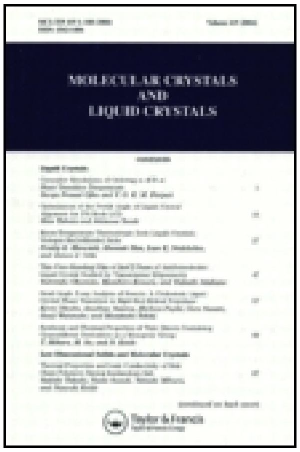

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Directly Addressed Matrix Liquid Crystal Display Panel With High Information Content

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Directly Addressed Matrix Liquid Crystal Display Panel With High Information Content

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The present states of two refreshing type matrix LCD (liquid crystal display) panels are discussed. The present multiplexing limit of the TN–FE (twisted nematic–field effect) mode matrix LCD panel is about 400 rows using a divided signal electrode configuration. Above this limit, the SBE (super twisted birefringency) display panel should be applicable if presentation of colored images is not a problem.

Keywords: liquid crystal display, directly addressing matrix LCD, high information content LCD, flat panel display, multiplexing limitation of matrix LCD, refreshing type matrix LCD

I. INTRODUCTION

A comparison between two directly addressed matrix LCD panels, a refreshing type and a memory type, is made at first. The refreshing type display is more suitable than the memory type display for quick operation. There are two types of refreshing type matrix LCD panels, the TN–FE mode panel and the SBE display. The former has been applied to many kinds of electronic equipment over the last 10 years, and the addressable number of rows in these panels has become larger and larger. This number is now fast approaching its limit of about 400. The newly developed SBE display should be applicable to panels which display more than 400 rows, if their colored images are suitable. However, some improvements in the production process are required before the displays can be produced in volume. A matrix full page LCD panel which has more than 1,000 rows should become a reality, using a memory type display such as a smectic C* mode, if quick response time is not required.

II. TWO TYPES OF DIRECTLY ADDRESSED MATRIX LCD PANELS

Directly addressed matrix LCD panels consist of many row and column electrodes, which cross each other as depicted in Figure 1. A pixel is located at each crossing point. Images are produced by controlling the bright and dark conditions of the individual pixel on the panel.

The row electrodes are usually referred to as scanning electrodes. Pixels aligned in one row are selected at one time by choosing corresponding scanning electrodes, while all the other pixels are not being selected. The column electrodes are referred to as data or signal electrodes, because the displayed conditions of the individual pixel in each row are determined by signals fed to the signal electrodes, corresponding to that pixel, while the row is being selected.

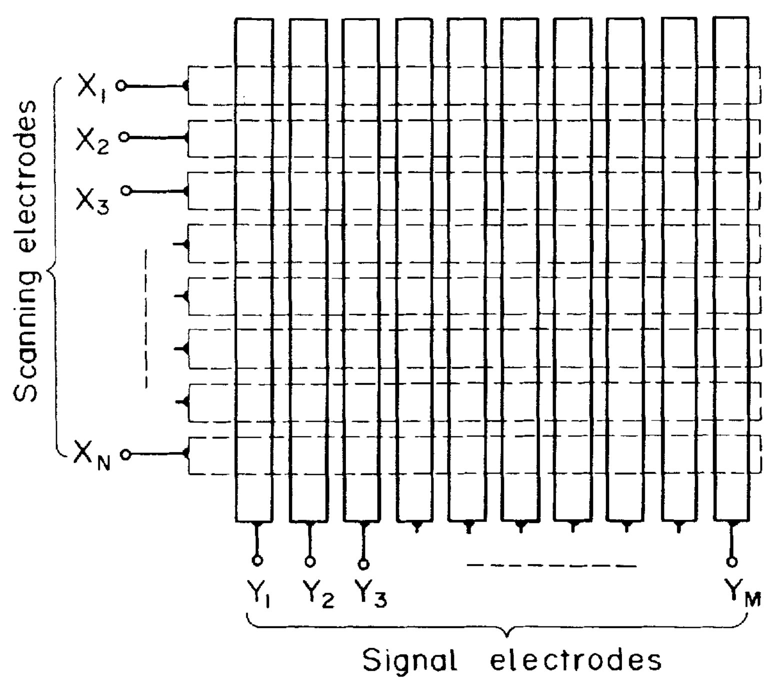

FIGURE 1 Electrode structure of conventional matrix liquid crystal display panel.

There are two types of directly addressed matrix LCD panels with high information content, the refreshing type and the memory type matrix LCD panels. In the refreshing type matrix LCD panels, all the pixels aligned on every scanning electrode are addressed line-by-line successively from the first to the last rows to complete one field addressing. This addressing operation is repeated several times until the contrast ratio of the image on the whole panel becomes high enough to be discernible by the human eye.

In the memory type matrix LCD panel, all the pixels aligned on one scanning electrode are addressed completely in one scanning period. The scanning operation is carried out only once from the first to the last scanning electrode. That is, pixels in the whole panel are addressed only one time in one frame period, although these pixels are addressed intermittently many times in the refreshing type matrix LCD panels. Thus, the image appears successively from the first to the last rows in the former, but it appears simultaneously over the whole panel in the latter. The minimum frame time is proportional to the number of scanning electrodes in the former, whereas it is nearly independent of their number in the latter. On the other hand, the contrast ratio of the displayed image is independent of the number of scanning electrodes in the former, but highly dependent in the latter.

There are two modes of memory type LCD panels, the smectic A mode and the smectic C* mode. The former uses a thermo-electro-optic effect and the latter uses a ferroelectric effect of the LC material in order to display images. As the two modes are described in another part of this issue, the refreshing type LCD panels are focused on here.

III. REFRESHING TYPE MATRIX LCD PANEL

Presently, the widely used refreshing type of matrix LCD panels are of the TN–FE mode type. Figure 2(a) shows a cutaway view of a TN–FE mode matrix LCD panel. Many striped thin film transparent electrodes are mounted parallel to each other on the inner surface of the upper and lower glass substrates. These electrodes are placed crosswise to each other as shown in Figure 2(b). A polarizer is pasted on the outer surface of each glass substrate. The polarizing axes of these polarizers are parallel to each other. Nematic LC material, having positive dielectric anisotropy, fills the space between the glass substrates. The orientations of the LC molecular axes near the upper

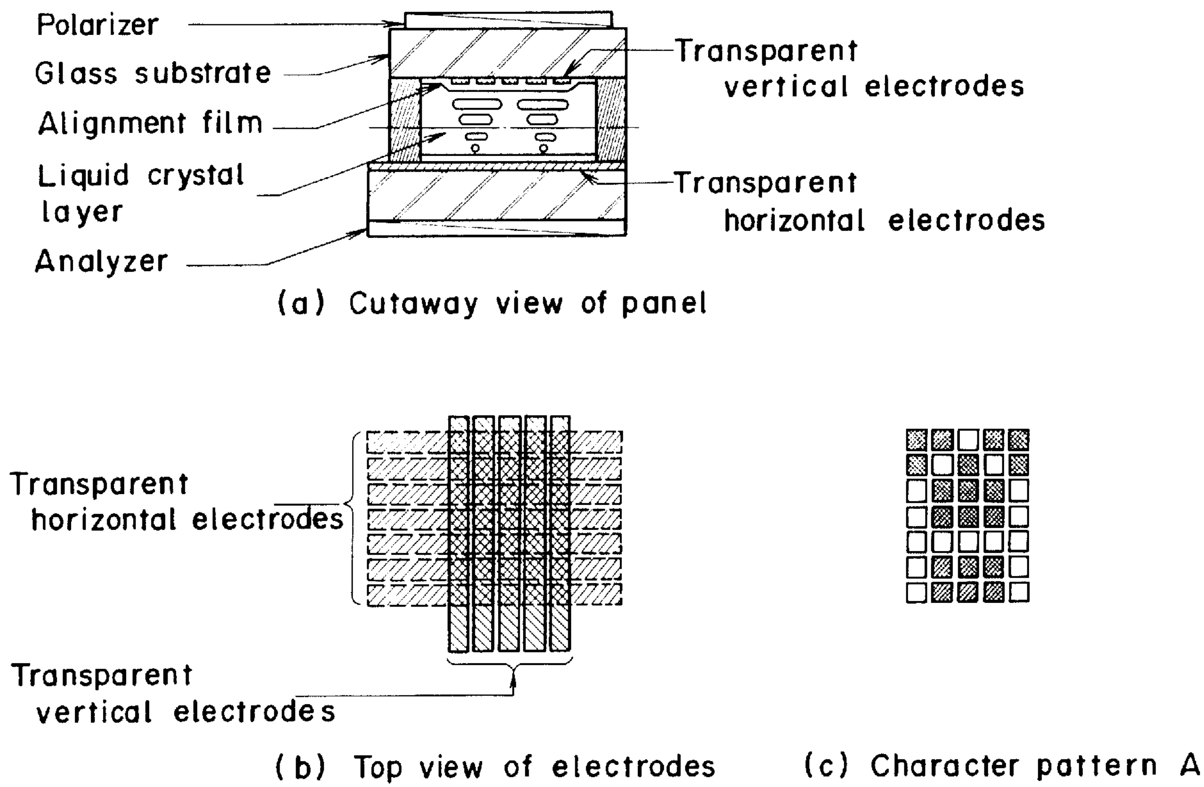

FIGURE 2 Construction of a TN–FE mode matrix liquid crystal display panel and example of character display.

glass substrate are parallel to the axis of the upper polarizer and they are twisted gradually through 90° going from the top to the bottom in the LC layer. Incident light is linearly polarized when it passes through the upper polarizer. Then, it is twisted gradually through 90° in its polarizing plane while passing through the LC layer. Therefore, the light cannot pass through the lower polarizer and the LCD panel looks dark when it is viewed from the bottom.

This type of panel is called the classic XY matrix LCD panel. When sufficient voltage is applied between two electrodes which cross each other, the light can pass through the pixel sandwiched in between the electrodes, making the pixel appear brightly. That is, the twisted structure of the LC layer is destroyed by the voltage and the polarizing plane of the linear polarized light becomes parallel to the axis of the lower polarizer. When the applied voltage is increased high enough, light passing through the surrounding pixels also increases. This tends to produce crosstalk, which is the most serious problem when fine images are to be displayed using matrix LCD panels.

In order to minimize crosstalk, an optimized amplitude selective addressing scheme is widely used. In this scheme, the scanning voltage is applied to the selected scanning electrode, while bias voltages are simultaneously applied to the other scanning electrode as shown in Figure 3. The maximum voltage ratio α_{max} is the ratio between the maximum voltage applied to the selected pixel and the minimum voltage applied to the unselected pixels, and is expressed as follows:[1,2]

$$\alpha_{max} = \sqrt{\frac{\sqrt{N} - 1}{\sqrt{N} + 1}}$$

The α_{max} becomes very small as the number of scanning electrodes N becomes larger. Thus, the changeable voltage range is very narrow when the number of scanning electrodes is large.

Figure 4 shows the relationship between α_{max} and the electro-optic characteristics of an LCD panel. Here, L_t and V_a represent the relative transmission of light through the LC layer and the applied voltage to that panel, respectively. The steepness γ is defined as the ratio between the voltages which correspond to 90 and 10% brightness for the panel.[13] For instance, it can be seen from Figure 4(a) that α_{max} is 1.1 when N is nearly 100. From Figure 4(b), the selected state voltage is $\alpha_{max} \cdot V_{10}$ and equal to 3.2 V, if the unselected state voltage is set at the threshold voltage V_{10} = 2.9 V. The L_t corresponding to these voltages are about 30 and 10%, respectively. Therefore, the

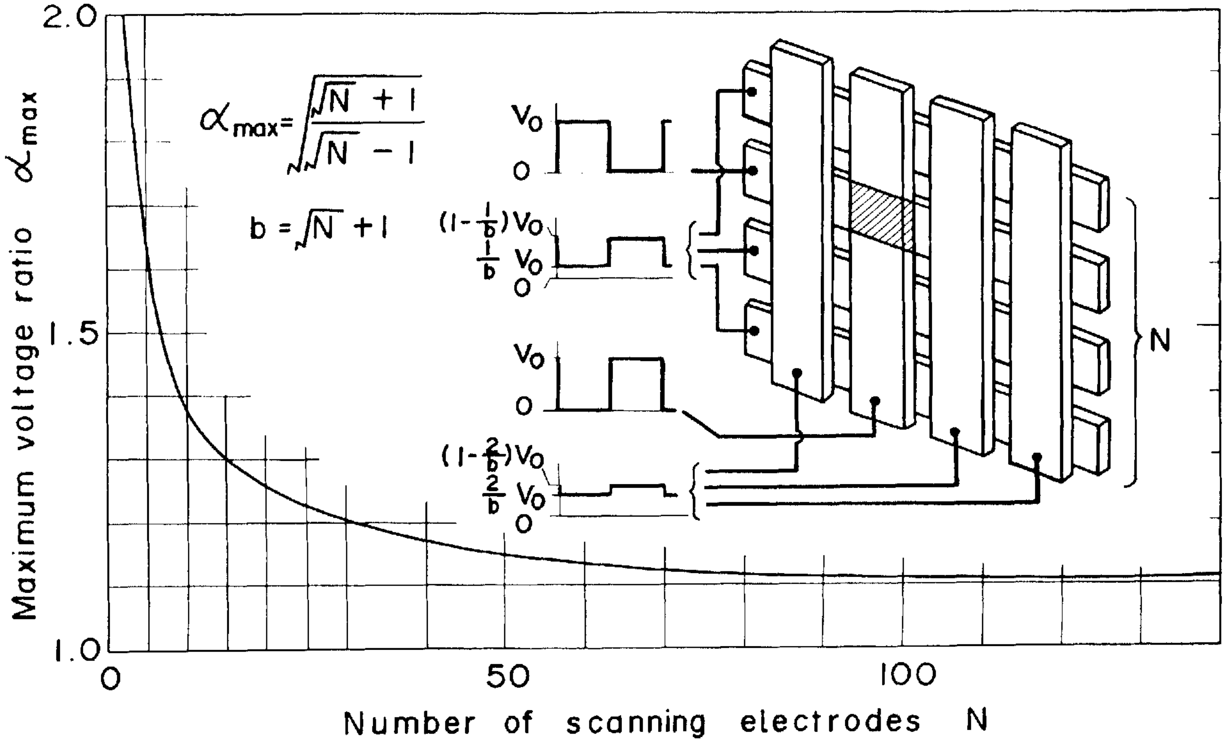

FIGURE 3 Relation between the maximum voltage ratio and number of scanning electrodes in the optimized amplitude selective addressing scheme.

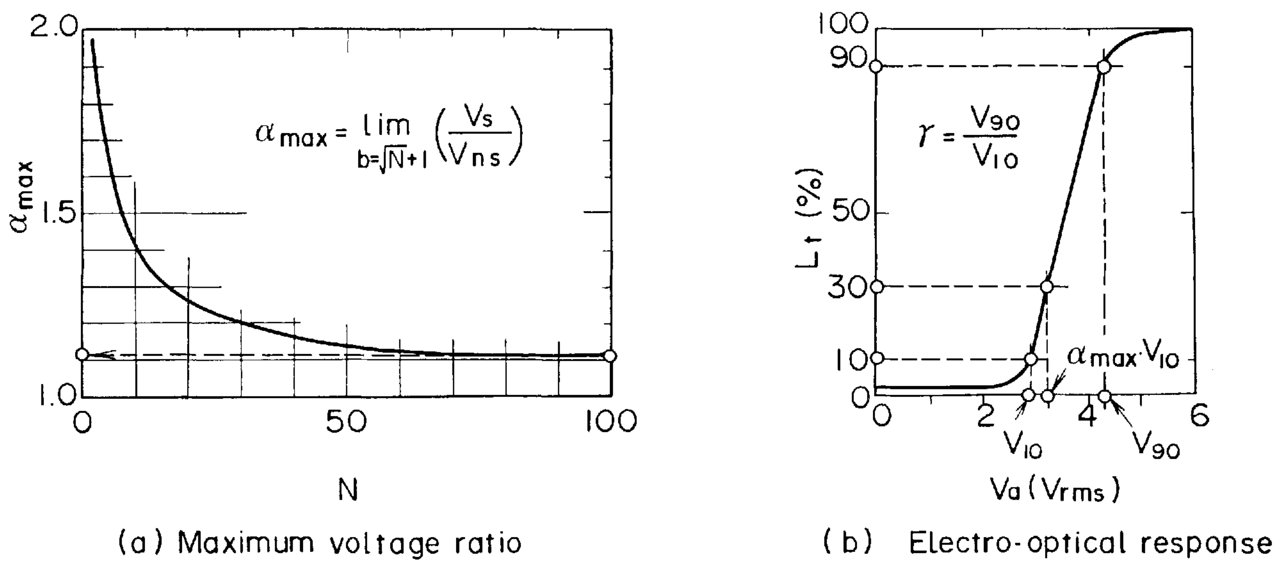

FIGURE 4 Relation between the maximum voltage ratio α_{max} and the steepness γ.

contrast ratio, which is defined as the ratio of these two light transmissions, is 30/10, or 3. This value is not large enough for the human eye to discriminate the two states clearly. From the above discussion, it can be seen that γ must be smaller relative to α_{max} if the matrix LCD panel is to show images which are reproduced over the entire brightness range. However, in most cases, the maximum contrast ratio cannot be obtained when the number of scanning electrodes on a panel becomes large, because this condition cannot be satisfied. For instance, α_{max} is less than 1.1 when the number of scanning electrodes exceeds 100. On the other hand, no LCD panels have a γ of less than 1.1 at present.

Here, attention should be paid to the fact that this relationship is between γ and the number N of the scanning *electrodes*, and is not the number of scanning *lines* in the panel.

There are two main approaches to overcome this serious problem. The first approach is to improve the characteristics of the LC materials themselves so as to have a steep slope in the electro-optic characteristics curve. The second approach is to develop some kind of electrode structure for the panel which makes it possible to decrease the number of scanning electrodes while keeping the number of scanning lines in order to maintain high image density. Much effort has been directed towards improving material characteristics. For example, γ has been lowered from 1.6 to 1.2 during the past 10 years. Unfortunately, γ usually becomes higher when the threshold voltage V_{th} is reduced, if the slope of the electro-optic curve is held constant.

Figure 5 shows electro-optic characteristics of recently developed LCD panels and the ranges of relative transmission of light which are determined by the number of scanning electrodes N in the panels. Here, the bias voltage V_{min} is fixed at the voltage V_{10}, and the maximum voltage V_{max} corresponds to α_{max} times V_{10}. As can be seen from this figure, nearly a 20% relative transmission of light and a 9 : 1 contrast ratio can be obtained when N equals 30, for cell A, which has a γ equal to 1.20.

It is important to recognize that the relative transmission of light cannot be increased much more even if the TFT (thin film transitor) switch matrix addressing scheme is applied on such an LCD panel, because there is only a 10% margin remaining for improving the image contrast ratio.

The response time of images displayed on the LCD panel should be short enough to allow an increase in the number of displayable scanning lines in the panel at a given refreshing rate, because the

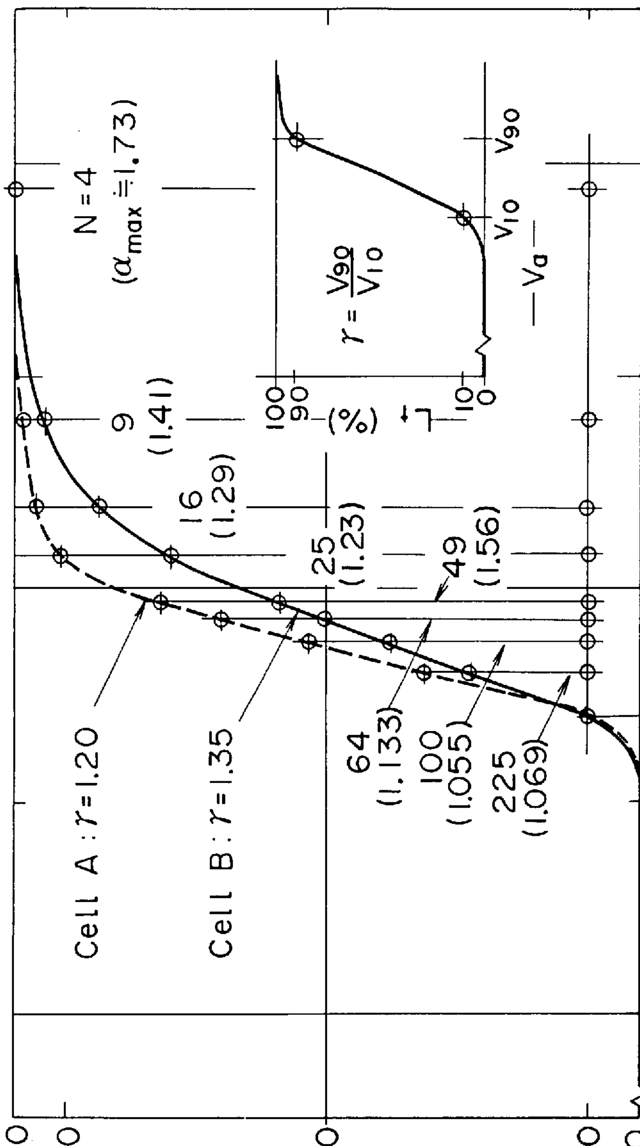

FIGURE 5 Relation between light transmission ranges and number of scanning electrodes of two liquid crystal display panels.

effective γ is affected by the response time when the refreshing rate is high.

Figure 6 summarizes the shortening of image response times for unit cells which have about the same dimensions. The response time has been shortened by 3.5, as compared with that of panels 10 years ago.

The divided signal electrode type LCD panel structure is shown in Figure 7.[3] All the signal electrodes are divided into two groups at the center of the panel. The upper and the lower signal electrodes are driven by different drivers. When a still image is to be displayed on the entire panel, each driver should have a half frame memory in order to drive the upper and lower halves of the panel independently and simultaneously. Thus, the scanning electrodes can be driven in a two lines at-a-time scanning scheme, (1) and ($N/2 + 1$). Therefore, the number of scanning lines can be doubled when this scheme is used. The contrast ratio of the obtainable image is the same as that of the classic XY matrix LCD panel which has $N/2$ scanning electrodes. This type of electrode construction is being applied to panels which have more than one hundred scanning lines.

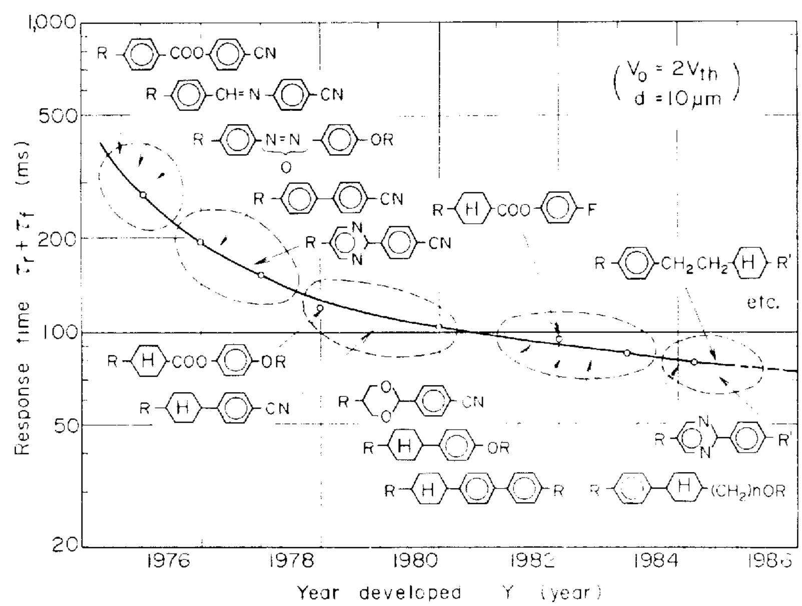

FIGURE 6 Shortening of response time of liquid crystal display cell and typical liquid crystal materials.

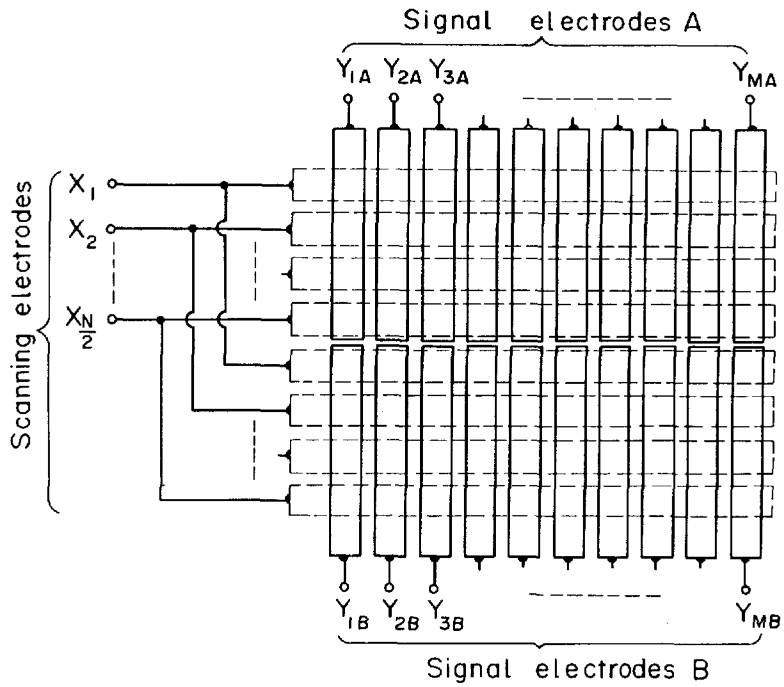

FIGURE 7 Electrode structure of divided signal electrode type liquid crystal display panel.

An example of an image displayed on a commercially available divided signal electrode type matrix LCD panel is shown in Figure 8.[4] There are 640 signal and 400 scanning lines in this panel. But the effective number of scanning electrodes is only 200. Therefore, the contrast ratio for this panel is the same as that of a classic XY matrix LCD panel which has 200 scanning electrodes. The actual display area of the panel is 227 × 144 mm. Relatively good images with a high contrast ratio and wide viewing angle can be displayed using this panel.

The divided signal electrode type panel is also applied to TV displays.[8] In this case, a TV picture signal is fed to the pixels successively from the first to the last scanning electrodes. All the pixels in the upper and lower halves of the panel are alternately fed no voltage in a half frame period. Thus, a crosstalk does not occur in that period and the image contrast ratio in the entire panel can be increased. No half memory is required because the picture signal is continuously fed from a video circuit within the TV display.

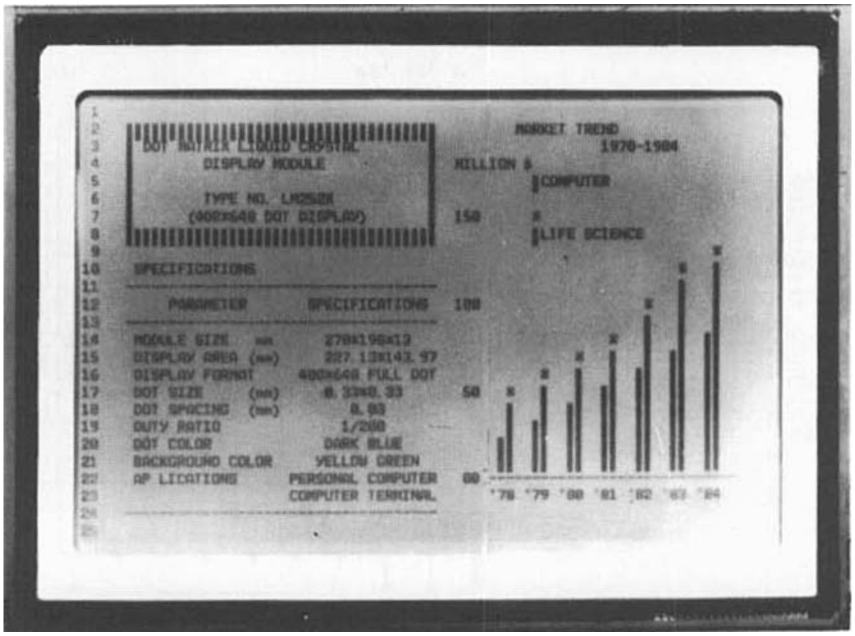

FIGURE 8 Example of image displayed on a divided signal electrode type liquid crystal display panel. (Courtesy of Hitachi Ltd.)

A multi layered type LCD panel structure is shown in Figure 9.[5] In this scheme, an odd and even number of scanning electrodes are mounted on the inner surfaces of the upper and the lower glass substrates, respectively. There are $N/2$ scanning electrodes on each glass substrate. On the other hand, M signal electrodes are mounted on both surfaces of the center glass substrate. The scanning electrodes can be driven successively line-by-line from the first to the N-th electrodes. That is, the scanning electrodes are selected from the upper and the lower glass substrates alternately. Every scanning electrode is driven for two scanning periods. The upper and the lower signal electrodes must be driven independently by different drivers. The signal voltage must be maintained for two scanning periods and synchronized to changes in the scanning voltages applied to the corresponding scanning electrodes. Thus, the duty ratio of the voltage applied to each pixel in this panel can be doubled as compared to that in the classic XY matrix LCD panels. And the total number of scanning electrodes can also be doubled, without decreasing the contrast ratio of the displayed images.

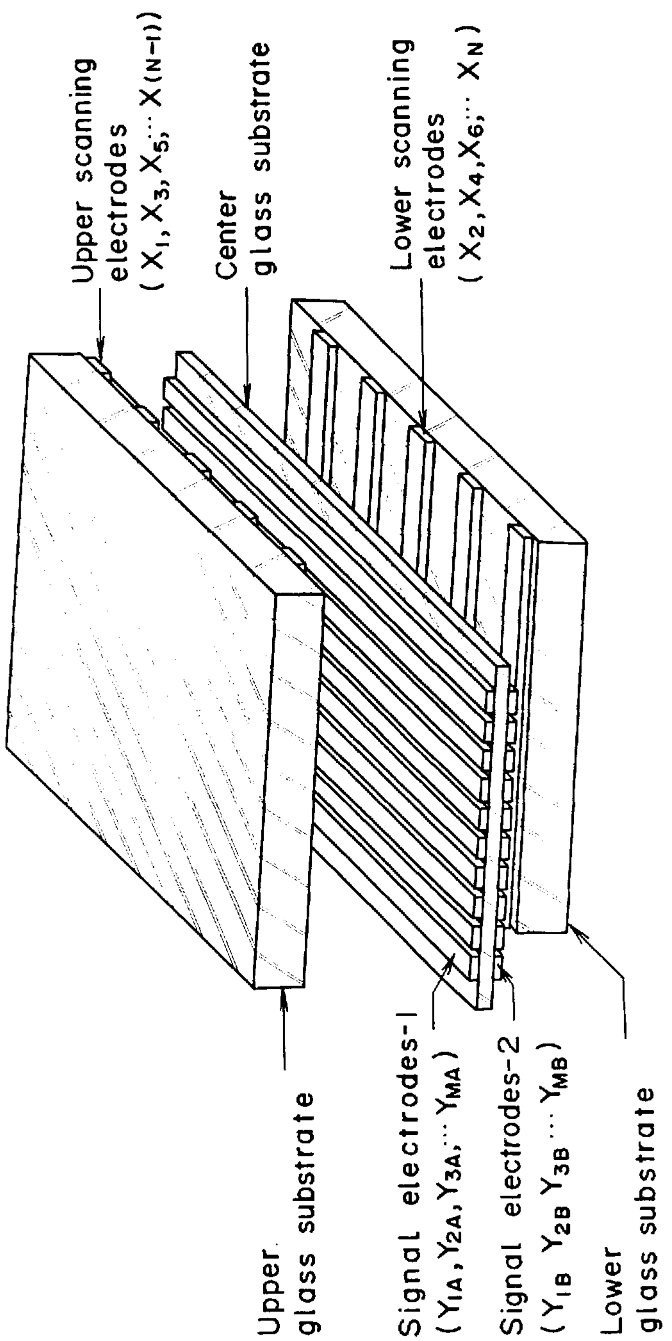

FIGURE 9 Configuration of electrodes for a double layer matrix liquid crystal display panel.

However, it is not easy to produce this type of panel economically if it has a large display area, because a very thin center glass substrate must be used in order to decrease the parallax of the images which are displayed in the two individual LC layers. Double layer type LCD panels are used only for very small sized panels, such as for watches.

Figure 10 shows the electrode structure for a double matrix LCD panel.[6] The scanning electrodes are transparent and have the usual rectangular shape, but the signal electrodes have a somewhat unusual flag-like shape. Many transparent, square electrodes are connected to a thin metal conductor. Every scanning electrode contains two rows of pixels. On the other hand, every other pixel in a column is connected to one signal electrode. Then, the two signal electrodes combine to produce one signal line. The number of scanning lines can be doubled with this scheme without decreasing the contrast ratio of the image displayed, because the effective number of scanning electrodes is halved and the scanning duty ratio is doubled in comparison to the values obtainable for the classic XY matrix LCD panel. On the other hand, the number of signal electrodes in the panel is doubled in comparison.

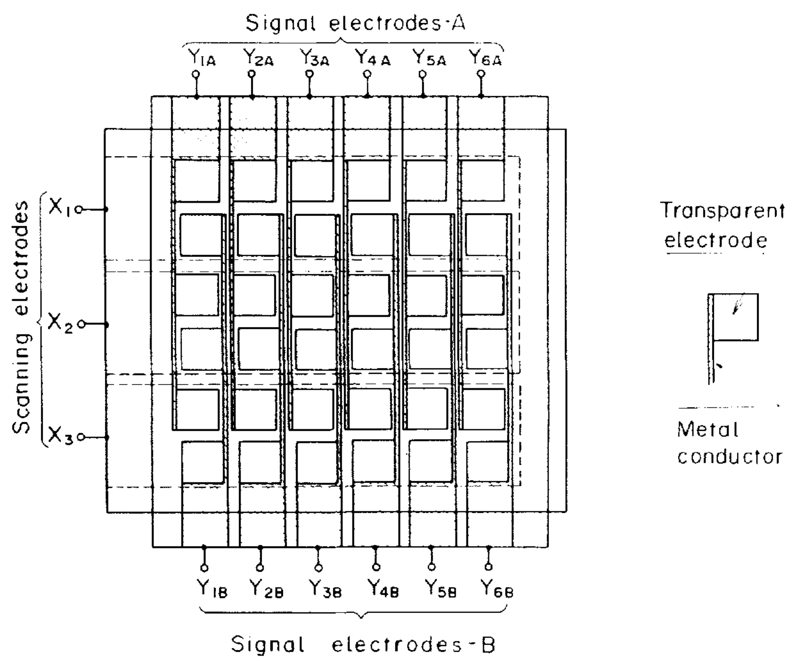

FIGURE 10 Electrode structure of double matrix liquid crystal display panel.

Figure 11 shows the electrode construction of the quad matrix LCD panel.[7] Four rows of pixels correspond to one scanning electrode. The number of scanning electrodes is decreased by 1/4 compared with that in the classic XY matrix LCD panel. But the number of signal electrodes is increased by four, because four signal electrodes combine to produce only one signal line.

A broadcast TV image displayed with the quad matrix LCD panel is shown in Figure 12. The panel has 160 signal and 120 scanning lines. Therefore, there are about 20,000 pixels. The actual display area is 60 × 45 mm, corresponding to a 3-inch diagonal. The multiplexing is 32.6, including the flyback period of the TV broadcasting signal. A sufficiently good image quality is obtained to view usual TV broadcast programs with this display. The total image response time, which is less than 50 ms, just allowed viewing of broadcast programs without excessive smear. Even quick motions in sports program can be followed. LC–TV displays using the double matrix LCD panel are commercially available at present.

From the above discussion, it can be seen that a reasonable high contrast ratio TN–FE mode dot matrix LCD panel which has more than 400 scanning lines should be commercially available in the very near future, if the divided signal electrode and the double matrix electrode configurations are combined into one panel.

Almost all the on-off operations for the light passing through the

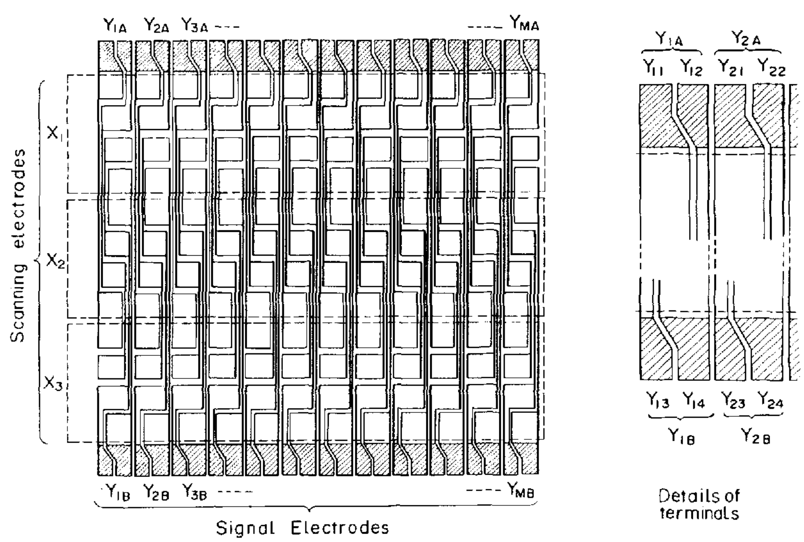

FIGURE 11 Electrode structure of a quad matrix liquid crystal display panel.

FIGURE 12 Examples of TV broadcast images displayed on a quad matrix liquid crystal display panel. (Courtesy of Hitachi Ltd.)

panel are performed by using the light twisting property of the LC layer in the TN–FE mode LCD panels. The multiplexing limit is caused by poor threshold characteristics of the panel while the twisted molecular structure of the LC layer is destroyed by the applied electric field. However, this limitation can be largely eliminated if the birefringent property of an LC layer is introduced to control the light passing through the layer.

Figure 13 illustrates theoretical curves for various twisted angles β, showing the voltage dependence of the director in the mid-plane of a chiral nematic LC layer with a 28° pretilt angle at both surfaces of the upper and lower glass substrates.[9,10] A nearly infinite value of the slope can be expected when β is set at 245°. This steep slope can be utilized to realize a very high multiplexed matrix LCD panel. Optimum multiplexing can be achieved at a somewhat larger twisted angle where a narrow bistable range is present.

Figure 14 schematically shows orientations of the LC molecules when the panel is in the unselected (a) or selected (b) state. The molecular orientations in the actual SBE display are twisted gradually through 270° in the unselected state. High pretilt angles, of about 20° at both surfaces of the glass substrates, are used to eliminate a competing distortional structure which has 180° less twist. The LC layer

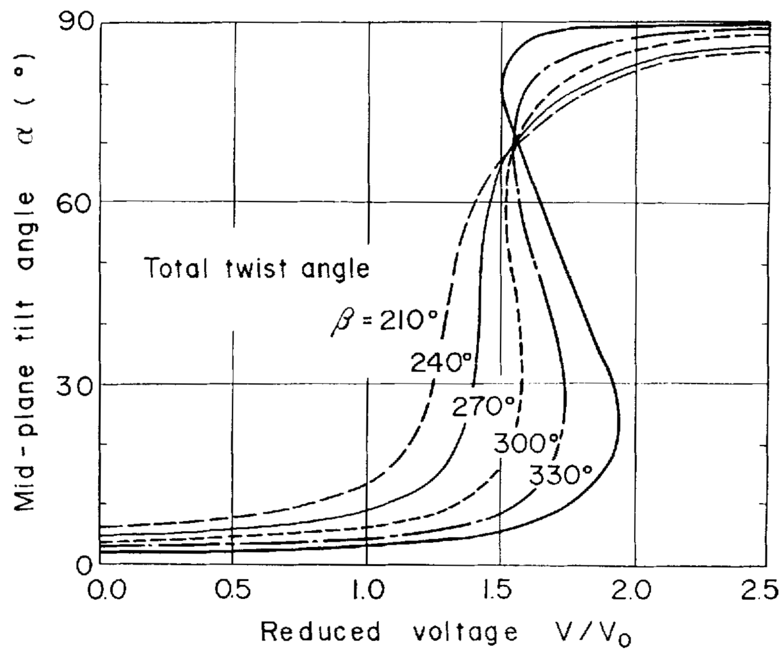

FIGURE 13 Relation between the tilt angle of the local optic axis in the midplane layer and reduced voltage (V_0: Freedericksz threshold voltage) after Scheffer[10]

consists of a nematic mixture of the appropriate birefringent value to which both right-handed and left-handed chiral agents are added. The two chiral agents are used to compensate for temperature dependency in the electro-optic properties of the display.

Figure 15 shows the relationships of angles between polarizing axes of polarizers and optic axes of the liquid crystal molecules in the unselected state. The pretilt angles of the LC molecules are ignored in this Figure for simplicity. In order to obtain a high contrast ratio image, it is necessary to use an off-axis polar orientation in a birefringent mode so that both ordinary and extra-ordinary light waves are excited in the twisted layer and noticeable interference occurs between them when they emerge from the layer.

An SBE display which has the above relationships appears bright yellow when the unselected voltage is applied and black when a sufficient selected voltage is applied. This display mode is referred to as a "yellow mode". Rotating either of the two polarizers through an angle of 90° results in a complementary mode of operation to the previous "yellow mode" which has a bright, colorless appearance in

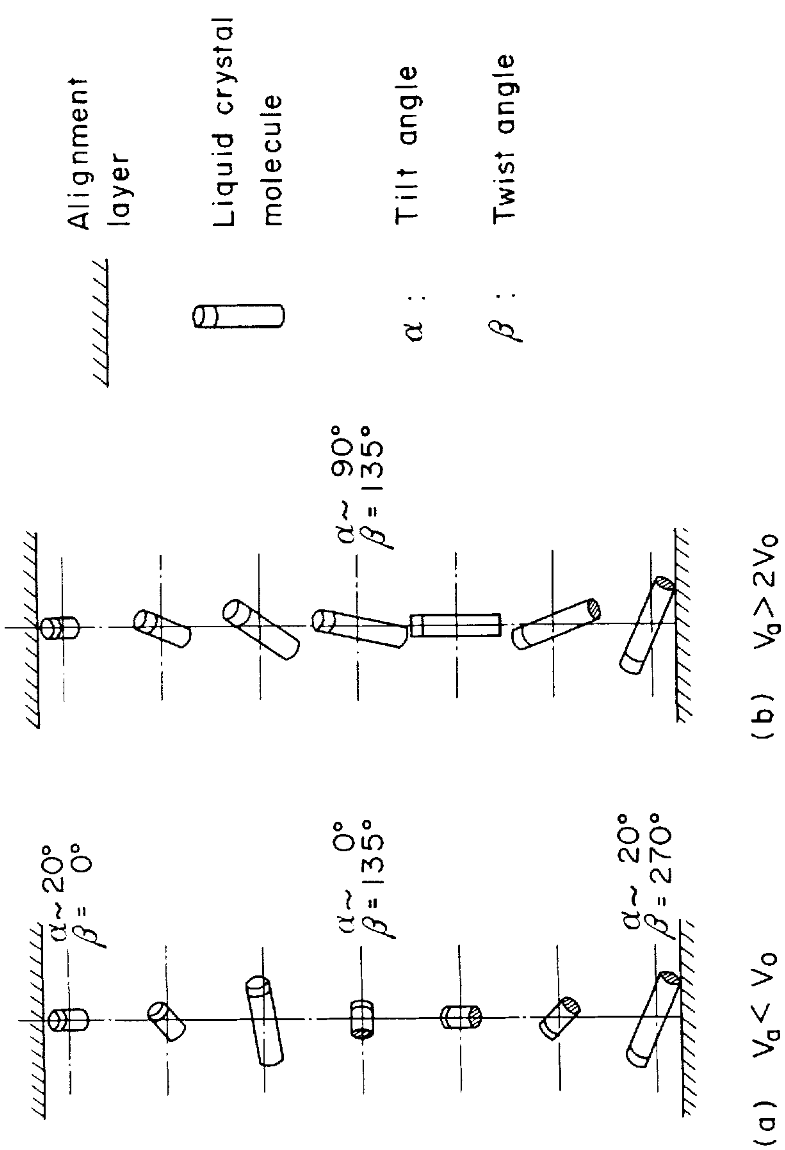

FIGURE 14 Control of orientation of liquid crystal molecules in super twisted birefringency effect cell by applying voltage.

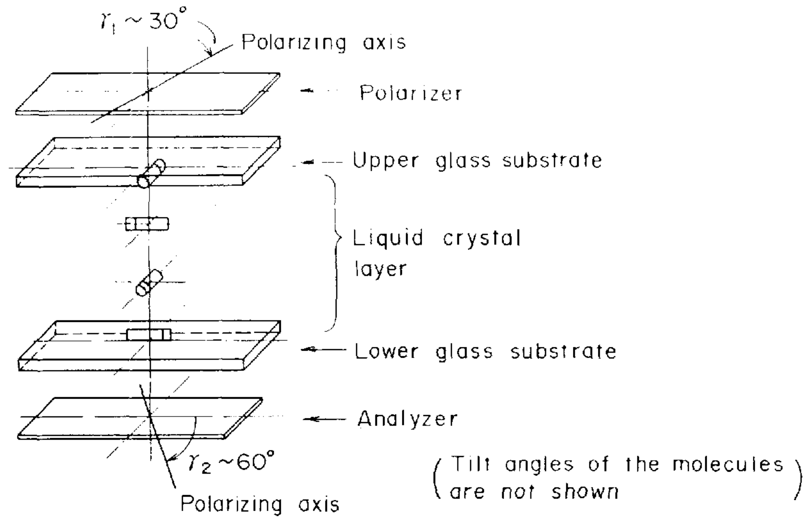

FIGURE 15 Relation between directions of the axes of polarizers and the optic axes of the liquid crystal molecules.

the selected state and a dark, purplish-blue appearance in the unselected one. This latter mode is referred to as the "blue mode".

Figure 16 is a photograph of a matrix SBE display which shows a blue mode image.[11] The display has 540 × 270 lines in a divided signal electrode configuration and is driven in a multiplexed duty cycle of 1/135. The pixel size is 0.40 × 0.40 mm with 50 μm separation lines, resulting in an actual viewing area of 243 × 121.5 mm. A 6 × 10 font is used to display alphanumeric characters. The displayed image shows a very high contrast ratio over a wide viewing angle. Test show that the SBE display has a capability of displaying images which have more than 600 scanning lines, without much loss in the image contrast ratio.

The SBE display is not suitable for applications which require a gray scale, because the display uses bistable characteristics for its operation. One of the most serious shortcomings with the SBE display is its intrinsic colored images which are not always received favorably by many observers. Also, a full color display cannot be obtained with this display, even if a matrix color filter layer is used. Finally, response times are not fast enough for displaying moving picture images.

The key requirements for fabrication of the SBE display are the attainment of uniform layer thickness and a high pretilt surface alignment for LC molecules. The former is needed to eliminate color

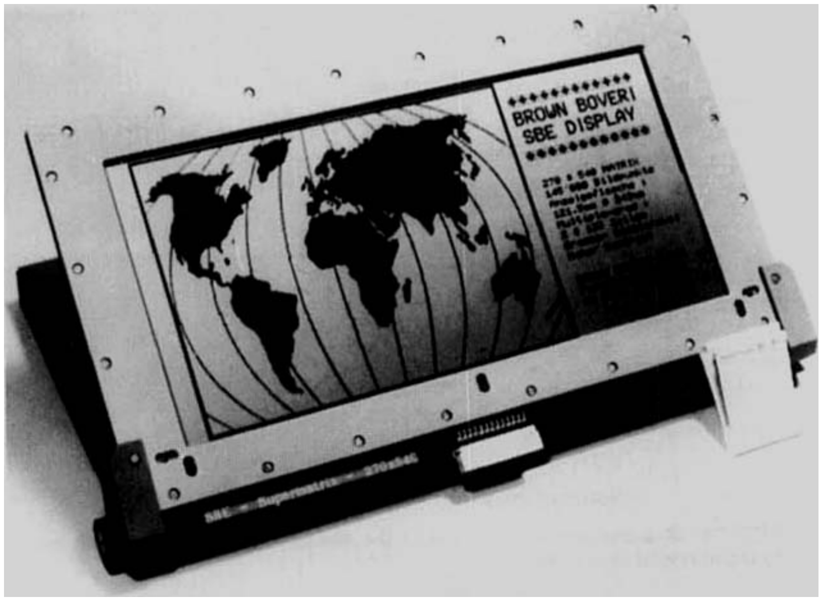

FIGURE 16 Example of image displayed on a super twisted birefringency effect display. (Courtesy of BBC, Brown, Boveri & Co. Ltd.)

patches in the active display area. It seems rather difficult to attain a high pretilt alignment of more than several degrees using the conventional, low cost rubbing method.

Figure 17 shows the results of progress in the number of addressable rows of the above described two refreshing type matrix LCD panels. The number has increased ten times every four years. It is reasonable to visualize of a matrix LCD panel which has more than several hundreds scanning lines within the next two or three years.

IV. CONCLUSION

At present, TN–FE mode matrix LCD panels are the most widely used for high information content displays. The contrast ratio of the displayed image, however, decreases as the number of addressed rows increases. Concerning the favorable discernible image level, an applicable multiplexing limit may be about 400 lines, using a divided signal electrode configuration. Above that limit, the SBE display can be adapted, if it becomes possible to develop a volume production technique which requires less production cost. Colored images essential for the SBE display are a weak point, which may slow their future

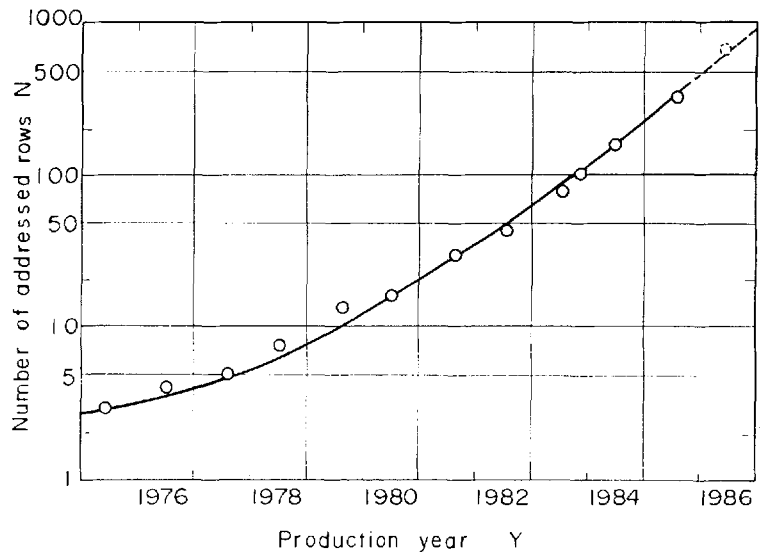

FIGURE 17 Increase in number of addressed rows in a refreshing type liquid crystal display panel.

progress. To obtain a high information content display of more than 1,000 rows, the memory type, such as a chiral C* mode matrix LCD panel can be used, if its response time can be shortened.

Acknowledgments

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References

1. P. M. Alt and P. Pleshko, *IEEE Trans. Electron Devices*, **ED-21**, 146 (1974).
2. H. Kawakami, *1976 Biennial Disp. Res. Conf. Rec.*, 50 (1976).
3. K. Odawara, *Proc. SID*, **19**, 55 (1978).
4. Hitachi Ltd., "*Hitachi LCD Catalogue*," **CE-E599**, (1985).
5. S. Yasuda and T. Takamatsu, *8th Internat. Liquid Crystal Conf.*, 374 (1980).
6. E. Kaneko, *Proc. SID*, **19**, 49 (1978).
7. E. Kaneko, *Proc. SID*, **23**, 3 (1982).
8. H. Hirohara, *Japan Display '83*, Post deadline paper, (1983).
9. T. J. Scheffer, *Japan Display '83*, 400 (1983).
10. T. J. Scheffer and J. Nehring, *Appl. Phys. Lett.*, **45**, 1021 (1984).
11. T. J. Scheffer, *SID 85 Digest*, 120 (1985).
12. E. Kaneko, "*Liquid Crystal Matrix Displays*," Advances in Image Pickup and Display, vol. 4, 1–86 (Academic Press, New York) (1981).
13. E. Kaneko, "*Liquid Crystal TV Displays*," Advances in Optoelectronics, vol. 1, (Reidel International, Amsterdam) (in print).