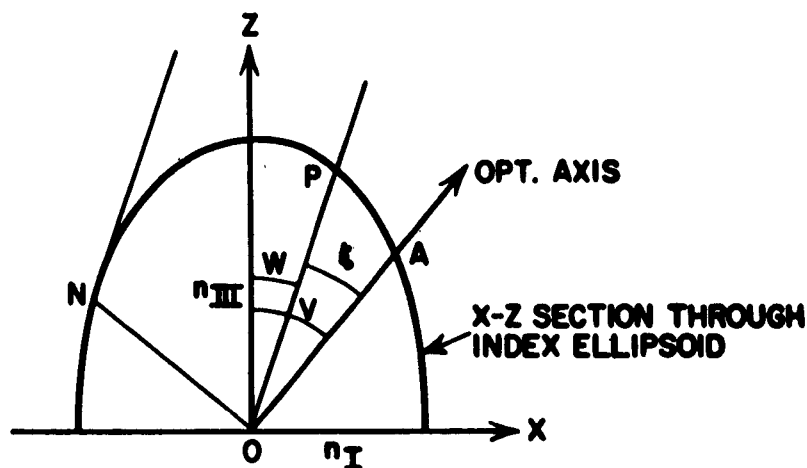


Figure 14. Calculation of cone angle ξ .

OP is the propagation direction of a beam having its wave normal parallel to the optic axis and being polarized in the X-Z plane. Its polarization direction ON is perpendicular to its wave normal OA. According to the theory of crystal optics the direction of propagation OP is parallel to the tangent to the index ellipsoid at N.

If n_I , n_{II} , n_{III} are the principal axes of the index ellipsoid, the angle V between the Z and the optic axis is⁵

$$\tan V = \sqrt{\frac{\frac{1}{n_I^2} - \frac{1}{n_{II}^2}}{\frac{1}{n_{II}^2} - \frac{1}{n_{III}^2}}}$$

With $\tan W = \frac{n_I^2}{n_{III}^2} \tan V$, ξ becomes

$$\xi = \arctan \sqrt{\frac{\frac{1}{n_I^2} - \frac{1}{n_{II}^2}}{\frac{1}{n_{II}^2} - \frac{1}{n_{III}^2}}} - \arctan \frac{n_I^2}{n_{III}^2} \sqrt{\frac{\frac{1}{n_I^2} - \frac{1}{n_{II}^2}}{\frac{1}{n_{II}^2} - \frac{1}{n_{III}^2}}}$$

⁵ Fluegge, S: Encyclopedia of Physics, Vol. XXV/1, P. 70.

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