

The invention relates to an electrooptical liquid-crystal switch element, comprising a liquid-crystal layer with at least one substrate, and a polarizer and an analyser, and
5 to an electrode structure, disposed on the substrate, for generating an electric field having a field component which is aligned predominantly parallel to the liquid-crystal layer,

- 10 (a) the liquid-crystal layer having a twistable structure and the direction of polarization of light which passes through the liquid-crystal layer depending on the degree of twisting of the liquid-crystal layer;
- 15 (b) the liquid-crystal layer being anchored in an initial orientation in which its axis of twisting remains perpendicular, or essentially perpendicular, to the liquid-crystal layer; and
- 20 (c) that field component of the electrode structure which is aligned predominantly parallel to the liquid-crystal layer being capable of alteration in such a way that the degree of twisting of the liquid-crystal layer is consequently altered.

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An electrooptical liquid-crystal switch element which comprises a liquid-crystal layer with at least one substrate, and a polarizer and an analyser, and an electrode structure, disposed on the substrate, for
30 generating an electric field having a field component which is aligned predominantly parallel to the liquid-crystal layer is disclosed in US-A-3 854 751. In this liquid-crystal switch element, the field-generating electrode structure generates two electric fields, of which one has a
35 field component aligned predominantly parallel to the liquid-crystal layer, while the other has a field component aligned predominantly perpendicular to the liquid-crystal

layer, the liquid-crystal layer being switched by one electric field to the state of minimum light transmission and by the other electric field to the state of maximum light transmission, while the optical axis of the liquid crystal is aligned perpendicular to the liquid-crystal layer by one electric field and parallel to the liquid-crystal layer by the other electric field. In the cases where use is made of compensated cholesteric liquid crystals which, in the absence of electric fields orient themselves spontaneously so that their optical axis is perpendicular to the liquid-crystal layer, one electric field may optionally be dispensed with, although, according to US-A-3 854 751, it is preferable, even in these cases, to use both fields because the self-alignment time of the liquid crystals which orient themselves is relatively long and therefore very unfavourable.

DE 24 59 533 A1 and DE 23 58 581 B2 also disclose electrooptical liquid-crystal switch elements which have a reorientation device comprising a field-generating structure whose electric field has a field component aligned predominantly parallel to the liquid-crystal layer. In the liquid-crystal switch element according to DE 23 28 581 B2, however, as in that according to US-A 2 854 751, two mutually perpendicular electric fields are generated in order to align the optical axis of the liquid crystal in two orientations extending mutually perpendicularly, of which one extends parallel to the liquid-crystal layer and the other perpendicular to it. This type of reorientation of the optical axis of the liquid crystal also takes place in the liquid-crystal switch element according to DE 24 59 533 A1, in which case, however, the optical axis of the liquid crystal is automatically aligned perpendicular to the liquid-crystal layer by means of homeotropic edge orientation of the liquid crystal.

Finally, WO 84/04601 also discloses, in connection with a liquid crystal, a comb-like field-generating structure whose field has a component aligned predominantly parallel to the liquid-crystal layer. The device according to this publication is, however, a light guide in which the coupling-out of light is controlled by changing the effective refractive index of the core, which is composed of the liquid crystal, or of the cladding, which is formed by the liquid crystal, by means of the field-generating structure.

From JP 1-33521 (A) in Pat. Abstr. Jap. P-875, 23.05.89 vol. 13, No. 219 it is known, incidentally, to dispose electrodes in parallel planes, but for the purpose of generating a storing scattering state in an optical liquid-crystal modulator.

Furthermore, JP 1-179912 (A) in Pat. Abstr. Jap. P 946, 18.10.89, vol. 13 No. 460 and JP 1-161217 (A) in Pat. Abstr. Jap. P-936, 25.9.89, vol. 13 No. 428 disclose liquid-crystal display-element components which serve to improve the blocking state of a display, twisted liquid-crystals with a particular orientation being used. In addition, JP 1-44422 (A) in Pat. Abstr. Jap. P-880, 7.6.89, vol. 13 No. 242 describes a liquid-crystal display element in which the nematic liquid crystal has an orientation with an pitch angle of 20° to 30° . This is, however, a conventional liquid-crystal structure in which the optical axis of the liquid crystal is switched between a direction parallel to the liquid-crystal layer and one perpendicular to it by the application of an electric field.

Finally, GB 1 506 570 and JP 54-17756 (A) in Pat. Abstr. Jap. E-101, 30.3.79, vol. 3 No. 38 disclose liquid-crystal display devices with optical compensator or reflector and with dichroic dyestuffs.

Further known electrooptical liquid-crystal switch elements are described, for example, by M. Schadt and F. Leenhouts in "Appl. Phys. Lett.", vol. 50, pages 236 ff. (1987) and by T. J. Scheffer and J. Nehring in "J. Appl. Phys.",
 5 vol. 58, pages 3022 ff. (1985), furthermore by L. Phl, G. Weber, R. Eidenschink, G. Baur and W. Fehrenbach in "Appl. Phys. Lett.", vol. 38, pages 497 ff. (1981) and by M. Schadt and W. Helfrich in "Appl. Phys. Lett.", vol. 18, pages 127 ff. (1971).

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Furthermore, from the paper by K. Fahrenschon et al.: "Deformation of a Pretilted Nematic Liquid Crystal Layer in an Electric Field" in Appl. Phys. 11 (1976), pages 67 to 74, it is known to predeform liquid crystals in
 15 electrooptical liquid-crystal switch elements in their deformation direction so that a uniform deformation direction consequently results when the deforming electric field is applied.

20 Electrooptical liquid-crystal switch elements are used, in particular, in liquid-crystal display devices such as, for example, in viewing screens of television sets, computers, central control rooms and of other devices, installations or the like for switching the pixels of these liquid-
 25 crystal display devices, i.e. for altering the brightness and/or colour of a pixel.

In the liquid-crystal display devices or displays constructed with electrooptical liquid-crystal switch
 30 elements of the above known types, the observation-angle or viewing-angle range, i.e. the angular range from which a display generated by means of the liquid-crystal display device can be viewed without substantial optical distortion, is considerably limited because the contrast of
 35 the display depends fairly strongly on the viewing angle.

This angular dependence of the contrast of the known liquid-crystal display devices is, as shown by the investigation results appended hereto, a consequence of the earlier reorientation of the optical axis of the liquid-crystal layer between an alignment parallel to the liquid-crystal layer and an alignment perpendicular to the liquid-crystal layer. The investigations, which have been carried out as part of the present invention, established that it is the deformation of the liquid crystal effected by such a reorientation which results in a strongly pronounced angular dependence of the transmission of the liquid crystal switch element and, consequently, of the contrast.

An electrooptical liquid-crystal display switch element of the type mentioned at the outset having the features (a), (b) and (c) which are specified there and which eliminate the angular dependence of the transmission and consequently of the contrast is disclosed in the publications by R. A. Soref, namely in the paper entitled "Field effects in nematic liquid crystals obtained with interdigital electrodes" in the Journal of Applied Physics, vol. 45, No. 12, December 1974, American Institute of Physics, and from the paper entitled "Interdigital twisted-nematic displays" in Proceedings of the IEEE, December 1974, pages 1710-1711. A problem with these known electrooptical liquid-crystal switch elements is that, on applying an electric field which deforms the liquid crystal, i.e. which twists or detwists it, regions of different deformation of the liquid crystal are produced depending on whether the particular region is an interdigital region, i.e. whether it is situated between the comb electrodes of the field-generating electrode structure, or an intradigital region, i.e. extends inside the region of the comb electrodes. These regions of different deformation of the liquid crystal, which are due to the fact that that deformability of the liquid crystal which is achievable on applying the

electric field in the immediate vicinity of the anchoring layer, situated near the comb electrodes, for the liquid crystal is poor, result in an undesirable and optically interfering structural formation in the liquid-crystal layer and also in the fact that, depending on the polarizer-analyser arrangement (mutually parallel or perpendicular), either adequate locking or satisfactory transmission of the electrooptical liquid-crystal switch element is not achievable on applying an electric field, even if a comparatively high electric field is applied. This means that such electrooptical liquid-crystal switch elements have either an unsatisfactory contrast or a reduced brightness.

The object of the invention is to provide an electrooptical liquid-crystal switch element which simultaneously both has essentially a viewing-angle independent of the transmission and of the contrast and a favourable deformability of the liquid-crystal layer by the applied electric field in the immediate vicinity of its anchoring layer.

This object is achieved by an electrooptical liquid-crystal switch element of the type mentioned at the outset which is distinguished by the fact that the initial orientation of the liquid-crystal layer, at least on its layer side adjacent to the electrode structure, encloses an pitch angle which is greater than 0° and less than 30° with a plane parallel to the liquid-crystal layer, with the result that a deformability of the liquid-crystal layer is produced in the immediate vicinity of the anchoring of the liquid-crystal layer on applying the electric field.

In this way, an electrooptical liquid-crystal switch element is obtained which has not only an essentially angle-independent transmission and an essentially angle-independent contrast but, in addition, also has a

favourable deformability of the liquid crystal in the vicinity of the anchoring layer for the liquid crystal on applying the electric field.

- 5 The statement that the angle of twisting remains "essentially" perpendicular to the liquid-crystal layer and that the optical axis is rotated "essentially" parallel to the liquid-crystal layer is hereinafter intended to imply that there is provided a certain pitch angle α_0 of more
10 than 0° and 30° which the initial orientation of the liquid-crystal layer encloses, at least on its layer side, adjacent to the field-generating electrode structure, of the liquid-crystal layer, with a plane parallel to the liquid-crystal layer, the initial orientation of the
15 liquid-crystal layer being understood here as meaning the preferred direction of the molecular axes of the liquid crystal in the initial orientation of the liquid-crystal layer.
- 20 Preferably, the liquid-crystal switch element according to the invention is designed so that that field component of the field-generating electrode structure which is aligned predominantly parallel to the liquid-crystal layer can be altered in such a way that the degree of twisting of the
25 liquid-crystal layer is altered continuously or stepwise for the purpose of continuously or stepwise setting different degrees of light transmission in the range between essentially maximum and minimum light transmission.
- 30 As shown by the investigation results, attached hereto, on the angular dependence of the transmission in liquid-crystal switch elements according to the invention, the transmission is virtually not angle-dependent in the liquid-crystal switch elements according to the invention.

The electric field having the field component aligned predominantly parallel to the liquid-crystal layer can be obtained in that the field-generating electrode structure comprises strip or line electrodes which extend parallel to one another and parallel to the liquid-crystal layer and are alternately acted on by a different electrical potential.

Preferred embodiments of such a field-generating electrode structure are designed so that

- (a) the strip or line electrodes are disposed alternately in at least two planes parallel to the liquid-crystal layer, and the two planes may be formed, in particular, by the two opposite surfaces of an insulating film, thin plate, layer or the like; or
- (b) the strip or line electrodes acted on by a different potential are disposed in the same plane so as to intermesh in comb fashion, and said plane may be formed, in particular, by that surface of the substrate bounding the liquid-crystal layer which is adjacent to the liquid-crystal layer or an insulating film, thin plate, layer or the like applied to such a substrate.

A further development of the electrooptical liquid-crystal switch element according to the invention is distinguished by the fact that the field component aligned predominantly parallel to the liquid-crystal layer forms an alignment angle which is greater than 0° and less than 90° with the preferred direction which the liquid-crystal layer has on its layer side, adjacent to the field-generating electrode structure, in its initial orientation. In this way, on the one hand, a domain formation as a result of different direction of rotation of adjacent liquid-crystal switch

elements or element regions is prevented and, on the other hand, short switching times are achieved since, as a result of the acute angle between the field component extending predominantly parallel to the liquid-crystal layer and the initial orientation of the liquid-crystal layer on its layer side adjacent to the field-generating electrode structure, a clearly directed initial torque of sufficient magnitude is produced on switching on the electric field, which torque predetermines the direction of rotation and, consequently, the liquid-crystal switch element is switched in the shortest possible time.

Preferably, said liquid-crystal switch element is designed so that

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(a) the alignment angle is greater than 70° and less than 90° for positive dielectric anisotropy of the liquid crystal, or so that

20 (b) the liquid crystal has a negative dielectric anisotropy, in which case the alignment angle is less than 20° and greater than 0° .

If liquid-crystal materials having positive dielectric anisotropy $\Delta\epsilon$ are used, a torque is specifically induced which rotates the preferred direction (director) of the liquid crystal in the direction of the electric field, whereas if liquid-crystal materials having negative dielectric anisotropy are used, a torque is induced which rotates the preferred direction (director) in a plane perpendicular to the direction of the electric field. In this connection, taking into consideration electro-optical characteristic curves and switching times, the alignment angle should, as specified above, not be less than $|70^\circ|$ for positive $\Delta\epsilon$ and not be greater than $|20^\circ|$ for negative $\Delta\epsilon$.

Particularly preferably, a liquid-crystal material, in particular a non-ferroelectric liquid-crystal material, having negative dielectric anisotropy $\Delta\epsilon$ is provided in the liquid-crystal switch element according to the invention since this makes it possible to prevent a further type of domain formation if the electric field has, in addition to the component aligned parallel to the liquid-crystal layer, also a component oriented perpendicular thereto, which is generally the case in practice. Such a case occurs, for example, if the electric field is generated, as is preferably done, by strip or line electrodes since, in that case, a component which is likewise active at high fields is present perpendicular to the liquid-crystal layer simultaneously with the component which extends parallel, or virtually parallel, to the liquid-crystal layer. In liquid-crystal materials having positive $\Delta\epsilon$, this results in a reorientation of the liquid crystal at high fields, during which reorientation the preferred direction is rotated out of the plane of the liquid-crystal layer. This is associated with a domain formation and is undesirable in many cases, with the result that only the lower region of the electrooptical characteristic line is usable. In the case of materials having negative $\Delta\epsilon$, this field component induces a torque which rotates the preferred direction of the liquid crystal in the plane of the liquid-crystal layer. The reorientation described above is consequently prevented and a substantially larger portion of the electrooptical characteristic line is usable.

In relation to the initial orientation of the liquid crystal, it is preferable that

- (a) the liquid crystal has an untwisted structure in its initial orientation and can be reoriented in a twisted structure by the field component aligned predominantly parallel to the liquid-crystal layer, in which twisted

structure the angle of twisting is perpendicular to the liquid-crystal layer, or that

- 5 (b) the liquid crystal has a twisted structure in its initial orientation whose angle of twisting is perpendicular to the liquid-crystal layer and which can be detwisted by the field component aligned predominantly parallel to the liquid-crystal layer.
- 10 The remaining basic structure of the liquid-crystal switch element is preferably designed in such a way that
- 15 (1) to operate the electrooptical liquid-crystal switch element in the transmitted-light mode, a polarizer is provided on one side of the liquid-crystal layer and an analyser on the other side; or so that
- 20 (2) to operate the electrooptical liquid-crystal switch element in the reflection mode, a polarizer/analyser is provided on one side of the liquid-crystal layer and a reflector on the other side.

At the same time, a birefringent optical compensator may be provided between the liquid-crystal layer and the

25 polarizer. The optical compensator can be provided at the point where, as in the first case, a separate analyser is provided, but instead of this, also between the liquid-crystal layer and the analyser.

30 In particular, the liquid-crystal layer may contain a dichroic dyestuff and be provided with a polarizer on at least one side of the latter.

Preferably, the liquid-crystal switch element is

35 furthermore designed in such a way that its light transmission has its maximum or minimum value in the

initial orientation of the liquid-crystal layer and can be altered to its other extreme value in the reoriented state of the liquid-crystal layer.

5 Particularly preferably, the liquid-crystal switch element according to the invention is used to alter the brightness and/or colour of a pixel of an electrooptical display device, the latter preferably being a viewing screen. The liquid-crystal switch elements of the electrooptical
10 display device may be driven, in particular, by a transistor matrix or by a direct drive device in time-division multiplexing.

The above and further advantages of the invention will be
15 explained in greater detail below on the basis of preferred embodiments of electrooptical liquid-crystal switch elements according to the invention with reference to Figures 1 to 7 of the drawing insofar as they show the structure of the preferred embodiments of electrooptical
20 liquid-crystal switch elements according to the invention which are intentionally not drawn to scale for reasons of representation; in the drawing:

Figure 1 shows a partial section through an embodiment of
25 an electrooptical liquid-crystal switch element according to the invention which preferably forms a pixel of an electrooptical display device while controlling the brightness and/or colour of said pixel so that the viewing screen of an
30 electrooptical display device therefore comprises a multiplicity of such liquid-crystal switch elements which are incorporated in a planar matrix array;

35 Figure 2 shows a perspective view of an embodiment of an electrooptical liquid-crystal switch element

according to the invention for the transmitted-light mode, the individual parts, apart from the liquid-crystal layer indicated by orientation arrows, being shown in the exploded state;

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Figure 3 shows a perspective representation of an embodiment of an electrooptical liquid-crystal switch element according to the invention for the reflection mode, the individual parts, apart from the liquid-crystal layer indicated by the orientation arrows, likewise being shown in the exploded state;

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Figure 4 shows a perspective representation of a further embodiment according to the invention;

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Figure 5 shows a diagrammatic representation of a pitch angle α_0 which the initial orientation of the liquid-crystal layer preferably encloses with a plane parallel to the liquid-crystal layer, and the alignment angle β_0 which the field component, aligned predominantly parallel to the liquid-crystal layer, of the electric field which reorients the liquid crystal preferably forms with the initial orientation which the liquid-crystal layer has on its layer side adjacent to the field-generating structure;

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Figure 6 shows an experimentally determined curve showing the transmission of the vertically incident light as a function of the applied voltage for a typical exemplary embodiment of an electrooptical liquid-crystal switch element according to the invention;

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Figure 7 shows values determined by calculation for the transmission in the case of a typical exemplary embodiment of an electrooptical liquid-crystal switch element according to the invention, which values show that said liquid-crystal switch element has virtually no angular dependence of the transmission and of the contrast;

Figure 8 shows transmission values determined by calculation in the case of a known electrooptical liquid-crystal switch element, a so-called TN cell, which illustrate the angular dependence of the transmission in polar coordinates, the representation scale being exactly the same as in Figure 6, with the result that the high angular dependence of the transmission present in the case of the known TN cells becomes clear from a comparison between the two Figures 6 and 7 and that, on the other hand, virtually no angular dependence of the transmission is present in the case of the electrooptical liquid-crystal switch element according to the invention over a large range.

In the detailed description of the preferred embodiments of the invention which now follows, reference may first be made to Figures 1 and 2, of which Figure 1 shows a cross-section through an embodiment of an electrooptical liquid-crystal switch element for the transmitted-light mode in the assembled state, while Figure 2 illustrates this same liquid-crystal switch element in the exploded state of the individual parts of the same and on a scale which is reduced compared with Figure 1, the lower orientation layer and the lower insulation layer also being shown in Figure 2, in contrast to Figure 1, as flat layers for reasons of representation.

The electrooptical liquid-crystal switch element 1 for the transmitted-light mode as shown in Figures 1 and 2 comprises a liquid-crystal layer 2 which is enclosed between two substrates 3 and 4 which, according to the graphic representation, are denoted below as lower and upper substrate although, in practice, they may have any desired position. Preferably, said substrates 3 and 4 are glass substrates but they can also be composed of other suitable transparent, preferably insulating, materials, such as, for example, plastics. In addition, the substrates 3 and 4 are preferably of flat design and disposed parallel to one another, with the result that the liquid-crystal layer 2 is preferably an essentially flat or planar layer.

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In order to hold the liquid-crystal layer 2 with a predetermined initial orientation in the liquid-crystal switch element 1, it does not immediately adjoin the two substrates 3 and 4 but, on the contrary, it adjoins in each case an orientation layer 5 and 6, which are denoted below as lower and upper orientation layer on the basis of the graphic representation. The upper orientation layer 6 is applied directly to the upper substrate 4, whereas, on the other hand, a field-generating structure 7 and, optionally, an insulating layer 8 is provided between the lower substrate 3 and the lower orientation layer 5, so that the field-generating structure 7, the insulating layer 8 and the lower orientation layer 5 are applied in the sequence specified above to the lower substrate 3.

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The field-generating structure 7 comprises strip or line electrodes 9 and 10 which extend parallel to one another and parallel to the liquid-crystal layer 2. At the same time, the strip or line electrodes 9 alternate with the strip or line electrodes 10, as Figures 1 and 2 show, the strip or line electrodes 9 being connected to a different

electrical potential from the strip or line electrodes 10, with the result that an electric field is produced in each case between the strip or line electrodes 9 and 10 which electric field has a field component aligned predominantly parallel to the liquid-crystal layer 2. For example, as Figure 2 shows, the strip or line electrodes 9 are connected to one terminal of a voltage source 11, while the strip or line electrodes 10 are connected to the other terminal of said voltage source 11. Although the voltage source 11 is shown for reasons of principle as a direct-current source and could, in principle, also be such a direct-current source, an alternating-current voltage source 11 is used in practice to avoid a degradation of the liquid-crystal layer and the difficulties associated therewith.

In the embodiment of the liquid-crystal switch element 1 shown here, the strip or line electrodes 9 and 10 are designed so as to intermesh in comb fashion in the same plane, namely on the surface of an insulating base layer 12, which may also be formed by the surface of the substrate 3, the strip or line electrodes 9 being electrically interconnected to form a first comb structure by a strip- or line-type transverse electrode 13 extending transversely, in particular perpendicularly, to the strip or line electrodes 9, and the strip or line electrodes 10 being interconnected electrically to form a second comb structure by a further strip- or line-type transverse electrode 14 extending transversely, in particular perpendicularly, to the strip or line electrodes 10, and, furthermore, the two comb structures being disposed so as to intermesh, as can be seen particularly well from Figures 2 and 3.

Another possibility, not shown in the figures, is to dispose the strip or line electrodes 9 on the top of the

insulating base layer 12, while the strip or line electrodes 10 are disposed on the bottom of the insulating layer 12. In this case, the strip or line electrodes may be designed as simple, parallel strips or lines without comb-like structures being required.

In addition, the liquid-crystal switch element shown in Figures 1 and 2 also comprises a polarizer 15 on the outside of the substrate 3 and an analyser 16 on the outside of the substrate 4. Depending on the direction of light passage, polarizer and analyser may also be interchanged. Finally, an optical compensator 17 is also provided between the polarizer 15 and the substrate 3. Said optical compensator 17 may also be disposed instead between the analyser 16 and the substrate 4.

Figure 3 shows a perspective view of an embodiment of an electrooptical liquid-crystal switch element 18 for the reflection mode in an exploded representation of the individual parts of said liquid-crystal switch element 18, which differs in its external structure from the liquid-crystal switch element 1 shown in Figures 1 and 2 only in that, instead of the analyser 16 shown in Figures 1 and 2, a reflector 19 is provided which, in the embodiment shown, comprises a substrate 20, for example a glass substrate, and a reflecting layer 21, which is provided on that side of the substrate 20 which is adjacent to the liquid-crystal layer 2. According to this structure, the polarizer, which still remains, is at the same time also the analyser and is accordingly denoted as polarizer/analyser 22 for the purpose of differentiation from Figures 1 and 2.

A further embodiment of an electrooptical switch element 28 for the reflection mode, which is shown in Figure 4, differs from the electrooptical switch element 1 shown in Figures 1 and 2, for example, in that, instead of the

insulating layer 8 in Figures 1 and 2, a dielectric mirror 8a is provided and the birefringent compensator 17 is optionally provided between the substrate 4 and analyser 16. Provided as analyser 16 is an analyser/polarizer 22, which then acts as polarizer and analyser, with the result that the polarizer 15 of Figures 1 and 2 is omitted. This embodiment has, in particular, the advantage that neither the electrode structure 7 nor the substrate 3 needs to be transparent if the dielectric mirror 8a is provided between the liquid crystal 2, on the one hand, and the arrangement comprising the electrode structure 7 and the substrate 3, on the other, as shown in Figure 4, the orientation layer 5 being situated between the liquid crystal 2 and the dielectric mirror 8a. The orientation layer 5 may also be a component of the dielectric mirror 8a. The electrode structure 7 may also be provided on the dielectric mirror 8a, in particular on its side adjacent to the liquid crystal 2.

Incidentally, since the outer structure of the liquid-crystal switch element 18 and 28 is otherwise identical to that of the liquid-crystal switch element 1, the same reference symbols are used as in Figures 1 and 2 and, consequently, to avoid repetitions, reference is made to the corresponding explanations relating to Figures 1 and 2.

The internal structure of the liquid-crystal switch elements 1, 18 and 28 will now be dealt with in greater detail, that is to say the respective parameters of the liquid-crystal layer which are important for the operation of the liquid-crystal switch elements 1, 18 and 28, the orientation layers, the polarizers, the field-generating structures etc., which are specified in Table 1 below and are shown, as far as possible, in Figures 2 and 3:

Table 1

The following parameters are used to describe the preferred
embodiments of the liquid crystal switch elements in
5 relation to their physical design:

10	β	=	angle of twisting of the liquid crystal 2 in its initial orientation, that is to say the angle between the director at the substrate 3 or in the orientation layer 5 and the director at the substrate 4 or in the orientation layer 6.
15	β_0	=	alignment angle which electrical field component which is aligned predominantly parallel to the liquid-crystal layer 2 and is generated by the field-generating structure 7 to the preferred direction of the molecular axes of the liquid crystal 2
20			which the latter have in the initial orientation of the liquid crystal 2 on that layer side of the liquid-crystal layer 2 which is adjacent to the field-generating structure 7, that is to say at the
25			orientation layer 5; this angle is equal to the angle between the director at the substrate 3 or in the orientation layer 5 and the perpendicular to the longitudinal direction of the strip or line electrodes 9,
30			10 in the plane of said strip or line electrodes.
35	α_0	=	pitch angle which the initial orientation of the liquid-crystal layer 2 encloses, at least on its layer side of the liquid-crystal layer 2 adjacent to the field-generating structure 7, with a plane
40			parallel to the liquid-crystal layer 2, the initial orientation of the liquid-crystal layer being understood here as meaning the preferred direction of the molecular axes of the liquid crystal 2 in the initial orientation of the liquid-crystal layer.
45	ψ	=	angle between the director at the substrate 3 or in the orientation layer 5 and the transmission direction of the polarizer 15 or of the polarizer/analyser 22.

	ψ'	=	angle between the director at the substrate 3 or in the orientation layer 5 and the transmission direction of the analyser 16.
5	$ \psi - \psi' $	=	angle between the transmission direction of the polarizer and analyser.
	d	=	thickness of the liquid-crystal layer 2
10	$\epsilon_{ }, \epsilon_{\perp}$	=	permittivities parallel to, or perpendicular to, the director of the liquid crystal
	$\Delta\epsilon$	=	dielectric anisotropy of the liquid crystal = difference between $\epsilon_{ }$ and $\epsilon_{\perp}$, i.e.
15			$\Delta\epsilon = \epsilon_{ } - \epsilon_{\perp}$.
	n_o, n_e	=	ordinary or extraordinary refractive index of the liquid crystal
20	λ	=	wavelength of light
	Δn	=	$n_e - n_o$

In Figures 2 and 3, the arrows 23 to 27 indicate preferred directions of the liquid crystal 2, the preferred direction at the orientation layer 5 being indicated, in particular, by the arrow 23 and the preferred direction at the orientation layer 6 by the arrow 27, while the arrows 24, 25 and 26 represent preferred directions in the intermediate region which are shown to illustrate the twisting of the liquid crystal better. The pitch angle α_0 and the alignment angle β_0 are shown in Figure 5, the x-axis and y-axis defining a plane extending parallel to the liquid-crystal layer 2, while the z-axis extends perpendicular to the liquid-crystal layer 2, that is to say it corresponds to the thickness direction of the liquid-crystal layer, while the x-axis and y-axis correspond to the width and length direction of the liquid-crystal layer 2.

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In Tables 2 and 3 below, preferred initial states are given for the transmitted-light mode and the reflection mode, the initial state being understood as meaning the state which

is present when no electric field is applied across the field-generating structure 7.

Table 2: Preferred initial states in homogeneous planar orientation for transmitted-light mode of operation

Initial state	β	Δc	$d \times \Delta n / \lambda$	α_0	β_0	ψ	$ \psi - \psi' $
D1	$0^\circ \pm 15^\circ$	> 0	$> 0, < 4$	$> 0^\circ, < 30^\circ$	$> 70^\circ, < 90^\circ$	$0^\circ, 90^\circ$	$90^\circ, 0^\circ$ 90° preferred
D2	$0^\circ \pm 15^\circ$	< 0	$> 0, < 4$	$> 0^\circ, < 30^\circ$	$> 0^\circ, < 20^\circ$	$0^\circ, 90^\circ$	$90^\circ, 0^\circ$ 90° preferred
D3	$90^\circ \pm 15^\circ$	> 0	$> 0, < 4$ Preferred: $1/2\sqrt{3}, 1/2\sqrt{15},$ $1/2\sqrt{35}$	$> 0^\circ, < 30^\circ$	$> 70^\circ, < 90^\circ$	$0^\circ, 90^\circ$	$0^\circ, 90^\circ$ 0° preferred
D4	$90^\circ \pm 15^\circ$	< 0	$> 0, < 4$ Preferred: $1/2\sqrt{3}, 1/2\sqrt{15},$ $1/2\sqrt{35}$	$> 0^\circ, < 30^\circ$	$> 0^\circ, < 20^\circ$	$0^\circ, 90^\circ$	$0^\circ, 90^\circ$ 0° preferred

Table 3: Preferred initial states in homogeneous planar orientation for reflection mode of operation

Initial state	β	Δc	$d \times \Delta n / \lambda$	α_0	β_0	ψ	$ \psi - \psi' $
R1	$0^\circ \pm 15^\circ$	>0	$>0, <2$ Preferred 0.36	$>0^\circ, <30^\circ$	$>70^\circ, <90^\circ$	$0^\circ, 90^\circ$	$90^\circ, 0^\circ$ 90° preferred
R2	$0^\circ \pm 15^\circ$	<0	$>0, <2$ Preferred 0.36	$>0^\circ, <30^\circ$	$>0^\circ, <20^\circ$	$0^\circ, 90^\circ$	$90^\circ, 0^\circ$ 90° preferred
R3	$60^\circ \pm 5^\circ$	>0	$>0, <2$ Preferred: 0.36	$>0^\circ, <30^\circ$	$>70^\circ, <90^\circ$	$0^\circ, 90^\circ$	$0^\circ, 90^\circ$
R4	$60^\circ \pm 5^\circ$	<0	$>0, <2$ Preferred: 0.36	$>0^\circ, <30^\circ$	$>0^\circ, \leq 20^\circ$	$0^\circ, 90^\circ$	$0^\circ, 90^\circ$

It may be pointed out here that the figures for the values of $d \times \Delta n / \lambda$ and of α_0 and of β_0 are range figures, that is to say the two values provided with the symbol $\geq$ or $\leq$ or $>$ or $<$ indicate the range limits in each case, and specifically, including or excluding this range limit depending on the sign.

If the electrooptical liquid-crystal switch element 1 or 18 or 28 is used to alter the brightness and/or colour of a pixel of an electrooptical display device, the respective liquid-crystal switch element 1 or 18 shown in Figures 1, 2 or 3 forms a single pixel, so that a large multiplicity of such liquid-crystal switch elements 1, 18 or 28 are integrated to form a viewing screen, the substrates, the orientation layers, the polarizers, the analysers or the polarizers/analysers, the reflectors and the optical compensators, which have been shown as individual parts in Figures 1 to 3 for reasons of representation, form in each case a preferably integral component which is common to all the pixels, while each individual pixel has its own field-generating structure 7. Provided it is not a comb structure of the type shown in Figures 1 to 3, said field-generating structure may also be made up of strip or line electrodes extending in total over the entire area of the electrooptical display device, provided they are driven intersect-by-intersect in a suitable manner, for example in time-division multiplexing.

Preferred sizes for the liquid-crystal switch elements will be given below, which sizes are applicable, in particular, for the case where the liquid-crystal switch elements are used as pixels in an electrooptical display device:

	Thickness of the liquid-crystal layer:	1 μm to 10 μm
5	Areal size of the field-generating structure corresponding to a pixel	Square with an edge length of 10 μm to 1 mm
	Spacing between adjacent strip or line electrodes	2 μm to 50 μm
10	Voltage between adjacent strip or line electrodes at maximum contrast:	1 volt to 80 volt

It may be pointed out that the provision of a polarization film, that is to say of the polarizer/analyser 22 in front of the reflective liquid-crystal switch element 18 or 28 corresponds to parallel polarizers 15, 16 (that is to say an analyser 16 parallel to the polarizer 15 in the transmission direction). The use of a reflective liquid-crystal element 18 or 28 in combination with a polarizing beam splitter (McNeille prism) corresponds to crossed polarizers 15, 16 in the transmissive liquid-crystal switch element 1. This arrangement is suitable, in particular, for high-intensity projectors.

The mode of operation, in particular the optical behaviour, of the liquid-crystal switch elements 1 and 18 and also 28 described was investigated by means of computer simulation and confirmed by experimental investigation of suitably designed liquid-crystal switch elements.

The results of these investigations are shown in Figures 6 and 7, and the result of a comparison investigation on a TN liquid-crystal switch element, that is to say a known liquid-crystal switch element with spiral nematic liquid crystal, is shown in Figure 8.

The liquid-crystal switch element on which the investigation result of Figure 6 is based and which had the structure shown in Figures 1 and 2 had the following design parameters.

	Thickness of the liquid-crystal layer	= 6.9 μm
	Dielectric anisotropy	= -1.5
5	Optical wavelength $d \times \Delta n / \lambda$	= 0.865
	Initial twisting angle β	= 0°
	Alignment angle β_0	= 5°
10	Pitch angle α_0	= 5°
	Angle between polarizer and analyser	= 90°

- 15 The following may be added by way of explanation in relation to Figures 7 and 8:

The angle THETA is the angle between the observing direction and the perpendicular to the liquid-crystal layer. The intensity of the transmitted light is indicated on the axes of the polar-coordinate representation. The transmission is approximately 25% for vertical incidence.

It may be pointed out that, in the electrooptical switch element 1 shown in Figure 1 and 2, the orientation layer 6 and the substrate 4 may optionally be omitted if, for example, liquid-crystalline polymers are used. The embodiments of the electrooptical switch element can be modified accordingly for the reflection mode. The term "liquid crystal" therefore also comprises, in the present description and in the claims, liquid-crystalline polymers or other liquid-crystalline substances.

The liquid crystals used in the invention are preferably, but by no means exclusively, nematic liquid crystals or nematic liquid-crystalline polymers.

PATENT CLAIMS

1. Electrooptical liquid-crystal switch element,
comprising a liquid-crystal layer (2) with at least one
5 substrate (3), and a polarizer and analyser (15, 16; 22),
and an electrode structure (7) disposed on the substrate
(3) for generating an electric field having a component
which is aligned predominantly parallel to the liquid-
crystal layer (2),
- 10 (a) the liquid-crystal layer (2) having a twistable
structure and the direction of polarization of light
which passes through the liquid-crystal layer (2)
depending on the degree of twisting of the liquid-
15 crystal layer (2);
- (b) the liquid-crystal layer (2) being anchored in an
initial orientation in which its axis of twisting
remains perpendicular, or essentially perpendicular,
20 to the liquid-crystal layer (2); and
- (c) that field component of the electrode structure (7)
which is aligned predominantly parallel to the
liquid-crystal layer (2) being capable of alteration
25 in such a way that the degree of twisting of the
liquid-crystal layer (2) is consequently altered;
characterized in that the initial orientation of the
liquid-crystal layer (2), at least on its layer side
adjacent to the electrode structure (7), encloses a pitch
30 angle (α_0) which is greater than 0° and less than 30° with
a plane parallel to the liquid-crystal layer (2), with the
result that a deformability of the liquid-crystal layer (2)
is produced in the immediate vicinity of the anchoring of
the liquid-crystal layer on applying the electric field.



2. Electrooptical liquid-crystal switch element according to Claim 1, characterized in that that field component of the electrode structure (7) which is aligned predominantly parallel to the liquid-crystal layer (2) can
5 be altered in such a way that the degree of twisting of the liquid-crystal layer (2) is altered continuously or stepwise for the purpose of continuously or stepwise setting of different degrees of light transmission of the liquid-crystal switch element (1, 18, 28)) in the range
10 between essentially maximum and minimum light transmission.

3. Electrooptical liquid-crystal switch element according to Claim 1 or 2, characterized in that the field component aligned predominantly parallel to the liquid-
15 crystal layer (2) forms an alignment angle (β_0) which is greater than 0° and less than 90° with the preferred direction which the liquid-crystal layer (2) has on its layer side, adjacent to the electrode structure (7), in its initial orientation.

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4. Electrooptical liquid-crystal element according to Claim 3, characterized in that the alignment angle (β_0) is greater than 70° and less than 90° for positive dielectric anisotropy ($\Delta\epsilon$) of the liquid crystal (2).

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5. Electrooptical liquid-crystal switch element according to Claim 3, characterized in that the liquid crystal (2) has a negative dielectric anisotropy ($\Delta\epsilon$), the alignment angle (β_0) being less than 20° and greater than
30 0° .

6. Electrooptical liquid-crystal switch element according to one of Claims 1 to 5, characterized in that the electrode structure (7) comprises strip or line
35 electrodes (9, 10) which extend parallel to one another and



parallel to the liquid-crystal layer (2) and are alternately acted on by a different electrical potential.

7. Electrooptical liquid-crystal switch element
5 according to Claim 6, characterized in that the strip or line electrodes (9, 10) are disposed alternately in at least two planes parallel to the liquid-crystal layer (2).
8. Electrooptical liquid-crystal switch element
10 according to Claim 6, characterized in that the strip or line electrodes (9, 10) acted on by different potential are disposed in the same plane so as to intermesh in comb fashion.
- 15 9. Electrooptical liquid-crystal switch element according to one of Claims 1 to 8, characterized in that, to operate the electrooptical liquid-crystal switch element (1) in the transmitted-light mode, the polarizer (15) is provided on one side of the liquid-crystal layer (2) and
20 the analyzer (16) on the other side.
10. Electrooptical liquid-crystal switch element according to one of Claims 1 to 8, characterized in that, to operate the electrooptical liquid-crystal switch element
25 (18, 28) in the reflection mode, a polarizer/analyser (22) is provided on one side of the liquid-crystal layer (2) and a reflector (8a, 19) on the other side.
11. Electrooptical liquid-crystal switch element
30 according to Claim 10, characterized in that the reflector (8a, 19) is a dielectric mirror.
12. Electrooptical liquid-crystal switch element according to Claim 11, characterized in that the dielectric
35 mirror (8a) is disposed between the liquid-crystal layer (2) and one substrate (3).



13. Electrooptical liquid-crystal switch element according to one of Claims 9 to 12, characterized in that a birefringent optical compensator (17) is provided between the liquid-crystal layer (2), on the one hand, and the
5 polarizer (15) and/or analyser (16) or the polarizer/analyser (22), on the other.
14. Electrooptical liquid-crystal switch element according to one of Claims 1 to 13, characterized in that
10 the liquid-crystal layer (2) contains a dichroic dyestuff and a polarizer (15) is provided on at least one side of the latter.
15. Use of the electrooptical liquid-crystal switch
15 element according to one of Claims 1 to 14 to alter the brightness and/or colour of a pixel of an electrooptical display device.
16. Use according to Claim 15, characterized in that the
20 electrooptical display device is a viewing screen.
17. Use according to Claim 15 or 16, characterized in that the electrooptical liquid-crystal switch elements (1, 18, 28) of the display device are driven by a
25 transistor matrix.
18. Use according to Claim 15 or 16, characterized in that the electrooptical liquid-crystal switch elements (1, 18, 28) of the display device are driven by a direct drive
30 device in time-division multiplexing.