DISPLAYS FOR PORTABLE PRODUCTS ISSUE

Information DISPLAY

July 2004
Vol. 20, No. 7

SID

Official Monthly Publication of the Society for Information Display

Interface Standards for Mobile Displays

- ***Palmtop Television***
- ***Display Interfaces for Mobile Telephones***
- ***Displays for HDTV***
- ***Making Small- and Medium-Sized Displays***
- ***ASID '04 Report***

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A well-designed and widely adopted standard can benefit all companies involved in a market, both large and small. The Mobile Pixel Link open standard could do just that for mobile handsets, according to James E. Schuessler in his article that begins on page 16.

National Semiconductor Corp.

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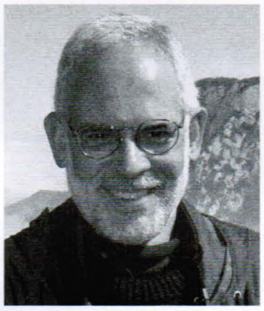
INFORMATION DISPLAY (ISSN 0362-0972) is published eleven times a year for the Society for Information Display by Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; Leonard H. Klein, President and CEO. EDITORIAL AND BUSINESS OFFICES: Jay Morreale, Managing Editor, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; telephone 212/460-9700. Send manuscripts to the attention of the Editor, ID. Director of Sales: Kate Dickie, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; 212/460-9700. SID HEADQUARTERS, for correspondence on subscriptions and membership: Society for Information Display, 610 S. 2nd Street, San Jose, CA 95112; telephone 408/977-1013, fax -1531. SUBSCRIPTIONS: Information Display is distributed without charge to those qualified and to SID members as a benefit of membership (annual dues $75.00). Subscriptions to others: U.S. & Canada: $55.00 one year, $7.50 single copy; elsewhere: $85.00 one year, $7.50 single copy. PRINTED by Sheridan Printing Company, Alpha, NJ 08865. Third-class postage paid at Easton, PA.

editorial

The 50th Anniversary of All-Electronic Color Television



Fifty years ago last March, the first RCA CT-100 color-television sets left the production line on their way to retail stores. This 15-in.-diagonal direct-view color TV was the first commercially available all-electronic color-television set. It had an MSRP of $1000 – about the same as that of a low-priced new car of the period – but it also had all of the essential features of a modern NTSC color-TV receiver, including a shadow-mask "tri-color" picture tube.

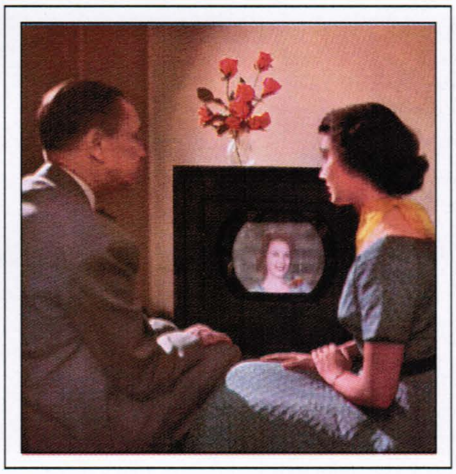
The CT-100 had a total of 1012 parts, including 36 receiving tubes and the color picture tube, along with approximately 150 ft. of wire. A single set weighed more than 160 pounds. Fewer than 5000 CT-100s were produced in that first production year of 1954.

In 1997, the SID International Symposium included an exhibition in honor of the 100th anniversary of the Braun tube – the first CRT. A restored CT-100 was arguably the most popular exhibit at that exhibition. The set – supplied, installed, and lovingly tended by Thomson Consumer Electronics – was driven by a DVD player. (There had been some difficulty locating a DVD player with a 300-Ω output.) The picture quality was remarkably good. Frank Koch, the Thomson engineer caring for the CT-100, said he had never seen it look better, and gave credit to the digital signal source. The CT-100 operated flawlessly for the three days of the exhibition.

The initial production of CT-100s on March 25, 1954, was accompanied by RCA's immediate decision to license the technology to 70 competing manufacturers. "Despite the substantial investments in color TV and the early introduction of color-TV models by more than two dozen manufacturers," says TV historian Ed Reitan, "RCA was the lone holdout still selling color-television models by 1960. There just was not enough color-TV programming on the air to make it a viable business for most manufacturers."

According to RCA Thomson, the premiere of NBC's "Walt Disney's Wonderful World of Color" in September of 1961 made a dramatic impact on the buying public, and rejuvenated sales of color-TV sets. CBS began regular colorcasts in the fall of 1965, and in 1966 NBC became the first network to broadcast all of its programming in color. It had taken 12 years since the CT-100's introduction.

– KIW



David Sarnoff Library

Fifty years ago, the RCA CT-100 brought compatible all-electronic color television to the home. In 1954, 5000 sets were sold.

We welcome your comments and suggestions. You can reach me by e-mail at kwerner@nutmegconsultants.com, fax at 203/855-9769, or phone at 203/853-7069. The contents of upcoming issues of ID *are available on the SID Web site (http:// www.sid. org).*

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my turn

India's Special Economic Zones

by Vikram Kothari

On January 8, 2004, the Indian Government announced key measures to greatly stimulate the domestic market for electronic hardware. Given low Indian labor costs; the availability of engineering, supervisory, and managerial personnel; and the potential of a rapidly growing Indian domestic market, my colleagues at iSuppli Corp. and I believe that operations in Indian Special Economic Zones (SEZs) are worth investigating.

India has eight functioning SEZs today. These are large enclaves (more than 1000 hectares in size) where manufacturing, service, and trading activities are being carried out in duty-free, tariff-free, and income-tax-free environments.

The largest SEZ, interestingly named SEEPZ, is located in Mumbai (Bombay) and had exports of more than US$1.3 billion in 2002–2003. Table 1 lists the eight functioning SEZs and their exports in 2002–2003.

Table 1: Special Economic Zones in India

SEZ	Exports 2002–2003 (Millions of Rupees)
SEEPZ	60,830
Noida	10,011
Chennai	8,191
Kandla	7,293
Falta	5,124
Vishakhpatnam	3,573
Surat	2,807
Cochin	2,704
Total	**100,533**

Source: Government of India.

As of March 2003, there were a total of 86,646 employees in 659 units operating out of the eight SEZs. The total investment made by these units is approximately US$2.2 billion.

SEZs are key pillars of the Indian Government's export thrust, and 19 more are in the process of being established. On January 6, 2004, the Indian Government extended income-tax benefits on profits made by units operating from SEZs to 20 years from 10 years.

Units operating from SEZs have other benefits.

- Acceptability of 100% foreign ownership.
- Capital goods, raw materials, consumables, spares, and packing materials can all be imported or procured from Indian sources duty free, and no licenses are needed for this.
- Export revenues can be kept in foreign currency and can be repatriated.
- Exemption from local sales taxes, service tax, and excise taxes.
- Ability to subcontract part of their production to units outside India and to units operating from the domestic-tariff area in India.
- Ability to sell part of their production in the Indian market.

The main commitments that units operating from SEZs have to make are as follows:

- Be net positive earners of foreign exchange.
- Follow local environmental, sewerage, and pollution control regulations.
- Make the necessary security arrangements to ensure that companies meet the customs bonding requirements and other SEZ rules and procedures.

It is worth noting that Indian labor laws do apply to units operating from SEZs and that these laws are enforced by the government of the Indian state in which

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Palmtop Television

Component and system advances are bringing TV to cellular telephones and portable video recorders, but designers must still work hard to achieve acceptable video quality together with low power consumption.

by Kevin Chalmers

THE DEMAND FOR portable communications has been a major driver of the electronics industry for some time, bringing us cellular telephones, PDAs, MP3 players, digital cameras, and ever-smaller notebook PCs, to name only a few. These devices have become all but ubiquitous in an unprecedentedly short period of time. Even video, with its massive bandwidth and processing requirements, has made its appearance in PCs on wireless networks and in multimedia cellular-telephone services.

However, television, the main source of moving images in our daily experience, has remained outside the reach of handheld devices. Despite the availability of over-the-air TV transmissions almost everywhere, consumers have not been able to receive these broadcasts using handheld devices because the technology has not been sufficiently advanced. Today, that situation is changing.

In general, TVs will be added both to cellular telephones, many of which are currently image-ready by the addition of digital cameras, and to portable video recorders (PVRs). First-generation products – some of which have already appeared – must solve formidable technical problems throughout the signal chain, from the antenna to the display. Perhaps the most important is power consumption, which is always a key concern in portable systems and one that affects component selection in virtually any design. Size is also critical in handheld devices, and viewers are also certainly concerned about the quality of the picture.

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Aided by advances in the underlying component technologies, equipment manufacturers are vigorously addressing all of these problems. By 2005, component suppliers will introduce advances that should make high-quality broadcast-TV reception by portable devices affordable – and in high demand by consumers.

New Portable-TV Products

Although the component technology is just emerging, manufacturers are beginning to offer portable products that play video, and they are making plans for more. Some cellular telephones, such as those implementing Sprint's MobiTV service, accept paid video programming, and the first mobile telephones with integrated TV tuners were introduced in Japan late last year.

As for PVRs, Sony has announced the Mobile Movie concept, which would enable users to record TV programs or other moving images onto a memory stick. The concept would extend to playback devices that integrate a 1.3-Mpixel CCD camera that takes pictures at SXGA (1280 × 960 pixels) resolution.

Sony currently offers a mobile AV viewer that records and plays TV. Styled like a mobile telephone, the foldover unit measures 6.1 × 2.3 × 9.5 cm and contains a TV tuner. When placed in a battery-charger stand, it can record programs onto a memory stick using MPEG-4 compression. The amount of video stored varies with quality. A 1-Gbyte Memory Stick Pro typically holds about 250 minutes of high-quality programming, defined as having a video bit rate of 384 kbits/sec (kbps) at 15 frames/sec, a resolution of 320 × 240 pixels, a 24-kHz sampling rate, and stereo sound with an audio bit rate of 128 kbps. The same memory can store as much as 1000 minutes using the Long Play 2 scheme, which drops the video bit rate to 64 kbps, the resolution to 176 × 144 pixels, and the audio bit rate to 64 kbps.

Also in development are a number of mobile telephones that make maximum use of the new color displays by including TV tuners. Of course, TV shown on such small displays requires users to adjust their expectations. Because it is difficult to discern small detail on the screen of a mobile-telephone display, it makes little sense to present closed captioning or other information inserted into the vertical blanking interval.

Picture reception may be of poorer quality than viewers are accustomed to on home sets, owing to antenna constraints, and battery-charge life is another limitation. The first-generation mobile TVs offer about 2 hours of viewing time – barely enough for most movies. And the processors in mobile TVs are not yet offering features such as noise reduction or echo cancellation, which will be necessary for correcting problems arising from low signal reception and noise.

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Technical Issues

The major functional blocks of remote TV systems include the antenna, tuner, video decoder, controller, and display (Fig. 1). Each block presents its own challenges in the design of a system that delivers acceptable performance and battery life. Systems and component manufacturers are addressing these problems vigorously, and also turning to system processors that help integrate the TV with other functions, such as PDA applications and games. OMAP™ 2 technology from Texas Instruments, for example, is designed to help transform Gens 2.5 and 3 mobile telephones into all-in-one entertainment devices with TV functionality.

Antennas are critical in mobile TVs that rely on terrestrial broadcast signals. The VHF channels (2–13) and UHF channels (14–83) are transmitted over wavelengths ranging from 5.5 m to 34 cm, which are too long for completely integrated antennas, even those receiving a half- or quarter-wavelength. To increase antenna size, mobile TVs are generally built with antennas integrated into a lanyard or special headphone leads (Fig. 2).

Unfortunately, such systems involve significant compromises in signal reception; even the direction the user faces can affect reception. The headphone sets have antenna wires of a specific length, so users may have trouble finding replacements. Since an antenna designed for one band (VHF or UHF) will not work well on another band, manufacturers often choose to optimize the antenna for the more popular VHF channels, and users must accept whatever performance they get for UHF.

Given the limitations of the antennas, handheld TVs might have trouble pulling in anything other than strong local signals. But the high signal strength in densely populated areas should compensate to a large extent, hence the benefit of having advanced digital-video correction that can considerably enhance the quality of a weak or noisy signal.

When a handheld TV is operating, the low-level RF signal is fed from the antenna to the tuner, which amplifies the input and converts it into an analog video signal. Traditionally packaged as "cans" with air-core inductors, tuners have the greatest effect on overall system size and power consumption. Recognizing the need for new portable-tuner technology, suppliers have begun serious development of semiconductor tuners that are a fraction of the size and draw much less power – about 800 mW today – than the older cans. When the tuner and video decoder are combined, TV in a portable unit draws less than 1 W, a figure that is within the acceptable range for use in mobile systems.

Fig. 1: The major functional blocks of remote TV systems include the antenna, tuner, video decoder, controller, and display. Systems and component manufacturers are turning to system processors, such as Texas Instruments' OMAP™ 2, that help integrate the TV with other functions, such as PDA applications and games.

To lower power consumption even further, component suppliers are investing a considerable amount in tuner development. By late 2004, manufacturers expect to have tuners that draw 600–650 mW, and technology roadmaps indicate a drop to 200 or 250 mW sometime in early 2005. This level will decrease the power consumption of portable TV to one-third of today's levels, considerably extending battery life.

A universal tuner with support for NTSC, PAL, and SECAM – the three analog broadcasting standards worldwide – would considerably simplify manufacturing and distribution. Some of the developers involved in creating portable TVs have set a goal of having a single tuner available by early 2005.

To date, worldwide standards for digital over-the-air TV broadcast to portable devices have not been defined, although there are pilot programs. Finland's leading broadcasters and mobile-service providers are scheduled to start using Internet Protocol Datacasting (IPDC) to send commercial TV programs to cellular telephones later this year. A service based on the DVB-H standard for digital video broadcasting to handheld devices, IPDC uses the IP to combine delivery of digital content formats, software applications, programming interfaces, and multimedia services. A trial with 500 subscribers will start this fall in the Helsinki area.

TV Video Decoders

From the tuner, the signal is fed to the video decoder, which digitizes a TV signal and performs some preprocessing to correct or to enhance the signal. For example, Texas Instruments converts the baseband NTSC, PAL, and SECAM analog video into digital video for use by the system processor and display. In addition to automatic gain control, the device features patented sync-detection technology that locks onto weak, noisy, or unstable signals. These features are extremely valuable in a system such as cellular-telephone TV, in which signal reception may be very weak.

To reduce both cross-luma and cross-chroma artifacts, the device makes four-line adaptive comb filtering available for both the luma and chroma data paths. Video characteristics such as hue, contrast, brightness, saturation, and sharpness can also be programmed. The typical operating power of the device is rated at 115 mW, with reduction to less than 90 mW planned for the next generation.

Video decoders are already well suited for use in cellular-telephone TVs and PVRs, but there is room for improvement. Video decoders today require a dedicated crystal at a frequency determined solely by the video decoder's manufacturer. Future video decoders will introduce phased-locked loops (PLLs) that work on the cellular-telephone clock, allowing designers to drop a component from the bill of materials.

Another issue is how the output format affects component size. The generally accepted standard today for digital decoding of TV signals is the ITU-R BT.656 standard, which outputs digital $Y'C_BC_R$ 4:2:2 component video. (The 4:2:2 represents a ratio of sampling frequencies used to digitize the luminance and color difference components in a video signal.) Blanking, embedded sync words, and video multiplexing formats are also defined by the standard. Today's video-decoder chips that implement the ITU-R BT.656 standard come with eight or ten parallel output lines, but there are discussions in the industry about how to serialize the data in order to reduce the number of pins.

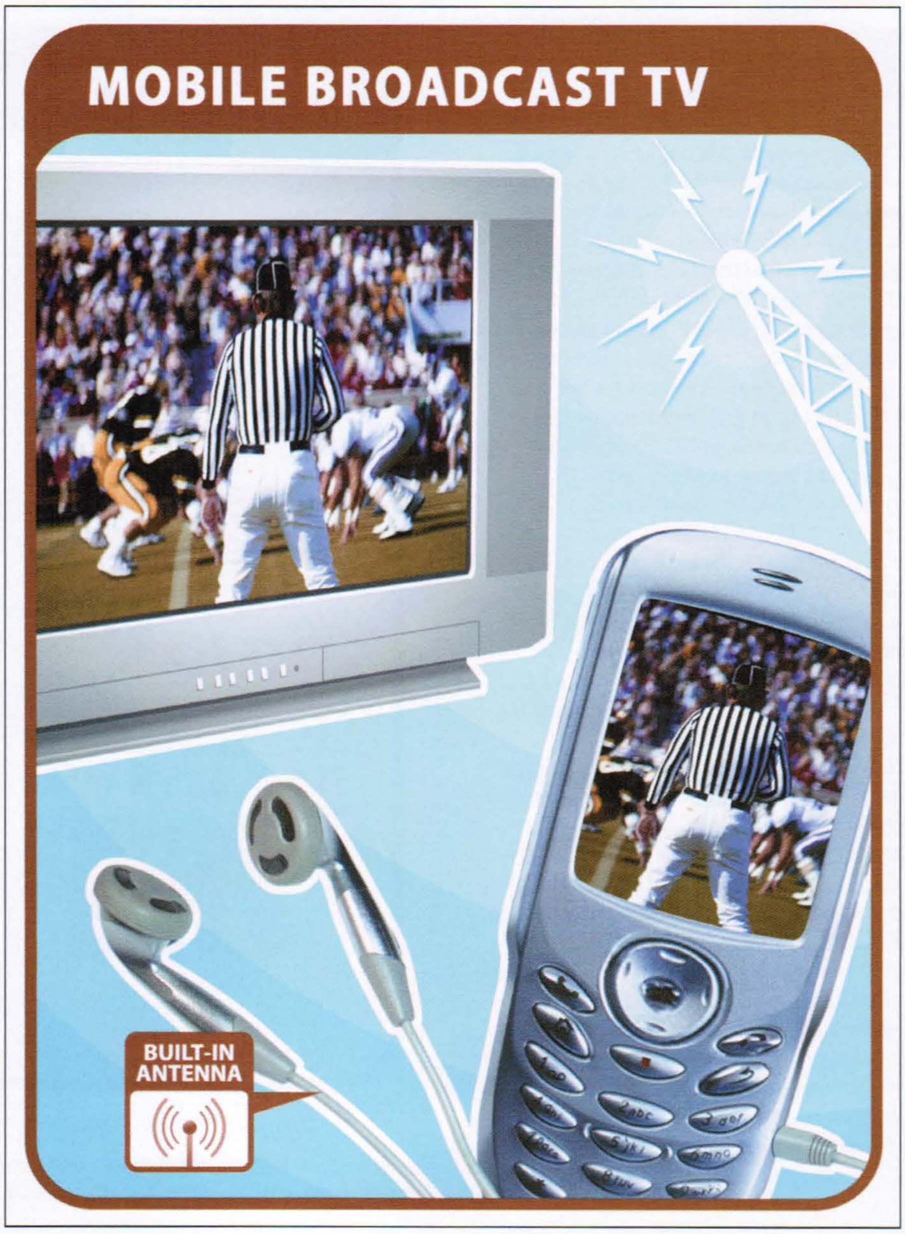

Fig. 2: To increase antenna size, mobile TVs are generally built with antennas integrated into a lanyard or special headphone leads – a solution with its own problems.

Format and Display

When over-the-air TV functionality is added to a cellular telephone, PVR, or any other handheld device, it is efficient to use the same processor to accept video-decoder signals and format them for the display. Although most video decoders generate 640 × 480, 720 × 480, or 720 × 576 pixels, only a few perform the scaling necessary to generate the formats used in the displays of cellular telephones, which include quarter common intermediate format (QCIF, 176 × 144) and quarter-VGA (QVGA, 320 × 240). As a result, scaling is left to the main system processor.

In the future, cellular telephones will utilize small-format memory cards for recording over-the-air programs, which can then be viewed on a telephone or on a larger screen. Some high-end Sony HDTVs already have a memory-stick port that allows users to take a stick from a digital camera and view the snapshots on a TV. The same HDTV set could also act as a digital video recorder if an MPEG-4 encoder were added. Digital-signal processors (DSPs), which are optimized for running compression-type algorithms, become very attractive as the central processor.

Cellular-telephone displays today offer color and higher resolution than a few years ago, but they are still generally meant for static information. The refresh rates are not fast enough for motion, causing apparent streaking in a moving image. Manufacturers are devoting considerable effort to develop displays that can operate at a 50-Hz refresh rate – the minimum for adequate video quality.

The components in the signal chain must operate on low voltages in order to save power and reduce the need for boost stages. A typical cellular-telephone battery operates in the range of 3.0–3.6 V, depending on the level of charge. For a chip operating on a 3.3-V supply, the system has to boost the supply from the battery when the available voltage drops. Devices that utilize a 1.8-V core and I/O eliminate this need and consume less power, so they are more suitable for mobile applications. In addition, some state-of-the-art 90-nm processors feature transistors that can be "tuned" for different functions on a single chip in order to meet a variety of requirements for performance, density, and power consumption. Transistors with the highest performance can be used in performance-critical functions such as signal processing, while those with lower power consumption can be used to support functions with more restrictive active and standby power requirements.

What to Look For

TV is on the verge of entering the mobile world in cellular telephones and PVRs. Component suppliers will lower the power requirements and reduce the size of TV tuners and video decoders in the next few years, allowing equipment manufacturers to integrate the most up-to-date IC technology into their products. These IC advances – combined with developments in antennas, displays, batteries, and storage devices – will bring better TV reception to smaller devices, along with longer battery life. Before long, TV will join the many other forms of communication available to mobile-device users. ■

Standardizing Display Interfaces for High-Performance Mobile Telephones

A well-designed and widely adopted standard can benefit all the companies involved in a market, both large and small. The Mobile Pixel Link open standard could do just that for mobile handsets.

by James E. Schuessler

SOME WOULD ARGUE that standards stifle innovation, so it is legitimate to ask if *any* standard is beneficial to the electronics industry. After sufficient architectural maturity, the answer is an emphatic yes! Without an open standard, the pace of innovation will actually decline. But why?

Manufacturers with the largest market share tend to drive *de facto* interface standards into the market. Smaller suppliers are either forced to adapt to these interfaces, being relegated to "follower status," or they try to establish their own interface by influencing peripheral and/or module vendors. These module vendors are forced to choose from a smaller set of customers and to support the multiple interfaces of the major manufacturers, slowing time to market for each platform as they apply limited resources to multiple interfaces. This ultimately slows the pace of peripheral innovation because suppliers are forced to spend a larger portion of their research-and-development budget on a plethora of interfaces, which adds no value to the end user.

A standard interface benefits the industry because it frees the entire market chain to compete on features that add value to the end user, thus making the entire market larger. In the short run, however, a peripheral vendor having a unique interface may see an open standard as a threat to the lock it has on a particular customer. The unique interface discourages customer switching, which is seen as a good thing by these suppliers – especially in markets with few major customers – because one model has enough volume to achieve a sufficient economy of scale. This leads to the conclusion that manufacturers higher in the market chain need to lead the standards effort, since they supply the purchasing power that drives their supplier's roadmap.

One excellent example of these forces for and against standardization can be found in the choice of interface for cellular-telephone displays. Fortunately, the larger manufacturers in the cellular-telephone market have begun to take a leadership role toward standardization, and, as a result, the future for standards looks very bright indeed.

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The Mobile-Display Dilemma

When large-format-LCD interfaces in portable computers made the transition from transistor-transistor logic (TTL) to low-voltage differen-

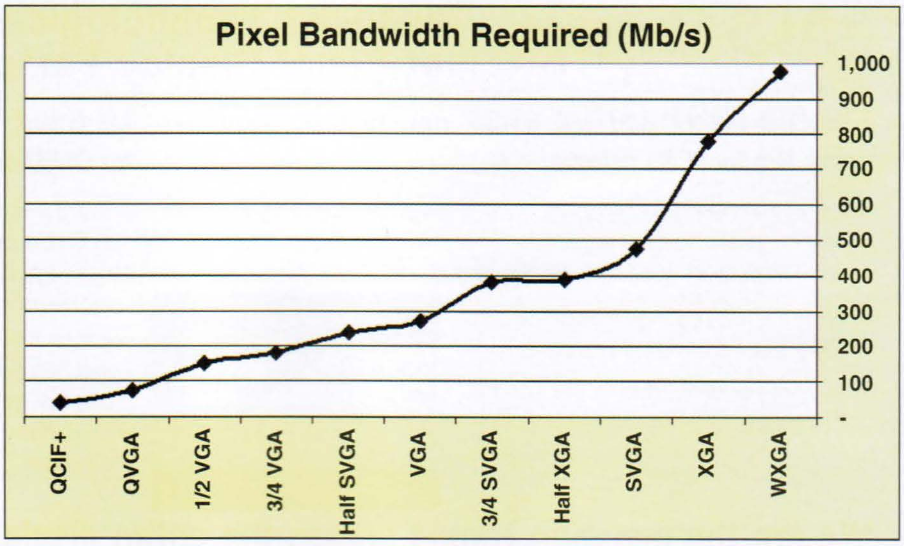

Fig. 1: *As the resolution of portable displays increases, the required bandwidth also increases, which places increased demands on components and system design.*

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tial signaling (LVDS) starting in 1994, no one thought we would be facing exactly the same set of problems almost a decade later for the mobile-telephone handset. In fact, much of the architectural evolution we have recently seen in handheld portable electronics mirrored that of the notebook PC, but at a much faster pace. Over the last 2 years, the majority of mobile telephones have moved from black-and-white (B/W), to passive-matrix color STN displays, and then to active-matrix color thin-film-transistor liquid-crystal displays (TFT-LCDs) with added camera functions. The "old way" of interfacing these devices has hit the wall.

In absolute terms, color screens will overtake B/W screens this year and active-matrix color screens will become dominant in mobile phones in 2005, according to DisplaySearch. The implications for the interface are profound. B/W screens typically use a slow serial interface, while color STN and TFT screens moved rapidly through 8-bit CPU-style interfaces to a wider 16-bit data bus. As screens move beyond QCIF+ formats – typically 176 × 220 pixels – the frame buffer will increasingly be part of the graphics controller, and the interface will move to an 18-bit RGB style familiar to notebook-PC designers. The fine-pixel-pitch QVGA – 240 × 320 pixels – and larger screens based on polysilicon TFTs that will be introduced in volume toward the end of 2004 are truly stunning in their clarity.

Although the practical crossover point for on-display frame buffers is increasing, most high-information-content displays will require updating at the frame refresh rate, which places corresponding pressure on design factors including interface power consumption, electromagnetic interference (EMI), mechanical size, and reliability (Fig. 1).

Engineers at National Semiconductor Corp. identified two different paths that offered potential solutions. One had a faster time to market and just focused on solving today's wide-interconnect problem. The other fully exploited the rare architectural breakpoint in the move from parallel to serial interfaces and used that as an opportunity to create a standardized solution for these interfaces. This second path has the potential to lower system costs further by reducing the impact on firmware in supporting many displays and cameras. These two paths are referred to as Mobile Pixel Link (MPL) Level-0 and Level-1 (Fig. 2).

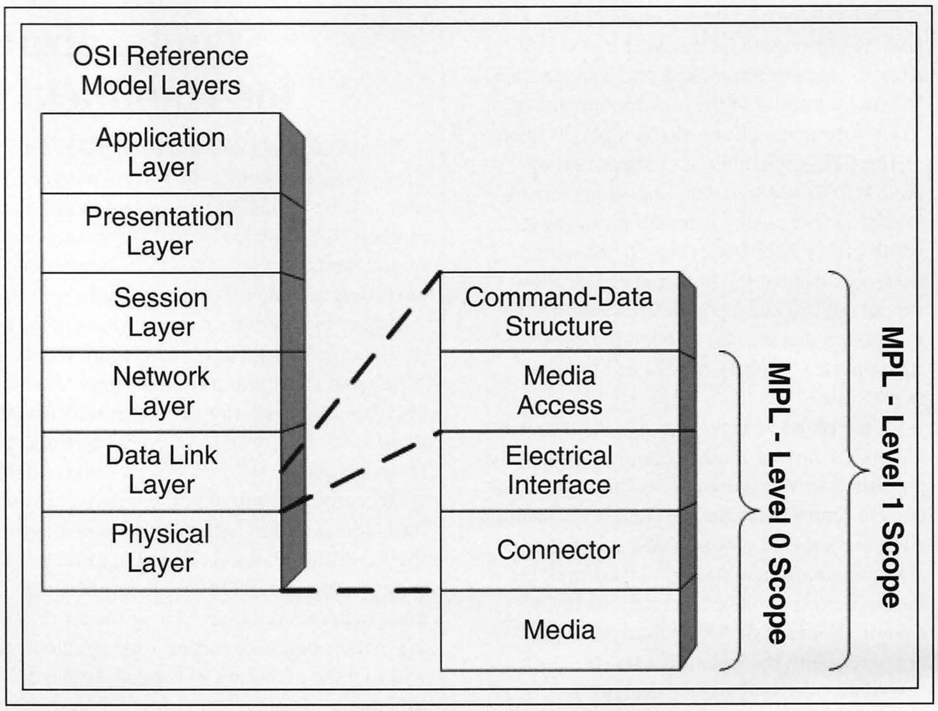

Fig. 2: Two levels of the Mobile Pixel Link (MPL) interface have been developed. MPL Level-0 is the more pragmatic and limited solution, while MPL Level-1 provides support for higher-resolution displays in the future.

The Expedient Solution: MPL Level-0

When establishing any new electrical interface standard, it is important to make separate translator devices, allowing users to develop familiarity with the technology. With MPL Level-0, the reasons are even more pragmatic. So much time and money are being spent on wide multi-layer flex interconnects within cellular-telephone handsets that the reduction in size and complexity can almost pay for the translator – or "bridge" – chips on either end. As an added benefit, market delays due to unexpected electromagnetic emissions can be shortened and mechanical constraints can be eased, freeing designers to create swivel and other innovative hinges between segments of the case.

These benefits did not come without a few negative consequences, however. Although the net bill-of-materials (BOM) cost increase is small, it is not small enough in this highly competitive market unless it can be made zero or negative. In addition, space had to be found for these new chips, although some of this was offset by the space savings due to a smaller connector footprint.

There is no doubt that the market needs a solution to the display-interface problem, and right now. It needs a translation from three common parallel interfaces into something as small, cheap, and serial as possible. These interfaces include 8- and 16-bit microcontroller or CPU-style interfaces, raw RGB display interfaces, and 8-bit *YUV* ($Y'C_BC_R$, or BT.656) camera interfaces. The easy part of the design is latching these bits into a shift register so they can be delivered serially. The hard part is obtaining a clock signal fast enough to push the data through the link. Building an add-on feature that did not burden the existing system with difficult clocking requirements meant that this clock needed to be generated within the translator device.

With this high-level definition, National Semiconductor engineers designed the LM2501 camera interface and the LM2502 dual-display interface. The protocols for each are different, based simply on the direct serialization of the parallel data path. Each generates a high-speed – up to 80 MHz – clock internally from low-speed external sources, and transfers data on both edges of the clock signal. This results in the frequency of the clock and data being the same – with a worst-case data pattern – and the ability to transfer

160 Mbits/sec or 2 bits per clock cycle. The LM2501 also includes a master clock path from the host to the camera and a single data channel returning to the host for support of VGA-format image sensors at up to 30 fps.

The CPU-style interfaces supported by the LM2502 use two data lines, transferring 20 bits in five clock cycles for a raw bandwidth of 320 Mbits/sec (Fig. 3). System designers wanted the higher speed to allow support of fast baseband or application processors that wanted to burst the entire frame buffer to the display in as little time as possible.

At the physical layer, the signals use a single-ended current-mode technique previously published as WhisperBus™ technology. The current return paths for the signals are through a common signal ground that could either be isolation grounds in a single-layer implementation or ground plane(s) in a multi-layer design. Because the serial rates are high enough to turn the link into a transmission line, controlled-impedance designs will require ground lines for any similar implementation, including differential current-mode types of physical layers. The MPL physical layer does not require any external components for termination.

A further practical benefit is built-in – or intrinsic – level shifting. Because the transmission of data is through controlled currents, the operating voltage of each end is completely independent, limited only by the process technology each uses. This solves another common problem faced by system designers today because baseband processor interfaces tend to be at lower voltages than those of camera and display modules.

The various MPL Level-0 interfaces can easily be integrated into a high-end mobile-handset design (Fig. 4). The interfaces are

Standardization of Interfaces for Handheld Portable Devices

Many comparisons have been made between the evolution of the PC market and that of the cellular telephone. As the PC market matured, it sought standards to lower costs and reduce time to market from a number of standards organizations. In the handset and PDA markets, the "trial and error" marketing of the last decade has given way to a consolidation of architectures that now allows huge economies of scale to reduce costs. However, those costs only will be reduced if standard interfaces allow those economies to be fully realized.

Rather than reduce competition as some argue, standards that focus on areas that end users never see and don't care about free resources to focus on features and benefits for which end users will pay. There may be tremendous elegance in a display or processor interface, but even engineers that build these devices don't make their buying decisions on interfaces. Engineers, like consumers everywhere, are attracted to the brilliant displays, long operating time, and superior image quality of a well-designed mobile device.

Recently, a group of companies have come together to standardize many low-level interfaces found within handheld portable devices. The Mobile Industry Processor Interface (MIPI) Alliance, with a Board of Directors consisting of ARM, Intel, Motorola, Nokia, Samsung Electronics, STMicroelectronics, and Texas Instruments, now includes companies that manufacture more than 75% of the world's cellular handsets. The MIPI Alliance clearly has the market pull necessary for the development of successful industry-wide standards which will fuel the evolution of handset architecture. As the 40+ member companies build products that implement future MIPI Specifications, switching barriers will be lowered and end users will benefit as competition moves to features that users can see, hear, and touch.

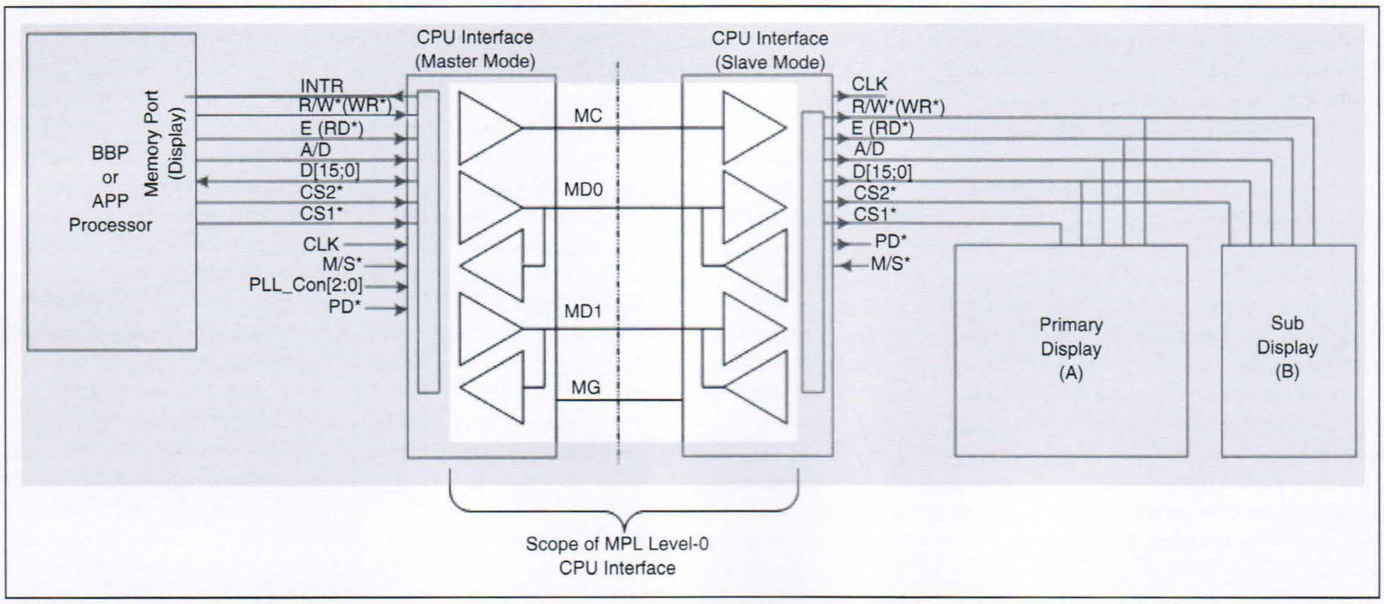

Fig. 3: *The MPL Level-0 design greatly simplifies the interconnects between the processor and displays of a mobile telephone.*

equally applicable to low-end telephones and do not impose any restrictions on the telephone architecture.

Because these chips need to exactly replicate the data patterns of legacy interfaces and be completely transparent or unaware of the data content, all the control signals are sent along with each sample of the data. For instance, the horizontal and vertical synchronization signals are sampled on every pixel-clock transition in the LM2501, even though they change very rarely. The result is that in most cases, the protocol is very inefficient, carrying about 20% overhead for control information.

Taking a step back to consider alternative approaches, designers concluded that it could be much more efficient to use a very simple packet-based protocol that could be implemented in a few hundred gates and deliver a significantly improved bandwidth in the process. This led to the development of MPL Level-1.

Stepping Forward by Stepping Back

Fully realizing the goals for MPL Level-1 requires a wider industry collaboration than that used for the Level-0 development. It requires stepping back to first principles and taking a fresh look at the natural constraints and desired goals of future video links. This future standardization can best be developed by the recently formed Mobile Industry Processor Interface (MIPI) Alliance, which has a Board of Directors consisting of ARM, Intel, Motorola, Nokia, Samsung Electronics, STMicroelectronics, and Texas Instruments. The MIPI Alliance now includes companies that manufacture more than 75% of the world's cellular handsets, and clearly has the market pull to develop successful industry-wide standards that will fuel the evolution of handset architecture. Now let us take that step back and take a closer look at some of the ideas that could feed this future solution.

First, it is important to reduce the problems of wide parallel interconnects to their essential elements. Because this interface is primarily internal, engineers have the freedom to choose the components at design time. However, end users and third-party manufacturers would lose the freedom to choose external interfaces to connect almost anything. Because components are mated in a limited number of known pairs, the complexity of the protocol can be minimized, and the link can be made essentially transparent to existing software.

Designers must have the freedom to change components at assembly time when mistakes must be caught, so the protocol must support some form of identification.

Handheld-device interconnect problems are not limited to camera and display interfaces, but extend to processor-to-processor and processor-to-external-world interconnects as well. Rather than attempt to solve all these problems with one complex structure, designers should choose to focus only on camera and display interfaces, which have many common elements. Other solutions emerging in the marketplace focus on just camera or display interfaces, and there are certain proposals at the other end of the spectrum promoting interconnect solutions throughout a handheld device. The middle-of-the-road approach utilized by MPL Level-1 recognizes that certain specific steps to optimize video interfaces should ensure a reasonably fast time to market without taking on the grander problems of a completely new handheld-device interconnect architecture. The complete set of guiding principles are straightforward:

- Few wires – just clock and data (totaling only two wires total if possible).
- Very low power and EMI.
- Initial speed to accommodate VGA-format cameras and displays, yet scalable to gigabit-per-second link speeds for megapixel cameras. Initial speeds will

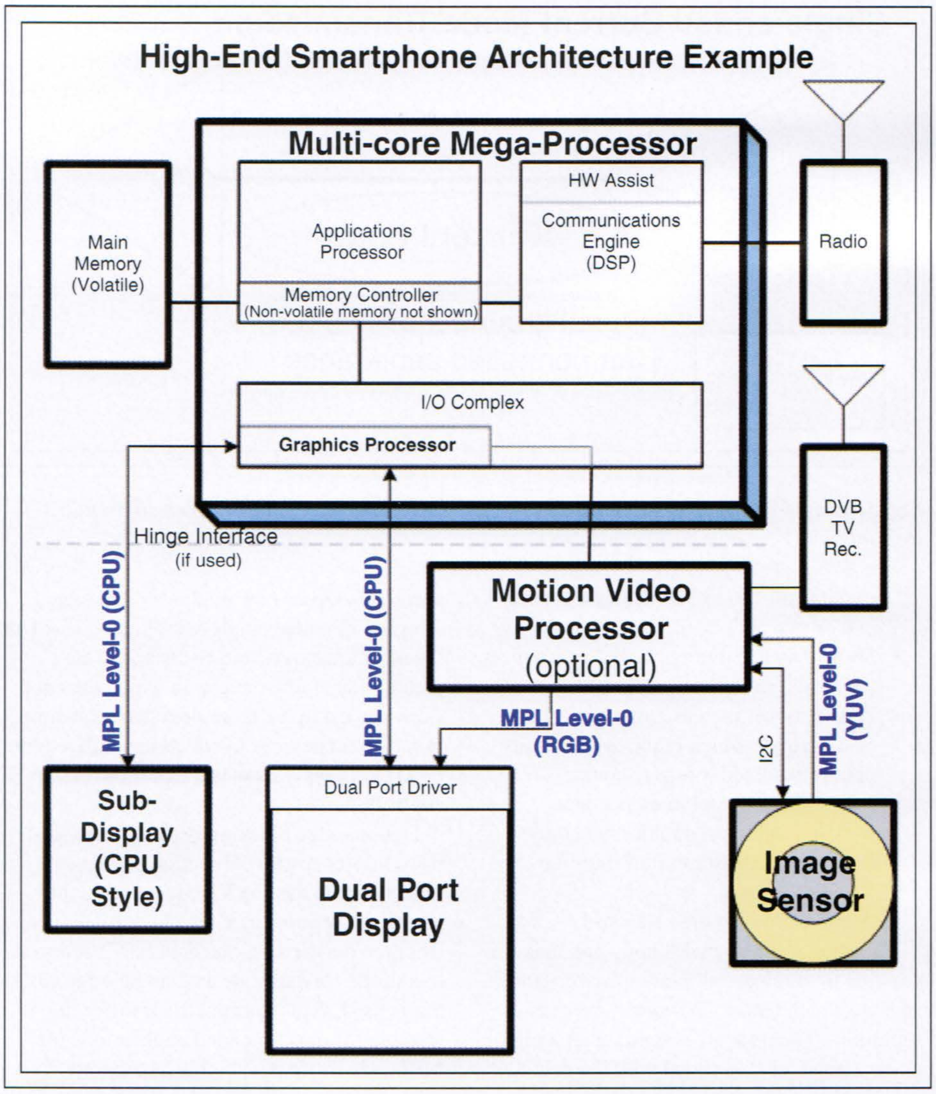

Fig. 4: MPL Level-0 interfaces can play an important role in a typical "smart phone" design.

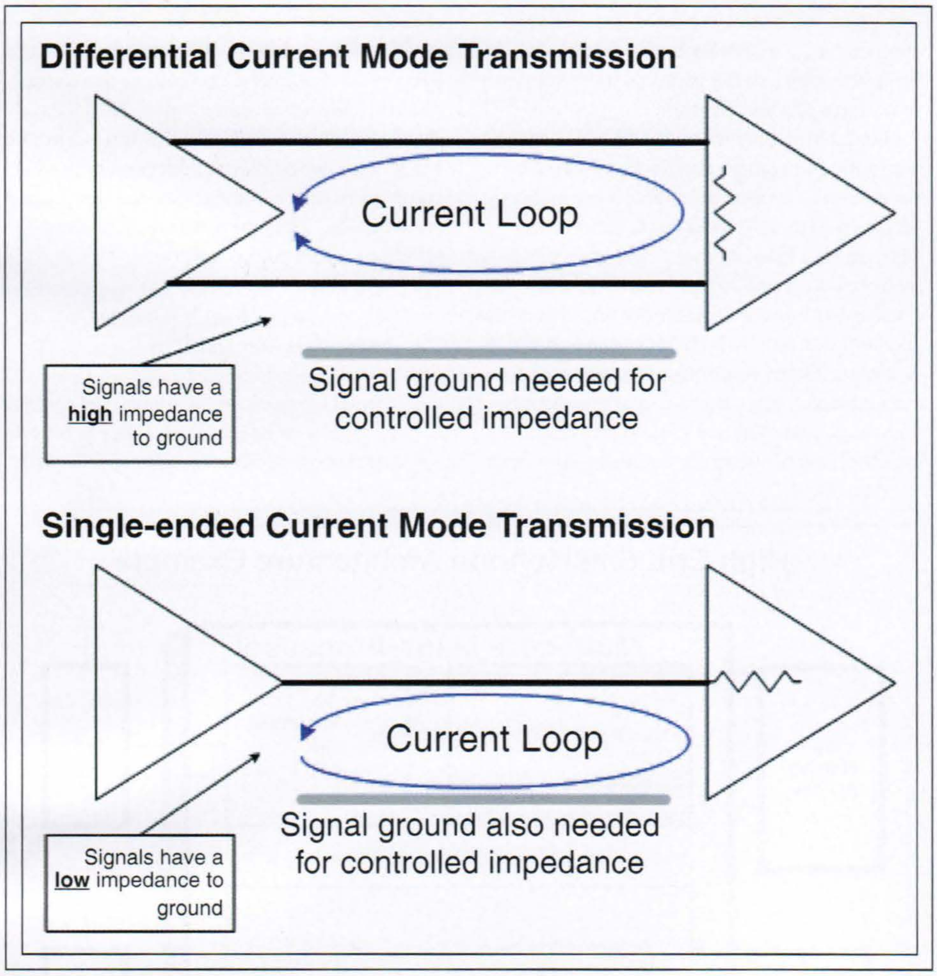

Fig. 5: Single-ended transmission designs offer some distinct advantages over differential transmission.

range from 160 to 320 Mbits/sec using one or two data lines.

- Short-distance internal-only interconnect (about 0.2 m typical).
- Zero-net-cost increase; or even better, cost savings, which requires a very simple protocol and low gate count.
- Low voltage, supply independent.
- Initially, video or graphics data only.
- Integration capability into fine-line CMOS.
- An open, royalty-free standard.

Choosing a fully synchronous link makes it possible to eliminate all clock-recovery mechanisms, which tend to increase power consumption. The tradeoff is sending a parallel clock, strobe, or flag signal with the data, but the additional power required for this is generally not as much as that consumed by high-speed clock-recovery methods. The signal integrity of coded single-wire gigabit links has the advantage over longer distances, *i.e.*, greater than a few meters, in which the cable skew can easily be more than half a bit-time. In handheld devices in which the path length is 20 cm or less, skew is much more easily controlled.

Double-edge clocking is used in the forward master-to-slave direction, so the data rate is double the clock frequency. In the reverse direction, since the clock is sourced from the master side, the data rate is reduced to half the forward rate and single-edge clocking is used. This asymmetric transfer rate is suitable for most intended applications for MPL, which are also highly asymmetric and makes the design task easier. In order to keep the interface narrow, without too much parallelism, very-high data rates are desired. A 3-Mpixel CMOS image sensor can require almost 1 Gbit/sec.

Finally, to accelerate adoption and allow the quick development of multiple interoperable sources of products, all companies in the value chain agreed that an open royalty-free standard model was necessary. Further development of new interfaces with features like these will be supported through the MIPI Alliance standardization process.

Alternative Interconnects

Architectural breakpoints, such as a move from parallel to serial interfaces in a market of half a billion units, have not gone unnoticed in the industry. Recently, several other companies introduced products that address part of the interconnect problem. These solutions are mostly based on a lower-voltage version of LVDS, and thus are differential current-mode interfaces. The advantage of this type of physical layer is that it is well understood, coming from the PC and high-speed-backplane worlds, and that EMI is cancelled on a per-signal basis. Essentially, each signal is its own current loop, with the emitted fields cancelling each other because the current flow is in opposite directions.

It is often suggested that a negative aspect of any current-signaling technique is that even when *no* data are being transferred, power is being consumed. True enough, but let us take a look at the power consumed in the voltage-mode alternative. The problem is not the absence of data transmission because the power is essentially zero; rather, the problems present themselves when designers try to attain very high speeds at low power and minimum EMI.

One constant we are dealing with is the impedance of the transmission line. Measured at only one end, it ranges from 50 to 80 Ω, while in the differential mode it doubles. It turns out that developing a sufficient voltage differential (ΔV) to achieve a reliable noise margin at the receiver consumes an excessive amount of dynamic power. Each transmission line has a parasitic capacitance that must be charged and discharged at each transition. The power is more a function of voltage than current, being proportional to fCV^2. It is easy to see why sending current with very-small ΔV results in very-large efficiency increases when measured in watts per bit per second. So, from a power standpoint, it may be preferable to permit the disadvantages of turning the link off when it is not being used and to use a current-signaling technique when it is in use.

Now that most of the industry has resolved to use current-signaling techniques, the next choice is between single-ended or differential transmission (Fig. 5). Because differential signals cancel their own EMI, aren't they the better solution? If EMI were the only parameter we needed to optimize, differential transmission might be better. However, another constraint that is equally – if not more – important is the absolute number of wires that need to be connected. Here, the single-ended approach clearly requires half the number of wires of the differential approach. To achieve an equal-link bandwidth, either the single-ended approach can be smaller (narrower) or additional data lines with slower rates can be used. But what about EMI? The current return path in the single-ended approach is through the signal ground. Several active lines can share this signal ground, for a net savings in wires.

Signal grounds are also necessary in differential current-mode interfaces for the same reasons as in single-ended interfaces, *i.e.*, to control impedance and for shielding. In the single-ended case, they perform a triple function, being useful not only for controlling impedance and EMI but also for providing the current-return path.

Another major difference between differential and single-ended current-mode interfaces is susceptibility to or tolerance of radiated noise. The differential scheme, although having a low impedance between the wires of the signal pair (based on the transmission-line impedance), has a rather high impedance (several kilohms) between that pair and ground. Thus, the amount of coupled energy required to move the common mode of the signal pair is relatively small. This is normally rejected by the receiver, which is actually detecting a differential voltage (not a current), if enough voltage headroom is available.

Conversely, the single-ended current-mode technique has a very-low impedance to ground, again based on the impedance of the transmission line, since ground is used as the current-return path for the signal. So, even though the ΔV of the signal may be measured in tens of millivolts, the coupled energy required to move this signal is relatively high because this energy is trying to move a 50-Ω system. Current is converted to voltage in the receiver itself, not the termination resistor as in differential schemes. The point is that our intuitive ways of thinking about noise margin, based on voltage, do not apply when dealing with single-ended current-mode transmission techniques.

Connecting to the Future

The MPL Level-1 design is a good example of how a new standard can help an industry move forward. It enhances the performance of the end products while encouraging broader competition and delivering economies of scale across the entire industry. A rising tide can raise all boats, and a well-designed and widely adopted standard can do just that for all companies involved in a market, both large and small. ■

Displays for HDTV

HDTV presents a variety of challenges to display designers – some obvious and others not so obvious – that must be overcome before HDTV can become a commercial success.

by Charles Poynton

TELEVISION has become an integral part of contemporary culture on a worldwide basis, from giant urban centers such as New York City to tiny Chinese villages. And now a revolution in television is under way, representing perhaps the most significant advance since full-color broadcasts started half a century ago. High-definition television (HDTV) promises to deliver higher-resolution images with greater clarity and better image quality than is possible with standard-definition television (SDTV) (Fig. 1). But there are numerous obstacles that stand in the way of broad adoption, and only careful design will ensure success.

HDTV was standardized a decade ago by the Advanced Television Systems Committee (ATSC) and is already broadcast by many hundreds of television stations as part of their digital-television (DTV) programming. Consumers have been slow to adopt HDTV, in part because of the high cost of HDTV receivers, but also because it can be difficult to achieve reliable reception of terrestrial broadcasts. Other sources of HDTV content are on the way, however, including digital cable service. Development of high-definition videodiscs is also under way; when HD-DVD movies become available in just a few years, they will likely accelerate consumer acceptance of HDTV and bring many consumers closer to the home-theater experience.

There are several official definitions of HDTV; unfortunately, some of them conflict with each other. Different organizations have different political agendas, resulting in differing definitions. A working definition of HDTV might be that it has an image format with at least three-quarters of a million pixels, an aspect ratio of 16:9, and a frame rate between 24 and 60 Hz.

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Sharp

Fig. 1: *HDTV promises to deliver higher-resolution images with greater clarity and better image quality than is possible with SDTV. This 45-in. 1080-line LCD TV from Sharp is scheduled for a 2004 introduction.*

0362-0972/07/2004-022$1.00 + .00 © SID 2004

Image Formats

During the development of HDTV, a debate raged concerning whether scanning should be interlaced or progressive (non-interlaced). After many years of work culminating in the early 1990s, the ATSC – as the industry-standards body – agreed upon a set of image formats, aspect ratios, and frame rates. These specifications are listed in Table 3 of ATSC document A/53 (see Table 1). There are two HDTV image formats described in ATSC Table 3.

- The 1-Mpixel format has an image structure of 1280 × 720 pixels, with square sampling. Scanning is progressive at frame rates of 24, 30, or 60 frames per second (fps). This format is accurately denoted as 720*p*; the 720 is the count of image rows and the *p* denotes progressive scanning.
- The 2-Mpixel format has an image structure of 1920 × 1080 pixels, also with square sampling. Scanning is progressive at frame rates of 24 or 30 fps or interlaced at 30 fps (60 fields). The progressive 2-Mpixel format is accurately denoted as 1080*p*, followed by the frame rate. The interlaced 2-Mpixel format is denoted as 1080*i* – the *i* represents interlacing – followed by the frame rate.

The 2-Mpixel format can encode images in either interlaced (up to 60 fields per second) or progressive (up to 30 fps) scanning, so it is not accurate to denote it simply as 1080*i*. Movies originate at 24 fps, and can be encoded in 1920 × 1080 progressive format, which can be denoted as 1080*p*24. This format is becoming popular for the capture and broadcast of movies.

The layout of ATSC Table 3 was confusing, especially when compared with several standard PC graphics standards, so I rearranged it to improve its readability (Fig. 2). ATSC Table 3 has been described by some as standardizing 18 formats, but there are really just four basic formats, two for SDTV and two for HDTV.

Although the image formats described in ATSC Table 3 were an important part of the standards proposed by the ATSC to the Federal Communications Commission (FCC), the computer industry argued in the early 1990s that total flexibility in image formats would encourage competition in the consumer domain. Intense lobbying by the computer industry resulted in deletion of ATSC Table 3 from FCC regulations for broadcast, so today's FCC regulations do not restrict the choice of scanning format; any format allowed by MPEG-2 is technically permissible. However, the ATSC Table 3 formats have effectively become standards because these are image formats that are guaranteed to be implemented in consumer receivers.

ATSC and FCC standards call for MPEG-2 compression at main profile at high level (MP@HL), which requires a data-transmission rate of about 20 Mbits/sec. An additional layer of standards describes encoding and modulation. Other countries have adopted the ATSC's image formats.

Format Conversion

As we move to higher-resolution images with HDTV, the issues of signal processing take on even greater significance, even though they still apply to SDTV applications as well. Key to processing television signals is the ability of the display to convert one format to another. In order to display today's analog terrestrial broadcasts, as well as cable, satellite, VHS, and DVD signals, HDTV receivers must also handle SDTV formats. Therefore, any HDTV display must be capable of converting one signal format to another. At a minimum, format conversion includes spatial resampling; ordinarily, this will involve a polyphase finite impulse response (FIR) filter. Format conversion may also include deinterlacing, frame-rate conversion, and/or handling of 2–3 pulldowns.

Most CRT computer displays are capable of "multiscan" or "multisync" features because their scan and frame rates can be modulated. However, the most economical way to design CRT drive and scanning circuits is to limit the frequency to a narrow range of operation. The designer of an HDTV display typically chooses a fixed scan rate, usually 1080*i*30. Format conversion is then used to accommodate formats other than the display's native format. For example, if the native display scanning is 1080*i*30, then 720*p*60 is displayed by up-conversion to 1080*i*30.

New display technologies such as DLP, LCD, and PDP have discrete pixels that are addressed individually. Conversion is required for any format other than the native format. It is also possible for the display designer to choose a panel that does not match any of the ATSC's formats. In that case, spatial resampling is necessary for the display of any of the ATSC formats.

Temporal Aspects

It is important to lock the display's frame rate to the incoming signal's frame rate. If the incoming signal is 1080*i*29.97 or 720*p*59.94, then the native display field rate is dropped by the 1000/1001 fraction to be driven at 29.97 fps. If the display operated at exactly 60 fields per second, a duplicate field would have to be displayed once every 16 sec or so, and this would be likely to cause a visual disturbance.

The image produced by a CRT flashes, and viewers will perceive flicker if the flash rate is slower than about 50 times per second. Historically, film at 24 fps was converted at the broadcast plant to the 60-field-per-second rate of video by the 2–3 pulldown process. Much

Table 1: Specifications for HDTV and Other Formats

Format	Progressive/ Interlaced	*Frame Rate (Hz)	Image Aspect Ratio	Sample Aspect Ratio
1920 × 1080	*p*	24, 30	16:9	Square
	i	30		
1280 × 720	*p*	24, 30, 60	16:9	Square
704 × 480	*p*	24, 30, 60	4:3	Nonsquare
	i	30		
	p	24, 30, 60	16:9	Nonsquare
	i	30		
640 × 480	*p*	24, 30, 60	4:3	Square
	i	30		

Note. This material appears as Table 3 in the ATSC document A/53, although presented in a somewhat different form.
*Frame rates modified by the ratio $^{1000}/_{1001}$; *i.e.*, frame rates of 23.976, 29.97, and 59.94 Hz are permitted.

DVD and HDTV material originates on film at 24 fps. Nowadays, MPEG-2 allows encoding at 24 frames.

In digital television, the 2–3 pulldown process – or some comparable technique – must be implemented during decoding or at the display. Displays such as DLPs have no intrinsic flashing, so, in principle, updates can take place at an arbitrary rate, such as 24 Hz. However, most display-interface subsystems impose a fixed frame rate, making a technique such as 2–3 pulldown necessary.

Interfaces

Traditional analog NTSC and PAL interfaces suffer the artifacts of composite encoding; color and brightness information contaminate each other. The S-video interface, which transmits separate luma and chroma using a four-pin connector, provides great improvement. Unfortunately, S-video is limited to analog SDTV. Even greater improvement is obtained by using separate luma and component chroma – denoted $Y'P_BP_R$ – at the analog interface. DTV and HDTV are based upon $R'G'B'$ components. However, these components are recoded to $Y'C_BC_R$ for recording, processing, and transmission. (The notations $Y'UV$ and $Y'IQ$ are both archaic, even for SDTV.)

Consumer-electronics devices would obviously benefit from digital interfaces. Movie studios tolerate copying of analog NTSC and PAL content, but they are terrified that consumers will decode and copy HDTV movies. Their concern was heightened by the cracking of the DVD content scrambling system (CSS). Owing to concerns of the content industries, digital interfaces for HDTV consumer devices have been very slow to be standardized and deployed.

The Digital Visual Interface (DVI, see www.ddwg.org) was initially developed for computer monitors, but has also been adopted in some consumer HDTV displays. DVI itself has no provision for content protection, although a content-protection scheme was retrofitted (DVI-HDCP). The scheme is implemented in many HDTV receivers and displays today. But the DVI connector is somewhat bulky, and it has no provision for audio or control connections. The High Definition Multimedia Interface (HDMI) augments DVI with a smaller connector, content protection, audio, and control – all in a single connector (see www.hdmi.org). The image signal is electrically compatible with DVI, so cable adapters are possible.

Gamma

In virtually all commercial imaging systems, intensity is coded nonlinearly so as to mimic the way the human visual system perceives light levels. In video, gamma correction is imposed at the camera, and the signal is conveyed in nonlinear form throughout recording, processing, and transmission. In traditional television, the nonlinear coding is effectively inverted by the power-law response of the CRT itself; no explicit components are required at the receiver.

Many have come to the conclusion over the decades that the purpose of the nonlinear encoding at the camera is to compensate for the undesirable nonlinear characteristic of the CRT. But the real story is that the CRT's nonlinearity is a nearly perfect match to the light-level perception of human vision. If the CRT did not have a power-law characteristic by virtue of its physics, we would have had to provide circuitry to make it so.

Display devices such as PDPs and DLPs have an intrinsically linear relationship between the code value applied and the light intensity produced. In order to accept signals that have been coded for video – in other words, signals coded for display on a CRT – these displays have to be driven by electronics that imposes inverse gamma correction. While about 8 bits per component are sufficient to match the human visual system's light sensitivity, 10 or 12 bits are necessary if adequate perceptual performance is to be achieved from linearly coded signals.

Historically, signal processing in television has been accomplished in the gamma-corrected-signal domain. With the advent of linear-light display devices such as PDPs and DLPs, the opportunity arises to do processing in the linear-light domain. In theory, this would seem preferable to the traditional nonlinear method. However, certain operations are best done in the nonlinear domain, and certain other operations are best done in linear space.

Enhancement

Consumer-electronics engineers have, for many decades, devised signal-processing circuits to attempt to overcome the most objectionable artifacts of analog NTSC and PAL transmission and recording. One example is flesh-tone, or skin-tone, correction. If the hue of a pixel was within 20 or 30° of Caucasian skin color, then the hue was artificially brought closer to ideal skin color. In

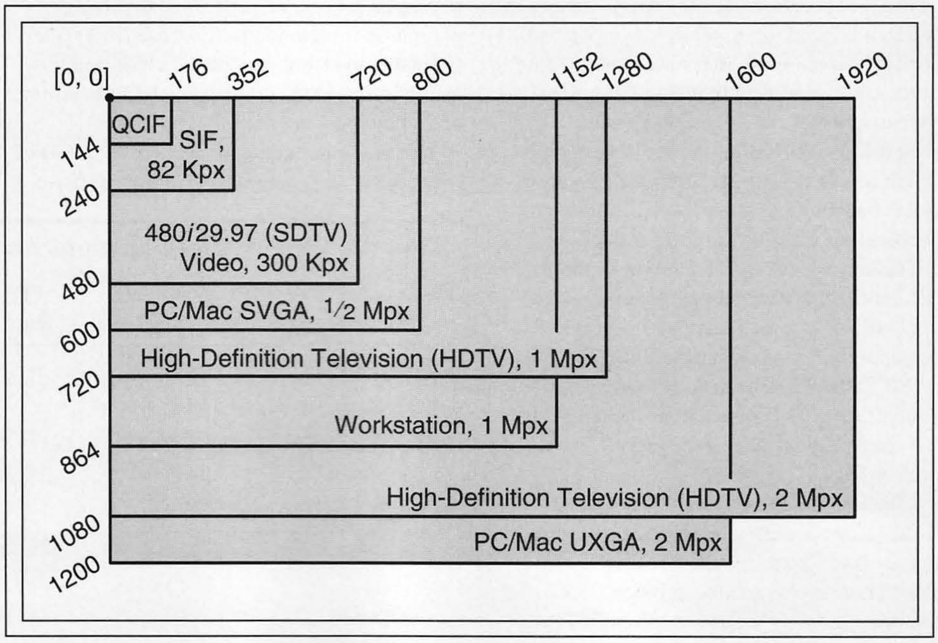


Fig. 2: *A graphic representation of several common display formats, each drawn to scale, suggests the need for spatial resampling in modern display systems.*

the very, very early days of NTSC – when hue errors were severe – this mechanism restricted the magnitude of errors in skin-tone reproduction, preventing skin from turning green on a seriously maladjusted receiver.

The signal path to the home no longer suffers from the artifacts that required the invention of these techniques, and such techniques have no place in the modern world. Terrestrial DTV and DVD content delivers exactly the same decoded bit stream that was viewed and approved by the creative team responsible for the content. Signal-processing algorithms can never improve upon the director's intent. At best, they can have no influence on the "look" of the creative content, and at worst they can degrade it significantly.

If necessary, the director has already optimized the skin-tone colors in the bit stream, and certainly wants to avoid having consumers adjusting the colors capriciously on their own receivers, based upon the settings provided by a design engineer attempting to improve upon an arbitrarily selected test signal.

Signal processing may be necessary to accommodate some particular aspect of the physics of a display device. If a particular device has an unusual transfer function, for example, then the driving electronics must obviously compensate for it. However, design engineers would do well to reject any modification of the image signal that is not justified by known defects in the signal path or by requirements arising from the physics of the display device.

Wide Color Gamut

The range of colors reproduced by HDTV – its gamut – is virtually identical to that of conventional television. However, many saturated colors cannot be reproduced by an additive mixture of the Rec. 709 primaries standardized for HDTV – and now used in SDTV as well. The colors that cannot be reproduced by SDTV and HDTV are fairly saturated, but they are found in nature. They also can be reproduced in offset printing, in color photography, and in motion-picture film, but not television. The classic example of an out-of-gamut color is the cyan color of a Salem cigarette package. Back in the era when cigarette advertisements could legally be shown on television, the makers of Salem cigarettes could not accurately show the color of their product on the screen.

The sRGB primaries that are now the *de facto* standard for desktop computing were chosen to be the same as the Rec. 709 primaries of HDTV. Computer monitors operating in conformance with the sRGB standard cannot display certain colors – such as the cyan on the Salem cigarette package – that can be easily reproduced in offset printing. Graphic artists working in print media face a challenge when using computer displays to develop their projects; they cannot display the full range of colors available in their end result!

The development and deployment of wider-color-gamut displays are likely to appear within the next few years, initially for desktop pre-press applications, although image-exchange standards and color-management workflows will have to evolve to accommodate these displays. One drawback is that today's display technologies require a trade-off: wider color gamut is necessarily accompanied by a decrease in luminance.

Motion-picture film can capture and reproduce a wide gamut of colors, but today's film color gamut is reduced to the Rec. 709 range when film is transferred to video or HDTV media. Wide-color-gamut displays will move quickly into the consumer arena, to bring a better approximation of the motion-picture experience into the home theater. As in pre-press applications, image-exchange standards will have to evolve. Unlike the graphic-arts market, the consumer domain offers little opportunity for incremental deployment. One saving grace is that wide-color-gamut program material is already "in the can" in the form of motion-picture film. Although today's 1080*p*24 cameras have roughly the Rec. 709 gamut, wide-color-gamut 1080*p*24 cameras are likely to emerge within the next few years.

Another limitation to reproduced gamut is imposed by the contrast ratio of the display; dark colors cannot be reproduced if dark shades of gray cannot be reproduced. Coding, recording, and transmission systems do not impose any contrast-ratio limit, and dark colors are present in program material even if these colors are not displayed. The gamut of dark colors will improve as display contrast ratios improve.

At last year's SIGGRAPH conference, Sunnybrook Technologies (www.sunnybrook-tech.com) demonstrated a high-dynamic-range (HDR) display that produced a contrast ratio of several thousand to one. Digital-cinema projectors now rival the contrast ratio of motion-picture film. We can expect improvements in contrast ratio in consumer displays over the next several years.

Making the Most of HDTV

Digital television is already available through terrestrial and satellite broadcast, cable delivery, and DVDs, although most of the programming is in SDTV format. Given the slow acceptance rate to date, many terrestrial broadcasters have opted to use their 20-Mbit/sec digital-channel allotment to broadcast several digital SDTV streams instead of a single HDTV stream. As the prices of HDTV receivers come closer to those of SDTVs, more consumers may opt to pay a premium for improved image quality and a more satisfying viewing experience.

However, if the experience is not significantly better, then consumers will not have reason to make the change. HDTV must offer much more than just increased pixel counts. The industry must not only develop and deliver sufficient HDTV broadcast content to warrant the purchase of the receiver, but also incorporate the technological advancements that make the equipment user-friendly. If HDTV is to be as successful in the marketplace as color TV was 50 years ago, consumer expectations must be met before its full potential can be realized. ■

Manufacturing Small- and Medium-Sized Displays

Large-area displays get the glory, but the market for small- and medium-sized displays will grow just as fast – and will absorb Gens 3 and 4 fab capacity as large-area-display production migrates to Gens 5, 6, and 7.

by David Hsieh and Barry Young

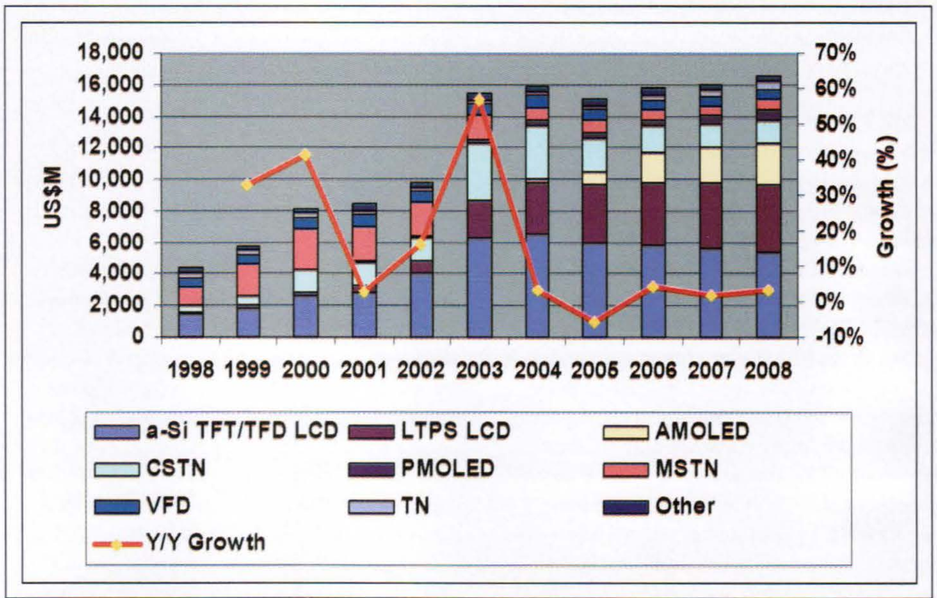
WHEN THE DISPLAY INDUSTRY is building flat-panel displays (FPDs) as large as 80 in. on the diagonal and is clearly focusing on how large a substrate it can build efficiently, the art of making small- and medium-sized FPDs may seem quaint – or at least behind the growth curve. Nonetheless, the growth in the small- to medium-sized-display market is substantial and is an enabling agent for new products.

While large-area FPDs are taking market share from CRTs, small- to medium-sized displays are thriving in products – such as mobile telephones, digital cameras, portable DVD players, camcorders, sub-displays, handheld games and TVs, PDAs, digital viewfinders, and picture viewers – that did not exist 5–10 years ago. And there appears to be no end to the applications requiring small- or medium-sized displays. Intel Corp., at its recent Developer Forum, showed, for the first time, an example of Extended Mobile Access (EMA), which enables closed-lid instant access to e-mail as well as other information through a secondary display on the lid of a notebook PC. The notebook PC functions as a wireless device without being opened. The mechanism consists of a WiFi or, perhaps, a GSM/CDMA receiver and an external display and keyboard. If this particular application was widely adopted, it would create a net increase of approximately 60 million 3–4-in. displays by 2006.

In contrast to the large-area-display market, where a-Si TFT-LCD and PDP are the only two viable commercial technologies, the technologies for small- and medium-sized displays are quite varied. They include a-Si TFT-LCD, LTPS LCD, OLED, PMOLED, VFD, MSTN-LCD, CSTN-LCD, TN-LCD, cholesteric LCD, electronic-ink, and a number of other technologies (Fig. 1).

Figure 1 also shows that in 2004 and beyond the majority of small- to medium-sized-display revenue will come from three technologies: a-Si TFT/TFD LCD, LTPS LCD, and AMOLED (LTPS OLED). By 2008, these three technologies should account for almost 74% of the total small- to medium-sized-display revenue. The remainder of this article will focus on these technologies.

In 2003, by application, mobile telephones represented 48.0% of the total revenue, followed by a close grouping of digital cameras, automobile monitors, and PDAs at 9.9, 8.2, and 7.2%, respectively (Fig. 2). Using 2002



DisplaySearch

Fig. 1: Small- to medium-sized-display revenue by technology.

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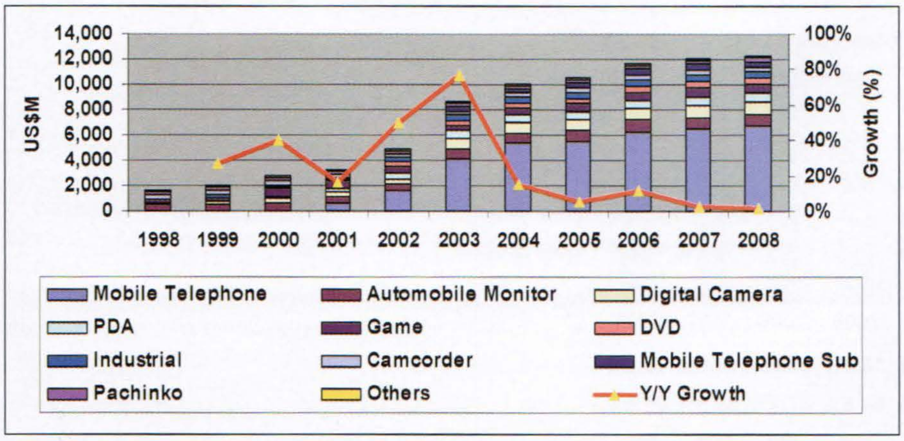


Fig. 2: Small- to medium-sized active-matrix-display revenue by application.

as a base year, DisplaySearch forecasts that the CAGR will be 16.6% through 2008, based on existing applications. The growth could be even higher if some of the new applications take hold.

Glass Capacity

Total active-matrix-display glass capacity is expected to experience a CAGR of 34.3% from the base year 2002 through 2008, with the source of the growth being fab generations 5 through 7 (Fig. 3). As a result, Gens 5–7 should grow faster than the total fab capacity because the smaller and older fabs will be phased out. To compensate for the shift, third- and fourth-generation fabs, which were primarily used for larger displays, are expected to be shifted to small- to medium-sized-display production. Despite the accelerated rate of growth of the glass capacity of the larger fabs, small- to medium-sized-display glass capacity is expected to maintain a market share of about 13% throughout the period, indicating a significant shift of existing capacity into small- to medium-sized-display manufacturing (Fig. 4).

Not surprisingly, the forecasted CAGR for small- to medium-sized-display glass capacity is 34.6%, with the majority of the capacity coming from Gen 3 (550 × 650 mm), Gen 3.25 (600 × 720 mm), Gen 3.5 (650 × 830 mm), and Gen 4 (730 × 920 mm). By 2008, it is forecast that these larger substrates will represent almost 92% of the small- to medium-sized-display capacity *vs.* 37% in 2002 (Fig. 5). In addition, all of the a-Si TFD-LCD capacity and the majority of the LTPS LCD capacity will be dedicated to small- and medium-sized displays, but a-Si TFT-LCD technology will remain dominant (Fig. 6).

Suppliers

In 2004, Sharp will have the largest small- to medium-sized-display capacity by more than twice its nearest competitor, TMDisplay (Fig. 7). Third in capacity is AU Optronics Corp., followed by ST-LCD, Hitachi, and Toppoly. Each of these companies produces LTPS LCDs, either completely (ST-LCD and Toppoly) or partially. Over the period, Sharp's market share is expected to drop to less than 15% as suppliers in Taiwan and Korea dedicate more and more capacity to the small- to medium-sized-display market. Japan is expected to maintain a majority of the capacity through 2008, but its share is forecast to drop from 65.9% in 2004 to 54.2% by 2008 (Fig. 8). Taiwan is forecast to grow from 26.2 to 31.7%, and Korea from 8.4 to 12.5%.

By 2008, there could be more than 25 suppliers in this market. The landscape is expected to be so competitive that there will likely be much more capacity than demand. Since Gen 4 and earlier fabs are not competitive for large-area displays, the only choice will be to close the smaller fabs faster than we have forecasted unless new demand develops. The resulting lowering of prices to keep the factories operating should continue the negative effect on the MSTN, TN, and CSTN supply as TV-set makers switch to higher-performing color active-matrix displays by replacing passive-matrix technology, except for the lower-end applications.

A large-area cell process can produce 15 or 20 displays per substrate, but the small- to medium-sized-display process can produce hundreds of displays per substrate and requires a much different module process. In the module process, the array-cell sandwich is connected to various electronic components and optical parts. The assembled components include the driver IC, power PCB, light-shield

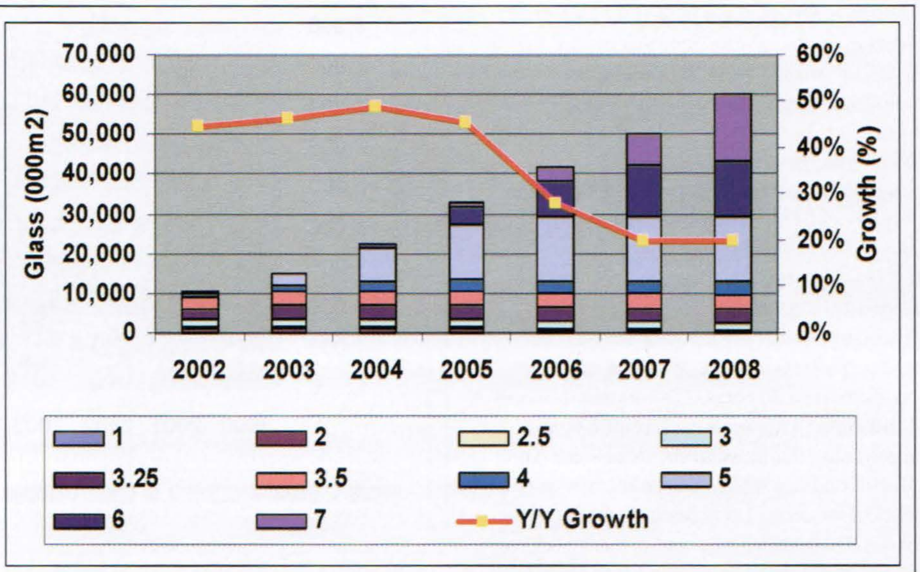
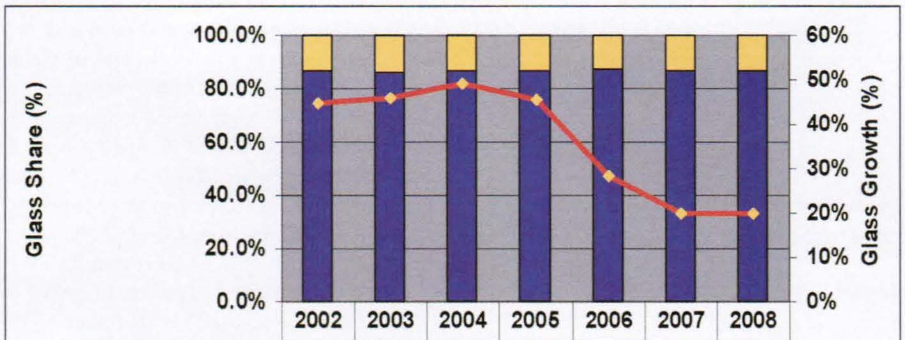


Fig. 3: Growth of active-matrix-display glass-capacity market share by fab generation.



	2002	2003	2004	2005	2006	2007	2008
Small/Medium	13.0%	14.0%	13.6%	13.5%	12.8%	13.2%	13.2%
Large Area	87.0%	86.0%	86.4%	86.5%	87.2%	86.8%	86.8%
Growth (%)	45%	46%	49%	45%	28%	20%	20%

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Fig. 4: Growth of active-matrix-display glass-capacity market share by application.

tape, backlight unit, bezel frame, and numerous connectors and miscellaneous mechanical fixtures. Module assembly is labor-intensive, with many visual-inspection and handling tasks. Since the fixed-asset investment is much less than in the array and cell process, smaller companies can compete in the back-end process.

The module process for small- and medium-sized TFT-LCDs is similar to that of large-area TFT-LCDs because the main steps are the same. It is not simpler or easier to control the assembly quality of small- and medium-sized displays within the tolerance levels even though the components are fewer. A typical process flow for the module process includes driver-IC bonding (generally called outer-leads bonding, or OLB), the surface-mount treatment (SMT), assembly of the power PCB and soldering of the PCB to the panel, backlight assembly, and aging test (Fig. 9).

Bonding Processes

There are distinct differences between the module process in large-area and small- to medium-sized displays. The standard driver-IC bonding in the manufacture of displays larger than 10.4 in. is tape-carrier-package (TCP) bonding, which acts as the bridge to connect the inner-leads bonding (ILB) of the driver-IC bump with the outer-leads bonding (OLB) of the glass cell. The leads are for applying the gray-level and on/off voltages to the display. The tapes are used to permit the connection of numerous leads, which match the resolution of the large-area panels.

Several methods can be used to attach the TCP to the glass, including the use of anisotropic conductive film (ACF), UV sealing, or indium-tin alloy. Because of a special chemical treatment and patent issues, TCP is in limited supply and has a relatively high cost. The ACF-TCP bonding is the most popular driver-IC bonding solution for the production of large TFT-LCDs. But for small sizes, such as mobile-telephone displays (typically 1.8-in. TFT-LCDs with 176 × 220 pixels), fewer leads and smaller die sizes make chip-on-glass (COG) a more cost-effective solution.

COG directly bonds the leads onto the glass without using TCP bonding (Fig. 10). TCP and COG equipment are different, and the COG process is much simpler. COG has both a lower cost and shorter cycle time. Given the lower cost, engineers have tried to apply the COG process to large-area TFT-LCDs, but the COG pads on the glass cell are sensitive and difficult to repair, whereas the TCP-bonding process simply requires that the TCP and bond be replaced.

In addition to TCP and COG bonding, chip-on-film (COF) bonding is also used in LCD mobile telephones. COF bonds the driver IC onto the flexible-printed-circuit (FPC) film that transmits the signals from the LCD processor to the display. It supports fine pitches at costs lower than those of TCP. The trend to integrate the source, gate, and control signals into one chip in mobile-telephone LCD controllers also benefits COF. A comparison of the TCP, COG, and COF bonding process is shown in Table 1.

Other Considerations

Small- and medium-sized LCD-module processes require greater manpower per display

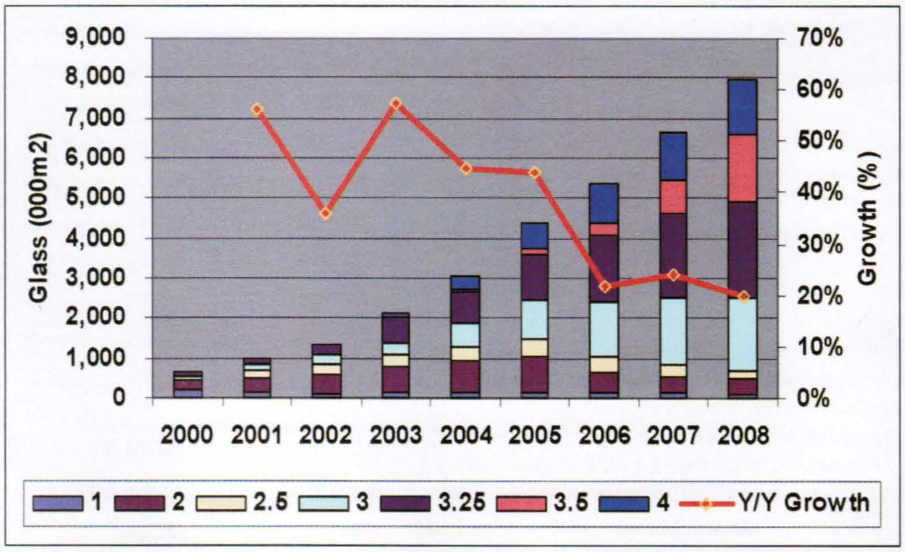

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Fig. 5: Growth of small- to medium-sized active-matrix-display glass-capacity market share by fab generation.

since the number of displays per substrate is so much higher. Furthermore, the automation used in large-area processes – including robots, conveyors, line automation, and process-engineering improvements applied to large-area TFT-LCD module manufacturing – is still rare in the small- to medium-sized-display process because of objective issues and quality concerns. However, in the cell process more automation is required to handle the hundreds of small- to medium-sized displays. While each company is different, a rough comparison indicates that 100 line workers can process 30,000 panels for 4-in. TFT-LCDs in three shifts, but the same number of workers can process 30,000 panels for 15-in. TFT-LCDs in one shift in a single production line. In addition, the manufacture of small- to medium-sized LCD modules involves more outsourcing than for large-area modules. As a result, more panel makers are moving their small- and medium-sized-module fab lines to regions with low labor costs.

Because of the differences in size, the handling of the work in process (WIP) is also different. The most obvious is the way in which WIP moves on the line. A tray is commonly used to produce 10.4–19-in. TFT-LCDs. As the size increases to the 20–30-in. range, automatic conveyors, or tray vehicles, are used because it is risky to manually transport such panels.

For small and medium sizes, the most common method is the partition-embedded tray, in which a single tray with 30 partitions can accommodate 30 1.8-in. mobile-telephone displays. To protect the WIP, the partitions are fixed and cannot be replaced. The number of trays used to process such high quantities of small modules is the most critical management issue in the production cleanroom. The processing of small modules requires many hand processes, such as LED-backlight assembly, polarizer attachment and repair, frame assembly, *etc.*

Touch panels are often used in small- and medium-sized displays for applications such as automotive monitors, PDAs, smart telephones, and e-books. Since the touch panels are mostly ITO inductive, capacitor driven, or electromagnetic inductive, attention to electromagnetic interference (EMI) and electrostatic destroy (ESD) is required during assembly.

The accelerated life testing that normally takes 4–7 hours for a 15- or 17-in. LCD module can be a critical throughput bottleneck. But for small- and medium-sized displays, the aging time is shortened to 1–2 hours because the driving voltage and the associated power are lower. To reduce the cycle time, the aging process can be waived in many cases when the product reliability reaches an acceptable level.

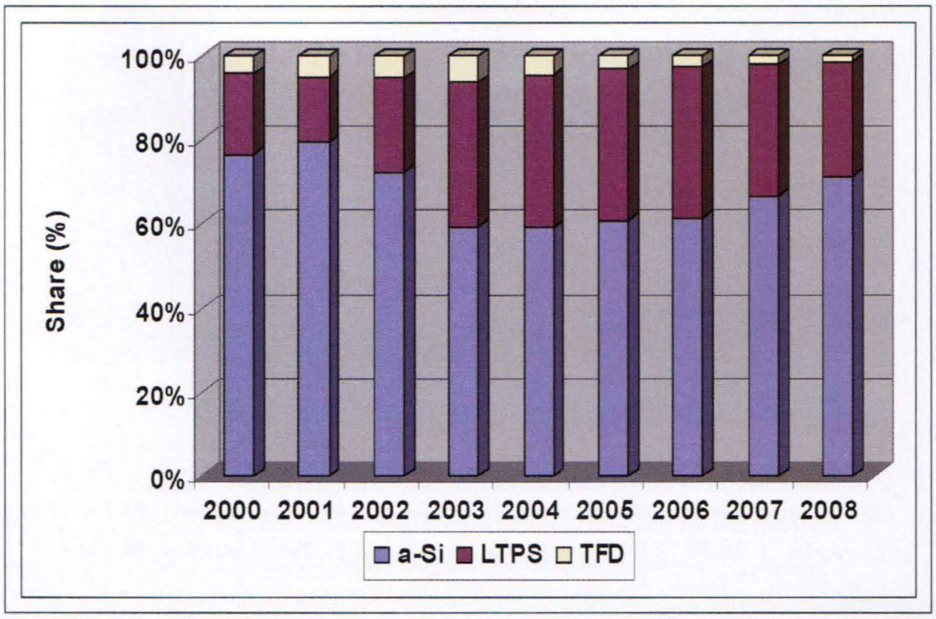

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Fig. 6: Small- to medium-sized active-matrix-display glass-capacity market share by technology.

Summary

Small- to medium-sized displays continue to create new markets and attract additional suppliers at the same time that the average fab is getting larger, with the result that supply is increasing faster than demand. New applications could reduce the impact of the prospective supply glut. Also, the economics of mak-

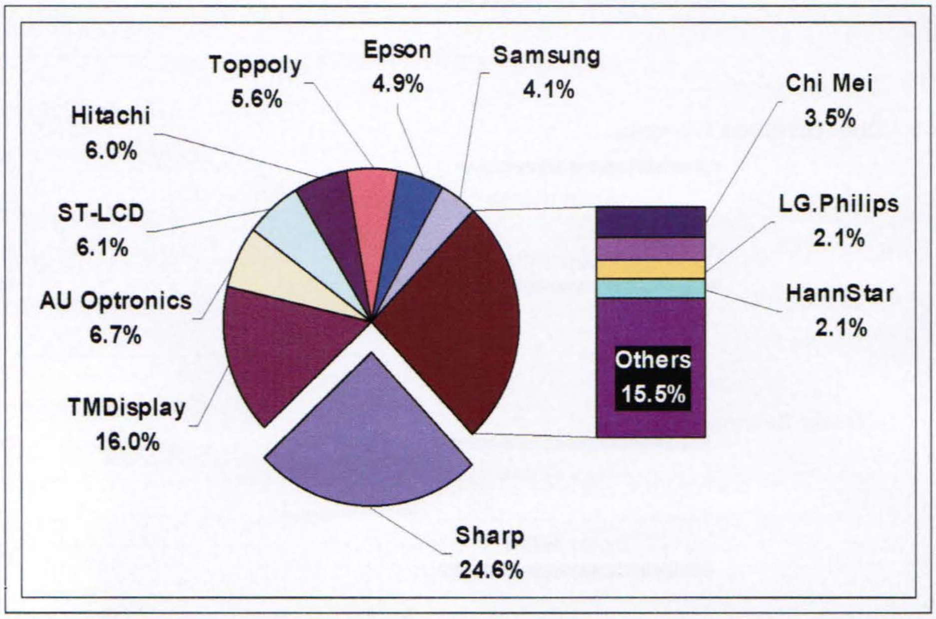

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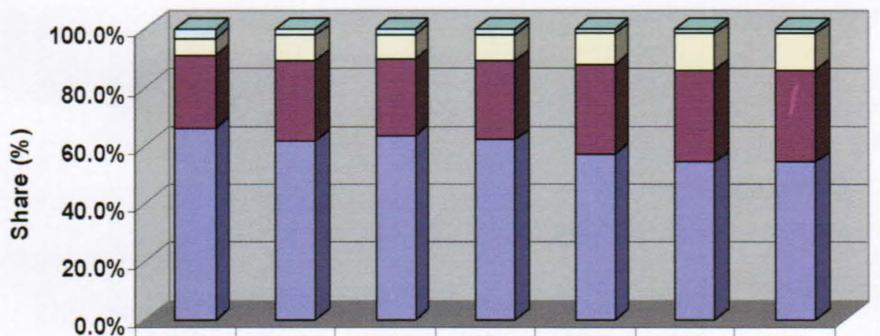
Fig. 7: Small- to medium-sized-display glass-capacity market share by supplier in 2004.



	2002	2003	2004	2005	2006	2007	2008
China	3.2%	2.0%	1.7%	1.9%	1.6%	1.6%	1.6%
Korea	5.7%	8.6%	8.4%	8.8%	10.6%	12.5%	12.5%
Taiwan	25.1%	27.7%	26.2%	27.4%	30.7%	31.7%	31.7%
Japan	65.9%	61.7%	63.6%	62.0%	57.2%	54.2%	54.2%

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Fig. 8: *Small- to medium-sized-display glass-capacity market share by country.*

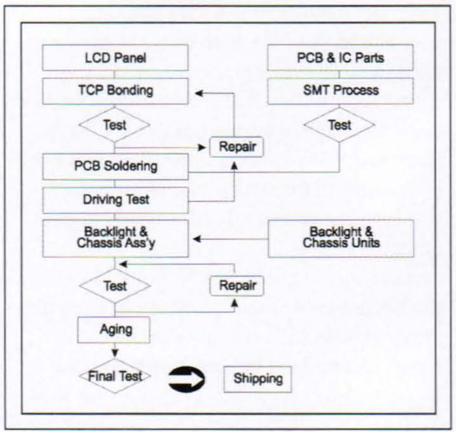

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Fig. 9: *A flow chart of a typical module process.*

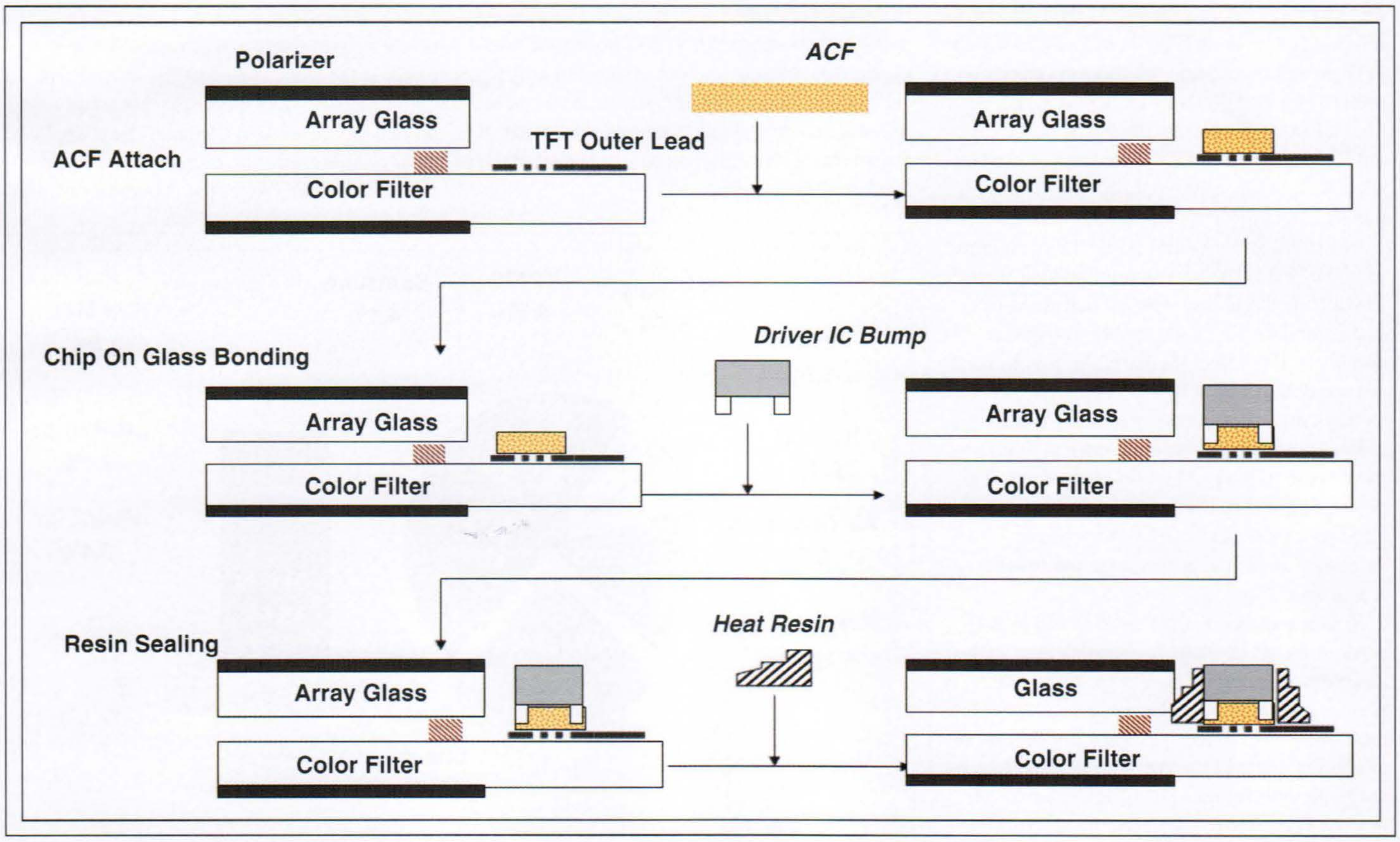

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Fig. 10: *ACF-TCP, COG, and COF bonding processes.*

Table 1: Comparison of TCP, COG, and COF Bonding Processes

	TCP	COG	COF
Full Name	Tape Carrier Package	Chip on Glass	Chip on Film
TFT-LCD Driver-IC Bonding	Large-area TFT-LCDs (10.4–42 in.)	Large-area TFT-LCDs (10.4–15 in.) Small- and medium-sized TFT-LCDs (Most common: 2–6 in.)	Small size (1.1–4.0 in.) Some 12.1 and 14.1 in.
Device Application	Notebook PC, LCD monitor, LCD TV	Notebook PC, LCD monitor, DSC, mobile telephone, PDA, auto TV	Mobile telephone PDA, notebook PC
Bonding Pitch	70–200 μm	60–200 μm	100–200 μm
Advantages	Higher yield Repair compliance	Simpler process Lowest cost	Lower cost Design flexibility in fine pitch
Disadvantages	Higher cost	Yield lower than TCP Repair difficulties	

ing small- to medium-sized displays is different from that of large-area displays because the back end is labor-intensive and is being rapidly exported to regions with low labor costs. The effect is to separate the array-cell process from the module process. It is possible that the learning curve for the back end of the small- to medium-sized-display process could cause the front-end process to migrate to countries with lower labor costs, such as China and India. ■

conference report

Eighth Asian Symposium on Information Display

A combination of international speakers and reports from Chinese display researchers drew 500 attendees to ASID '04 in Nanjing; PDP forces used the event to respond energetically to LCD claims.

by Ken Werner

DISPLAYS were front-page news in China as the Society for Information Display's 8th Asian Symposium on Information Display (ASID '04) opened in Nanjing on February 14, 2004. The February 14/15 issue of the English-language *China Daily* reported that Konka, a leading Chinese TV manufacturer, had dropped the price of its 46-in. PDP TV set by the equivalent of about US$725 to less than US$3625 on the previous Saturday. A Konka spokesman said that the price cuts were made possible by technical improvements and expanding production capacity.

The price cut induced the Suning Appliance Chains, one of China's largest appliance retailers, to reduce the price of all the PDP TVs they sell – not just Konka's – by 20%. An official from Suning's Beijing chains said that PDP-TV sales doubled after the price cut compared to sales of the previous week. One 42-in. set made by XOCECO was selling for less than 24,000 yuan (US$2899).

There were more than 500 attendees at ASID '04, which was held at the Nanjing Hilton Hotel, February 14–17 (Fig. 1). Of the registrants, 161 were from outside mainland China, said Executive Conference Chair Baoping Wang (Southeast University, Nanjing), and this was clearly a source of satisfaction to Prof. Wang. The international components of the conference were important to the organizers in general, which was underscored by the fact that three of the four tutorials given on February 14 were presented by non-Chinese speakers (although two of them held positions at Southeast University) and that five of the six keynote addresses, spread over two mornings, were presented by non-Chinese speakers.

In his room-filling tutorial on color plasma-display-panel (PDP) manufacturing, Harm Tolner (Consultant and Visiting Professor, Southeast University) began what was to turn into a steady counterattack by the PDP forces on many months of claims by LCD manufacturers that large-screen LCDs are superior to PDPs in a variety of ways. Tolner focused on LCD claims that PDPs have shorter lifetimes than LCDs and suffer from burn-in. He said that two manufacturers of color PDPs guarantee a lifetime (time to half-luminance) of 60,000 hours and that in TV applications burn-in is not an issue. In still-image applications, such as some advertising and public-information displays, there can be some burn-in, but a new blue phosphor being developed by Sumitomo should go a long way towards solving the problem, he said.

***Fig. 1:** ASID '04 was held at the Nanjing Hilton Hotel, February 14–17, 2004.*

***Ken Werner** is the editor of* Information Display *magazine.*

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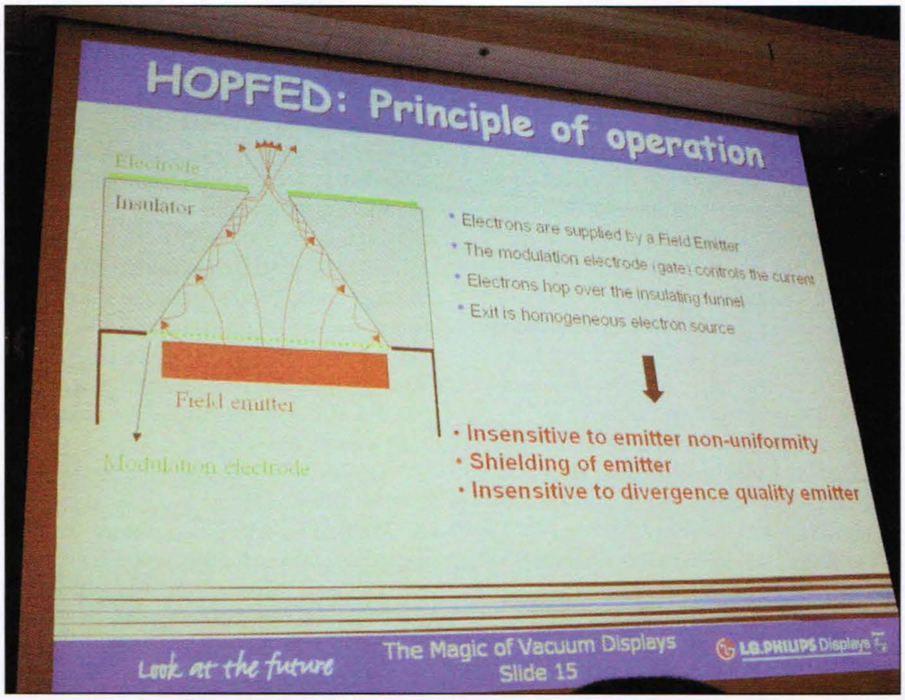

Fig. 2: Daniel den Engelsen (LG.Philips Displays) presented the HOPFED as a breakthrough solution that compensates for FED non-uniformities.

Tolner stated, "Any set price of over $2000 is not a consumer product," which is well-accepted in the consumer-electronics industry. Indeed, he continued, this highlights one of the PDP's strengths because the "PDP has been cheaper than the LCD and will continue to be." Production costs for PDPs are decreasing at an accelerating rate, and Tolner cited a variety of reasons. In the near future, the glass panel should cost $300–400, he said, and the electronics should cost $500–600. Add a bit for plastic and miscellaneous parts and then double the total to determine the retail price.

Business relationships also play a significant part in cost reduction. "Japanese set makers are buying modules from Korea – a watershed event," Tolner said. He added that the merger of NEC and Pioneer is a good thing because it represents consolidation of the industry, and will give the combined operation a market share large enough to compete with Samsung, LG, and FHP.

Vladimir Chigrinov (Hong Kong University of Science & Technology), also speaking to an overfilled room, presented a remarkably comprehensive tutorial on all aspects of liquid-crystal materials and device design, including non-display liquid-crystal devices.

The remaining tutorials were "Recent CRT Technology Trends" (Tsunenari Saito, Tokyo Cathode Laboratory) and "Organic Light-Emitting Displays – A Rising Star in the Display Industry" (Yong Qiu, Tsinghua University). Qiu concluded by observing that OLED-standardization work should be strengthened, that manufacturing yield remains a major problem, and that Asia will be the global OLED production base and the largest market.

Keynote Addresses

In his opening remarks preceding the keynotes on February 15, Program Chair Hsing-Yao Chen (Southeast University and Chunghwa Picture Tubes, Taiwan) noted that 212 papers had been accepted for the conference, 130 of them from domestic (mainland China) authors.

In the first keynote, Tsutae Shinoda (SID Fellow, Fujitsu Laboratories) reviewed the

Fig. 3: Chinese TV giant TCL showed several LCD TVs in the ASID exhibit area and two PDPs in a separate booth.

Ken Werner

development of PDPs and made projections about their future. In Harm Tolner's tutorial given the previous day, Shinoda was described in this way: "Shinoda-san is the father of the modern color PDP, together with Larry Weber." In his keynote, Shinoda said that the rumors circulated by LCD makers that LCDs have lower power consumption and longer lifetime are not true, and showed a slide with data that indicated the power consumption of PDPs is less than that of LCDs of the same size. "PDPs will maintain their market share in the 32–80-in. display area," he said. Shinoda concluded by saying that his next dream is to develop super-large-area displays using arrays of long (perhaps 1 m), thin (perhaps 1 mm) glass tubes containing plasma and phosphor.

In the second keynote, "The Magic of Vacuum Displays: Is the Spell Broken?," Daniel den Engelsen (LG.Philips Displays) predicted that "The end of the product life cycle of CRTs can be expected around 2015." He explained that what he meant by this is that only 10% of current CRT sales would remain in 2015. However, he said, "CRTs still have unequaled picture performance, the lowest cost, and the longest lifetime." The Super Slim CRT developed by LG.Philips Displays could significantly extend the product life cycle of large CRTs, he added.

Den Engelsen also looked at the "other" vacuum display, the field-emission display (FED), and noted that one of the FED's problems is luminance non-uniformity. A Philips development, the HOPFED, uses electron hopping to compensate for FED non-uniformities (Fig. 2). He called the HOPFED a breakthrough for FEDs, and a HOPFED plate is being successfully used by Printable Field Emitters, Ltd. But, he said, Philips has now officially stopped work on the project.

In "Development and Production of Flat-Panel Displays in Korea," Myung Hwan Oh (of Dankook University, Seoul, and formerly National Project Leader for Flat-Panel Displays at KIST) surveyed the past, present, and future of Korean FPD production. He noted that LG Electronics has a total production capacity of 65,000 PDPs per month, Samsung SDI has a capacity of 130,000 PDPs per month, and Orion has a capacity of 5000 PDPs per month.

He also presented the LCD-technology roadmap for Korea, which calls for LCD fabrication to go from 250 process steps to 100, the driving circuits to go from the hybrid circuits used today to single chips, and the cost per diagonal inch to go from today's $25 to $10. All of this is to occur between 2005 and 2007.

Fig. 4: LG.Philips Displays was enthusiastically informing ASID attendees that its cathodes, along with full engineering support, are now available to all CRT manufacturers, and are no longer reserved exclusively for the company's own CRTs.

The final three keynotes were delivered on the following morning. In "Recent Progress in Organic Light-Emitting Diodes," OLED co-inventor Ching Tang (Eastman Kodak Co.) exhibited a gentle, self-deprecating sense of humor. The now-famous paper Tang and co-author Steve Van Slyke published in *Applied Physics Letters* in 1987, he said, "described a simple device, but it had all of the essential OLED features – except long life."

Tang was optimistic about the future of OLEDs. In terms of picture quality, he called OLEDs ideal for television displays. In his summary, he asked himself whether OLEDs would take over from LCDs. His answer was no: OLED is a take-over target for LCD companies. He explained by saying that LCD companies see the OLED as another material to mate with the active-matrix backplanes because they mate so well; in fact, every significant LCD company now has an OLED-development program.

OLEDs are taking market share from LCDs in the portable arena, and the technology is on a "good learning curve" to low-cost manufacturing, Tang said. There are future possibilities for printable and flexible displays, and the technology is an excellent match for them.

David Choi (LG.Philips LCD), in "The Growth of the LCD-TV Market and Future Strategy," observed that the primary LCD-TV growth in 2004 will be in the 20–29-in. segment, with rapid growth in the 30-in.-and-greater segment coinciding with the coming on line of larger-sized substrates. The first Gen 6 fab (1500 × 1850-mm motherglass) will come on line this year. To accelerate the growth of the LCD-TV market, Choi proposed standardizing fab sizes, standardizing TV-panel sizes, and joint technology development by LCD-panel and TV-system makers.

Finally, as far as the keynotes were concerned, Man Wong, Zhiguo Meng, and Hoi S. Kwok (Hong Kong University of Science and Technology) described the creation of polycrystalline silicon (poly-Si) by the low-temperature (less than 500°C) nickel-based metal-induced lateral crystallization (MILC) of amorphous silicon (a-Si). The authors said that MILC is superior to other low-temperature-polysilicon (LTPS) technologies because, unlike excimer-laser crystallization (ELC), it is a low-cost batch process; and MILC provides poly-Si thin films of better quality than other batch processes, such as solid-phase crystallization (SPC). MILC can produce high-performance "systems-on-panel."

The Technical Program

There were a significant number of PDP papers from Chinese universities and research institutes as well as from Chinese electronics giant TCL. TCL showed two PDP-TV and several LCD-TV sets in the exhibit area (Fig. 3). FED papers were presented by research groups at Zhongshan University (novel cold-cathode materials), Southeast University (HOPFEDs), Fuzhou University, and the National Department of Science and Technology (20-in. printable FEDs), among others. But perhaps the largest group of papers from Chinese authors was on OLED research being conducted at Varitronix, Shanghai University, South China University of Technology, Nankai University, Southeast University, Jilin University, Tsinghua University, the Hong Kong University of Science and Technology, and many others. OLED papers were also presented by authors from Samtel (India), the Indian Institute of Technology, Nanyang Technological University (Singapore), and a variety of Japanese, American, and European organizations.

An evening panel session, moderated by the author of this article, explored the topic "Can PDP and LCD TV Follow the Projection-TV Wave in China?" The panelists were Samuel S. Chung (Samsung), Harm Tolner (Southeast University), Daniel den Engelsen (LG.Philips Displays), Shoji Shirai (Hitachi Displays), Ching Tang (Eastman Kodak Co.), and Xiaolin Yan (TCL FPD Research). Yan presented his company's research, which indicates that

- PDPs and LCD TVs are poised for strong growth through 2007 and beyond in China.
- The demand for CRT rear-projection TVs will decline in China starting in 2007.
- CRT rear-projection TVs will gradually be replaced by PDP, LCD, and DLP rear-projection TVs in some homes in urban areas of China.
- CRT TVs will be dominant in China for a long time.

Since CRTs are a very big business in China, it was appropriate that, in addition to showing an impressive array of LCD modules in its large exhibit booth, LG.Philips was also letting attendees know that its cathodes are now available to all CRT manufacturers and are no longer reserved exclusively for the company's own CRTs (Fig. 4).

There was a palpable excitement about the expansion of both display research and display manufacturing in China, and the organizers were clearly happy with the success of their conference. Symposium Chair Linsu Tong (Southeast University) compared ASID '04 with ASID '00, held in Xi'an, as evidence that "interest in display technologies has gone up tremendously" in China. In 2000, 136 technical papers were submitted for the conference; in 2004, the number was 212. Tong offered special thanks to Daniel den Engelsen for his efforts in soliciting high-quality papers, organizing follow-up reviews, and arranging conference sessions.

The Beijing Chapter of SID was the primary organizer of ASID '04, with substantial support provided by Southeast University, the National Science and Technology Ministry of China, and the Nanjing City Government, among others. The time and place for the next ASID has not been determined. When finalized, the information will appear on SID's Conference Calendar at www.sid.org. ■

For Industry News, New Products, Forthcoming Articles, and Continually Updated Conference Calendar, see

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SID 2005 honors and awards nominations

On behalf of the SID Honors and Awards Committee (H&AC), I am appealing for your active participation in the nomination of deserving individuals for the various SID honors and awards. The SID Board of Directors, based on recommendations made by the H&AC, grants all the awards. These awards include four major awards that are awarded to individuals, who are not necessarily members of the SID, based upon their outstanding achievements. The **Karl Ferdinand Braun Prize** is awarded for ***"Outstanding Technical Achievement in Display Technology."*** Scientific and technical achievements that either cover a wide range of display technologies or the fundamental principles of a specific technology are the prime reasons for granting this prize to a nominee. The **Jan Rajchman prize** is granted for ***"Outstanding Scientific and Technical Achievement or Research in the Field of Flat-Panel Displays."*** This prize is specifically dedicated to those individuals who have made major contributions to one of the flat-panel-display technologies or, through their research activities, have advanced the state of understanding of one of those technologies. The **Johann Gutenberg prize** is awarded for ***"Outstanding Technical Achievement in Printing Technology."*** This prize is specifically devoted to those who have excelled in the field of hardcopy printing. The Johann Gutenberg Prize is jointly sponsored by the SID and the Society for Imaging Science and Technology. Each of these above-mentioned prizes carry a $2000 stipend sponsored by Thompson, the Sharp Corporation, and the Hewlett-Packard Company, respectively. The fourth major SID award, the **Lewis and Beatrice Winner Award,** is awarded for ***"Exceptional and Sustained Service to the Society."*** This award is granted exclusively to those who have worked hard over many years to further the goals of the Society.

The **SID Fellow Award** is given each year to a number (up to 0.1% of the membership in that year) of **SID members** in good standing for at least five years at the time of the nomination, who have demonstrated ***"Outstanding Scientific or Technical Engineering Achievements in the Field of Displays over a Sustained Period of Time,"*** and who are recognized as significant technical contributors to knowledge in their area(s) of expertise by SID

SID honors and awards nominations

Nominations are now being solicited from SID members for candidates who qualify for SID Honors and Awards.

- KARL FERDINAND BRAUN PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, display technology.
- JAN RAJCHMAN PRIZE. Awarded for an outstanding *scientific* or *technical* achievement in, or contribution to, research on flat-panel displays.
- JOHANN GUTENBERG PRIZE. Awarded for an outstanding *technical* achievement in, or contribution to, printer technology.
- LEWIS & BEATRICE WINNER AWARD. Awarded to a SID member for exceptional and sustained service to SID.
- FELLOW. Conferred annually upon a SID member of outstanding qualifications and experience as a scientist or engineer in the field of information display, and who has made a widely recognized and significant contribution to the advancement of the display field.
- SPECIAL RECOGNITION AWARDS. Granted to members of the technical, scientific, and business community (not necessarily SID members) for distinguished and valued contributions to the information-display field. These awards may be made for contributions in one or more of the following categories: (a) outstanding technical accomplishments; (b) outstanding contributions to the literature; (c) outstanding service to the Society; (d) outstanding entrepreneurial accomplishments; and (e) outstanding achievements in education.

Nominations for SID Honors and Awards must include the following information, preferably in the order given below. Nomination Templates and Samples are provided at *www.sid.org/awards/nomination.html.*

1. Name, Present Occupation, Business and Home Address, Phone and Fax Numbers, and SID Grade (Member or Fellow) of Nominee.

2. Award being recommended:
   Jan Rajchman Prize
   Karl Ferdinand Braun Prize
   Johann Gutenberg Prize
   Lewis & Beatrice Winner Award
   Fellow*
   Special Recognition Award

*Fellow nominations must be supported and signed by at least five SID members.

3. Proposed Citation. This should not exceed 30 words.

4. Name, Address, Telephone Number, and SID Membership Grade of Nominator.

5. Education and Professional History of Candidate. Include college and/or university degrees, positions and responsibilities of each professional employment.

6. Professional Awards and Other Professional Society Affiliations and Grades of Membership.

7. Specific statement by the nominator concerning the most significant achievement or achievements or outstanding technical leadership which qualifies the candidate for the award. This is the most important consideration for the awards committee, and it should be specific (citing references when necessary) and concise.

8. Supportive material. Cite evidence of technical achievements and creativity, such as patents and publications, or other evidence of success and peer recognition. Cite material that specifically supports the citation and statement in (7) above. (Note: the nominee may be asked by the nominator to supply information for his candidacy where this may be useful to establish or complete the list of qualifications).

9. Endorsements. Fellow nominations must be supported by the endorsements indicated in (2) above. Supportive letters of endorser will strengthen the nominations for any award.

E-mail the complete nomination – including all the above material by **October 8, 2004** – to larryweber@ieee.org or sidawards@sid.org or by ordinary mail to Larry F. Weber, Honors and Awards Chairman, Society for Information Display, 610 South 2nd Street, San Jose, CA 95112 USA members practicing in the field. For this reason, five endorsements from SID members are required to accompany each Fellow Award nomination. Each Fellow nomination is evaluated by the H&AC, based on a weighted set of five criteria. These criteria and their assigned weights are creativity and patents, 30%; technical accomplishments and publications, 30%; technical leadership, 20%; service to SID, 15%; and other accomplishments, 5%. When submitting a Fellow award nomination, please keep these criteria with their weights in mind.

The Special Recognition Award is given annually to a number of individuals (membership in the SID is not required) of the scientific and business community for distinguished and valued contribution in the field of displays. These awards are given for contributions in one or more of the following categories: (a) ***Outstanding Technical Accomplishments,*** (b) ***Outstanding Contributions to the Literature,*** (c) ***Outstanding Service to the Society,*** (d) ***Outstanding Entrepreneurial Accomplishments,*** and (e) ***Outstanding Achievements in Education.*** When evaluating the Special Recognition Award nomination, the H&AC uses a five-level rating scale in each of the above-listed five categories, and these categories have equal weight. Nominators should indicate the category in which a Special Recognition Award nomination should be considered by the H&AC. More than one category may be indicated. The accompanying nomination should, of course, stress accomplishments in the category or categories selected by the nominator.

While individuals nominated for an award may not submit their own nomination, nominators may ask a nominee for information that will be used in his/her nomination. The selection and nomination process is relatively simple, but requires that you and perhaps some of your colleagues devote some time to preparation of the supporting material that the H&AC needs in order to evaluate each nomination for its merit. It is not necessary to submit a complete publication record with a nomination. Just list the titles of the most significant half a dozen or less papers and patents authored by the nominee, and list the total number of papers and patents he/she has authored.

Determination of the winners for SID honors and awards is a highly selective process. Last year less than 30% of the nominations were selected to receive awards. Some of the major prizes are not awarded every year due to the lack of sufficiently qualified nominees or, in some cases, because no nominations were submitted. On the other hand, once a nomination is submitted, it will stay active for three consecutive years, and will be considered three times by the H&AC. The nominator of such a nomination may improve the chances of the nomination by submitting additional material for the second or third year that it is considered, but such changes are not required. If a nomination is not awarded an award over this three-year period, the nominee will not be considered again.

Descriptions of each award and the lists of previous award winners can be found at *www.sid.org/awards/indawards.html.* Nomination forms are available at *www.sid.org/awards/nomination.html* where you will find Nomination Templates in both MS Word (preferred) and Text formats. Please use the links to find the Sample Nominations which are useful for composing your nomination since these are the actual successful nominations for some previous SID awards. Nominations should preferably be submitted by e-mail. However, you can also submit nominations by ordinary mail if necessary.

*Please note that with each **Fellow Award nomination,** only five written endorsements by five SID members is required.* These brief endorsements – *a minimum of 2–3 sentences* to a maximum of one-half page in length – *must state why, in the opinion of the endorser, the nominee deserves to receive the Fellow Award. Identical endorsements by two or more endorsers will be automatically rejected* (no form letters, please). Please send these endorsements to me either by e-mail (preferred) or by hardcopy to the address stated in the accompanying text box. Only the Fellow Award nominations need these endorsements. However, I encourage you to submit at least a few endorsements for all nominations of the other awards since these will frequently add further support to your nomination.

All 2005 award nominations are to be submitted by October 8, 2004. E-mail your nominations directly to larryweber@ieee.org or sidawards@sid.org. If that is not possible, then please send your hardcopy nomination by ordinary mail.

As I state each year: "In our professional lives, there are few greater rewards than recognition by our peers. For an individual in the field of displays, an award or prize from the SID, that represents her or his peers worldwide, is a most significant happy and satisfying experience. In addition, the overall reputation of the society depends on who are the individuals who are in its 'Hall of Fame.'

When you nominate someone for an award or prize, you are bringing happiness to an individual and his or her family and friends, and you are also benefiting the society as a whole."

Thank you for your nomination in advance.

– Larry F. Weber, Chairman
SID Honors & Awards Committee

Joint Russian optics seminar and conference

The Sixth International Applied Optics Congress (OPTICS — XXI CENTURY) and the First International Seminar on Display Optics (DISPLAY OPTICS '04) will take place in St. Petersburg, Russia, October 18–21, 2004.

Scope

The Display Optics seminar will provide a forum for the presentation of research work across the full range of display technologies to a wide international audience. The seminar program will include invited talks, and oral and poster presentations. Concurrently, the Sixth International Applied Optics Congress will continue its series of conferences on optics and its applications, which have been held since 1994, focused on optical engineering, optical materials and technologies, computer technologies, and optical-systems design. The official language of the seminar is English.

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Seminar topics

– Improvements in the optical characteristics of displays (resolution,
– brightness, gray scale, color, pixel number, etc.)

– Optical architecture of displays (front-lighting and backlighting, projection displays, head-mounted displays, retinal displays, etc.)
– 3-D displays
– New materials and components
– Characterization and testing of optical parameters
– Optical methods for the fabrication of displays
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backlight

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In small-screen displays, miniature polysilicon AMLCDs from Sony and Epson were having quite an impact, and the liquid-crystal–on–silicon (LCoS) alternative first arrived with the entry of Kopin Corp. and its novel process of transferring single-crystal-silicon circuitry to glass substrates. Elsewhere in miniature displays, Texas Instruments was touting a unique reflective technology based on rotating mirrors, the Digital Micromirror Device, which some folks thought might have some promise for electronic-projector applications. Also on the polysilicon front, there were reports of low-temperature fabrication processes that might make polysilicon appropriate for larger displays.

Field-emission displays (FEDs) were a very hot topic in 1994, touted as the second coming of the CRT in the form of a low-profile display technology and supported by a high volume of technical papers. The high-profile slate of developers included Micron Display Technology, Microelectronics and Computer Technology Corporation (MCC), PixTech, Texas Instruments, Futaba, Raytheon Corp., Coloray Display Corp., SI Diamond Technology, Inc., FED Corp. (now eMagin, a maker of miniature OLED-on-silicon displays), Silicon Video Corp. (later to become Candescent Technologies), as well as many others.

What a stunning mix of continuities and discontinuities the last decade has seen! So many failures and so many successes, many of them unforeseeable. So many stories of might-have-beens and might-not-have-beens, each a multifaceted drama dependent on many factors, some predictable and some not. I have to admit that after this brief stroll down memory lane, no unmistakable "big picture" comes clearly into focus; and perhaps the only lesson here is that for the long haul in flat-panel displays, almost anything can happen.

So I am looking forward to some surprises emerging in flat-panel displays over the next ten years as today's issues start to resolve themselves. How will AMLCDs and PDPs fare in the TV market? What impact will OLEDs have? Might second-generation FEDs really pan out?

And, one always wonders, is there some dark-horse display technology waiting in the wings to make all these questions the wrong ones? We will see. ■

David Lieberman, *a veteran display journalist living in Massachusetts, can be reached at davidlieberm@earthlink.net.*

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the SEZ is located. Indian labor laws provide for collective bargaining, and specific procedures have to be followed for laying off employees. The Indian Government is making efforts to implement more relaxed labor laws in SEZs. Indian labor laws are very similar to British labor laws, and since there has been no history of serious labor problems in Indian SEZs, we believe that the applicability of these laws should not constrain a decision to locate manufacturing or service operations in India.

Market Share and Economic Outlook

Indian SEZs seem very attractive; yet, out of more than US$62 billion of Indian exports in 2002–2003, exports from Indian SEZs were only a little more than US$2 billion. Why is that? Why are exports from Indian SEZs such a small fraction (3.5%) of the country's total exports? In China, by comparison, SEZs contribute a substantial percentage of the country's exports.

One reason is that, until now, it has not been very easy to do business in Indian SEZs. Indian SEZs have been governed by, and have had to comply with, almost 30 different Indian laws and acts, not all of which are consistent with each other.

Recently, however, the business climate has changed. Recognizing the problems faced by Indian SEZs, the Indian Government has cleared The Special Economic Zones (SEZ) Bill 2003. This bill is to be the enabling and over-riding law for all policies and concessions related to SEZs. Key features of this legislation are that

- It is the main compliance law for SEZs and cannot be changed except by approval of the Indian Cabinet and Parliament. This provides a stable environment for investors.
- It greatly improves upon the current scenario in which different government departments can change concessions through notifications.
- It defines SEZs as foreign territories within India, allowing for relaxed Indian labor laws in the SEZs.
- An SEZ authority will be set up, and it will act as a single node for all clearances.
- Units in SEZs can sell to each other.

Anticipated Rapid Domestic Growth

In the January 8th announcement, the Indian Government has included key measures to stimulate the domestic market for electronic hardware. Customs duties, tariffs, and excise duties have been slashed, unexpectedly and ahead of India's WTO/ITA commitments. We forecast the market for PCs to grow more than 50% in unit terms over the next 12 months. The number of cellular-telephone subscribers in India has also grown rapidly, to over 28 million users in December 2003. Non-urban demand in India is driven by agriculture, and the rains have been good. The Reserve Bank of India, India's central bank, has forecast a GDP growth in excess of 7% for the next year.

Given low Indian labor costs, availability of skilled personnel, and the potential of a rapidly growing Indian domestic market, we believe that operations in Indian SEZs are well worth investigating. ■

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letters

Letter to the Editor

In the recent article, "100 Years of Commercial Liquid-Crystal Materials," *Information Display* **20**, No. 2, 10 (2004), the authors Werner Becker and Hans Juergen-Lemp, in an otherwise quite interesting and complete review, omitted a very significant development in the history of liquid-crystal materials: the discovery of the well-known p-Methoxybenzylidene-p'-n-butylaniline (MBBA) by Kelker and Scheurle in 1969 at Hoechst AG in Germany [see, for example, H. Kelker and B. Scheurle, *Angew. Chem.* **81**, 903 (1969)].

MBBA was the first single-phase room-temperature nematic liquid crystal, and thus became a milestone in the history of liquid-crystal materials. Although it became commercially available, ultimately it was not widely used in displays because of its insufficient electrochemical stability and the general decline of interest in "dynamic scattering," after discovery of the "twisted nematic" effect. However, the very existence of MBBA demonstrated the possibility of room-temperature nematic liquid-crystal displays, thus providing a powerful impetus to further research in the field as demonstrated by the numerous research papers focused on MBBA. The molecular model of MBBA can be found through "Google."

Werner E. Haas
Fellow, SID ■

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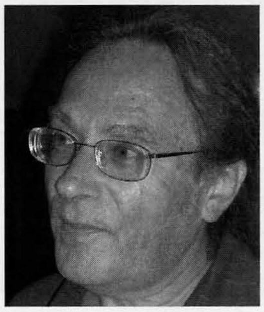

A Stroll Down Memory Lane

by David Lieberman

The flat-panel-display market is such a dynamic one that it is easy to get caught up in the issues of the day and forget about the big picture and the long haul. So travel back ten years with me, if you will, and let's take a look at some of the major phenomena in flat-panel displays in the year 1994 to see what history might have to teach us.

In 1994, PDPs were just starting to move beyond their monochrome roots to multicolor products by Thomson Tubes Electroniques, Fujitsu Ltd., and Photonics Imaging Systems, Inc. Plasmaco (not yet a part of Matsushita), having demonstrated its first multicolor PDP at the SID International Symposium in 1993, was also about to enter the fray. It was in the fall of 1994 that Fujitsu, which had steadfastly maintained its PDP efforts as many others abandoned the technology, dramatically placed production color PDPs on the floor of the New York Stock Exchange.

Active-matrix LCDs were still in their fairly early days in 1994, quite expensive compared to alternatives and only about 10 diagonal inches in size. The year saw major build-ups in manufacturing capacity, along with the beginning of a shift in LCD color capabilities from 3 bits per primary color to 6 bits, expanding color palettes from 512 to 262,000 colors and consequently the application range of these displays. Meanwhile, NEC introduced AMLCDs with analog drivers that enabled "full color" displays.

AMLCDs were primarily a Japanese phenomenon in 1994, with only two Korean companies (Samsung and Goldstar) in the market, along with one of three ill-fated U.S. ventures: OIS Optical Imaging Systems. The other two, Image Quest Technologies, Inc., and Xerox PARC (which would eventually spin off as dpiX), had not quite yet gotten into the game as yet. That year, however, one European company, NV Philips, joined the ranks of AMLCD makers with thin-film-diode displays from its joint venture with Thomson and Sagem: FPD Corp. It was also in 1994 that reports first surfaced on dual-domain AMLCDs, destined to expand the viewing angle possible with the technology and broaden its application range.

Elsewhere in LCDs, passive-matrix displays were making strides in size, picture quality, and color capability as split-screen driving techniques, for example, came on line. Both Motif and Optrex reported that year on multi-line driving techniques that promised better things to come. Meanwhile, Canon was readying its ferroelectric LCDs for introduction, Citizen Watch Company was preparing to bring its antiferroelectric LCDs to market, and Tektronix was touting its PALC (plasma-addressed liquid-crystal) displays.

Nineteen ninety-four was also a significant year for thin-film electroluminescent (TFEL) displays as Planar Systems, Inc., doubled contrast, and both Planar and Sharp Corp. doubled the luminance of their TFEL panels by implementing a split-screen driving technique. That same year, Planar delivered its first multicolor TFEL displays, based on red and green primary colors, while it developed full-color RGB devices.

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calendar

24th International Display Research Conference (Asia Display 2004). Contact: SID HQ, 408/977-1013, fax -1531, e-mail: www.sid.org.
August 24–27, 2004 Daegu, Korea

Advanced Display Technologies Symposium (FLOWERS 2004). Contact: Prof. A. Smirov, +375-17-2398858, fax -2398486, e-mail: smirov@gw.bsuir.unibel.by.
September 7–10, 2004 Minsk, Belarus

EL2004 International Conference and Workshop. Contact: Adrian Kitai, McMaster University, e-mail: el2004@mcmaster.ca.
September 20–23, 2004 Toronto, Canada

48th Annual Human Factors & Ergonomics Society Meeting. Contact: HFES, 310/394-1811, fax -2410, e-mail: info@hfes.org.
September 20–24, 2004 New Orleans, LA

PC Expo/Techxny 2004. Contact: CMP Media LLC, 1-888-234-9476, e-mail: www.techxny.com.
October 3–7, 2004 New York, NY

6th International Applied Optics Congress (OPTICS–XXI CENTURY) and the First International Seminar on Display Optics (DISPLAY OPTICS '04). Contact: V. Arpishkin, e-mail: arpishkin@mail.ru.
October 18–21, 2004 St. Petersburg, Russia

The Americas First Display Engineering and Applications Conference (ADEAC 2004). Contact: Mark Goldfarb, PCM, 212/460-8090 x202, fax -5460, e-mail: mgoldfarb@pcm411.com.
October 25–27, 2004 Ft. Worth, TX

12th Color Imaging Conference 2004. Contact: IS&T, 703/642-9090, fax-9094, e-mail: info@imaging.org.
November 9–12, 2004 Scotsdale, AZ ■

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