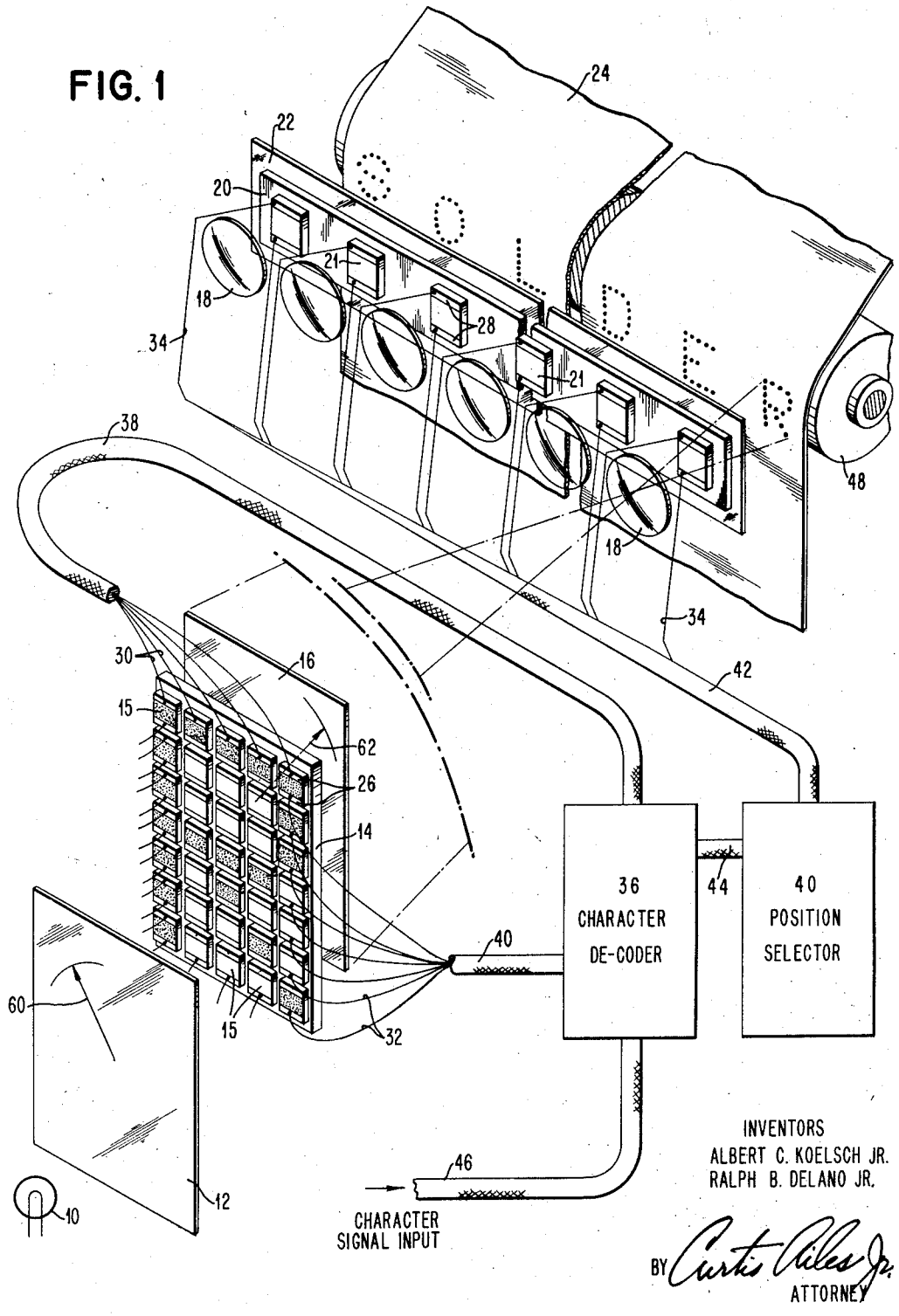
Oct. 27, 1959 A. C. KOELSCH, JR., ET AL 2,909,973

ELECTRO-OPTICAL DISPLAY APPARATUS

Filed Sept. 15, 1958 3 Sheets-Sheet 1

FIG. 1



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FIG. 2

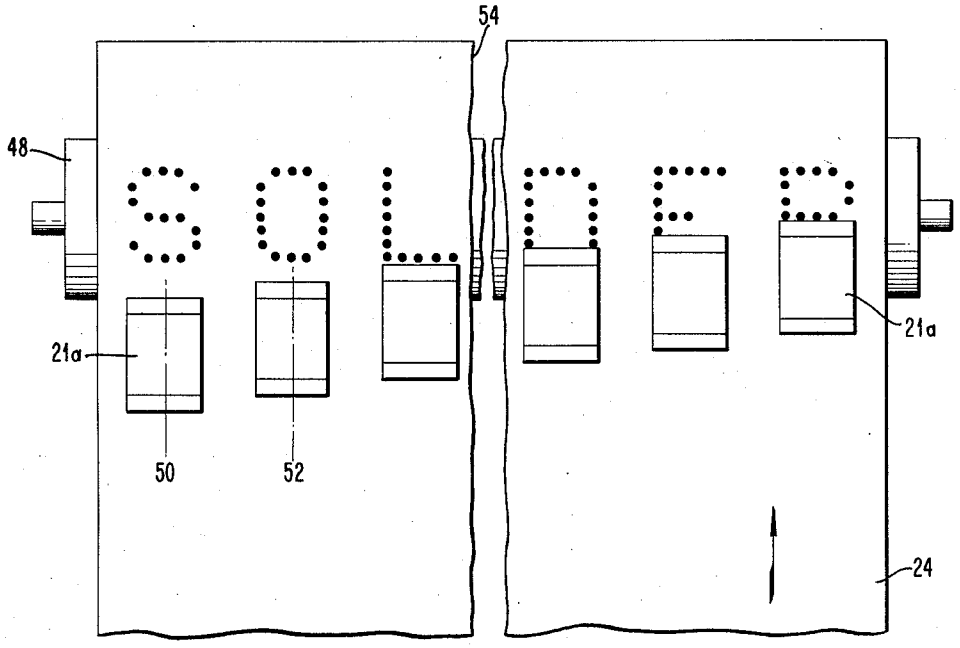


FIG. 3

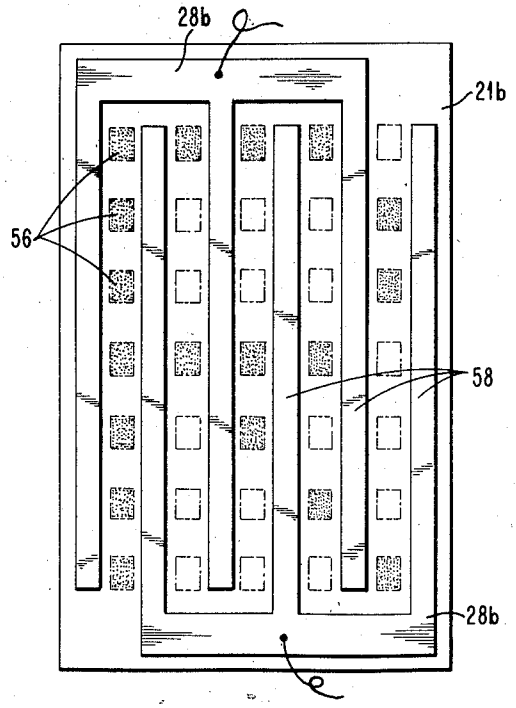


FIG. 4



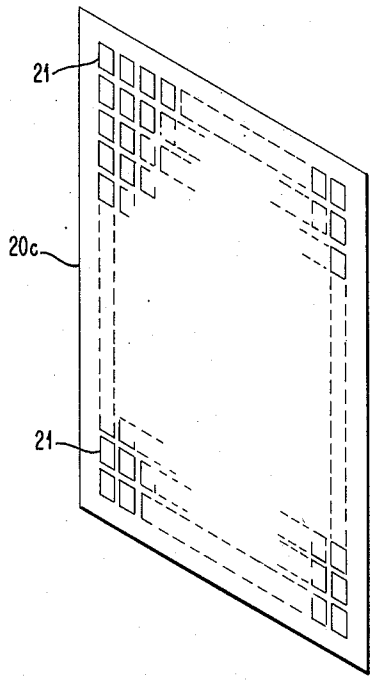
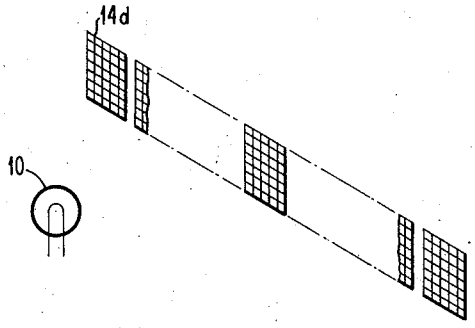
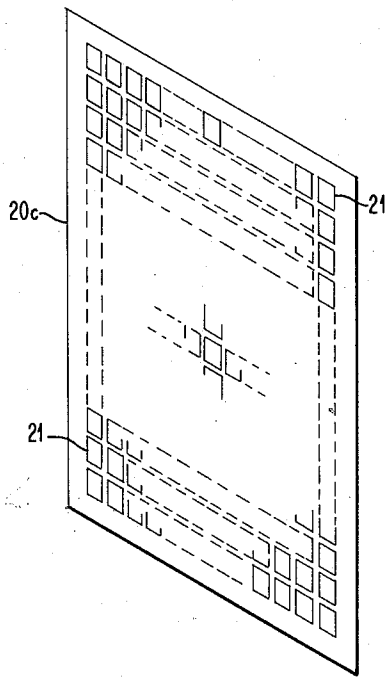


FIG. 5





United States Patent Office 2,909,973 Patented Oct. 27, 1959

2,909,973

ELECTRO-OPTICAL DISPLAY APPARATUS

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Application September 15, 1958, Serial No. 761,129

12 Claims. (Cl. 95—4.5)

This invention relates to fast acting apparatus for providing visual displays of intelligence in the form of characters, and more particularly this invention relates to display and printing apparatus employing light switching elements incorporating electro-optical materials which are responsive to electric signals in accordance with the Kerr electro-optic effect.

In modern technology there are many requirements for rapid handling of information in electrical signal form which has been transmitted from one location to another or which has been subjected to processing by logical computing apparatus. In such apparatus, it is presently quite common to process a large body of information in an extremely short period of time. A problem then arises of rapidly converting such information to a form such as a printed page, or a visual display which is comparable to a printed page, which can be comprehended at the slower pace of the human mind.

Accordingly, it is an important object of the present invention to provide display and printing apparatus which is extremely fast in operation.

Another object of the present invention is to rapidly provide information in the form of characters which are logically arranged in relation to one another to impart information.

Another object of the present invention is to provide display and printing apparatus which is fast enough to match the output speed of information in the form of electrical signals from modern electronic data processing apparatus.

In previous attempts to provide faster and faster printing apparatus for use with electronic communication and data processing equipment, one of the major problems has been the inertia of mechanical parts which must be accelerated and decelerated very rapidly in the printing process, and another problem is the mechanical wear encountered by such mechanical parts.

Accordingly, another important object of the present invention is the provision of an extremely rapid printing apparatus which avoids most of the previously encountered problems of moving mechanical parts.

Other objects and advantages of the invention will be pointed out in the following description and claims and illustrated in the accompanying drawings.

In carrying out the objects of this invention, in one preferred embodiment thereof, there are provided a light source and first and second light polarizers having a predetermined angular relationship between their axes of polarization, and a coordinate array of electro-optical elements positioned between the polarizers. Electric switching apparatus is provided for selectively energizing individual elements of the coordinate arrangement to provide a light switching effect to transmit information in the form of characters through the second polarizer. Apparatus is also provided for the purpose of transmitting such character information in sequence to desired relative positions to form a display which may be in the form of a printed page.

In the drawings:

Fig. 1 is a schematic representation of a simple preferred form of the invention in which the characters are printed rapidly one line at a time.

Fig. 2 is a view of a modified portion of the system of Fig. 1 in which more uniform movement of the paper on which the characters are printed is possible.

Fig. 3 is a detailed view of a modified electro-optical structure which may be advantageously employed for the purpose of fixing the position of the characters on the printed output page.

Fig. 4 is a schematic representation of a modification of the system of Fig. 1 which is arranged for displaying or printing the equivalent of an entire page with only one position of the display receiving material.

Fig. 5 is a schematic representation of a further modification of the system of Fig. 1 for the display of an entire page of information which is capable of operation at a rate faster than the rate of operation of the system of Fig. 4.

An important element of the present invention is a "light switch" or "light relay." As used in this specification, the light switch refers to a combination of apparatus which is capable of controlling the transmission of light in response to an electrical voltage signal. Light switches which are currently known, and of the type which are used in the present invention may employ, for instance, two light polarizers, each of which is capable of limiting the transmission of light therethrough to light which is in substantially one plane. The light polarizers are usually positioned such that the axis of polarization of each is displaced with respect to the other. Between the polarizers there is positioned an electro-optical material which, as will be explained more fully below, displays birefringement properties when the application of an electric potential across the material in effect rotates the plane of polarization of light passing therethrough. The angles of polarization of the light polarizers can be so arranged that, when the electro-optical material is energized by an applied voltage, polarized light entering the electro-optical material from the first polarizer is in effect rotated to the polarization angle of the second polarizer so as to be transmitted through the second polarizer. If such energization and rotation of polarization does not exist, the cooperative action of the two polarizers is effective, as is well known, to prevent the transmission of light through said second polarizer.

Referring more particularly to the drawings, in the embodiment of the system of the present invention as shown in Fig. 1, there is shown a light source 10 and the following components arranged to receive and transmit the light from source 10 in sequence: polarizer 12, electro-optical structure 14, polarizer 16, lenses 18, and electro-optical structure 20, and polarizer 22. Light which is transmitted through all of these elements is intercepted by a light sensitive paper 24.

Light from source 10 which is polarized by the polarizer 12 is normally stopped by polarizer 16 except where individual electro-optical portions 15 of structure 14 are subjected to a voltage change which effectively rotates the polarization of light transmitted therethrough. By proper selection of portions 15 to be energized, a pattern of light transmission is formed which can thus form alphabetical letters, or numbers, or information in the form of other characters. The character in the form of a light pattern transmitted through the polarizer 16 is focused by the individual lenses 18 upon the electro-optical portions 21 of the structure 20. The polarizer 22 is arranged with an angle of polarization different from that of polarizer 16 so that light transmitted through the electro-optical portions 21 is interrupted by the polarizer 22 unless the por-

tions **21** are energized by an appropriate voltage. By proper selection of the energized portions **21**, the character is transmitted to selected positions upon the paper **24**.

By a proper switching sequence, it is accordingly possible to provide for the production of a series of characters transmitted through the second polarizer **16**, which are transmitted in a desired sequence to selected positions upon paper **24** to display and print an entire line of characters. The paper **24** is then moved upwardly to provide space for another line, and the procedure is repeated to rapidly display and print the desired amount of information.

It is understood that the main bodies of both structure **14** and structure **20** are composed of transparent materials or are provided with window cutouts for transmission of light passing through active portions **15** and **21**.

The individual electro-optical portions **15** and **21** are preferably composed of barium titanate ($BaTiO_3$) crystals which are maintained above the Curie temperature. Conventional heating apparatus can be employed for this purpose. In order to avoid unnecessary complexity in the drawings, such apparatus is not shown. While other materials are available which display the Kerr electro-optical effect, barium titanate crystals are preferred because, when maintained above their Curie temperature, they are operative at extremely high speeds with applied voltage signals of smaller magnitude than required with other electro-optical materials. Electrodes for the application of switching voltages may be provided for instance at the upper and lower edges of each of the crystals **15** and **21** as respectively indicated at **26** and **28** by known methods such as by vapor deposition. To these electrodes, suitable switching voltage connections may be provided as indicated respectively at **30**, **32** and **34**. Appropriate electric signal voltages are provided to the coordinate arrangement of the structure **14** from a character decoder **36** through cables **38** and **40**, and appropriate switching signals are provided to the structure **20** from a position selector **40** through a cable connection **42**. The character decoder **36** and the position selector **40** are properly synchronized by means of synchronizing signals transmitted from the character decoder **36** through a synchronizing connection **44**. The input of information to the apparatus is through an input connection **46** to the character decoder **36**.

The input signals received at connection **46** can be in the form of coded electric signals or pulses which are decoded by the decoder **36** to provide energization, through connections **30** and **32**, of desired electro-optical material portions **15** to display a decoded character. The input signal through the input cable **46** may differ in various ways in order to signify different characters. For instance, different frequencies or different pulse durations or combinations may be employed. Or cable **46** may be a multiple conductor cable with a signal provided on a different conductor for each different desired character. In any case, the design of the character decoder can be along conventional lines and within the skill of those familiar with the electrical and electronic arts.

Similarly, the position selector **40** is preferably an electrical or electronic circuit which selects a given sequence of the crystal portions **21** upon energization in response to a sequence of signal pulses transmitted through the cable **44** from the character decoder **36**. In the embodiment of Fig. 1, the position selector preferably energizes one character position at a time beginning at the left and proceeding to the right and then successively repeating the sequence. The design of this position selector **40** can also be along conventional lines and within the skill of those familiar with the electrical and electronic arts.

Conventional provisions must also be made upon repetition of the sequence of the position selector **40** for indexing the paper **24** to the position for printing a new line. Such apparatus may consist for instance of an electric motor device for driving a paper feed roller **48** in response to a sequence repeat signal from position selector **40**. Since such apparatus is of conventional construction, it is not illustrated in detail in order to avoid unnecessary complexity in the drawing.

If the individual crystal portions **21** of the structure **20** are arranged in a stepped relationship as indicated at **21*a*** in Fig. 2, a substantially continuous movement of the paper **24** may be maintained. The stepped positions of the crystal portions **21*a*** are arranged in proper relationship, and coordinated with the uniform speed of the paper, so that the characters are uniformly horizontally aligned after printing on the paper. Thus, the first letter "S" indicated in Fig. 2, which is printed by the crystal portion in the first position indicated at **50**, is advanced upwardly by movement of the paper **24** so that when the next letter "O" is printed at the second position indicated at **52**, the "S" is in horizontal alignment with the "O." Thus the continuous sequence of character printing and paper advancement continues with the production of a uniform horizontally aligned arrangement of characters. The stepped arrangement of the crystal portions **21*a*** is such that when the last character in the first line is printed, the paper has advanced sufficiently to immediately permit printing of the first character in the second line at position **50**.

While for purposes of illustration a uniform stepped arrangement of the six crystal portions is shown in Fig. 2, it will be understood that a longer line of characters is contemplated, as indicated by the break at **54**, and additional uniform steps are therefore provided between the third and fourth positions.

In Fig. 3 there is shown a modification **21*b*** of the structure of crystal portions **21** of the system of Fig. 1. It will be appreciated from the drawings and from the above description that the characters produced by the apparatus of the present invention are composed of a combination of individual spots of light which are projected together to a display position to form a character from a combination of "spots." Printing produced in this manner is sometimes referred to as monograph printing. The individual crystal portions **15** of the electro-optical structure **14** cause transmission of individual beams or spots of light which appear beyond polarizer **16**. The identity and integrity of these spots is continued during transmission of the character through the lens **18** and the electro-optical structure **20** to the paper **24**. Because of the separate nature of these spots of light transmitted by separate beams, it is possible to provide a crystal portion **21*b*** as shown in Fig. 3 which employs separate elemental active areas of the crystal as indicated at **56** for each of the small separate beams of light making up the character. In such a structure it is possible to provide specially shaped vapor deposited electrodes **23*b*** which may, as shown in Fig. 3, have extended legs **58** which alternately straddle the separate elemental active areas of the crystal **56**, thus reducing the physical spacing between the effective portions of the electrodes and consequently reducing the voltage required for the purpose of achieving the electro-optical effect.

In Fig. 4 there is shown a simplified schematic view on a reduced scale of a modification of the system of Fig. 1 in which a modified electro-optical structure **20*c*** is employed which incorporates an entire page of active portions **21**. A corresponding number of lenses **18** and other associated apparatus is, of course, also provided so that an entire page of information may be displayed or printed with only one position of the sensitive paper **24**, when sensitized paper is employed.

Fig. 5 is another simplified schematic view corresponding to Fig. 4 and showing a further modification of the system which employs a plurality of character-forming electro-optical structures as indicated at **14*d***. This sys-

tem is faster than the system of Fig. 4 because preferably an entire line of character generator structures **14***d* is provided so that an entire line can be formed and printed simultaneously.

It will be appreciated, of course, that with the more elaborate arrangements of Figs. 4 and 5, the nature of the position selector **40** will be considerably more complicated and, in the embodiment of Fig. 5, the character decoder **36** will also be considerably more complicated.

As previously mentioned above, barium titanate crystals are the preferred electro-optical materials in the apparatus of the present invention. As previously indicated, the barium titanate is maintained at a temperature above its Curie point. Barium titanate is not ordinarily birefringent when maintained above its Curie temperature. However, when subjected to an electric field the material becomes birefringent. The light output of a system wherein a crystal of barium titanate, maintained above its Curie temperature, is placed between a pair of crossed polarizers, varies with the sine squared of the product of π and the square of the ratio of the applied voltage to a constant. The constant depends upon the particular crystal used. The curve depicting this relationship contains a plurality of nulls and peaks and by applying voltage signals of predetermined magnitude to a pair of electrodes on such a crystal, switching can be accomplished as desired.

A more detailed description of the operation of the light switch arrangement is as follows: The light source **10** is preferably a very powerful source such as an arc lamp and it is preferably provided with a suitable reflector to concentrate the entire light output upon the first polarizer **12**. As previously indicated, the directions of light acceptance (or polarization) of the polarizers **12** and **16** are angularly displaced with respect to one another, preferably by approximately 90° as respectively indicated by arrows **60** and **62**. These polarizers are effective, when no voltage is applied to the electro-optical portions **15** to prevent any light from reaching the output side of the polarizer **16**.

The polarizer **12** is effective to absorb all of the incident light except a component in one predetermined direction as indicated by arrow **60** and thus the light incident on crystal portions **15** is plane polarized. When no voltage is applied to crystal portions **15**, this plane polarized light is passed through the crystal undisturbed and is incident on polarizer **16**. The direction of acceptance of polarizer **16** as indicated by arrow **62** is substantially at right angles to the direction of acceptance of polarizer **12** and thus all of the incident light is absorbed and no light passes beyond polarizer **16**.

The plane polarized light incident upon the crystal portions **15** of Fig. 1 may be considered to have two components in a plane normal to the direction of propagation, one perpendicular to the electrodes **26** and one parallel to the direction of the electrodes. When no voltage is applied to the crystal, the light incident on the crystal passes therethrough undisturbed. However, when a voltage is applied between the electrodes **26**, the barium titanate becomes birefringent and, therefore, the component of the incident light vector perpendicular to the electrodes propagates through the crystalline material at a greater rate than the component at right angles to the applied electric field. The light component parallel to the applied field is usually termed the extraordinary ray and that normal to the applied field the ordinary ray and where, as here, the extraordinary ray propagates through the material at a rate greater than the ordinary ray, the phenomenon is known as negative birefringence. Conversely, when an applied field is effective to slow down the propagation rate of the extraordinary ray, the phenomenon is known as positive birefringence. As a result of the aforesaid difference in the rate of propagation in the crystal of the ordinary and extraordinary rays, the crystal in effect rotates the plane of polarization of the light passing therethrough and the light leaves the crystal portion **15** "eliptically polarized" and containing a component parallel to the direction of acceptance of polarizer **16**. In order to effectively rotate the plane of the light passing through a crystal portion **15**, it is necessary that the light contain components in directions both normal to and parallel to the electrodes **26**. Thus the direction of acceptance of polarizer **12** must not be parallel to either of these two directions.

It will be understood that the apparatus of the present invention may be modified by arranging the second polarizer **16** with a polarization angle which is co-incident with the angle **60** of the first polarizer **12** so that all of the light which is polarized by polarizer **12** will be transmitted through the crystal portions **15** and the polarizer **16** unless the crystal portions **15** are energized. In such a modification the output from the energized crystal portions **15** is then blocked from transmission by the polarizer **16**. Thus, it is possible to modify the arrangement so that energization of crystal portions **15** causes blocking, where transmission otherwise would occur; rather than transmission, where blocking would otherwise occur.

Using either method of light switching, it will be recognized that it is possible to employ the apparatus of this invention to transmit full background patterns of light spots which are interrupted in appropriate positions to form characters. Reverse printed characters are thus possible.

A remarkable feature of the present inventive arrangement is that the output from the polarizer **16** is polarized so that the combination of polarizers **16** and **22** together with the electro-optical crystal structure **20** serves as a light switch which operates similarly to the combination of polarizers **12** and **16** and the electro-optical structure **14**. Thus, the polarizer **16** serves a double function as the output polarizer of the first electro-optical switch, and as the input polarizer of the second electro-optical switch.

As taught in a related prior application, Serial No. 645,995, filed March 14, 1957, by Albert C. Koelsch, one of the present co-inventors, and Donald R. Young, and assigned to the assignee of the present application, the light output of a light switch employing two polarizers and an electro-optical crystal with electrodes arranged as shown in Fig. 1 on crystal elements **15** is proportional to the sine squared of the product of π and the square of the ratio of the applied voltage to a constant. The constant is determined by the particular crystal. Accordingly, the curve of light output versus voltage has a series of peaks and nulls and it is important, therefore, to employ an energization voltage which is sufficient to hit a peak when a maximum switching effect is desired. It will be understood, of course, that various combinations of input voltages may be employed to achieve the desired optic effect. Also, it may be desirable to supply alternating voltages to the crystals rather than direct current voltages.

It is obvious that the present optical apparatus can be employed for display and printing methods other than on chemically treated surfaces that are light sensitive. For instance, the present apparatus can also be used for optical charging of localized areas of a zerographic plate for subsequent use in making zerographic reproductions.

The improvement in the speed of operation which is possible by the present invention cannot be over-emphasized. As pointed out in the related application Serial No. 645,995, these electro-optical switches are capable of very rapid response in periods which are so brief as to be measured in millimicro seconds. Accordingly, the speed with which the present system is capable of operating is primarily limited by the sensitivity of the photographic paper **24** and the speed with which the paper **24** can be effectively moved to synchronize with the oper-

ation of the rest of the system. Accordingly, it is possible to employ the display and printing arrangement of the present invention to accomplish the work which previously required the simultaneous operation of a number of slower printing mechanisms.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to a preferred embodiment, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art without departing from the spirit of the invention. It is the intention therefore, to be limited only as indicated by the scope of the following claims.

What is claimed is:

1. Display apparatus comprising first and second polarizers having a predetermined angular relationship between their respective axes of polarization, an electro-optical structure positioned between said polarizers and having a plurality of pairs of electrodes associated with a regular pattern of active portions of said structure, said active portions being responsive to voltages applied by the associated pairs of electrodes to effectively change the angle of polarization of light passing therethrough to thus change the light transmission through the combination of said polarizers and said active portions, means for concurrently energizing selected electrode pairs to form a desired character pattern of transmitted light, a substantially flat light sensitive medium, means for transmitting said character pattern of light to a desired position on said light sensitive medium to form a visual display thereon, and means for transmitting similarly formed character patterns to other positions upon said light sensitive medium to form an organized display of the information conveyed thereby.

2. Display apparatus comprising first and second polarizers having respectively displaced axes of polarization, an electro-optical structure positioned between said polarizers and having a plurality of pairs of electrodes associated with a regular pattern of active portions of said structure, said active portions being responsive to voltages applied by the associated pairs of electrodes to effectively change the angle of polarization of light passing therethrough from the polarization angle of said first polarizer to the polarization angle of said second polarizer, means for energizing selected electrode pairs to form a desired character pattern of transmitted light, a substantially flat light sensitive medium, means for transmitting said character pattern of light to a desired position on said light sensitive medium to form a visual display thereon, and means for transmitting subsequent character patterns to other positions upon said light sensitive medium to form an organized display of the information conveyed thereby.

3. Apparatus for rapidly converting electrical signal information into a visible display form comprising a first polarizer having an axis of polarization, a second polarizer positioned with a displaced axis of polarization to receive and interrupt light transmitted through said first polarizer, an electro-optical structure positioned between said polarizers to intercept light traveling therebetween and having a plurality of pairs of electrodes associated with a regular pattern of active portions of said structure, said active portions being responsive to voltages applied to the associated pairs of electrodes to effectively change the polarization of light passing therethrough from said first polarizer to an angle which will pass through said second polarizer, means for energizing selected electrode pairs to form a desired character pattern of transmitted light, a substantially flat light sensitive medium, means for transmitting said character pattern of light to a desired position on said light sensitive medium to form a visual display thereon, and means for transmitting subsequent character patterns to other positions upon said light sensitive medium to form an organized display of the information conveyed thereby.

4. Display apparatus comprising first and second polarizers having respectively displaced axes of polarization, a first electro-optical structure positioned between said polarizers and having a plurality of pairs of electrodes associated with a regular pattern of active portions of said structure, said active portions being responsive to voltages applied by the associated pairs of electrodes to effectively change the angle of polarization of light passing therethrough from the polarization angle of said first polarizer to the polarization angle of said second polarizer, means for energizing selected electrode pairs to form a desired character pattern of transmitted light, a third polarizer positioned in alignment with said first and second polarizers and having an axis of polarization displaced from the polarization axis of said second polarizer, a second electro-optical structure positioned between said second and third polarizers and having a plurality of pairs of electrodes associated with a regular pattern of active portions of said second structure, a focusing lens positioned between each of said active portions of said second structure and said second polarizer and arranged to focus said character pattern of light transmitted through said second polarizer upon the associated active portion of said second structure, said active portions of said second structure being responsive to voltages applied by the associated pairs of electrodes to effectively change the angle of polarization of light passing therethrough from the polarization angle of said second polarizer to the polarization angle of said third polarizer, and means for energizing selected electrode pairs of said second structure to transmit the character pattern of light from said second polarizer through selected portions of said second structure and corresponding portions of said third polarizer to form a visual display in desired positions.

5. Optical display apparatus comprising a light source and first, second and third polarizers positioned to sequentially intercept the light from said source, the second of said polarizers having an axis of polarization displaced with respect to the axes of the first and third polarizers, a first electro-optical structure positioned between said first and second polarizers and a second electro-optical structure positioned between said second and third polarizers, each of said electro-optical structures having a plurality of pairs of electrodes associated with a regular pattern of active portions of said structure, said active portions being responsive to voltages applied by the associated pairs of electrodes to effectively change the angle of polarization of light passing therethrough from the polarization angle of the preceding polarizer to the polarization angle of the succeeding polarizer, means for energizing selected electrode pairs of said first structure to form a desired character pattern of light transmitted through said second polarizer, a focusing lens positioned between each of said active portions of said second structure and said second polarizer and arranged to focus said character pattern of light transmitted through said second polarizer upon the associated active portion of said second structure, means for energizing selected electrode pairs of said second structure to transmit the character pattern of light from said second polarizer through selected portions of said second structure and corresponding portions of said third polarizer to form a visual display in desired positions.

6. Apparatus in accordance with claim 1 in which said active portions consist essentially of barium titanate crystals.

7. Apparatus in accordance with claim 5 in which said active portions consist essentially of barium titanate crystals.

8. Apparatus in accordance with claim 6 in which the regular pattern of active portions of said second struc-

ture includes an entire line of active portions to form a visual display of an entire line of characters.

9. Apparatus in accordance with claim 6 in which the regular pattern of active portions of said second structure corresponds to an entire page of characters to provide for the formation of a visual display of an entire page of characters.

10. Apparatus in accordance with claim 8 in which said first structure includes a sufficiently large pattern of active portions to form an entire line of characters concurrently.

11. Apparatus in accordance with claim 1 in which said active portions consist essentially of materials which display the Kerr electro-optical effect.

12. Apparatus in accordance with claim 1 in which the angular relationship between said first and second polarizers is one of coincidence.

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