

The Emerging Application Potential of LTPS Technology

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Abstract

Low-temperature polysilicon (LTPS) technology has continued to mature with the passing of each year since LTPS mass production began. The integration of complex circuits has become possible with advances in microprocessing, leading to the realization of panels with highly advanced functions. At the same time, efforts have been made to meet market demands for lower costs, thereby boosting competitive strength. Today, LTPS-TFT LCDs have become standard equipment for the monitors of digital still cameras, and inroads are being made into the massive cellular phone market. Micro displays such as electronic viewfinders, which were previously only possible with high-temperature polysilicon technology, can now also be made with LTPS, thus expanding the scope of the technology. AMOLED displays using the LTPS-TFT as a back plane are also approaching the stage of industrialization. The hidden potential for the OLED to replace the familiar LCD has prompted widespread anticipation for this emerging technology. This paper reflects on the history of LTPS technology, then looks forward to its future prospects and suggests a variety of potential fields of application.

1.Introduction

With a level of electron mobility that is 2 to 3 orders of magnitude higher than that of amorphous silicon (a-Si), low-temperature polysilicon (LTPS) TFTs

make it possible to integrate peripheral circuits onto their glass substrates and to greatly reduce the size of pixel TFTs, thereby increasing the aperture ratio. This offers distinct advantages for creating displays with superior characteristics, such as higher resolution, brightness, reliability, and narrower borders. When LTPS-TFT LCDs were first mass-produced in 1996, the only application that existed for them was the digital still camera(DSC) monitor, which required both high resolution and high image quality. As this was yet the introductory phase of the DSC, however, it represented an extremely small-scale market demand, yet it served as an appropriate niche for the new LTPS-TFT LCDs to fill. Since then, the DSC market has expanded rapidly, growing to a level of demand that is forecast to reach around 35 million units in 2003. This growth has been supported, of course, by the development of the megapixel CCD, but also by technical advances toward super-thin, low-power-consuming LTPS-TFT LCD modules, and lower costs made possible by improvements in productivity. Remarkable progress has also been seen in LTPS-related technologies such as laser recrystallization using excimer laser annealing (ELA), and ion doping. In the early stages of mass production, the unstable output of the XeCl excimer laser led to varying levels of quality in the recrystallized polysilicon, which increased the fluctuations in TFT characteristics and lowered production yield(1). The insufficient output and short lifetime of the laser also placed limits on throughput. ELA-related advances revolutionized

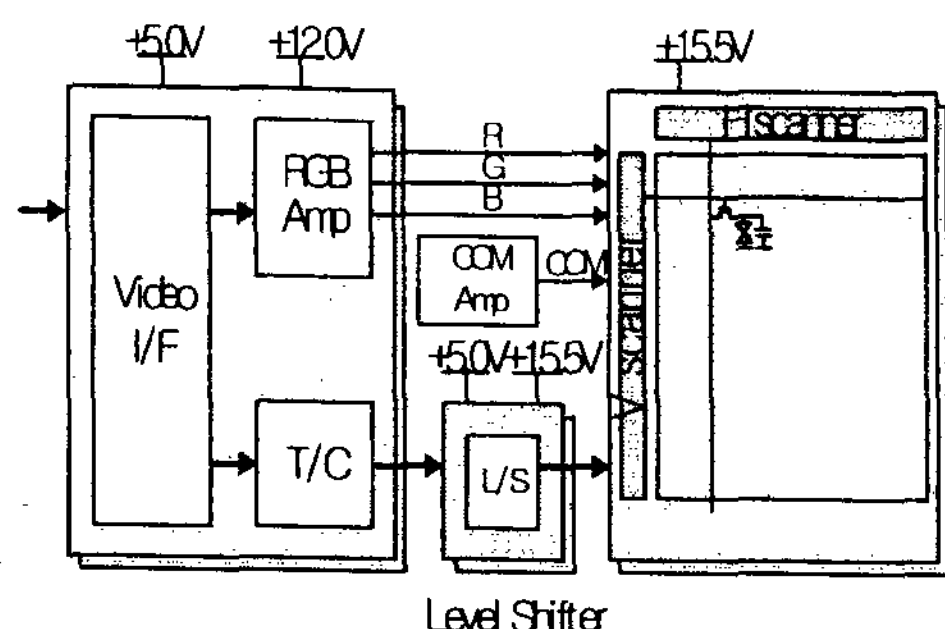


Fig.1 circuit block diagram of 2.0 inch display

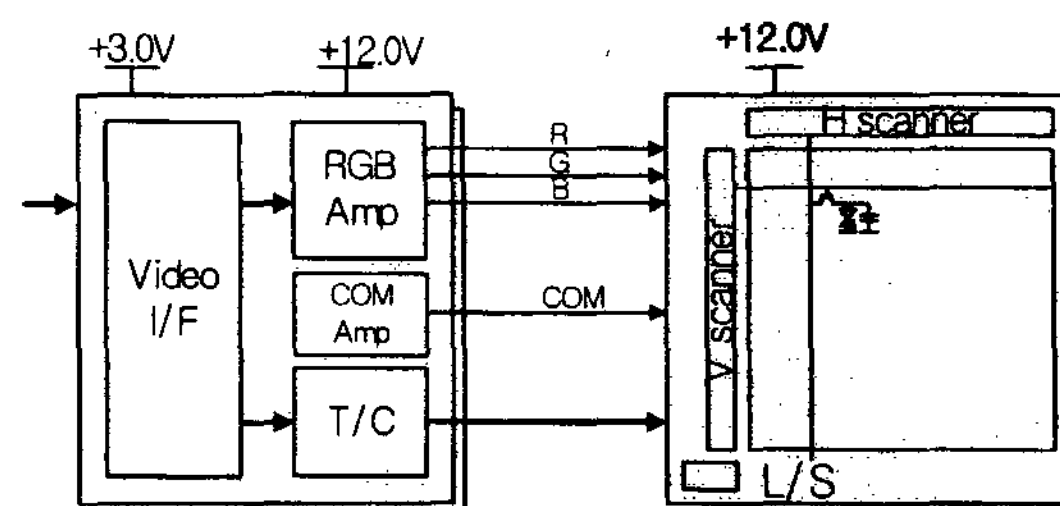


Fig.2 circuit block diagram of 2.0 inch display (H and V scanner, LS, 12V drive)

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this technology by enabling stable, high-output laser power. In the area of ion doping, the shift from a single-implantation to a scan-implantation method ensured sufficient productivity regardless of substrate size(2). These achievements led to the production of the 4th generation LTPS-TFT LCD modules, which paved the way for the manufacture of 15-inch and larger LTPS-TFT LCDs, and also brought about drastic cost reductions. With the recent widespread use of 3rd generation cellular phones equipped with cameras, the need to transfer still and moving pictures has increased, prompting strong demand for high-resolution (over 200 PPI) color TFT LCD displays. Widespread expectations for the LTPS-TFT LCD to meet this demand signal a perfect opportunity for the creation of a huge market. In the last seven years, LTPS-TFT technologies have made great strides in aspects such as microprocessing and increasing mobility, which have allowed them to open up entirely new fields of application. One such application is an attempt to use the LTPS-TFT substrate as a back plane to develop and commercialize an active matrix organic EL display with a variety of performance aspects that far exceed those of the LCD. The development of new microprocessing methods at levels below 2 μm has also enabled LTPS application to electronic viewfinders (EVF), which were previously limited to High Temperature Poly-Silicon (HTPS) technologies and LCDs on silicon (Si) substrates (LCOS). These new EVFs are now carving out a solid position in the marketplace. As an entirely new and different field of application, uses in sensors are also being explored. Efforts are presently being made to develop and commercialize products such as fingerprint sensor arrays and photosensor scanners. Nonetheless, the ultimate target for LTPS-TFT technology is the system-on-glass, and the first step toward achieving this is represented by the development of an 8-bit CPU employing high-mobility LTPS-TFT(3).

Against this background, this paper will reflect the steps taken by LTPS-TFT technology in each of these application fields, discussing how the technology might progress in the future, and envisioning what kinds of new application fields might lie in its path.

2. Application to Mobile Tools

Digital Video Cameras and Digital Still Cameras

The digital video camera(DVC) was the first application product for the LTPS-TFT LCD. At the time, full-color a-Si TFT LCDs were being used as DVC monitors, in either 3-inch or 3.5-inch sizes with 130,000 pixels. Narrow-border LTPS-TFT LCDs were employed to meet requests for slightly smaller, more portable camera bodies. These displays were 2.5 inches in size and had a resolution of 180,000 pixels, which was quite high at the time. Integrated peripheral circuits consisted of the horizontal scanner, vertical scanner, and pre-charge circuit. However,

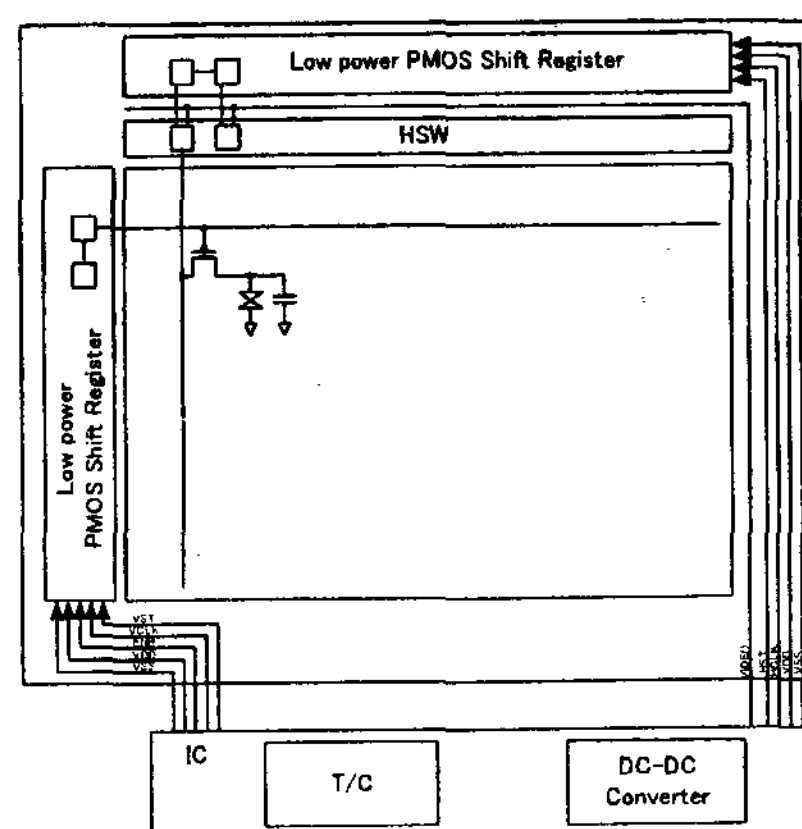


Fig. 3 circuit block diagram of P-MOS

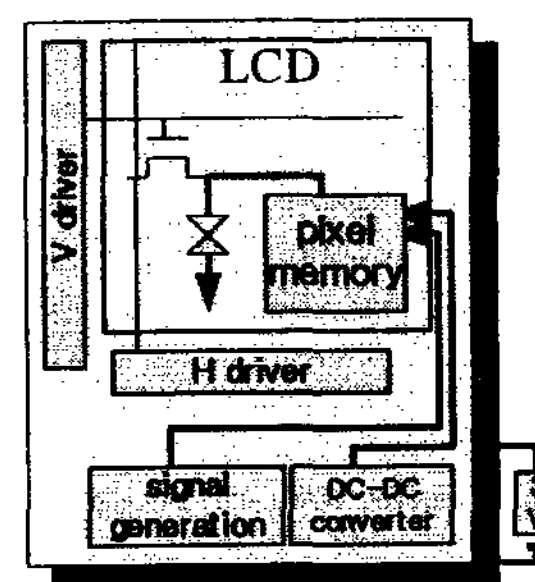


Fig. 4 SRAM circuit block diagram

extremely high resolution was not actually necessary in the DVC monitor. Priority was given instead to screen size and cost. With cost being a weak point in the LTPS-TFT LCD, there were many cases when it was simply not selected for use. This situation continues largely unchanged today.

At the same time that plans were being made to use the LTPS-TFT LCD in DVC monitors, however, DSC with LCD monitors were launched and immediately became hit products. Soon after, manufacturers began competing to increase CCD performance from VGA to megapixel class in order to satisfy customers who wanted the photos that they take with their DSC to be as beautiful as those taken with an ordinary film camera. This led to the increasingly frequent use of high-resolution, 110,000 to 130,000-pixel LTPS-TFT LCDs for the monitor instead of the 1.8-inch, 60,000-pixel a-Si TFT-LCDs of the VGA era. Backed by the resulting position as the DSC monitor of choice, LTPS-TFT LCD business grew steadily together with the market for DSCs. The LTPS-TFT LCD monitors initially used had the same external dimensions as the 1.8-inch a-Si TFT-LCD. Under the concept of also enabling video images similar to the DVC, these monitors had a screen size of 2.0 inches with 113,000 pixels in 218 columns by 512 rows, in a delta configuration. The power consumption of the LCD panels at the time, as shown in Fig. 1, was 100 mW for the internal circuitry, and 550 mW including the external drive LSI. As with DVCs, the circuits built into the panel consisted of the horizontal scanner, vertical

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scanner, and pre-charge circuit. The TFT design rule was 8.5 μm , and the line voltage was 15.5 V. Following strong demands for lower power consumption, the line voltage was reduced to 12 V by adding a level shifter to the internal circuits, and scaling down the TFT design rule to 6 μm in Fig.2. This cut the power consumption of the panel by more than half. In response to recent requests to drive the panel with an AA-size battery, the LCD drive has been changed from DC to AC, and the line voltage has been reduced to 8.5 V, thus lowering the total power consumption to 85 mW. Further reductions in power consumption are expected in the future, by building the DAC and memory into the panel. One more major topic for the LTPS-TFT LCD as a DSC monitor has been to see how low the cost could go. The DSC initially created a market with its image as a high-end camera, but it continued to become more compact and more widely used as the market grew. Today, while the resolution may remain the same, the screen size in many cameras has been reduced from 2 inches to 1.5 inches to achieve greater cost advantage. Even so, strong requests for yet greater cost reduction continue to be made by camera manufacturers. To meet these requests, the CMOS structure was applied to the original LTPS-TFT LCD internal circuits, but recent attempts to lower costs even more have led to circuits comprising only a p-MOS structure. Because the CMOS structure contains both n-channel and p-channel TFTs, it requires the use of eight or nine masks. This is 1.5 times the number of masks (five or six) required by the a-Si TFT LCD, resulting in a cost disadvantage. By building circuits using only p-MOS, at least two masks can be eliminated, which brings the cost close to that of the a-Si TFT. On the downside, however, the power consumption of the p-MOS type rises. Still, Fig. 3 shows a circuit-based method for suppressing this rise in power consumption. It is believed that the use of the p-MOS structure for integrating peripheral circuits will become increasingly common in the future, but questions remain as to the scale of the circuits that can be built into these panels.

Cellular Phones

There have been numerous attempts to apply the LTPS-TFT LCD to cellular phone displays, but all have ended without achieving any final conclusion.

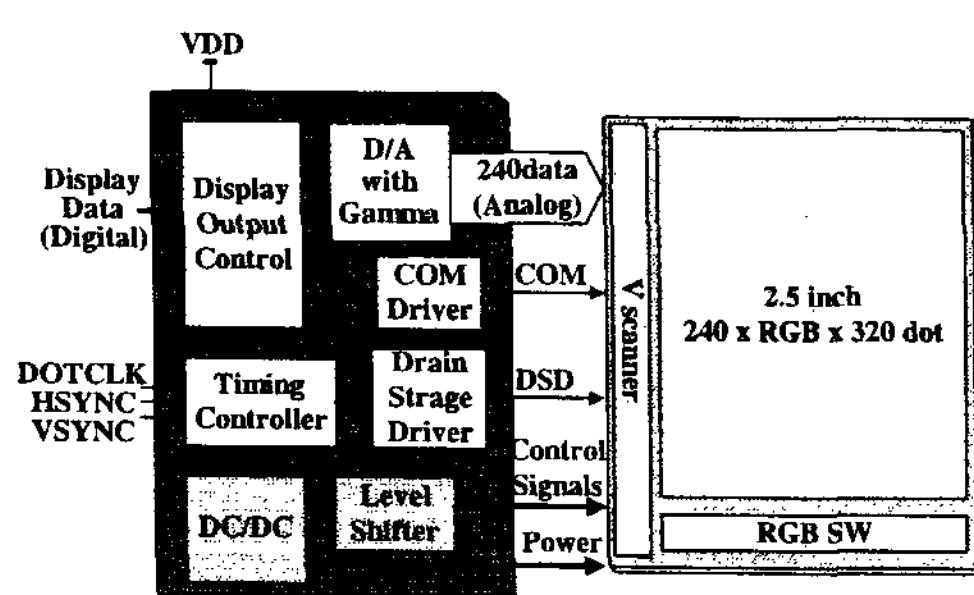


Fig. 5 circuit block diagram of QCIF panel

Two of the reasons for this are that high resolution has not been a real necessity in conventional cellular phone displays, and the requested uses of the display have continued to change due to the ways in which people have come to use the transmitted content. Originally, cellular phone displays only needed to display characters, so they used monochrome STN-LCDs. When NTT introduced its i-mode data transmission system, however, its popularity immediately soared. This led to a preference for color displays, and eventually prompted a trend toward displays with a larger number of colors as manufacturers added "wallpaper" idle screens and the ability to transmit still images. A shift was then made from color STN LCDs to color TFT LCDs to achieve higher display quality. At the time, however, the quality of the images being sent was not extremely high, and rather than displays with higher image quality, users were asking for reflective color LCDs that placed the priority on low power consumption. The existing LTPS-TFT LCDs with built-in circuits were inferior to a-Si TFT LCDs in terms of power consumption. One of the main reasons why LTPS-TFT LCDs were not used was that they consumed more than 1 mW of power just to display the idle screen. One proposal to counter this was to lower the power consumption all the way to 0.07 mW by embedding an SRAM circuit into each pixel, as shown in Fig. 4. However, since the embeddable memory was limited to 1 bit due to the level of microprocessing at the time, this would limit the application to 8-color displays(4). At the same time, a different company suggested embedding a DRAM instead of the SRAM(5). Another aspect desired in displays was a left-right symmetrical, three-side-free LCD module with narrow borders. The LTPS-TFT LCD had an advantageous position in this regard, but the a-Si TFT LCD was reconfigured to cope with the need for a three-side free LCD module. Whereas the a-Si TFT LCD originally had a source driver and a gate driver attached to two sides of the panel in a chip on glass (COG) configuration, a technology was developed that placed only the gate driver on the bottom side of the panel in a COG configuration, and mounted the source driver externally using the chip on film (COF) structure. The tremendous popularity of

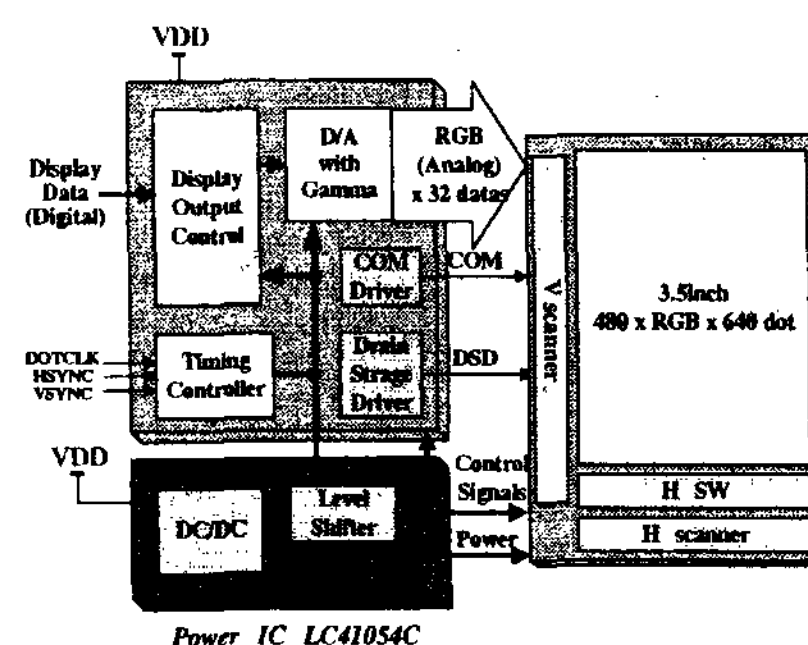


Fig. 6 circuit block diagram of VGA panel

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camera-equipped 3rd generation cellular phones since their market launch in Japan resulted in sales of more than four million units in 2002. One of the main reasons for this popularity was the enjoyment of being able to easily and instantly send photos, both still images and moving pictures, to friends. In response to the need for displays with good color reproducibility for truly beautiful images, cellular phone manufacturers are now moving in the direction of equipping their phones with transfection TFT LCDs capable of displaying more than 260,000 colors. QCIF, 2-inch class transfection panels with 176 x RGB x 220 pixels are now commonly used. LTPS-TFT LCDs and a-Si TFT LCDs are currently competing fiercely at this level of specifications, but there has recently been an increasing number of manufacturers using QVGA panels with the higher resolution of 240 x RGB x 320 pixels. While the a-Si TFT LCD faces extreme difficulties in achieving this level of resolution, the LTPS-TFT LCD is in a position of distinct advantage. Figure 5 shows block diagrams of the internal circuit and interface controller blocks of an LTPS-TFT LCD used to lower power consumption for moving picture display. The H-scanner that was built into the QCIF panel is incorporated into the external controller in the QVGA panel, with only the RGB switch positioned inside the panel. The one-chip configuration of the external controller drops the power consumption of moving picture displays to 10 mW for a 2.5-inch QVGA panel with 160 PPI.

PDA's

PDA's have generally been used as simple business tools with functions like scheduling and taking notes at meetings. Their displays have commonly been reflective 4-inch class QVGA LCDs that were either monochrome or capable of reproducing a maximum of 4,096 colors. However, faced with the increasingly rich content of recent cellular phones and the rapid move toward multifunctional designs capable of using this content, together with the advanced functions made possible by higher-speed notebook PCs, the original application domain of the PDA has become ill-defined and ambiguous. There is a danger that the PDA may cease to exist if a

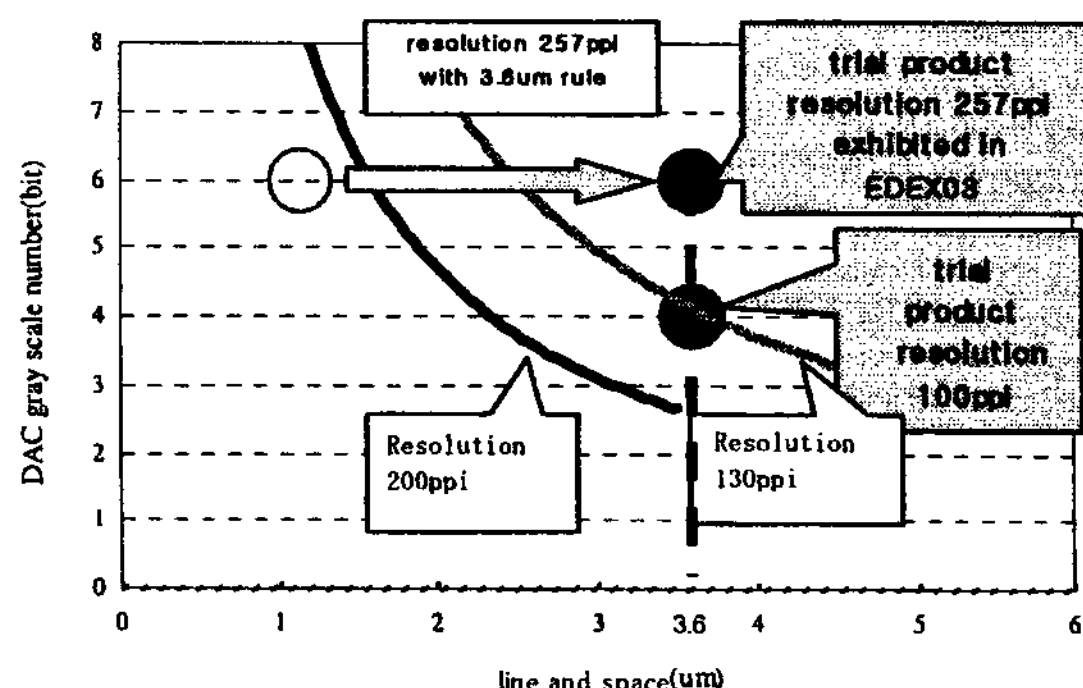


Fig. 7 circuit block diagram of 6 Bit D-A converter

version cannot be developed that maximizes both the easy use of the cellular phone and the diversity of the notebook PC, while adding entirely new concepts that are not possible with either the cell phone or the notebook PC. As a result, the demands for the PDA's display are becoming increasingly severe. VGA panels that can display 260,000 colors on a 3.5-inch screen with a line voltage of 3.3 V are in strong demand. The type that existing LTPS technology can offer is a 3.5-inch VGA panel with internal circuitry and an external controller LSI, as shown in the block diagram of Fig. 6. A total of 96 (32 x RGB) analog video signals are input to the panel, which is powered by 8-V LCD drive. The high mobility of the LTPS-TFT and further advances in microprocessing, however, hold the possibility for more. As shown in Fig. 7, even with the present design rule of 3.5 μm , circuit enhancements enable a CIF 6-bit DAC, so reducing the design rule to 1.5 μm or less would make it possible to integrate a VGA 6-bit DAC and line memory. Furthermore, as shown in Fig. 8, if the mobility exceeded 200 $\text{cm}^2/\text{V} \cdot \text{s}$, a VGA-class timing controller could also be built in, bringing it closer to a system-on-panel. There is a possibility of achieving higher mobility in the LTPS-TFT by making improvements to conventional ELA technologies, such as Sequential Lateral Solidification(SLS)(6), Selective Enlarge Laser Crystallization (SELAX)(7), and the CW laser method(8). Their technologies offer mobility of more than 200 $\text{cm}^2/\text{V} \cdot \text{s}$ in n-ch LDD TFT horizontally aligned to recrystallized poly-grain.

3.Application to Microdisplays

While the present market scale is not so large for electronic viewfinders(EVF), light valves for projectors and projection TVs, or wearable computer displays, these are all areas with steady growth forecasts for the future. They were also previously the exclusive domains of HTPS-TFT LCDs, but competition is expected from the recent development

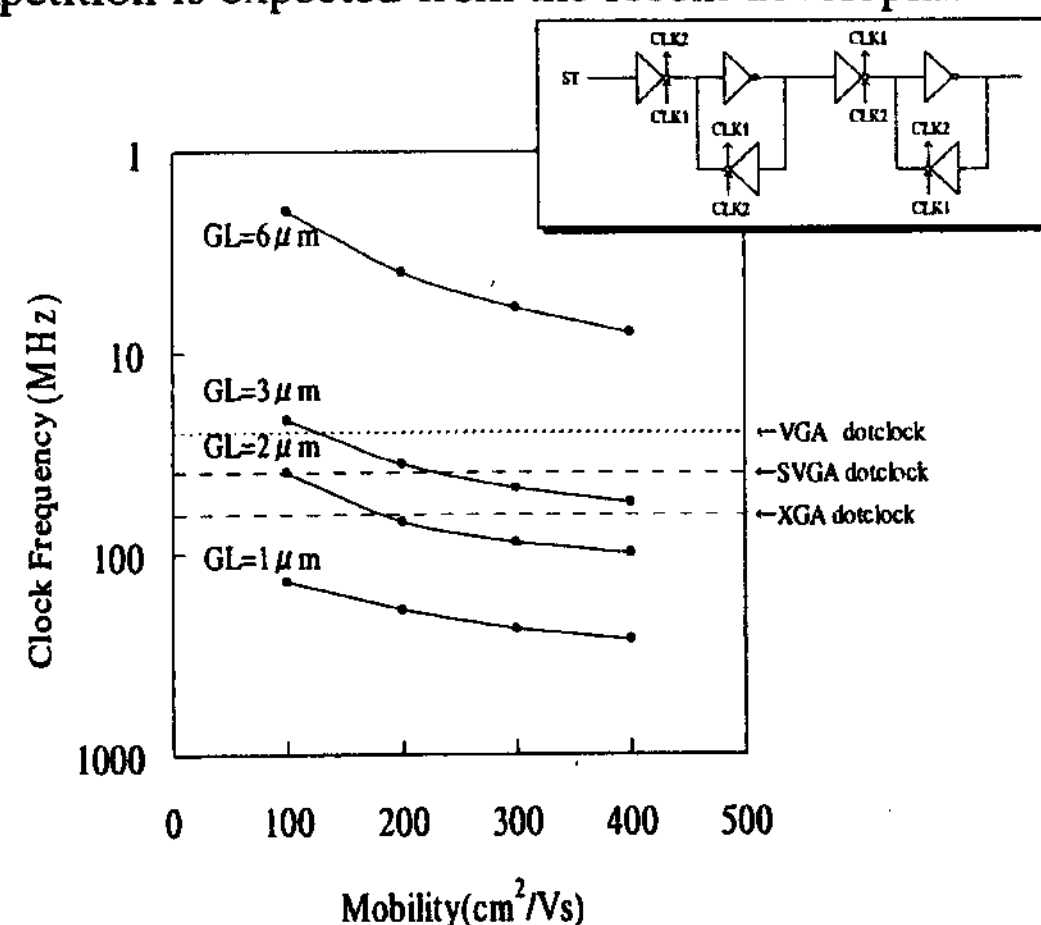


Fig. 8 simulated result of shift resistor

of the LCOS, and from LTPS-TFT LCDs as well, given further advances in microprocessing. Due to its cost advantage, the LTPS-TFT LCD has already begun to gradually eat into the HTS-TFT LCD domain of EVFs. Presently, the line-up of EVFs using LTPS-TFT LCDs includes a 0.44-inch color model with 180,000 pixels, and a 0.33-inch color model with 110,000 pixels. These products use a 2- μ m design rule, the most advanced for the LTPS-TFT. Enhancements such as stacking a 2-layer capacitor onto a Black Matrix (BM) provide a high aperture ratio for their EVFs. As products become increasingly compact, display sizes are going to have to shrink as well, but the question that remains is just how far the downsizing can go, and what kind of circuit scale can be integrated into the LTPS-TFT compared with the LCOS. If the LTPS-TFTs can win this battle, the path will be open not only to electronic viewfinders but also to light valves for projectors.

4. Application to OLED Displays

The world's first full-color, active matrix organic electroluminescence display (OLED) using an LTPS-TFT substrate as a back plane was jointly developed by Sanyo and Kodak, and exhibited at the Autumn 1999 Japan Electronics Show. The exhibited display had a 2.4-inch, 190,000-pixel panel using single-molecular organic materials, in which the emitted light could be individual colors of red, green or blue, or combined to create full-color images. Each pixel had a switching TFT and an OLED drive TFT, and peripheral circuits contained H and V scanners similar to an LCD(9). A 5.5-inch full-color active matrix OLED display (AMOLED) was announced the following year(10). This lit the fuse for OLED development competition, and a year later, in 2001, Sony announced a 13-inch full-color AMOLED with a top emitter construction using single-molecular materials at the Combined Exhibition of Advanced Technology (CEATEC)(11).

In 2002, Toshiba presented a 17-inch full-color AMOLED with an inkjet method using polymer materials at the Society for Information Display (SID) exhibition(12). The same exhibition also included AMOLED exhibits from Pioneer and Epson. In 2002, Sanyo and Kodak unveiled a full-color, maskless, 15-inch W-AMOLED at CEATEC using a single-molecular white organic EL (W-OLED) in which a color filter was attached to each pixel of the LTPS-TFT substrate(13). At the same time, AU of Taiwan showed two AMOLEDs, one with an LTPS-TFT back plane and the other with an a-Si TFT back plane. This year's SID exhibition saw the announcement by Taiwan's Chi-Mei of a 20-inch single-molecular full-color AMOLED using an a-Si TFT back plane(14). This level of competition clearly shows that the AMOLED is well positioned as a next-generation display to replace the LCD. Opinions differ on whether the use of LTPS-TFT or a-Si TFT for the back plane is more advantageous in producing the active matrix display, but it would seem that using the LTPS-TFT would lead to faster industrialization, when considered the instability of a-Si TFT characteristics. SK Display, a joint venture company established by Sanyo and Kodak, began mass-producing AMOLEDs using an LTPS-TFT substrate as the back plane this year. Because displays using the LTPS-TFT type of back plane are as well suited to compact, high-resolution displays as the LCD, AMOLEDs will initially be produced for DSC and cellular phones. Compared to an LCD, however, the AMOLED requires additional TFTs for OLED drive. The current-voltage (I-V) characteristics and current-luminance (I-L) characteristics of a typical OLED are shown in Fig. 9. To achieve a brightness of 500 Cd/m^2 on the screen, a current of no more than several μA is needed for each pixel. When a simple voltage-drive circuit, such as the one shown in Fig. 10, is applied and a low-drive-capacity LTPS-TFT is used for the drive TFT, an extremely irregular TFT

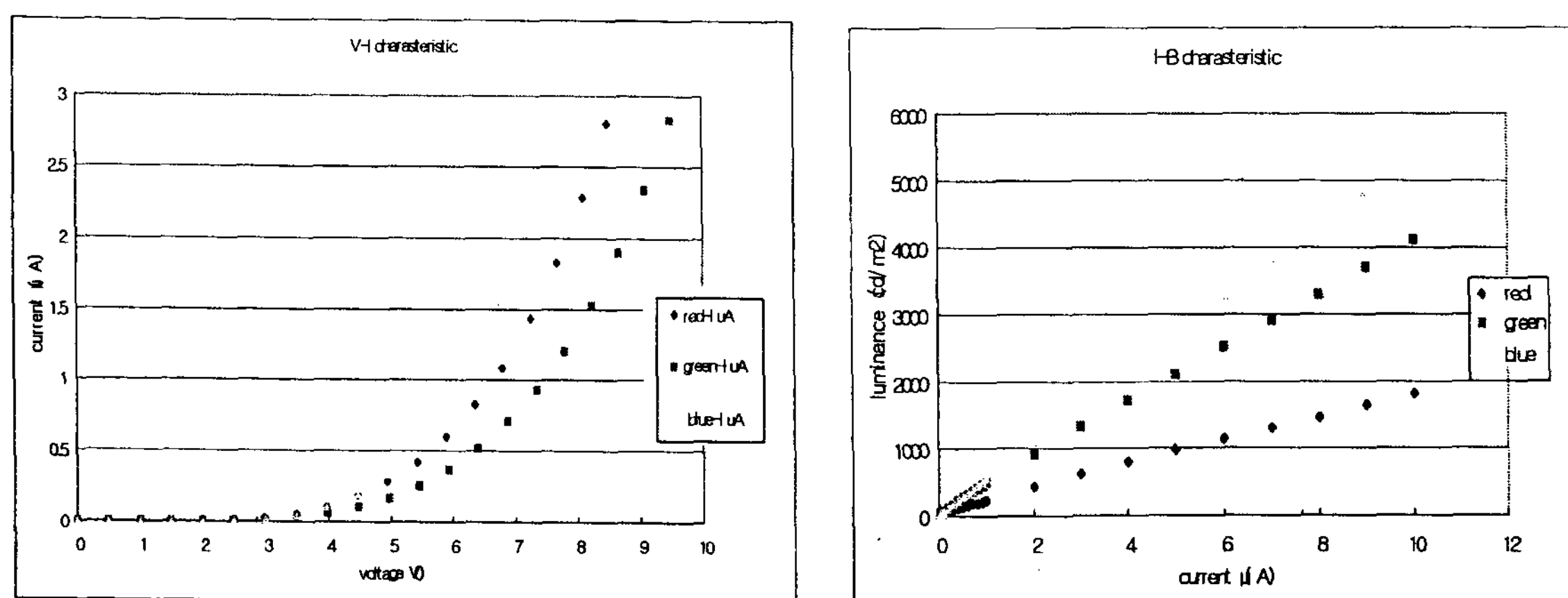


Fig. 9 L-V, V-I characteristic of OLED

design is required, with a channel length of 50 μm or more and a channel width of 5 μm or less. For the bottom emitter type high-resolution AMOLED, this raises a problem in securing the kind of aperture ratio that will allow the desired brightness and lifetime. Also, because the OLED's brightness is in direct proportion to its current, even a small change in current between pixels degrades the uniformity of the image. The characteristics of the drive TFTs, i.e., the V_{th} , within the panel must be uniform. In other words, minimizing variations is an effective way to prevent degradation in brightness uniformity. Differences in the film thickness of the PECVD-SiN used in the gate insulator or the SiO₂ film on the substrate surface, as well as hydrogenation, are all reflected in V_{th} variations, along with factors such as local electrostatic damage and contamination. Since this V_{th} variation control is much more exacting than the control required for the mainly on-off drive of the LCD, it is essential that process quality control (PQC) precision be raised in the production line. Fig. 11 shows an example of current drive, another OLED drive method. This method provides an effective countermeasure to the problem of non-uniform brightness because it allows precise current control, but it requires an amp circuit. The types of amp circuit available include current mirrors and a circuit proposed by the University of Michigan(15). However, since these circuits are each composed of numerous TFTs, they place more restrictions on the aperture ratio in the bottom emitter type construction than voltage drive does. This makes the use of the top emitter type construction essential. In using the LTPS-TFT substrate as a back plane for the OLED display, the features of LTPS technology will be realized only once the top emitter type AMOLED is developed and industrialized.

5. Application to Sensors

As an example of another use of LTPS technology, attempts are presently being made to apply the LTPS-TFT as a sensor TFT. Here, the basic concept is that the high cost of using an Si wafer for the large-area sensor chip can be lowered by using a

glass substrate, and that it represents an application to a new field of devices that do not require the high level of precision of Si LSIs and whose circuitry is relatively uncomplicated. Recently, considerable interest has been shown in LTPS-TFT use as a fingerprint sensor device, an application for the security industry. The fingerprint sensor device requires a minimal sensing area of 0.5 inch to authenticate a fingerprint. To enable widespread use, it also calls for excellent lightness, moisture resistance, durability, reliability, environmental resistance, and low cost. Fig. 12 shows a conceptual diagram of a fingerprint sensor. A pressure-sensitive sheet is applied to the LTPS-TFT array, and the fingerprint is authenticated by reading the differences in the finger's contact pressure as changes in electrical resistance, then processing the signal in peripheral circuitry and outputting the results. The special construction of the pressure-sensitive sheet enables sufficient detection even when there is moisture or perspiration on the finger. By embedding the signal processing circuit in the chip's periphery, the external signal processing LSI can be simplified for an additional cost reduction. Signal processing speed is an especially crucial point because the fingerprinting authentication must happen instantaneously. These factors take full advantage of inherent LTPS-TFT features. Another sensor application is a sheet scanner(exhibited by Toshiba on EDEX Japan 2003). Here, a photosensor TFT is embedded into each pixel on the same array substrate as a conventional LTPS-TFT LCD, allowing it to serve simultaneously as a display and a scanner. The scanned data can thus be displayed together with ordinary images on a single LCD screen. This is another new device proposal that takes advantage of the diversity of LTPS technology to enable the integrated formation of a sensor processing circuit on the periphery of the LTPS-TFT panel in addition to the image processing circuit.

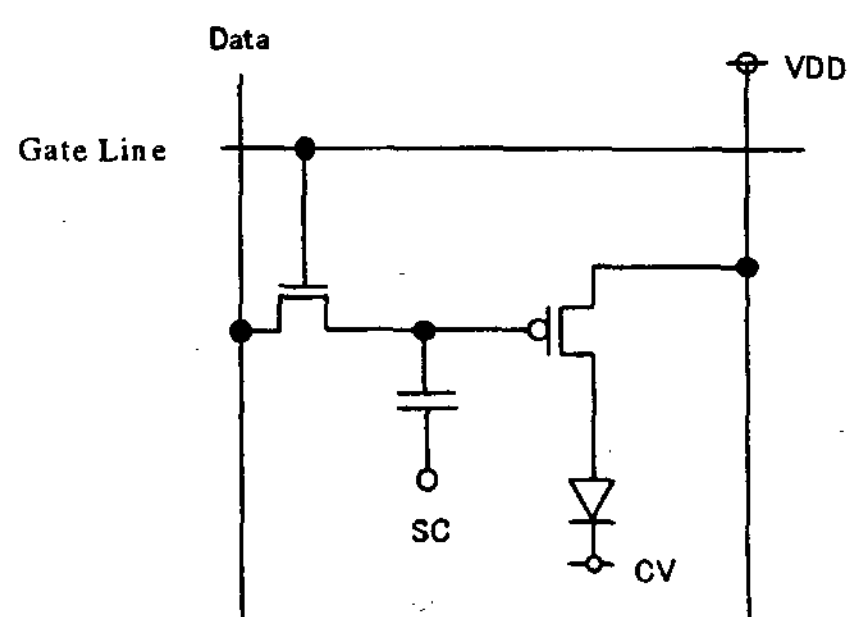


Fig. 10 Pixel circuit of OLED

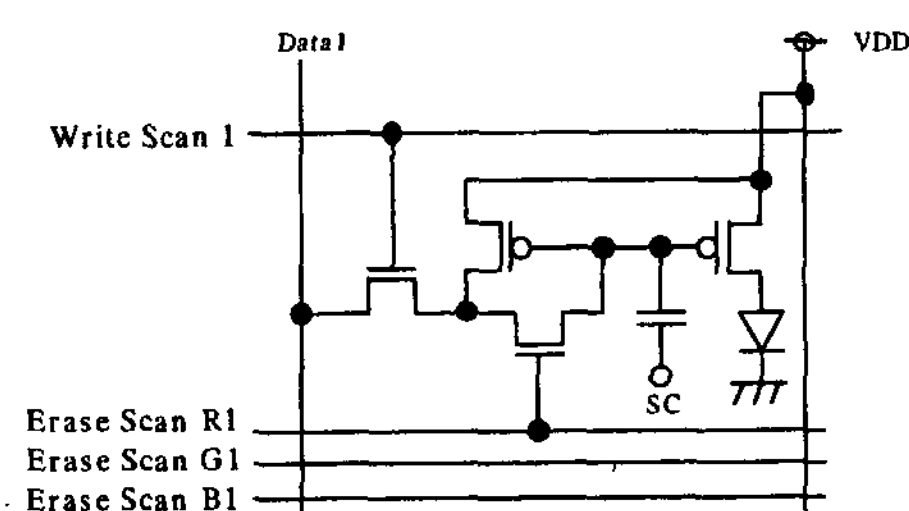


Fig. 11 current driving circuit diagram

6. Conclusion

The level of LTPS technology maturity has risen each year since the start of LTPS mass production, and its combination with microprocessing advances is now making it possible to embed increasingly complex circuits onto LTPS-TFT substrates to form panels with highly advanced functions. At the same time, active competition has been prompted by efforts to achieve cost levels that are in line with market demands. Against this background, we can expect a steadily expanding market for LTPS products. LTPS-TFT LCD monitors have already become standard equipment for DSC, and inroads are being made into similar applications in the massive cellular phone market. EVFs and other microdisplays that were once only possible with HTPS technology are now also possible with LTPS, thus widening the application scope of the new technology. Developments such as these make it clear that the time is approaching when LTPS technology will be an essential part of the compact LCD market. AMOLED displays using the LTPS-TFT as a back plane are also close to industrialization. Advances in the development of new technologies to raise the performance of OLEDs are raising expectations for the hidden potential of OLEDs to replace the LCD. Improving OLED performance, however, calls for more than just refining LTPS technology. Efforts must also be made to improve the light emitting efficiency and extend the lifetime of the organic EL material itself in order to achieve a true level of completeness in the OLED. This will require even greater collaboration among researchers. LTPS researchers have reached a critical stage where they are faced with new and profound obligations. They now need to accelerate the development of both microprocessing and mobility-enhancing technologies that will allow them to shape LTPS into an all-round player by applying it to fields other than displays and thereby carve out entirely new markets.

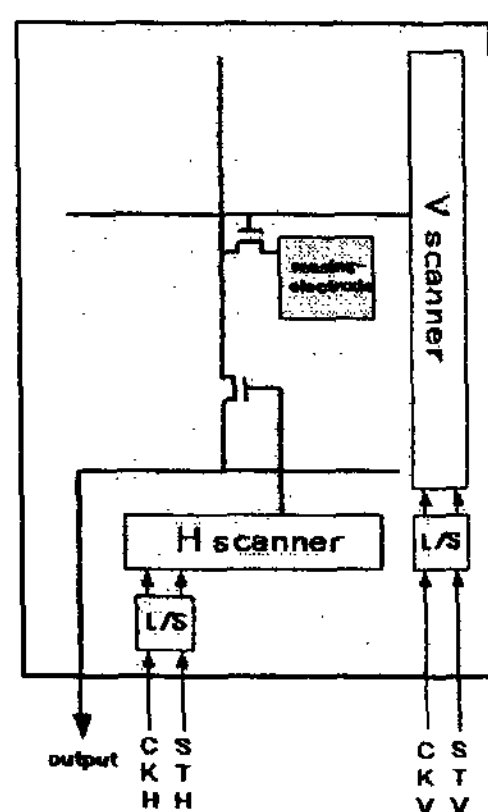


Fig. 12 conceptual diagram of fingerprint sensor

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