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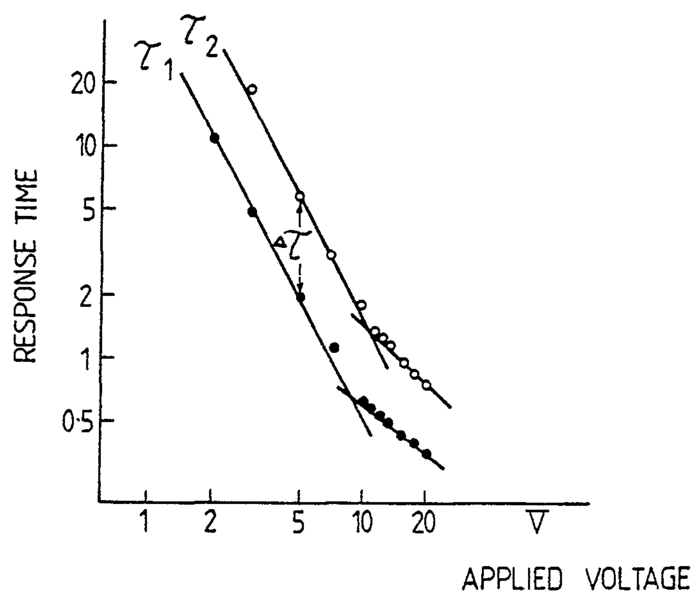
(54) **Chiral smectic liquid crystal electro-optical device and method of driving same.**

(57) A chiral smectic liquid crystal electro-optical devices uses switching between two states of chiral smectic liquid crystal molecules, the device being driven by utilising the difference ($\Delta\tau$) between the response time from one of said two states to the other state and the response time from the other state to the one state.

Fig.3.



EP 0 200 427 A1

CHIRAL SMECTIC LIQUID CRYSTAL ELECTRO-OPTICAL DEVICE AND METHOD OF DRIVING SAME

This invention relates to chiral smectic liquid crystal electro-optical devices and methods of driving same.

In recent years, liquid crystal devices using a chiral smectic C-phase liquid crystal material have attracted attention. Such devices are used as optical shutters in display devices, cameras and printers that operate at high speeds and have memory retentivity.

A widely known example of a ferroelectric liquid crystal compound having the chiral smectic C-phase is a 2-methylbutylP-(P-n-decyloxybenzylidene)amino). The liquid crystal molecules are arranged in a spiral structure being twisted in each of layers L_1, L_2, L_3, L_4 (Figure 8) by a given azimuthal angle ϕ.

When a liquid crystal compound having a chiral smectic C-phase is poured into a space between the two substrates B, B' having a gap (of, for example, about 1 micron) which is smaller than the spiral period (usually several microns) thereof to constitute a liquid crystal cell (Figure 9(a)), the liquid crystal molecules lose their spiral structure and establish a state where there is a domain that is tilted in the clockwise direction by an angle θ from a direction normal to the layer with the molecular axes thereof being parallel to the substrates B, B', and a domain that is tilted by θ in the counter-clockwise direction, i.e., by $-\theta$ (Figure 9(b)), and further establish electric dipole moments in a direction perpendicular to the molecular axes.

Therefore, if one of those domains has an upwardly directed electric dipole moment relative to the substrates B, B', the other domain has a downwardly directed electric dipole moment. If an electric field is applied between the substrates B, B', all of the liquid crystal molecules are orientated at positions tilted by either $+\theta$ or $-\theta$ from the direction normal to the layer. Further, if the electric field is applied in the opposite direct, the liquid crystal molecules are inverted and are orientated at positions tilted by either $-\theta$ or $+\theta$.

If polarising plates are disposed on both surfaces of the liquid crystal cell and an electric field applied thereto, bright and dark conditions are established by migration of the liquid crystal molecules, whereby the cell exhibits the function of a display panel or optical shutter (Figure 10). The liquid crystal panel thus constituted exhibits excellent characteristics, i.e. has a remarkably high response speed of the order of microseconds and retains displayed information even after the electric field has been removed.

The above memory retentivity is very advantageous from the standpoint of reducing electric power consumption. When display information is to be changed, however, writing of the dark condition and that of the bright condition must be effected by separate frame scannings. Namely, an extended period of time is required for changing display information.

The present invention seeks to provide a chiral smectic liquid crystal electro-optical device which is capable of effecting writing of bright and dark conditions in a single scanning frame at relatively high speed.

According to one aspect of the present invention there is provided a chiral smectic liquid crystal electro-optical device which uses switching between two states of chiral smectic liquid crystal molecules characterised by means for driving the device by utilising the difference between response time from one of said two states to the other state and the response time from the other state to the one state.

In the preferred embodiment said means are such that the change from said one state to said other state is performed by applying an AC voltage having an amplitude and a pulse width which may change the liquid crystal molecules from said one state to said other state but may not change from said other state to said one state, and the change to said one state is performed by applying an AC voltage having an amplitude and pulse width which may change the liquid crystal molecules from said state to said other state and from said other state to said one state.

The amplitude of the AC voltage may be constant. Alternatively, the pulse width of the AC voltage may be constant.

According to another aspect of the present invention there is provided a method of driving a chiral smectic liquid crystal electro-optical device which uses switching between two states of chiral smectic liquid crystal molecules characterised by utilising the difference between the response time from one of said two states to the other state and the response time from the other state to the one state.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1 is a perspective sectional view showing an embodiment of a chiral smectic liquid crystal electro-optical device according to the present invention;

Figures 2(a) and 2(b) are diagrams illustrating the direction of rubbing of substrates in the device of Figure 1;

Figure 3 is a diagram showing the applied voltage and the response speed of the device of Figure 1;

Figure 4 is a block circuit diagram showing the device of Figure 1;

Figures 5(a) to 5(e) are diagrams of waveforms illustrating the operation of the circuit of Figure 4;

Figures 6(a) to 6(e) are diagrams of waveforms illustrating the operation of another embodiment of a chiral smectic liquid crystal electro-optical device according to the present invention;

Figure 7 is a diagram showing the relationship between the time of applying the electric field and the concentration of picture elements;

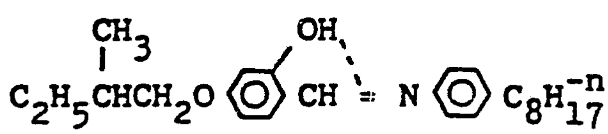
Figure 8 is a diagram which schematically illustrates the molecular arrangement of chiral smectic liquid crystal material;

Figures 9(a) and 9(b) are schematic diagrams showing the arrangement of molecules when the gap of a display cell is selected to be smaller than the spiral pitch of the liquid crystal molecules;

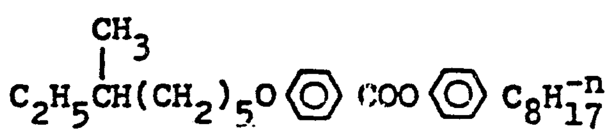
and

Figure 10 is a diagram showing the relationship between the domains and the polarisation of smectic liquid crystal material.

Referring first to Figure 1 there is shown an embodiment of a chiral smectic liquid crystal electro-optical device according to the present invention. A substrate 1 which constitutes a liquid crystal display panel is composed of a random horizontally orientated layer 1c that is uniformally orientated in all directions. The layer 1c is formed, e.g. by printing or dipping, of a thin polyimide film on the surface of an electrically insulating transparent plate 1b made of, e.g. glass on which are formed segment electrodes 1a, composed of transparent conductive material (Figure 2(a)). A second substrate 2 which together with the substrate 1 constitutes a liquid crystal display panel has a mono-axially orientated layer 2c. The layer 2c is obtained by forming a thin polyimide film on the surface of an electrically insulating transparent plate 2b on which are formed common electrodes 2a which are at right angles to the electrodes 1a. The surface of this thin polyimide film is rubbed in one direction so as to be orientated only in one direction (Figure 2(b)). These two substrates 1 and 2 are disposed so as to be parallel to one another with a gap therebetween. The gap is smaller than the spiral pitch of a ferro-electric chiral smectic liquid crystal compound 3. The random horizontally orientated layer 1c and the monoaxially orientated layer 2c are opposed to each other. The space between the two substrates 1, 2 is filled with a ferro-electric chiral smectic liquid crystal compound 3 obtained by mixing an S-4-O (2-methyl)-butyl-resorcylidene-4-alkyln-octylaniline



and a P-n-octylphenyl-P'-6-methyloctyloxybenzoate



in equal amounts. The peripheries of the substrates are sealed with a sealing agent to form a cellular structure, thereby to constitute a display panel 6. In Figure 1, reference numerals 4,5 denote polarising plates that are placed on the outer surfaces of the substrates 1,2 respectively.

A voltage is applied to the electrodes of the thus-constructed liquid crystal panel to examine the inversion speed of the domains. When a voltage of the same level is applied as shown in Figure 3, the speed τ_1 at which the bright condition changes to the dark condition is different from the speed τ_2 at which the dark condition changes into the bright condition. Namely, there is a difference $\Delta\tau$ in the response time between the two.

The present invention seeks to effect writing of the bright condition and that of the dark condition simultaneously by fully utilising the time difference $\Delta\tau$ when the display conditions are switched.

Figure 4 illustrates an embodiment of a drive circuit for the display panel 6 of Figure 1. The drive circuit has a common electrode drive circuit 7 connected to the common electrodes 2a of the display panel 6, and a segment electrode drive circuit 8 connected to the segment electrode 1a. When scanning lines successively, the electric field of a first mode or a second mode is applied to the picture elements depending upon the write condition. When not selecting, the electric field of a third mode is applied to the picture elements.

That is, when selecting the picture elements, the drive circuit selectively produces:

(1) a dark condition write signal which consists of a pulse P_1 (Figure 5(a)) in a negative direction having a voltage $|V_1|$, and an interval T_1 ranging from time τ_1 required for changing the bright condition into the dark condition to time τ_2 required for changing the dark condition into the bright condition and a pulse P_2 in a positive direction having the voltage $|V_1|$ as well as a first mode signal (Figure 5(b)) consisting of an alternating maintenance signal which has a voltage $-(V_1/N)$; and

(2) a bright condition write signal which consists of a pulse P_3 (Figure 5(c)) in a negative direction having a voltage $|V_1|$ of the same level and an interval T_2 longer than the time τ_2 that is required for changing the dark condition into the bright condition and a pulse P_4 in a positive direction having the voltage $|V_1|$ and the interval T_2, as well as a second mode signal (Figure 5(d)) consisting of an alternating maintenance signal which has a voltage $|V_1/N|$.

When not selecting the picture elements, the drive circuit produces:

(3) a third mode signal (Figure 5(e)) consisting of alternating signals having a voltage $|V_1/N|$ and an interval that does not cause inversion of the liquid crystal molecules.

Now operation of the display panel thus constructed will be described.

Under the condition where no electric field is applied to the electrodes 1a, 2a, the liquid crystal molecules contained in the narrow gat between the substrates 1,2 are captured at one end by the random horizontally orientated layer 1c. The liquid crystal molecules, however, have freedom in the direction of the plane. Therefore, the other ends of the liquid crystal molecules are biased in one direction by the monoaxially orientated layer 2c. Namely, all of the liquid crystal molecules held between the substrates 1,2 are arranged in one direction and maintain a uniform optical density over the whole surface to form a uniform background without developing any pattern.

Under this condition, if the first mode signal is applied, the liquid crystal molecules of selected picture elements are affected by the electric field for a period of time longer than the inversion time τ_1 at the voltage $-V_1$ of the pulse P_1 but shorter than the inversion time τ_2, and are sufficiently inverted into the dark condition. If the pulse P_2 is applied after the inversion, the liquid crystal molecules of the selected picture elements are not inverted into the bright condition since the interval T_1 of the pulse P_2 is shorter than the time τ_2 for changing the dark condition into the bright condition. Therefore, the dark condition is maintained, i.e. write condition of the pulse P_1 is maintained. Due to the maintenance signal applied after the write signal, the liquid crystal molecules of the selected picture elements are dynamically maintained in the dark condition.

If the second mode signal is applied, the liquid crystal molecules of the selected picture elements are affected by the electric field for the period of time T_2 which is longer than the inversion time at the voltage $-V_1$ of the pulse P_3 and temporarily change into the dark condition. However, since the pulse P_4 that is applied subsequently has the interval T_2 which is longer than the inversion time τ_2 for inverting the dark condition into the bright condition at the voltage V_1, the liquid crystal molecules are inverted from the dark condition written by the pulse P_3, and write the bright condition. Due to the maintenance signal applied after the write signal, the liquid crystal molecules of the selected picture elements are dynamically maintained in the bright condition.

Therefore, the writing of the dark condition and that of the bright condition can be effected at a high speed of the order of several hundreds of microseconds. It will be appreciated that, in the above mentioned step, the liquid crystal molecules alternately are affected by voltages having the same voltage level and the same interval. Therefore, the picture elements are free from any residual electric charge.

Thus, either the first mode signal or the second mode signal is selected depending upon the condition that is to be written, and the dark condition and the bright condition can be written by one-frame scanning.

In this embodiment, the displayed information is maintained by applying an AC voltage having a peak value which is 1/N of the drive voltage after the pattern is displayed. However, since the liquid crystal molecules are captured in a new axis of orientation in the random horizontally orientated layer 1c, directions of the liquid crystal molecules are maintained even after the application of the AC voltage is discontinued, so that the displayed information can be stored.

In this embodiment, furthermore, the first mode signal is used for writing the dark condition and the second mode signal is used for writing the bright condition. However, they can be suitably interchanged depending upon the operation characteristics of the liquid crystal panel.

Figure 6 shows a second embodiment of a display device according to the present invention which produces a graduation display by utilising changes in the concentration of picture elements relative to the time for applying the electric field as shown in Figure 7. When selecting the picture elements, the device applies:

(1) a dark condition write signal which consists of a pulse P_5 (Figure 6(a)) in a negative direction which has a peak voltage $|V_1|$ followed by pulses of voltage $V_1/2$ modulated with an interval Tx ranging from time τ_1 required for changing the bright condition into the dark condition to the time τ_2 required for changing the dark condition into the bright condition and a pulse P_6 in the positive direction which has a peak voltage $|V_1|$ and followed by pulses of voltage $|V_1|/2$ modulated with the interval Tx, as well as a fourth mode signal (Figure 6(b)) consisting of an alternating maintenance signal which has a voltage $|V_1/N|$; and

(2) a bright condition write signal which consists of a pulse P_7 (Figure 6(c)) in the negative direction which has a peak voltage $|V_1|$ followed by pulses of voltage $|V_1/2|$ is modulated with an interval Ty longer than the time τ_2 that is required for changing the dark condition into the bright condition, and a pulse P_8 in a positive direction which has a peak voltage $|V_1|$ and which is modulated with the interval Ty, as well as a fifth alternating mode signal (Figure 6(d)) which has a voltage $|V_1/N|$.

When not selecting the picture elements, the device applies:

(3) the above mentioned third mode signal - (Figure 6(e)).

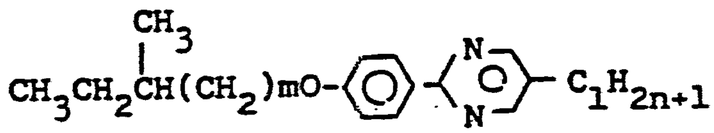
In this embodiment, if the fourth mode signal is applied, the liquid crystal molecules of the selected picture elements change to the dark condition - (Figure 7) at a concentration proportional to the volgate $-V_1$ of the pulse P_5 and the interval Tx. If the pulse P_6 is applied under this condition, the liquid crystal molecules cannot migrate to positions corresponding to the dark condition and maintain the concentration position written by the pulse P_5, since the interval Ty of the peak voltage V_1 is shorter than the inversion time τ_2 for inverting the dark condition into the bright condition. Due to the maintenance signal applied after the write signal, the liquid crystal molecules dynamically maintain the displayed concentration around the selected positions.

If the fifth mode signal is applied, the liquid crystal molecules temporarily change into the dark condition, since the interval Ty of the pulse P_7 is longer than the inversion time τ_2. However, since the pulse P_8 which is subsequently applied has the interval Ty which is sufficient to migrate the liquid crystal molecules from the dark condition to the bright condition, the liquid crystal molecules migrate from the dark condition written by the pulse P_7 to the bright condition, and write brightness which is proportional to the interval Ty. Therefore, it is possible to write information having graduation at a very high speed of the order of several hundreds of microseconds in one step.

In this embodiment, graduation is provided for both in the dark condition and the bright condition. It will, however, be appreciated that the same effect can be produced even when graduation is provided for in either one of these conditions, for example, for writing the dark condition.

In the above mentioned embodiments, the selecting pulses P_1 to P_8 have a constant amplitude and have different pulse widths T_1, T_2, T_X, T_Y in order to utilise the difference between the response time from one of the two states to the other state and the response time from the other state to the one state for driving. In order to utilise the difference of the response time, however, it is also possible to use selecting pulses which have a constant pulse width and have different amplitude between the case of ON to OFF and the case of OFF to ON.

In addition to the above mentioned ferro-electric smectic liquid crystal compound, it is also possible to use a chiral smectic liquid crystal compound such as a pyrimide-type liquid crystal compound represented by the general formula:



or 2-methylbutyl p-(P-n-decyloxybenzilidene)-amino), etc.

In the above described embodiments of the present invention, the monoaxially orientated layer and the random horizontally orientated layer composed of polyimide were formed on the surfaces of the substrates. However, it has also been found that the monoaxially orientated film may be composed of an organic material such as polyvinyl alcohol, fluororesin or silane, or an obliquely deposited SiO_2 film in addition to the polyimide. Similarly, the random horizontally orientated film on the other substrate may be composed of organic material such as epoxy, polyvinyl alcohol, fluororesin, polyurethane, silane, phenol or urea, or an inorganic film formed by depositing vapours of SiO_2 or MgF_2 in addition to the polyimide.

In the above mentioned embodiments of the present invention, on the inner surface of one of the two substrates a monoaxially alignment treatment is given and on the other inner surface of the other a random homogeneous alignment treatment is given. These treatments are proper in the case of using the liquid crystal compounds mentioned above. However, in the case of using other smectic liquid crystal compounds it may be proper that both of the inner surfaces of the two substrates are treated to produce monoaxial alignment.

According to the present invention described above, the liquid crystal panel comprising a smectic liquid crystal compound is affected by a write signal consisting of an AC signal having an interval ranging from the first inversion time to the second inversion time of the liquid crystal compound and an AC signal having an interval greater than one of said two inversion times whichever is the longer. Therefore, the bright and dark conditions can be written within a period of one frame of scanning maintaining memory retentivity and uniform background. Thus, it is possible to realise a display device such as an optical shutter which effects the scanning at high speed.

Claims

1. A chiral smectic liquid crystal electro-optical device which uses switching between two states of chiral smectic liquid crystal molecules characterised by means for driving the device by utilising the difference between response time from one of said two states to the other state and the response time from the other state to the one state.

2. A device as claimed in claim 1 characterised in that said means are such that the change from said one state to said other state is performed by applying an AC voltage having an amplitude and a pulse width which may change the liquid crystal molecules from said one state to said other state but may not change from said other state to said one state, and the change to said one state is performed by applying an AC voltage having an amplitude and pulse width which may change the liquid crystal molecules from said state to said other state and from said other state to said one state.

3. A device as claimed in claim 2 characterised in that, in operation, the amplitude of the AC voltage is constant.

4. A device as claimed in claim 2 characterised in that, in operation, the pulse width of the AC voltage is constant.

5. A method of driving a chiral smectic liquid

crystal electro-optical device which uses switching between two states of chiral smectic liquid crystal molecules characterised by utilising the difference between the response time from one of said two states to the other state and the response time from the other state to the one state.

6. A method as claimed in claim 5 characterised in that the change from said one state to said other state is performed by applying an AC voltage having an amplitude and a pulse width which may change the liquid crystal molecules from said one state to said other state but may not change from said other state to said one state, and the change to said one state is performed by applying an AC voltage having an amplitude and a pulse width which may change the liquid crystal molecules from said one state to said other state and from said other state to said one state.

7. A method as claimed in claim 6 characterised in that the amplitude of the AC voltage is constant.

8. A method as claimed in claim 6 characterised in that the pulse width of the AC voltage is constant.

Fig.1.

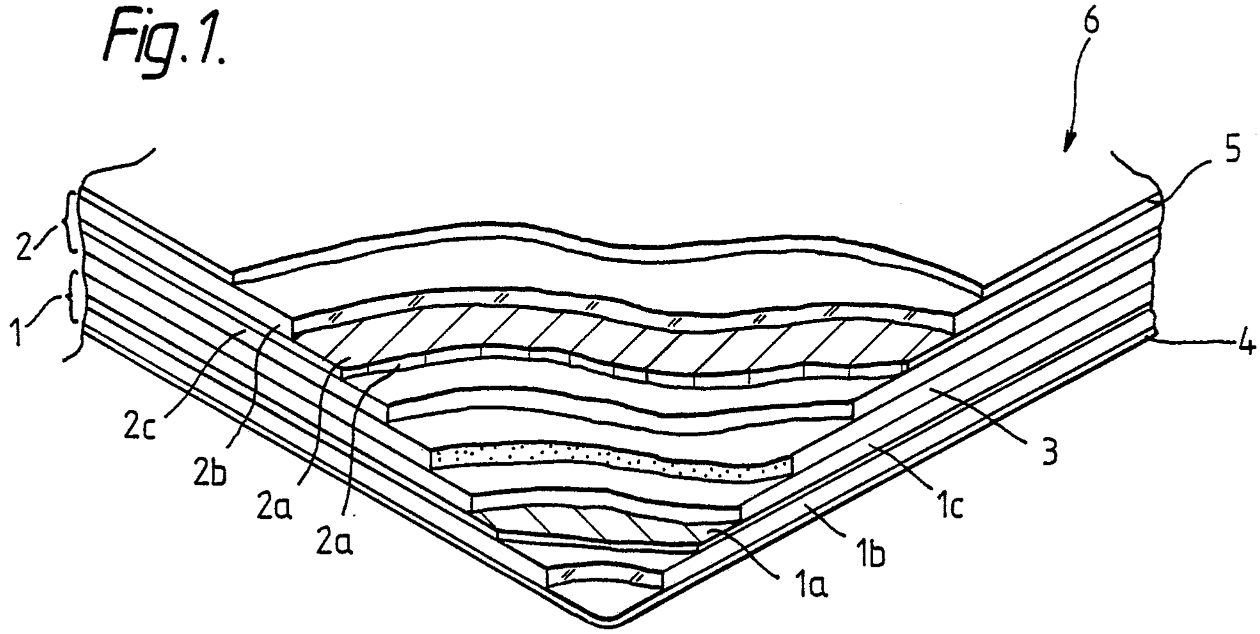


Fig.2.

(a)

(b)

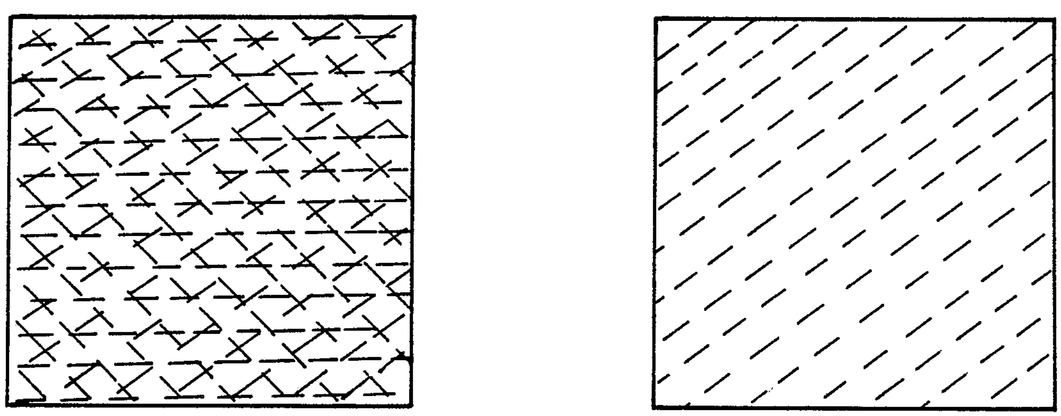


Fig.3.

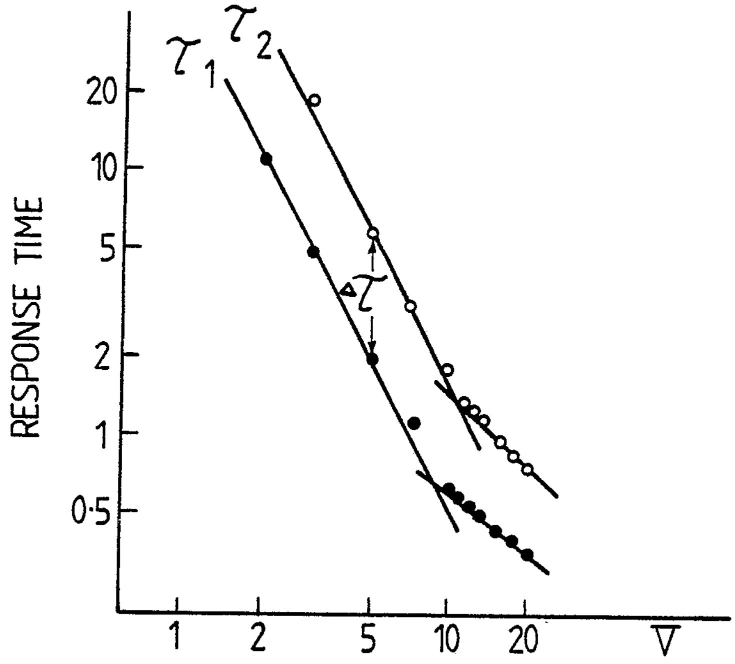

τ1
τ2
20
10
5
2
1
0·5
RESPONSE TIME
Δτ
1
2
5
10
20
V
APPLIED VOLTAGE

Fig.7.

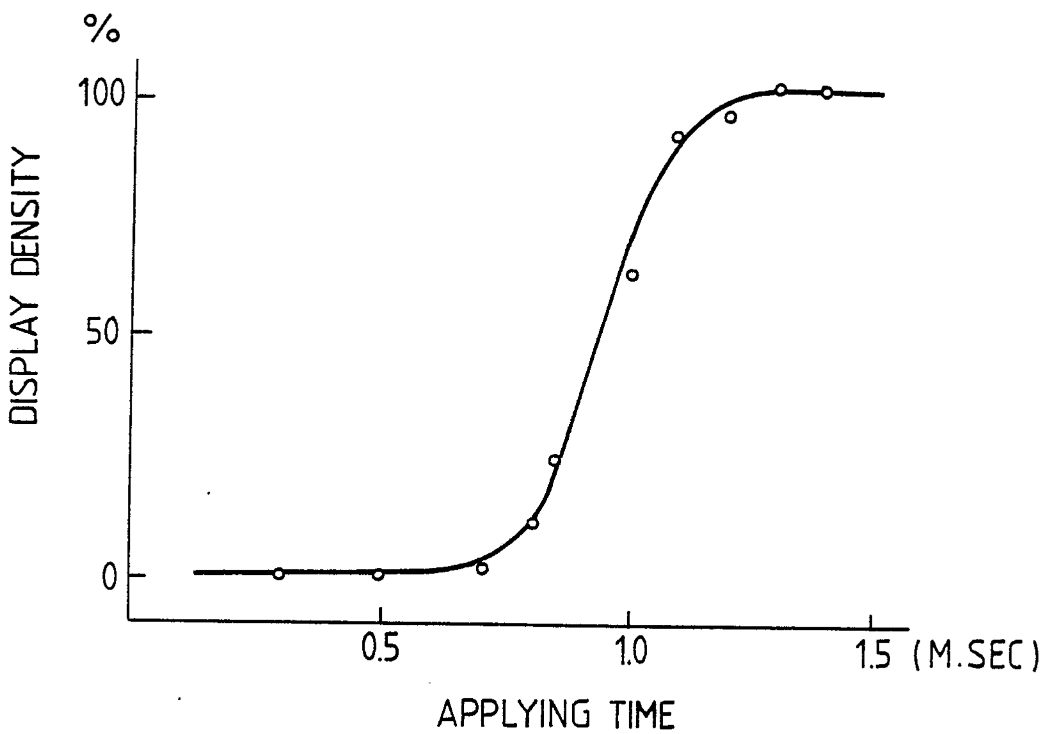

%
100
50
0
DISPLAY DENSITY
0.5
1.0
1.5 (M.SEC)
APPLYING TIME

Fig. 4.

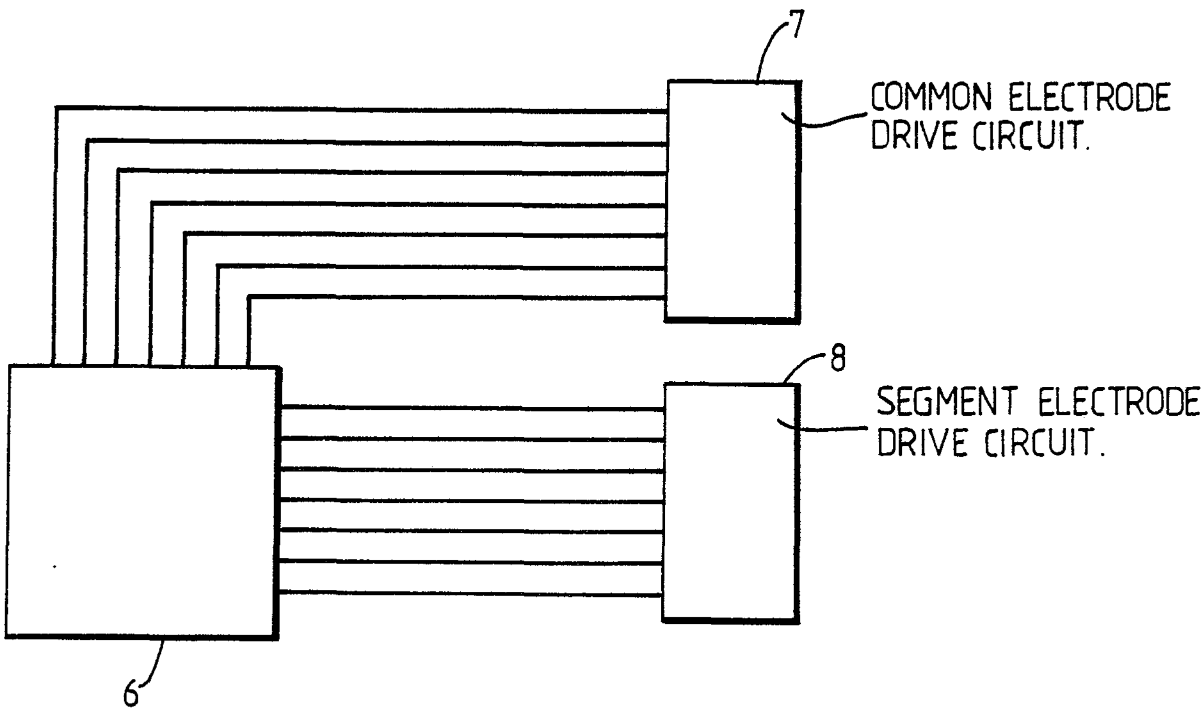

7
COMMON ELECTRODE DRIVE CIRCUIT.
8
SEGMENT ELECTRODE DRIVE CIRCUIT.
6

Fig.5.

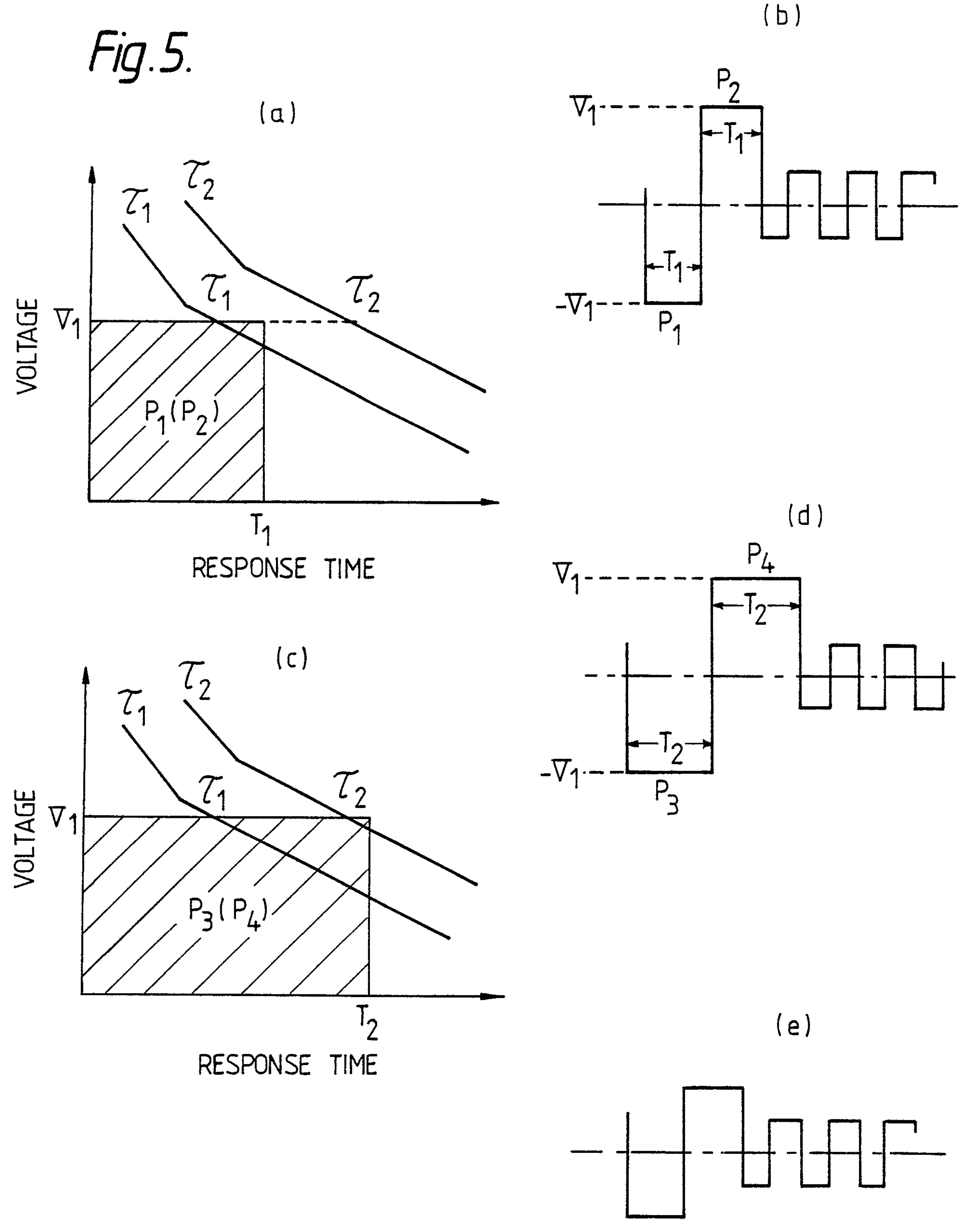

(a)
VOLTAGE
V_1
τ_1
τ_2
τ_1
τ_2
$P_1(P_2)$
T_1
RESPONSE TIME
(b)
P_2
V_1
T_1
T_1
$-V_1$
P_1
(c)
VOLTAGE
V_1
τ_1
τ_2
τ_1
τ_2
$P_3(P_4)$
T_2
RESPONSE TIME
(d)
P_4
V_1
T_2
T_2
$-V_1$
P_3
(e)

Fig.6.

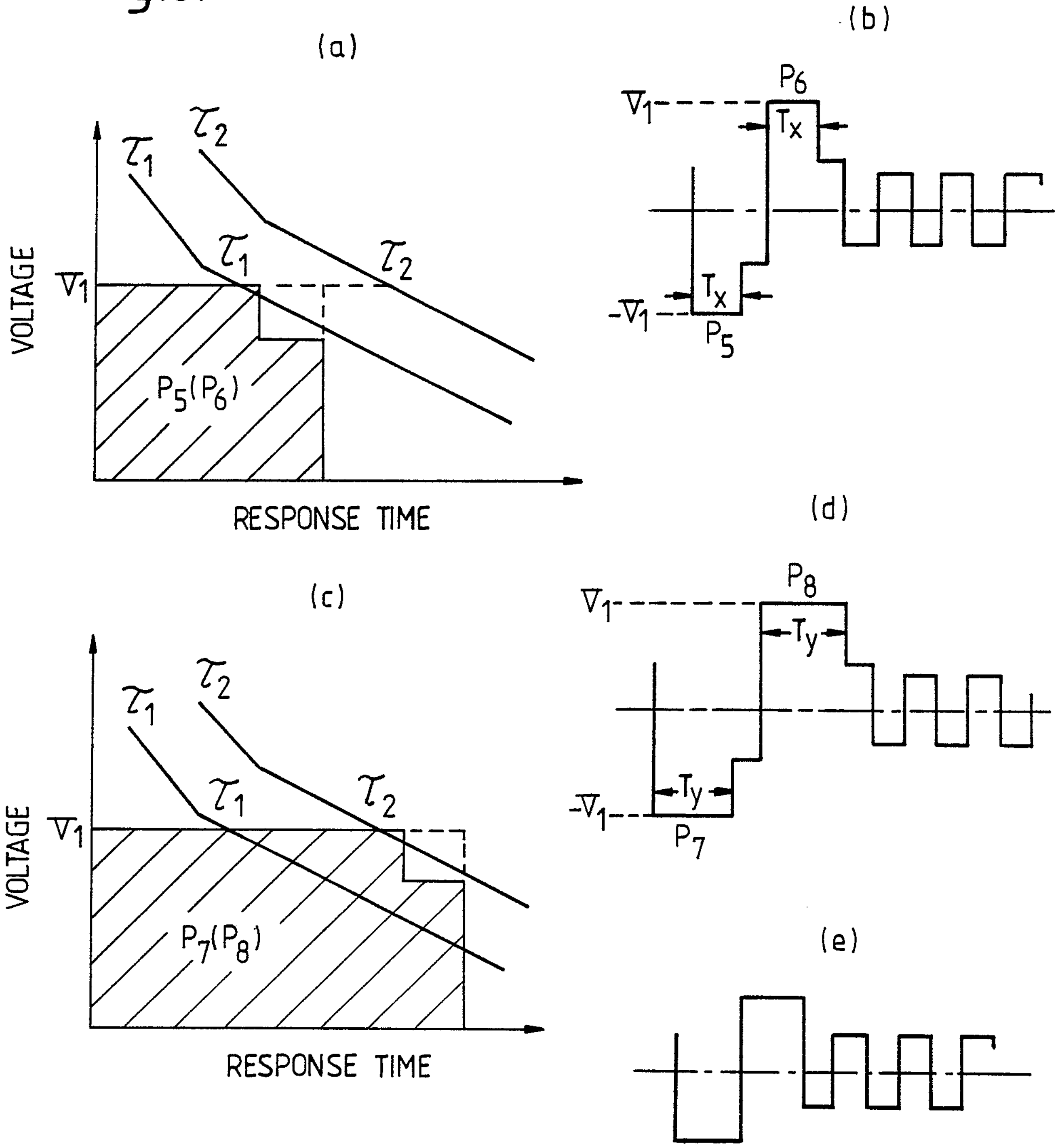

(a)
VOLTAGE
RESPONSE TIME
V1
τ1
τ2
τ1
τ2
P5(P6)
(b)
V1
-V1
P6
P5
Tx
Tx
(c)
VOLTAGE
RESPONSE TIME
V1
τ1
τ2
τ1
τ2
P7(P8)
(d)
V1
-V1
P8
P7
Ty
Ty
(e)

Fig.8.

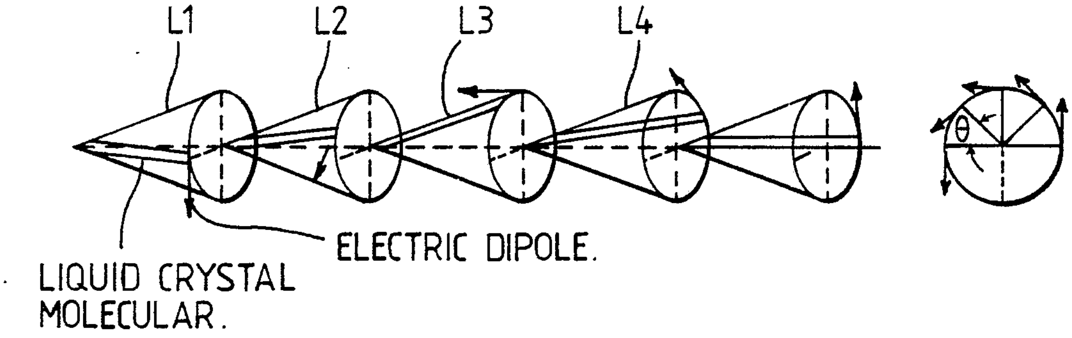


Fig.9.

(a) (b)

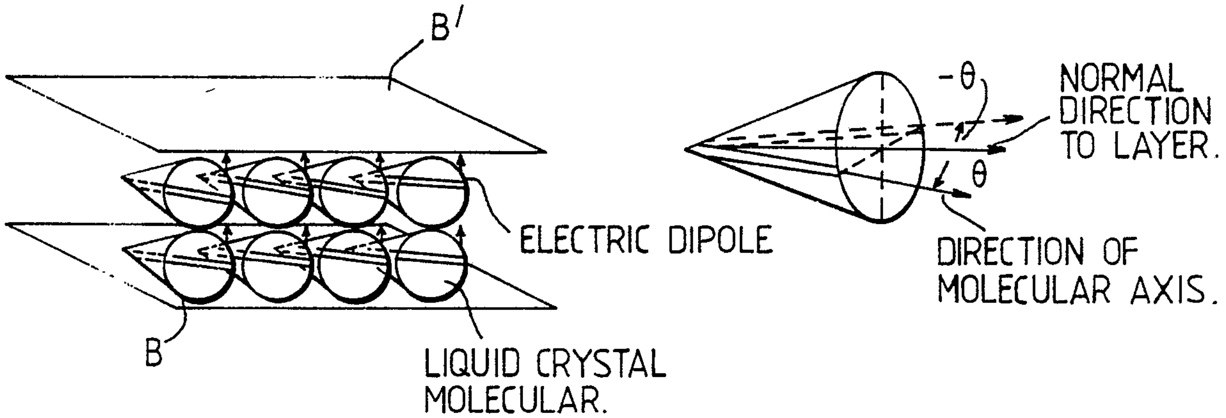
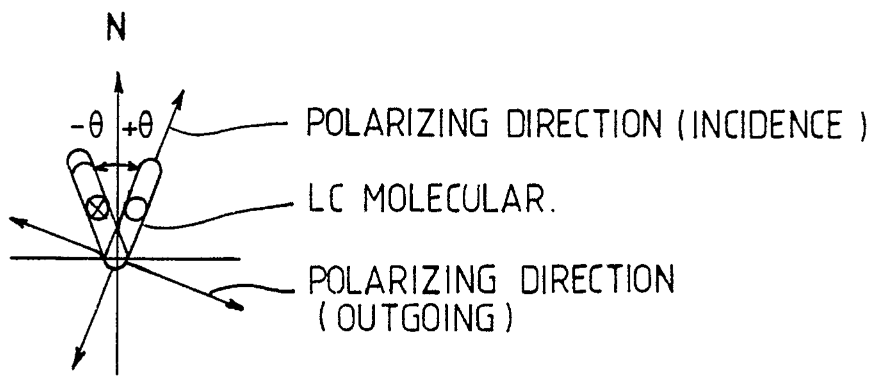


Fig.10.



European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 86302887.4

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
P,A	EP - A2 - 0 149 899 (SEIKO) * Page 19, line 3 - page 26, line 20; fig. 41 * --	1,2,5,6	G 02 F 1/137 G 02 F 1/133 G 09 G 3/36
A	DE - A1 - 3 414 704 (CANON) * Abstract; page 26, line 26 - page 31, line 19; page 32, line 20 - page 36, line 6; page 57, line 20 - page 60, line 30 * --	1,2,5,6	
A	US - A - 4 508 429 (NAGAE) * Column 4, line 48 - column 7, line 10; column 7, line 57 - column 8, line 13 * --	1,2,5,6	
A	EP - A2 - 0 106 386 (BBC) * Page 4, line 26 - page 5, line 34; fig. 1-4; page 14, line 14 - page 19, line 36 * ----	1-3,5-7	TECHNICAL FIELDS SEARCHED (Int. Cl.4) G 02 F 1/00 G 09 G 3/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	05-08-1986	GRONAU

CATEGORY OF CITED DOCUMENTS

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