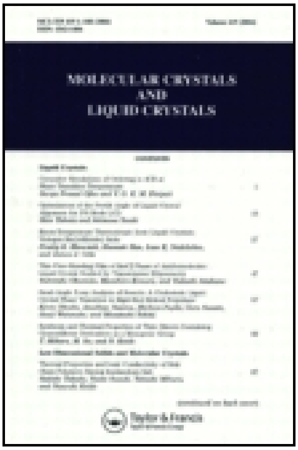

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Liquid Crystal Display Research in Japan

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Liquid Crystal Display Research in Japan†

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The technology development of liquid crystal display started having a remarkable influence on the technology innovation of up-to-date electronic calculator. While a digital display using liquid crystal display has been developed in its earlier stage as the segment type which sets a limit of display to numeric and certain symbols, it is also spent an effort to develop the X-Y matrix type which can display alpha-numeric and moreover kana characters. As a practical application of the X-Y matrix type liquid crystal display, an alpha-numeric type scientific electronic calculator and electronic translator will be reported.

Further, the present status of liquid crystal display applications and trend of R&D in other consumer and industrial electronic industries in Japan will be reported. Finally, activities in the Japanese academic circles will be presented.

1 INTRODUCTION

Liquid Crystal Displays are applied to many products such as electronic calculators, wrist watches, clocks, digital timers, audio equipment and so on. These new and novel products, possessing unique functions and characteristics, have had a widespread impact on the present market. Accordingly, the shares of those products in the market are rapidly increasing.

Among various products using Liquid Crystal Displays, it is described mainly the development process of electronic calculators of which we have been spending great efforts for research and development. Also it is explained how research on the Liquid Crystal Display has made an important impact and great contribution to calculator development. Further, it describes the impact of the Liquid Crystal Display on the development of electronic components, such as circuits, key boards, power sources, and also on price, capacity, and power consumption.

† Invited lecture, presented at Eighth International Liquid Crystal Conference, Kyoto (Japan), June 30–July 4, 1980.

At present, the technology development of the Liquid Crystal Display is still having influence on the technology innovation of the most advanced electronic calculator. For example, in the early stages the Digital Display using the Liquid Crystal Display, in which each digit was divided into seven segments, was introduced into the market. This system limited its display capacity in the numeric and specified symbols. The strong demand for increasing display information capacity in the market has made the industry spend a great effort on developing an X–Y matrix electrode type Liquid Crystal Display. This type can display alphanumeric, Japanese Katakana and Chinese characters. As an example of an X–Y matrix Liquid Crystal Display product, it describes briefly the alpha-numeric type scientific calculator and the electronic translator.

Also it reports on the present status of Liquid Crystal Display application to the fields of consumer and industrial equipment in Japan except for electronic calculators.

Finally, the current activities of Japanese Liquid Crystal Display Research and its related conferences, is introduced.

2 HISTORY OF THE ELECTRONIC CALCULATOR AND THE LIQUID CRYSTAL DISPLAY

Figure 1 shows an abacus and a mechanical calculator, which are examples of old-fashioned calculating equipment used in Japan before the electronic calculator became the main product in the business equipment market.

The abacus was invented in China in the 13th century. Eventually, it was exported to Japan and has been widely used for many centuries. Even now, the abacus is still very popular in Japan. On the other hand, the mechanical calculator was invented by B. Pascal of France in the 17th century. It has been improved with progress in machine processing technology, and has gradually become easy to use. However, such equipment did not have enough functions in the area of high speed calculation and special calculation ability, reliability, compactability and so on.

The first electronic calculator in the market was introduced by a British company, Sum Lock Comptometer in 1962. Its model name was ANITA MK–8. This calculator was composed of vacuum discharge counter tubes so that a reliability problem remained.

In 1961, we had started research and development of a portable desk-top electronic calculator coupling microelectronics technology and digital processing technology.

In 1964, we started marketing and production of the calculator using

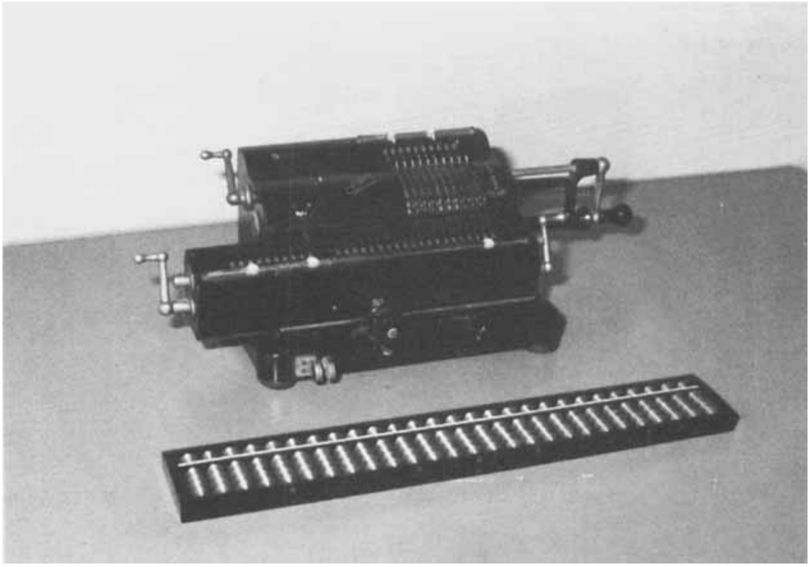


FIGURE 1 An abacus and a mechanical calculator.

solid state active devices such as germanium transistors and diodes for the operation circuits, which is shown in Figure 2.

That occasion had a great impact all over the world as well as in the domestic market. People began to envision the products popularity and the promising future of electronic engineering. Since then considerable development has been achieved.

The attitude toward electronic calculator development also enhanced the aggressive development of devices and components of the calculator. At the same time these new devices and components created new calculators and the newly created technology has had influence on other consumer products. The following are some examples of epoch making products.

The calculator which is shown in Figure 3 was introduced in 1965 for the first time using silicon transistors as a processor which enabled improvement in calculating speed and reliability. However, the market demand was shifting to less expensive products, particularly multi-function and portable calculators. To meet this market demand, we had to solve a contradiction, reducing the number of components while increasing the function of calculating circuits. On the other hand, in the late 1960's integrated circuits began to be the "key" for solving the said contradiction and we decided to introduce this technology in our calculators.

Figure 4 shows a calculator marketed in 1967. For the first time ICs were

FIGURE 2 The first desk-top calculator using solid state active devices.

FIGURE 3 A calculator using silicon transistors.

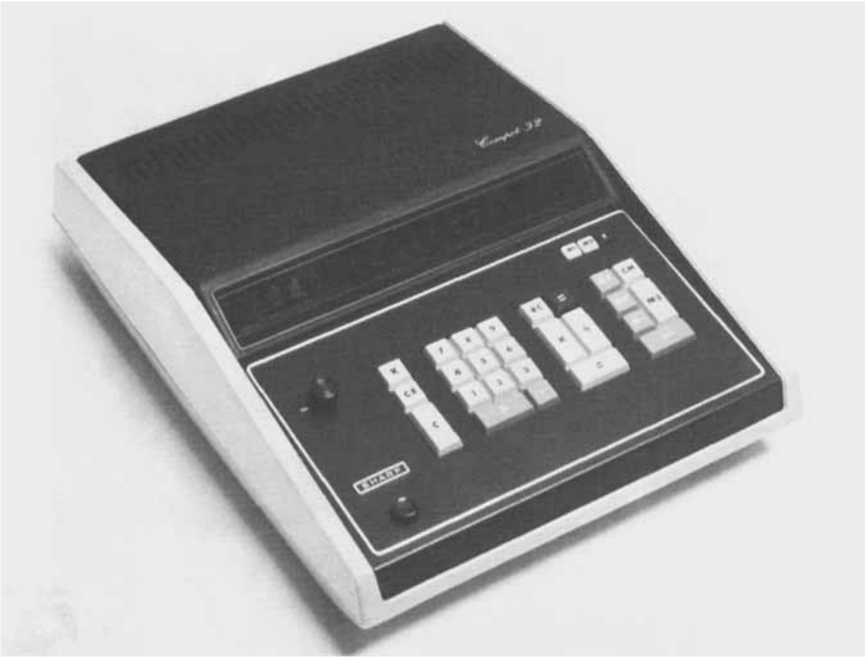


FIGURE 4 A calculator using integrated circuits.

applied to the calculator. The display used in the calculator up to then had been a discharge tube called "Nixie Tube" requiring high voltage close to 200 volts. Its compatibility with other solid state devices was not so good.

There are two methods to fabricate ICs in calculating devices. The one is the Bipolar transistor-based method and the other is MOS transistor-based method. The bipolar device can calculate at high speed, but regarding integration density and power consumption it is not as good as the MOS. Because the calculator does not require speed so much, we decided that the MOS is more advantageous.

Figure 5 shows the first calculator using MOS ICs marketed in 1967. For the display a thermal electron type fluorescent tube with comparably low voltage and low power consumption was used.

Figure 6 shows the first portable calculator announced in 1968 using Large Scale Integrated Circuits for the calculating device. As the circuit device became smaller, the proportion of power consumption, driving voltage and capacity of the display device to the whole calculator was brought to the fore. About the same time, Heilmeier and his co-workers of RCA research group[1] announced that Nematic Liquid Crystal could be

FIGURE 5 A calculator using MOS-IC's.

FIGURE 6 A portable calculator using LSI's.

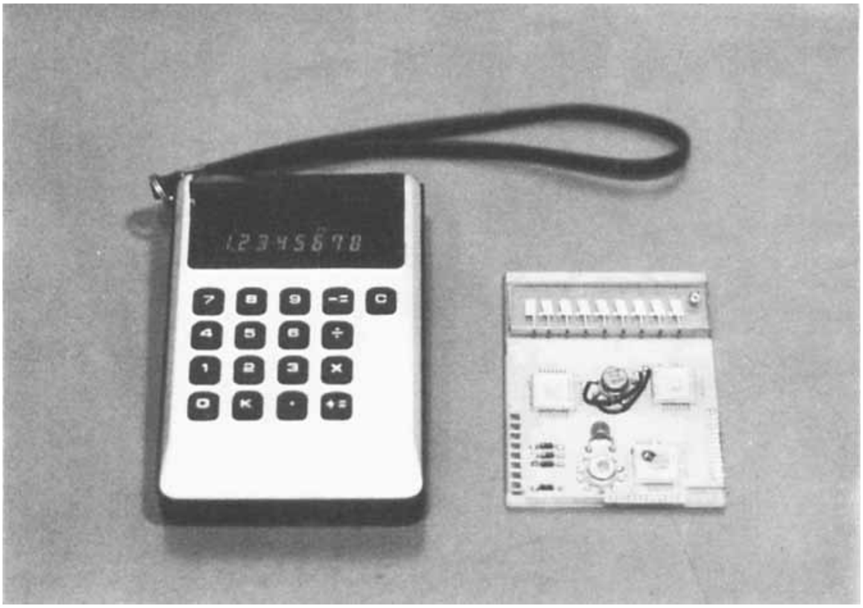


FIGURE 7 The first pocketable calculator with a LCD.

applied to the display. Among the current displays, the Liquid Crystal Display has the smallest power consumption. We had great hopes that the Liquid Crystal Display would be able to solve the technical problem of the display for the calculator. Since then, we have been spending great efforts on Liquid Crystal Display research.

The first pocketable calculator[2] with the Liquid Crystal Display was marketed in 1963, which is shown in Figure 7. For the display mode, it adopted the Dynamic Scattering Mode which could reduce total power consumption to 20 mW, and the operating life time of UM-3 reached 100 hours. This calculator also adopted the COS system, an abbreviation for Calculator On Substrate, integrating the system sections such as display, calculating section, keyboard, and wiring, on a piece of substrate. Thus we could realize an improved display with smaller capacity, lower driving voltage and lower power consumption. Properly speaking, we could say that this type of calculator is the epoch making outgrowth proceeding from labor intensive technology to knowledge intensive technology.

The place where you may need the calculator most is not always on or near a desk. For active businessmen especially, the need for calculations occurs in any minute of their activities. This meant that the desk-top calculator was not enough, it had to be handy and also small enough to carry. In

FIGURE 8 A pocketable calculator with a TN–FEM–LCD.

order to meet this demand, our research on the Liquid Crystal Display shifted from the DSM to the TN–FEM–LCD reported by Schadt–Helfrich[3] which could lower driving voltage and power consumption.

This pocketable calculator was marketed in 1976, which is shown in Figure 8. It used the TN–FEM–LCD and its power consumption was only 0.01 watt with a thickness of only 7 mm.

Such thin calculators were intended not only to be portable, but also fashionable products.

Figure 9 shows the 1.6 mm card type electronic calculator marketed last year.

Figure 10 shows the pendant type calculator combining the clock and the electronic calculator. As we have just described, supported by Liquid Crystal Display R and D, electronic calculators have been containing not only functionable but also newly fashionable values.

These represent an historical review of electronic calculator development. Table I shows a summary of them.

This table indicates the technology revolution of circuits, displays etc. which have made a contribution to the electronic calculator and their marketed chronology, also, it refers to the price, weight, capacity and power consumption of the standard electronic calculator in chronological order. From this table, several technology innovations have reduced the value of each factor very rapidly.

FIGURE 9 A card type calculator.

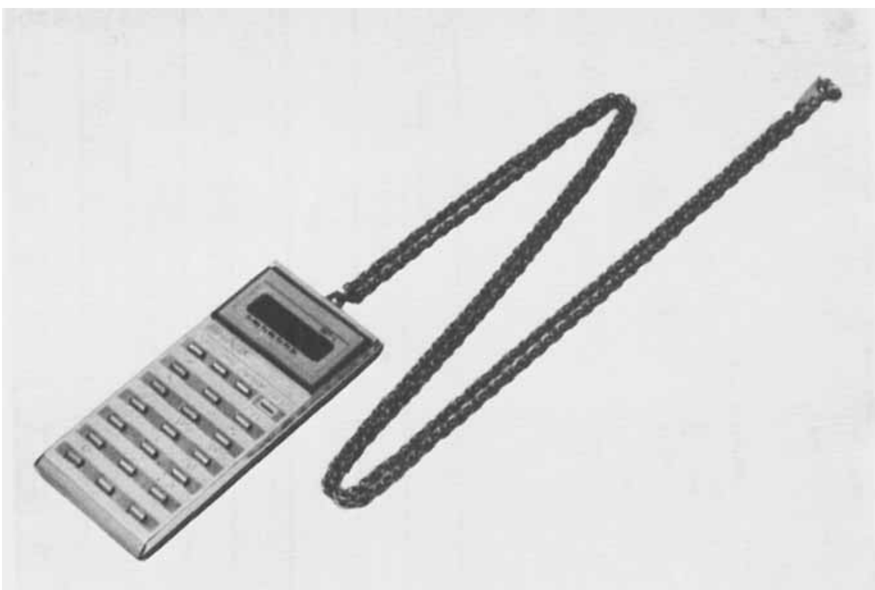
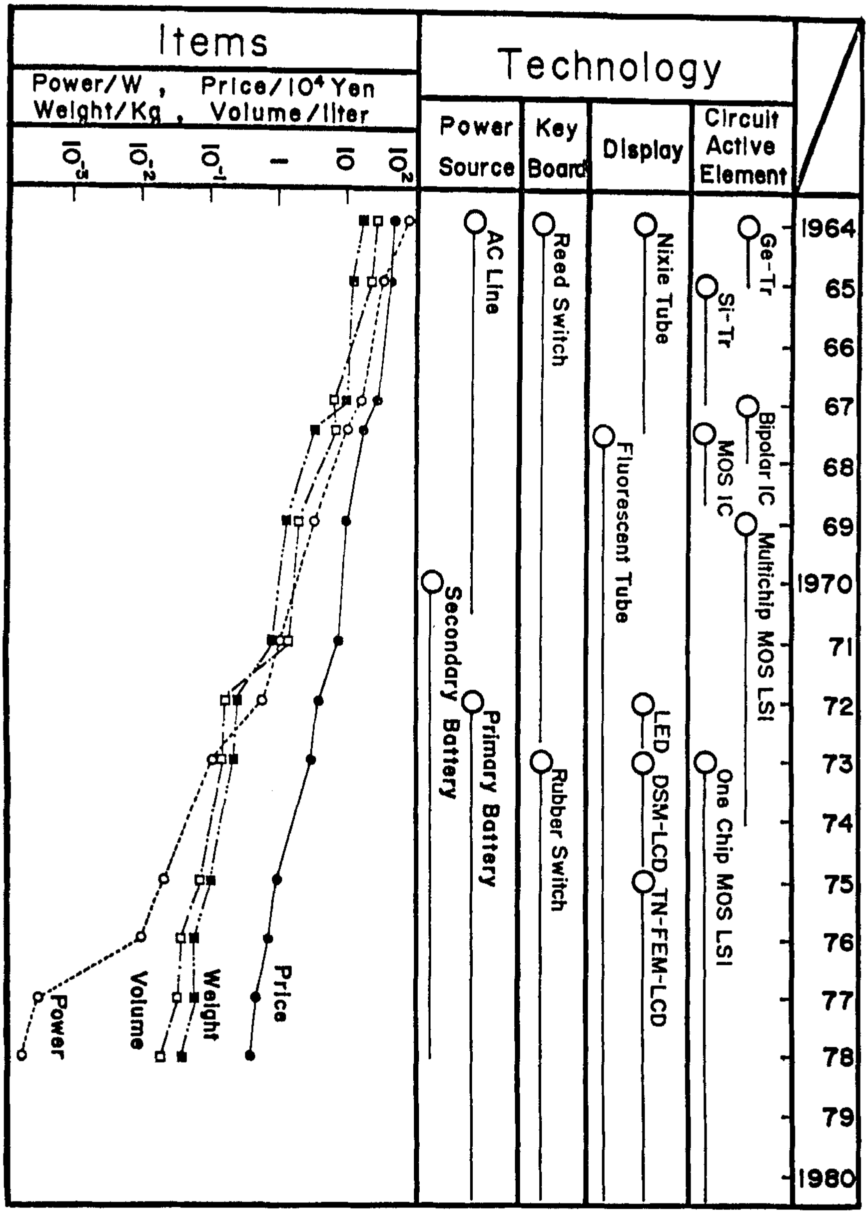


FIGURE 10 A pendant type calculator.

TABLE I

Chronological table of the electronic calculator.



In the Liquid Crystal Display characteristics are summarized in ten items as follows. First of all, the Liquid Crystal Display is a nonemmisive display and its power consumption is extremely low. Secondly, the driving voltage is low and by connecting it with C-MOS LSI the total power consumption could be reduced. Thirdly, the Liquid Crystal Display can be made thin. Item four shows that the Liquid Crystal Display can be fabricated in any size from very small to large and is easy to design. Item five shows that the Liquid Crystal Display is a nonemissive display that is easy to see under brighter ambient light. Item six shows that the Liquid Crystal Display has design flexibility. Item seven, it can display considerably high information in a limited area. Item eight, the capital investment for production is smaller than in any other current display device. Item nine indicates that there is a large possibility that the production cost of the LCD device can be lower. Finally, it is expected that the LCD device has a large volume in production for electronic calculators. Consequently, investment in research and technical improvement can correspond to quality improvement and social demand.

3 THE CURRENT APPLICATION OF LCD FOR THE ELECTRONIC CALCULATOR

The current trend in electronic calculator development is toward not only small and fashionable types, but also multi-functional types. The multifunctional type eventually will be related to enlargement of display information capacity. The research and development of the Liquid Crystal Display is now shifting from numeric display by the conventional segment type to alpha-numeric, Katakana, Chinese character displays by the X–Y matrix type.

Figure 11 shows a scientific calculator applying an X–Y matrix LCD. In this X–Y matrix type LCD, the degree of multiplex driving needs at least seven which is higher than the conventional segment type of 3 to 4. Therefore, LCD research further requires technical improvement in liquid crystal material, orientation, cell structure, etc. This X–Y matrix type can display alpha-numeric and Katakana. Combined with a C–MOS large capacity memory, it has become possible to make an electronic translator. An example is shown in Figure 15.

Figure 12 shows an electronic translator which can translate English to Japanese and vice versa by a C–MOS 96 K bits ROM.

FIGURE 11 A scientific calculator with a X–Y matrix LCD.

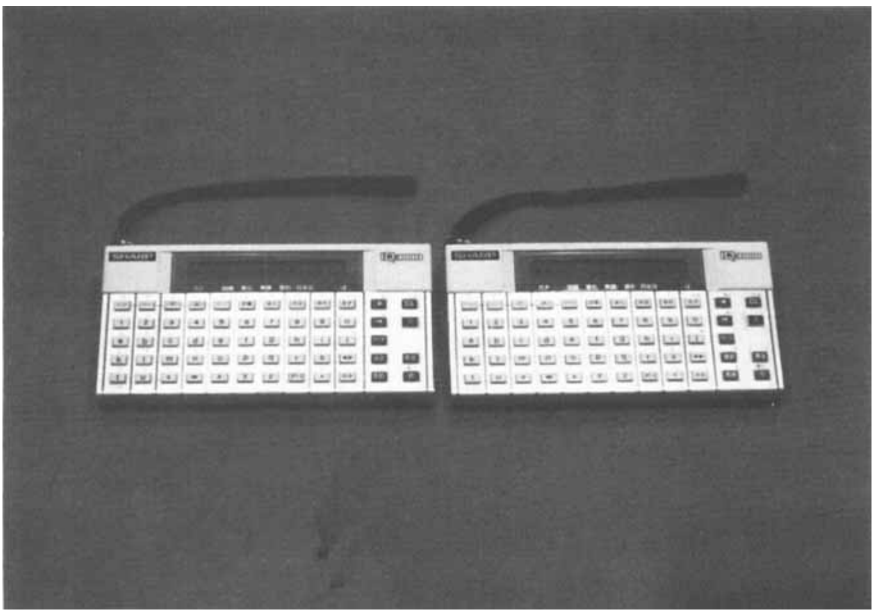


FIGURE 12 An electronic translator.

4 EXAMPLES OF LCD ADOPTED PRODUCTS EXCEPT ELECTRONIC CALCULATORS

We have been reviewing how largely the technical development of the Liquid Crystal Display has affected the technology innovation of the electronic calculator. Meanwhile, there are many products adopting the Liquid Crystal Display in varieties other than the electronic calculator, such as wrist watches, clocks, audio visual equipment, measuring equipment, industrial equipment and so on.

Figure 13 shows a wrist watch with a calculation function.

Figure 14 shows a worldtime watch that can indicate the standard time all over the world. This is a good example of unique LCD pattern functions.

Figure 15 shows an application of an LCD for a clock. The display mode of this LCD is DSM which is designed to appear in the mirror. Cosmetic properties, unique characteristic of DSM display, is well utilized in this clock.

Figure 16 shows another clock using a TN–FEM–LCD. By the way, there are some audio and video products which are adopting the Liquid Crystal Display.

Figure 17 shows a stereo cassette recorder where functions are displayed by

FIGURE 13 A wrist watch with a calculation function.

FIGURE 14 A world time watch.

FIGURE 15 A clock which is designed to appear in the mirror using DSM.

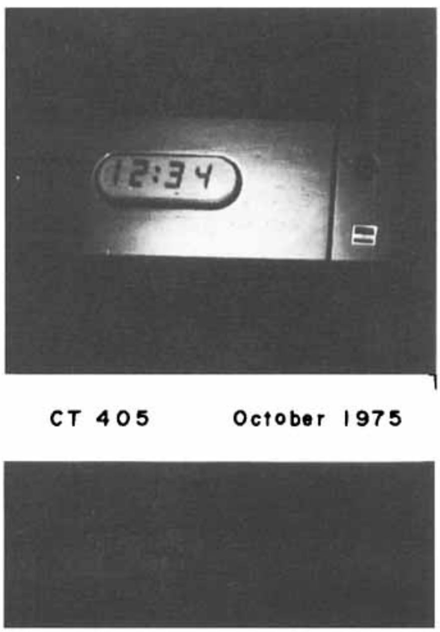


FIGURE 16 A desk-top clock with a TN–FEM–LCD.

FIGURE 17 A stereo cassette recorder whose function is displayed by the LCD.

the LCD. It is connected with a micro computer to display its operating condition intelligibly.

Figure 18 shows an example of the LCD being applied to a video cassette recorder. The LCD is a good partner of the LSI and the combination with the microcomputer enables it to display more information.

There are also some applications of the LCD other than home use.

FIGURE 18 A video cassette recorder with a LCD.

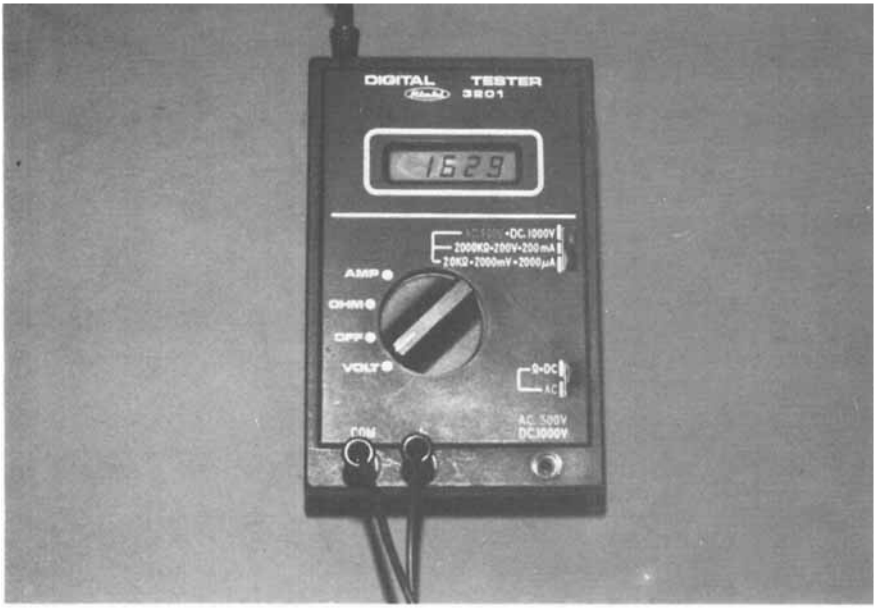


FIGURE 19 A digital multimeter with a LCD.

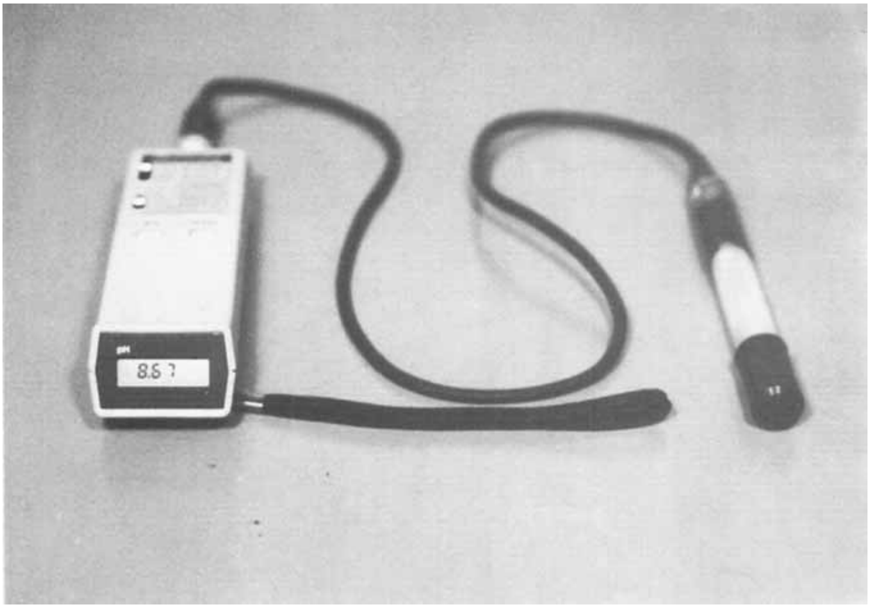


FIGURE 20 A P–H meter with a LCD.

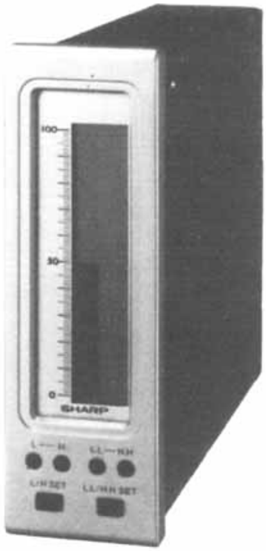


FIGURE 21 A bar-graph LCD.

FIGURE 22 A gasoline pump meter using DSM.

Figure 19 shows a digital multimeter for electronic circuits check-up using the Liquid Crystal Display. It can display any value of voltage, current or resistance. The advantages of the Liquid Crystal Display, which are low power consumption and under sun light readability, have been making the Liquid Crystal Display play an ever-increasing role in portable instruments.

Figure 20 shows an example of the P–H meter. It is quite convenient to measure under the outside environment.

The Liquid Crystal Display is also applied in other industrial equipment.

Figure 21 shows a bar-graph with the Liquid Crystal Display. The LCD can make not only digital figures, but also various analog patterns with the diversity of its display pattern.

Figure 22 shows an example of the Liquid Crystal Display utilized in a gasoline pump meter made by Toshiba. It makes the most of LCD advantages which are low operating voltage, safety and under-sunlight readability.

As I have mentioned, these unique advantages have enabled the Liquid Crystal Display to be utilized in many fields.

5 THE TREND OF CURRENT LCD RESEARCH IN JAPAN

In this chapter, the trend of current LCD research in Japan is discussed. LCD research and development has been emphasized on two points; the first point is to increase the display capacity and the second is to make a color display.

These are four approaches regarding the display capacity increase. Number 1 is research on the electrode structure improvement and the cell structure such as a multi-layer type. Number 2 is research on the system adopting nonlinear devices such as transistors in each picture element. Number 3 is research on the driving method. Finally, number 4 is research of the LCD mode for matrix display other than TN–FEM.

Some examples of these four approaches are reviewed briefly as follows.

Figure 23 shows a double matrix electrode structure which combines two independent column data electrodes on each scanning electrode as a unit.[4] Comparing with the typical matrix electrode, it can reduce the degree of multiplexing by half. A TV display as an application of this electrode which consists of a 160 by 120 dot matrix panel is shown in Figure 24.

This is a picture of an experimental TV display using the double matrix electrodes made by Hitachi. The LCD is the transparent X–Y matrix LCD using a TN–FEM.

Figure 25 shows two other ways to reduce the degree of multiplexing at the

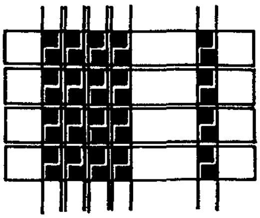


FIGURE 23 The double matrix electrode.

same number of picture elements. In this figure, the first approach is dividing the data electrode vertically and the second one is combining two liquid crystal layers where the picture elements of each layer do not overlap.[5]

Figure 26 shows the character display experimentally made by the above two methods.[6]

This character display was experimentally made by Sharp. It consists of 100 × 64 picture element dot matrix. The degree of multiplexing is reduced to one quarter and it improves the contrast. This method inevitably increases a number of the signal electrode and driving circuits. Nevertheless, it comes

FIGURE 24 A TV image using the double matrix electrode LCD.

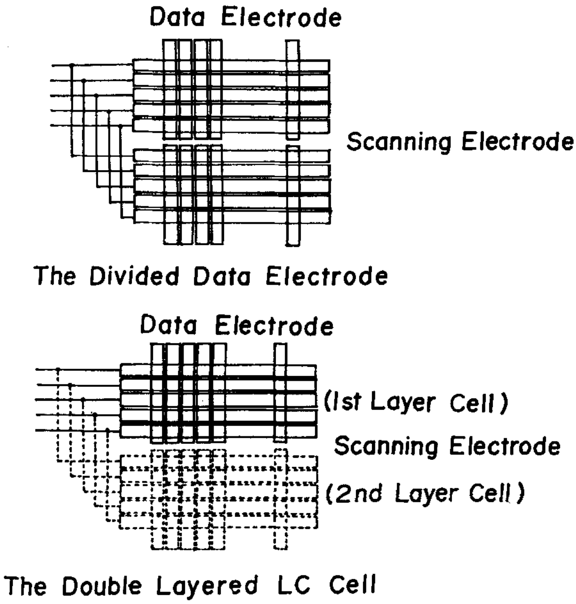


FIGURE 25 Methods of data electrodes partition.

FIGURE 26 A character display using data electrodes partition.

close to realization by improving the terminal connecting method and the cost of the driving circuit.

An example of the system combining non-linear devices with each picture element is shown in Figure 27.

Figure 27 shows a small TV-set which is experimentally made by Matsushita.[7] Its LCD is based on the silicon wafer substrate and X–Y electrodes on it. The MOS–FET switching elements are formed at the cross points. The number of elements is 240 × 240 and its screen display size is 2.4 inches diagonal. Further, the LCD mode in this display is the reflection type DSM due to the structure restriction. Another approach regarding the increasing method of driving margins, the TN–FEM two frequency driving method applying the dispersion phenomenon of a dielectric constant of the liquid crystal is under research.

Figure 28 shows the TN–FEM two frequency driving panel experimentally made by Suwa Seiko.[8] The display capacity is 512 characters and one character consists of 5 × 7 dots. This driving method requires high frequency and comparably higher voltage so that it still has problems such as power consumption increases, a high voltage driver is also required. However, it is a very effective method to increase the driving margin so that it can be applied to the field of CRT, PDP and EL in the future.

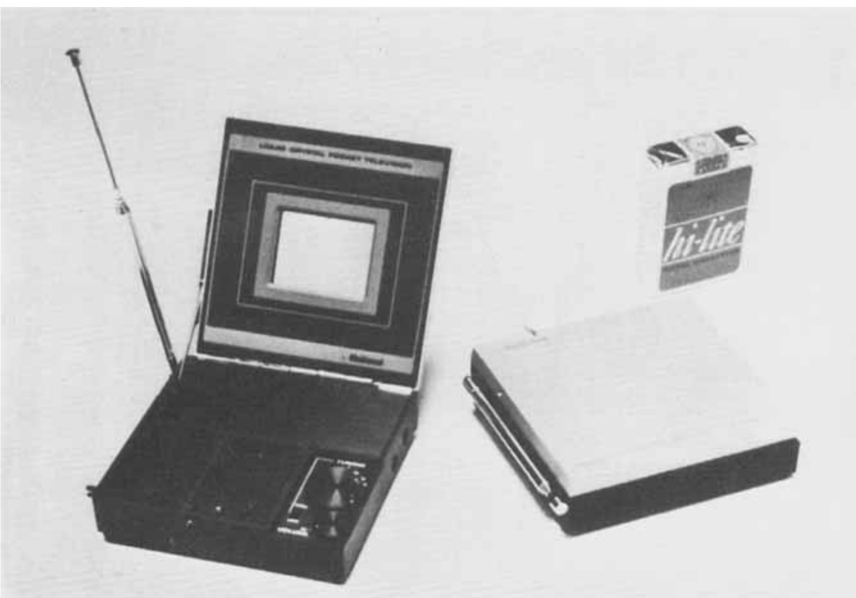


FIGURE 27 A small TV set using DSM.

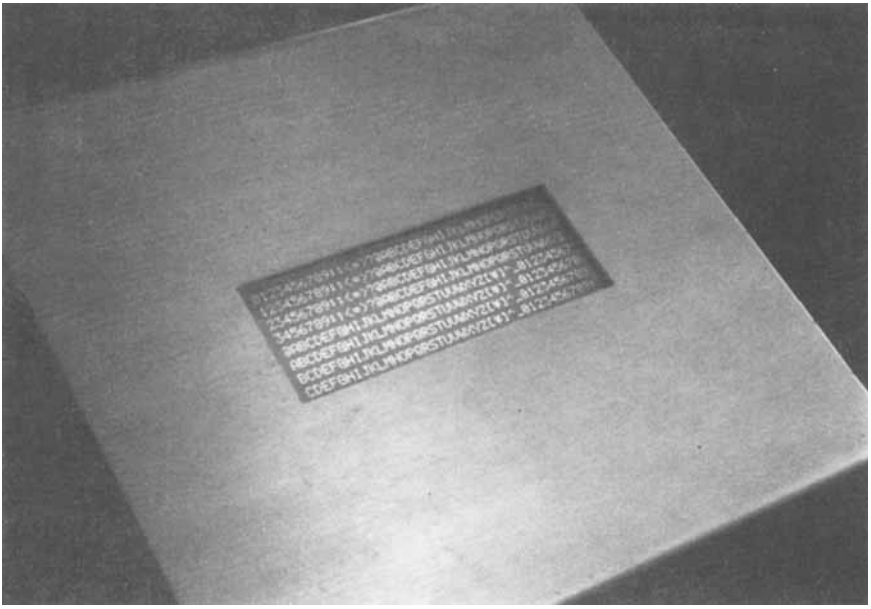


FIGURE 28 A character display derived from a two frequency addressing method.

So far we have explained the approach from driving. But also there are some efforts on the approach from the LCD electrooptic mode. This is research on the display mode with steep threshold characteristic in the electro-optical effect. The most typical example is the Cholesteric to Nematic Phase Transition Mode.

The LCD device which employs the phase transition mode is experimentally made by NEC[9] is shown in Figure 29. The number of picture elements is 72 × 180. The unit of one character is 7 × 9 dots. The liquid crystal display is the transmissive type.

These are examples of display capacity increase.

On the other hand, the color display methods with LCD are divided into the following three kinds. The first method is the system utilizing the TN–FEM with a color polarizer. This system is replacing one of a pair of conventional panchromatic iodine polarizers with a color polarizer made by a dichroic dye in the visible light region.

The second one is the system utilizing Electrically Controllable Birefringence. This system can display various colors by voltage, but on the other hand depending upon thickness of LC layer or viewing angle, the color varies. Therefore, it is not suitable for displaying a single color. But still we are

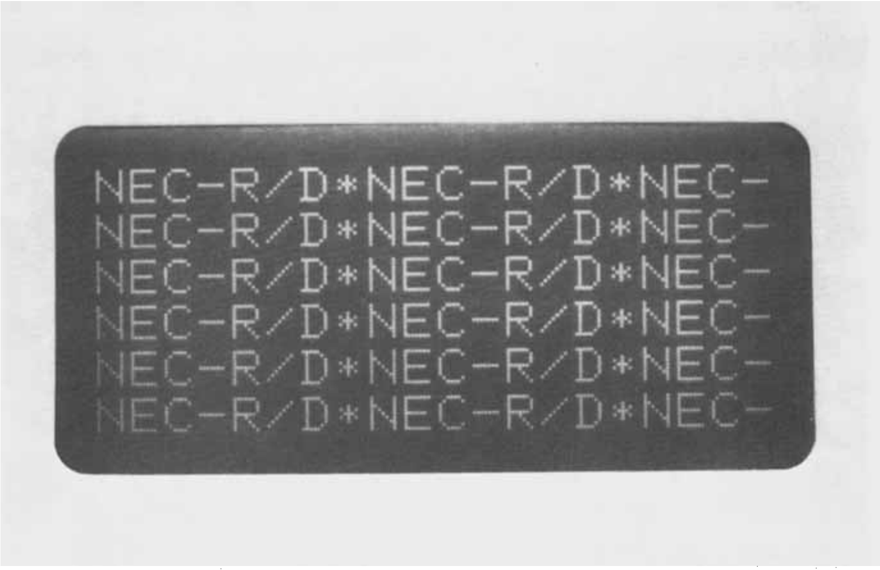


FIGURE 29 A character display using a cholesteric–nematic phase transition.

greatly interested in its fantastic multi color. Also this display system may be used as a light projection type or a transparent type.

The third one, Guest-Host Type, is the most widely studied color display now. This display mode is adding a pleochroic dye in to the Liquid Crystal and the applied voltage controls the orientation of LC molecule for modulating the light absorption spectrum of the dye. Also this display mode is modified in various ways depending upon the absorption mode of the dye, LC phase, dielectric anisotropy and state of orientation.

Figure 21 shows an example of a color display with a color polarizer.[10] This is the same type used for Bar-Graph display as we have seen before. But by changing a polarizer we can obtain various color displays.

Figure 30 shows a prototype audio output indicator using a DAP effect.[11]

Figure 31 shows examples of the Guest-Host type display[12] made by Tohoku University.[13] We can display various colors by selecting dyes and also combining multi-layers.

6 FUTURE TECHNOLOGY TREND OF LCD

As explained, LCD research has completed the first application stage and now is stepping into a new development phase. Briefly we touch upon the future technology trend. In the next stage, the LCD will continue to take its advantages on one hand, such as low driving voltage, low power consumption, flatness and low cost. On the other hand, it will tend to increase the display information capacity. The display contents will mainly be characters, graphics and pictures in the $X-Y$ matrix. We think those portable display panels having relatively large display capacity will be able to create a new business tool as a pocketable display equipment.

For instance, we can expect a portable hand-held Broadcast Teletext which will display valuable information very timely such as stock prices, product prices, weather broadcasts, news, and traffic information while walking on the street. This Broadcast Teletext can only receive information. In contrast, a display for wired teletext which can make a conversation through a telephone line is also greatly anticipated. Teletext usually puts character information in the main. On the other hand, a pocketable LCD television receiver for consumer use is expected to be realized as a result of past comprehensive technology.

For these products, the LCD which has under-sunlight readability, flatness and low power consumption will be very promising.

However, in order to market these products, there are still many technical problems not only in LCD improvements, but also in development of microelectronics complete arrangement of a TV broadcasting system, and many other problems to be solved as well as political problems.

7 INTRODUCTION OF LC RESEARCH ACTIVITY

Research on Liquid Crystal has been involved in Chemistry, Physics, Biology, Electric and Electronic Engineering and many other fields. Most of this research has been reported by the institutions.

These are, Japan Society for the Promotion of Science established "the 142nd committee on Organic Materials used in Information Science and Industry" which has held its research meeting bimonthly since 1974. The second is the Liquid Crystal Symposium. This has been held every year for the past six years. These two meetings are specializing in Liquid Crystal. Other than these, there are various meetings held by the Japan Society of Applied Physics, the Physical Society of Japan, the Institute of Electronics and Communication Engineers of Japan, the Institute of Television Engineers of Japan, the Chemical Society of Japan, twice a year for each society. Also Liquid Crystal research is reported in the conference on Image Science and Technology and the conference on Solid State Devices (Tokyo) held each year.

8 CONCLUSION

We have reported the past and present research of the Liquid Crystal in Japan. We believe that this the 8th International Liquid Crystal Conference can provide us with a great opportunity to enhance sincere cooperation and good competition in LC research around the world and also we wish to devote our continued efforts for LC development.

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