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DESIGN RULES FOR ARTWORK FOR LIQUID CRYSTAL DISPLAYS

by

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SUMMARY

Design of the artwork for liquid crystal cells follows a set of guidelines constrained by the electrical and mechanical characteristics of the material involved, the availability of connectors, and the suitability of process steps, as well as the artistic effect desired. This report discusses those aspects (other than artistic) of the design.

KEY WORDS

liquid crystal displays, artwork generation

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DESIGN RULES FOR ARTWORK FOR LIQUID CRYSTAL DISPLAYS

C.R. Stein

SCOPE

Liquid crystal display devices come in many types and styles. Under each classification are subgroups producing enormously complex jargon for basically simple displays. Cells can be classified as transmissive or reflective depending on the design for illumination. They can be classified by the electo-optic effect making the visual contrast: dynamic scattering, twisted nematic, planar nematic, cholesteric to nematic, etc. They can be classified as dichroic dye-bearing or not.

Electrically some cells are driven in a simplex fashion -- one driver per element in the display. Others are designed to time-share drivers in some X-Y matrix addressing scheme.

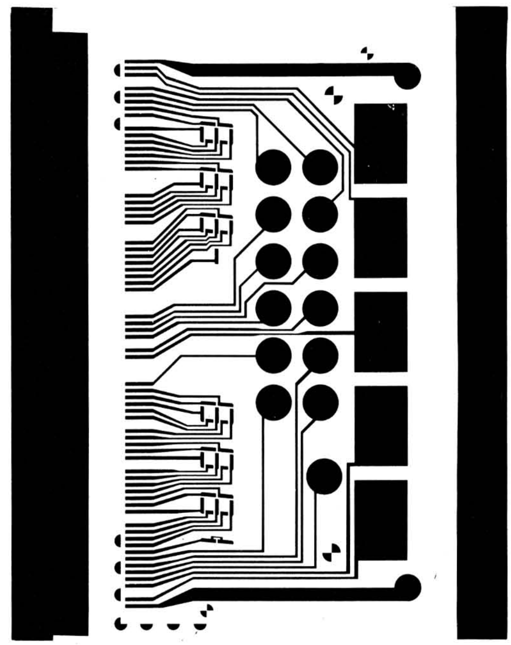
The following discussion presents design rules, or guidelines, for the generation of artwork for cells with a single driver per element, but it applies generally across the spectrum of reflective/transmissive, planar/cholesteric, and dichroic or non dye-bearing. The only exception is the specific case of dichroic dye displays in which the desired effect is to make all the background appear light colored with dark colored symbols in this light field. This exceptional case is discussed in a separate section.

Illustration of the ideas presented will be by an example of a recently constructed cell at the Research and Development Center -- the diesel engine monitor cell displayed at GOSAM (Group on Solid State Applications and Measurements) in 1979. It has 6-1/2 digits of numeric display and 18 individually controllable segments in the cell. Its artwork is illustrated in Figures 1A and 1B.

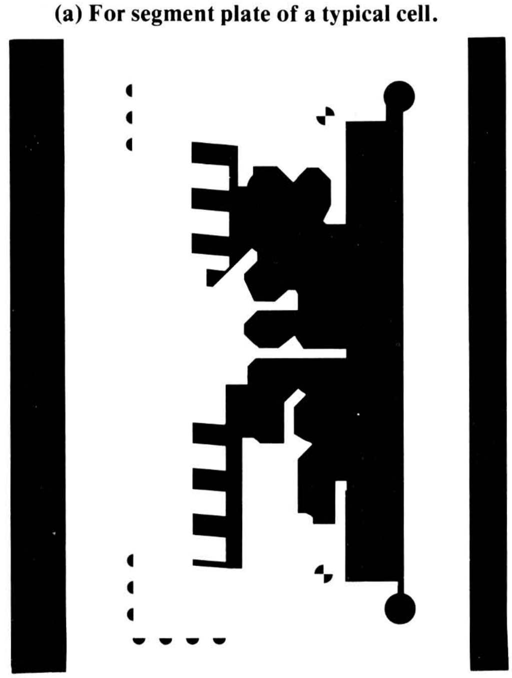
ELECTRODE PLACEMENT

The basic requirement for switching a liquid crystal display element is the ability to apply an electric field to the material. This means that an appropriately shaped section of conductive coating must be present on both of the confining plates of glass in those areas and that a lead must be brought out to the edge for the voltage application. The conductive coating is usually a transparent film, such as indium-tin oxide, but might be evaporated metal in some reflective display designs.

Ordinarily one of the plates is designated as a common counterelectrode, and all of the areas on that plate are gathered up into one or more common areas. Connection to this common area is made by one or more connections at the edge of the cell. This connection can be made more conveniently on the other piece of glass, which already has a number of connections to the individual segments, by means of a crossover. This crossover is a small dot of indium connecting a lead on the segment side to a lead on the common side.



(a) For segment plate of a typical cell.



(b) For common counter of a typical cell.

Figure 1. Indium/tin oxide pattern.

Manuscript received September 26, 1979

If the leads connecting the segments to the edge connector are not to be activated, they must never be in an area in opposition to the counterelectrode. This precludes the possibility of an electric field across the cell. Such a condition can be created by patterning the counterelectrode.

ELECTRICAL CONSIDERATIONS

The voltage drop along a lead in the indium-tin oxide is a determining factor in selecting the width of that lead. The liquid crystal material has a high dielectric constant, e.g., in the activated state, typically, ε_r=15 (see Table 1 for a list of symbols) and a modestly high resistivity, typically, $\varrho = 5 \times 10^9$ Ω-cm or 5×10^7 Ω-m.

Knowing the area of the segment to be activated and the thickness of the cell, one can calculate the values of impedances as usual:

$$R_c = \frac{\varrho d}{A};\ C = \frac{\varepsilon A}{d};\ X_c = \frac{1}{2\pi FC} \qquad (1)$$

Then the current drawn by a segment is:

$$I = \frac{V}{Z} = \sqrt{\left(\frac{V}{R}\right)^2 + \left(\frac{V}{X}\right)^2} \qquad (2)$$

Some numbers by way of an example:

$$\begin{aligned} \varepsilon r &= 15;\quad \varrho = 5 \times 10^7\ \Omega\,\text{m}; \\ F &= 60\ \text{Hz};\quad d = 12 \times 10^{-6}\text{m}; \\ A &= 10^{-4}\text{m}^2\ (1\ \text{cm}^2) \end{aligned} \qquad (3)$$

$$V = 10\ \text{V} \qquad (4)$$

$$R_c = \frac{(5 \times 10^7)\ (12 \times 10^{-4})}{10^{-4}} = 6 \times 10^6\ \Omega \qquad (5)$$

$$\begin{aligned} C &= \frac{(15)(8.85 \times 10^{-12})(10^{-4})}{12 \times 10^{-6}} \\ &= 1100 \times 10^{-12}\ \text{farad} \end{aligned} \qquad (6)$$

$$\begin{aligned} X_c &= \frac{1}{(2)(\pi)(60)(1100 \times 10^{-12})} \\ &= 2.4 \times 10^6\ \Omega \end{aligned} \qquad (7)$$

(This is a typical occurrence; the resistive and capacitive values of impedance are equal for some frequency in the 30 to 100 Hz range.)

$$\begin{aligned} I &= \left[\left(\frac{10}{6 \times 10^6}\right)^2 + \left(\frac{10}{2.4 \times 10^6}\right)^2\right]^{1/2} \\ &= 4.5\ \mu\text{a (for a segment area of 1 cm}^2) \end{aligned} \qquad (8)$$

or

$$J = \frac{I}{A} = 4.5\ \mu\text{a/cm}^2 \qquad (9)$$

The resistivity of the indium-tin oxide is specified in terms of ohms per square (σ), and, thus, the resistance of a lead is:

$$R_L = \frac{L}{w}\sigma \qquad (10)$$

and the voltage drop along it is:

$$V = RI \qquad (11)$$

Table 1

LIST OF SYMBOLS USED

A	Area of a Liquid Crystal Segment	m^2, cm^2
C	Capacitance of an LC Segment	farads
d	Thickness of the LC Layer	m, cm
ε	Dielectric Constant	farads/m
F	Frequency	hertz (Hz)
I	Current	amperes (A)
J	Current Density	A/cm^2
L	Length of a Lead in the Indium/Tin Oxide Electrode	cm
ϱ	Bulk Resistivity of the LC	Ω-cm
R_C	Loss Resistance of an LC Segment	Ω
R_L	Loss Resistance of a Lead-in	Ω
σ	Sheet Resistivity of the Indium/Tin Oxide Electrode	Ω/square
V	Voltages	volts (V)
W	Width of a Lead-in	cm
X_C	Capacitive Component of Impedance of the LC Segment	Ω

In the case of leads to individual elements in the display, voltage drops along the lead result in the application of less than the terminal voltage to an "on" element. This leads to a nonuniform activation of the cell and possibly a nonuniform appearance. In the case of leads to the common counterelectrode, voltage drops along the lead result in the application of that voltage to the elements that would otherwise have been off (zero voltage). Thus, the resistance of leads in the common counterelectrode becomes doubly important.

First is the opportunity for more current to flow (the sum of all the active elements), and second is the reduction of contrast by partial activation of off elements and less than total activation of on elements.

As a goal, it might be worth trying to hold these voltage drops to something like 1% of the applied voltage. Certainly a 10% variation in activation voltage, or the presence of 10% of the terminal voltage on the off elements, will result in less than satisfactory appearance.

Continuing the example, some numbers: V = 10 V; J = 4.5 μa/cm^2; A = 1 cm^2; L = 5 cm; and σ = 200 Ω/□.

The allowable drop is 1% of 10 V, or 0.1 V.

$$R_L = \frac{V_o}{I} = \frac{0.1}{4.5 \times 10^{-6}} = 22 \times 10^3 \quad (12)$$

$$R_L = \frac{\sigma L}{w}; \quad w = \frac{\sigma L}{R_L} = \frac{(200)(5)}{22 \times 10^3} = 4.5 \times 10^{-2} \text{ cm (or greater)} \quad (13)$$

(So a very thin lead could be sufficient for modestly small areas.)

In the counterelectrode the area can become much greater. Continuing,

$$A = 30\text{ cm}^2;\ L = 11\text{ cm};\ \sigma = 200\ \Omega/\ ;\ J = 4.5\ \mu a/\text{cm}^2 \quad (14)$$

$$I = JA = 135\ \mu a \quad (15)$$

$$R_L = \frac{V_D}{I} = \frac{0.1}{135 \times 10^{-6}} = 740\ \Omega \quad (16)$$

$$R_L = \frac{\sigma L}{w}; \quad w = \frac{\sigma L}{R_L} = \frac{(200)(11)}{740} = 3.0 \text{ cm (or greater)} \quad (17)$$

(In general, much wider leads must be used for the counterelectrode.)

The diesel cell has been built with the lead to the counterelectrode about 0.5 cm, and it is only marginally acceptable. If the cell has more than 30% of its area activated the unactivated, segments begin to light also.

Heat treatment of the glass will affect the resistivity of the indium-tin oxide (see Appendix A). In the case of cells to be sealed by a glass frit process, the higher value of resistivity must be used in these calculations.

MECHANICAL CONSIDERATIONS

The conductive coating on the glass is usually made by a diffuse process resulting, if controlled correctly, in a uniform coating. However, a number of problems can cause small area defects. Dirt specks on the glass before processing can cause pinhole defects. Dirt on the glass after processing can scratch the film.

Suppliers of coated glass specify a maximum level of these kinds of defects[1] (see Appendix A) for the material they manufacture. Such defects will continue to accumulate through the processing steps in the liquid crystal cell manufacturing.

This means that production of useful pieces of glass — and cells — is governed by a probability law. As the conductive lines on the glass become narrower, or as their length, their number or the number of processing steps increase, the yield of usable output will decrease.

While in the example electrical considerations suggest that a line width of 10^{-2} cm would be satisfactory for an area of 0.2 cm ^{2} and while in the laboratory some complex cells have been made with conductors that narrow, the yield of useful cells with leads that width will be disappointingly low in a production environment. The example uses leads that are 0.1 cm wide on the average.

CONNECTION CONSIDERATIONS

The artwork designer must have some plan in mind for making connection to the cell as the artwork is laid out. The following paragraphs outline some general guidelines.

While the creation of an electric field across the cell requires electrodes on both surfaces, customarily all connections to the external world come from only one surface. This necessitates one or more crossovers within the cell. It is, generally, a small dot of indium placed during assembly to make the desired connection between surfaces. In hand-assembled cells in the laboratory, placement of more than a few of these becomes a problem.

If the design will allow and the designer can find a standard printed circuit edge card connector, this is perhaps the easiest way to make connections. Standard spacings on the connectors are 0.100 in. center to center and 0.156, 0.125, and 0.050 in. center to center, respectively, with 0.100 the most popular. Standard thicknesses are 0.060, 0.090, and 0.120 in., respectively, with 0.060 in. the most popular. Most connectors of this sort want at least 0.25 in. finger length for insertion into the connector.

A second easy way to contact the cell is by using a flexible plastic/copper laminate on which the copper has been etched to match the etched indium-tin oxide with which it has to mate. Then it is wrapped around the edge of the cell and held in place by phosphor bronze spring clips. Several recent designs at Corporate Research and Development have used this method successfully.

Finally, on the market are several varieties of anisotropic, elastomeric conductors. They are sandwiched between the cell and mating printed circuit board. They have met with varying degrees of success. Schemes relying on an attempt to force wide expanses of unsupported flat surfaces together are prone to failure.

TOUCH PADS

Liquid crystal display cells offer an ideal means of providing input to the device. Superimposed over the display can be a transparent "keyboard" made of the same indium-tin oxide as inside the cell and patterned in exactly the same way. Various semiconductor houses offer integrated circuits designed to detect the presence of a finger on one of these pads.

This detection process always involves the loading of a circuit node by the body capacitance of the operator and, hence, a decrease in output voltage from the network as a result of this loading. It follows, then, that the conductive runs on the touch pad side of the cell's front glass have the same sort of series resistance problem that the inside electrodes have. Lead widths of 0.1 cm have been adequate.

As an operational enhancement, designs can require the simultaneous touching of two touch pads to create a valid entry. Then, if the two leads are brought together (within a finger span) only at the desired point on the display, random touching of isolated lead-ins will not cause false inputs to the device. Of course, two-fingered or two-handed people can defeat this modest protection scheme, but it is an advantage worth incorporating.

The diesel cell example has such a two-input scheme, and its touch pad artwork is illustrated in Figure 2.

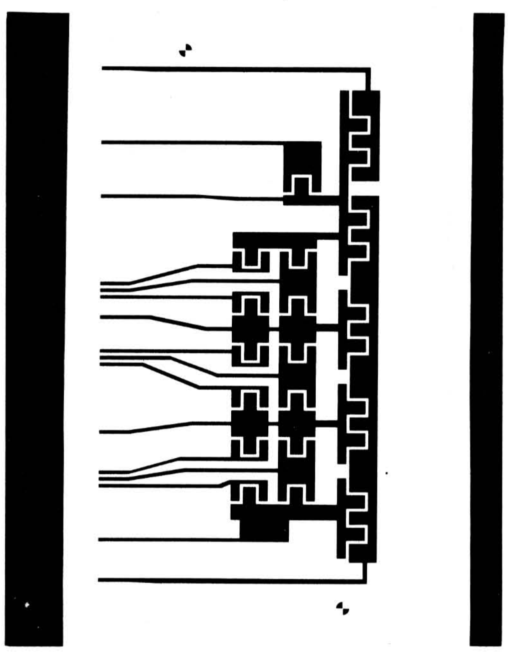


Figure 2. Indium/tin oxide pattern for touch pads.

GENERATION OF ARTWORK

While high-contrast pen and ink drawings have been used to generate artwork, the semiconductor industry long ago abandoned such input as too troublesome. The photographic processes that go on between the artwork and the final etching are high-contrast, and the operators take the exposures to saturation. Anything less than perfection in the original causes defects in the output.

Preferred schemes are rubylith or tape based. For simple geometric shapes these processes are no more difficult than pen and ink and are vastly superior. If there is a lot of "drawing" involved, these processes become more cumbersome.

Equally preferred, although not as easily available as rubylith, are the computer-aided generation schemes popular in the semiconductor and printed circuit board industries. Applicon is one of the hardware/software suppliers in this field.

Finally, of course, any number of custom artwork generation houses make this sort of thing their business.

DICHROICS WITH A LIGHT BACKGROUND

Since the usual dichroic dye-bearing cells appear dark in the unactivated areas, some special steps must be taken to make a cell which is everywhere in the high-transmission state except for the data displayed. Solutions to this problem affect the design of the artwork.

One solution is to provide a field in the cell that is activated everywhere except where the low-transmission state is required. This means additional counter-electrodes must be provided on both plates. These can be driven from a voltage source whose frequency or phase is sufficiently different from that on the data segments that the field on the leads never goes to zero.

A second solution is to provide different boundary conditions inside the data spaces from those outside. This scheme will work for planar nematics and very long pitch cholesterics but not for short pitch cholesterics. Of course, such differentiation is by an additional mask and artwork step.

ACKNOWLEDGMENTS

The author acknowledges helpful discussions with S. Aftergut, E.C. Buschman, and J.E. Bigelow.

REFERENCE

1. J. Wong and C. Shaw, *Glass and Electrode Materials for Liquid Crystal Display Fabrication,* 79CRD110, General Electric Corporate Research and Development.

APPENDIX

OCLI OPTICAL COATING LABORATORY, INC.

1.0 SCOPE

This specification defines a visually transparent conductive coating deposited on soda lime float and sheet glass which has been coated with an underlayer of vacuum deposited SiO_2.

2.0 PERFORMANCE SPECIFICATIONS

2.1 Sheet Resistivity

250 Ω/square maximum
100 Ω/square nominal

Resistivity will not exceed 1200Ω/sq. (400 Ω/sq. nominal) after 15 minutes at 550°C.

2.2 Spectral Transmittance @ 550 nm

83% minimum
87% nominal

2.3 Etch

Coating is removed within 60 seconds (25 sec. nominal) in an unagitated 55°C solution of equal parts of 37% hydrochloric acid and deionized water plus 3% nitric acid by volume.

2.4 Adhesion

Coating is not damaged or removed by a snap tape test using 3M Scotch Brand No. 610 or equivalent tape.

2.5 Abrasion

Coating is not damaged by a 200-rub eraser test at 2.2 pounds force (one kg).

2.6 Humidity

Coating is not deteriorated by a 24-hour exposure to 95% relative humidity at 50°C.

2.7 Stains

Coating will be 95% free of stain as inspected under fluorescent lighting.

3.0 PHYSICAL SPECIFICATIONS

3.1 Coating Thickness

300 Å nominal Indium Oxide
3000 Å nominal SiO_2

OCLI OPTICAL COATING LABORATORY, INC.

3.2 Standard Glass Thickness

.020"	±	.004"	0,5	±	0,10mm
.028"	±	.004"	0,7	±	0,10mm
.036"	±	.004"	0,9	±	0,10mm
.040"	±	.004"	1,0	±	0,10mm
.048"	±	.004"	1,2	±	0,10mm
.060"	±	.005"	1,5	±	0,13mm
.120"	±	.008"	3,0	±	0,20mm

3.3 Stock Sheet Sizes (± 1/16", ±1,6mm)

Glass	Coating	Coated Area
11.5" x 16.0" (292mm x 406mm)	10.8" x 15.5" (274mm x 394 mm)	1.16 sq. ft. (0,1080 m²)
14" x 14" (356mm x 356mm)	13.5" x 14" (343mm x 356mm)	1.31 sq. ft. (0,1265 m²)

Chips will not reduce coated area by more than 1%.

3.4 Pinholes

Diameter		Limit	
< .001"	(< 0,03mm)	Disregard	
.001" - .005"	(0,03 - 0,13)	1 per sq. in. (6,4cm²)	Average/sheet
> .005" - .010"	(> 0,13 - 0,25)	1 per 5 sq. in. (32cm²)	" "
> .010"	(> 0,25)	1 per 10 sq. in. (64cm²)	" "

3.5 Scratches

Accumulated length of visible scratches will not exceed 8 inches (20 cm).

3.6 Stock Material

Each stock sheet is selected to yield 95% or more acceptable parts if cut into 1/2" x 1" (1.25cm x 2,5cm) pieces.

4.0 PREPARATION FOR DELIVERY

Coated glass is packaged in a manner to ensure protection against damage from reasonable handling during shipment.

Each shipping lot is identified with the customer's name, coating type, glass size, and quantity.

5.0 QUALITY LIABILITY

Shipping lots are warranted to meet an acceptable quality level of 2.5%.

DOCUMENT TITLE	DOC. REV.	DOC. NO.
LCU-4004 InO COATING WITH SiO_2 UNDERLAYER		6031007

DOC. NO. 6031007

GALLARD SCHLESINGER

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Indium tin oxide coating on glass as electrodes in liquid crystal display devices

1. SUBSTRATE

1.1.	Substrate quality to Federal Specification DD-G-451C (U.S.A.) Quality Q4AA.	
1.2.	Standard substrate thicknesses	0.70 ± 0.10 mm 1.10 ± 0.10 mm 1.50 ± 0.10 mm
	Other possible substrate thicknesses	0.50 ± 0.10 mm 0.90 ± 0.10 mm
1.3.	Sheet size — Standard	305 mm x 305 mm ± 1.00 mm (nominally 1 ft square) 101 mm x 101 mm ± 0.50 mm (nominally 4" square)
	Maximum sheet size	For substrate thickness > 1.00 mm 600 mm x 900 mm subject to negotiation.
1.4.	Flatness	≤ 0.75 μ/cm
1.5.	Coefficient of thermal expansion	9×10^{-6} $^{o}K^{-1}$ (0 - 300°C) 10×10^{-6} $^{o}K^{-1}$ (300 - 450°C)
1.6.	Transformation point	550°C

2. COATING

2.1.	Conductivity ohms per square. Large volumes can be made to specification between 5-5,000 ohm/sq.	
	Standard manufacture	400, 200, 80, 20, 5 ohm/sq. ± 20%
2.2.	Bulk Resistivity	10×10^{-4} ohm cm ± 5% at 200 ohm/sq.
2.3.	Uniformity of layer over area	± 20% from any stated median.
2.4.	Resistive Behaviour	400 ohm per square @ 20°C in air x 2 @ 400°C x 4 @ 500°C Change is irreversible.

Layers at lower ohms per square show less change in resitivity with temperature.

2.5.	Temperature Coefficient	Reversible coefficient of resistance from 20°C to 100°C + 400 p.p.m/°C.
2.6.	Light Transmission (Photopic)	> 85% for layers in excess of 20 ohm/sq.
2.7.	Hardness	6 - 7 (Mhos scale)
2.8.	Etchability	400 ohm glass is etched in 3 minutes in 35% HCl at 20°C.
2.9.	Coating Limits	Complete to edge of glass -1.00mm
2.10.	Coating Quality	Pin holes and scratches not to be visible under visual inspection. Precise inspection parameters subject to agreement.
2.11.	Coating Thickness	400 ohm per square glass, 300 angströms.

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