Kopin Corporation

Miniature LCDs Enhance High-Definition Displays

In 1994, the computer industry was developing high-speed, advanced processors and high-capacity data storage. Display technology lagged behind; consumers wanted larger, faster, flicker-free video images and complex graphics (e.g., computer-aided design applications) on lighter weight, lower cost, energy-efficient displays. Kopin and Philips formed a joint venture and requested cost-shared funding from the Advanced Technology Program (ATP) to achieve numerous pre-commercial technical advances in liquid crystal display (LCD) color high-definition televisions (HDTVs). This project would have required additional years to accomplish without this joint venture collaboration and external funding. High-definition display technology was changing rapidly, and, at the time, the market was dominated 100 percent by foreign manufacturers.

ATP awarded funding from 1995 through 1998 to Kopin and Philips, who together with their subcontractor, Massachusetts Institute of Technology, planned to develop and integrate the optical and color system (e.g., lenses, mirrors, or light guides), digital signals, and LCDs into a single, integrated package. By 2003, Philips had successfully commercialized high-resolution projection HDTVs that used the ATP-funded technology.

Kopin applied the ATP-funded enabling technology in numerous applications to include miniaturized display applications for use in viewfinders for camcorders and digital cameras, wearable computers, virtual reality games, and military applications. LCD projection display technology is a key product differentiator in U.S. electronics manufacturing.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
* * * *

Research and data for Status Report 94-01-0304 were collected during June - September 2003.

Early Tests of Facilitated Transport Identify Problems

In 1994, the technology used to generate images for computer monitors, TVs, and projection televisions was the cathode-ray tube (CRT), a sophisticated glass vacuum tube with one to three tubes and accompanying lenses and/or a built-in filter wheel. CRT screens produce crisp, vibrant images, but they have serious drawbacks: they are heavy, bulky, and inherently analog rather than digital (consider the quality of a phonograph player, which is analog, compared to a compact disc player, which is digital). In order to increase the screen width and height, manufacturers had to increase the length of the tube (to give the scanning electron gun room to reach all parts of the screen). Scaling up this tube to create larger displays revealed its weaknesses: it loses high definition over large areas, becomes curved (which distorts the image), requires a glass plate up to an inch thick, and can produce distracting line and speckle patterns.

The basic process for a CRT television or computer monitor to display images involves lighting up thousands of tiny pixels with a high-energy beam of electrons based on the information in a video signal. In most systems, three pixel colors (red, green, and blue) are evenly distributed on the screen. By combining these colors in different proportions, the screen can produce millions of colors.

Kopin Corporation and Philips Electronics North America believed they could produce large, quality color images by projecting miniature high-definition liquid crystal displays (LCDs) onto a large screen (as in a slide projector). Small, direct-view monochrome LCDs were already being used in watches, calculators, and laptop computers, providing the lightweight and compact size (especially depth) that enabled these items to be portable. Liquid crystals are able to maintain their orientation, like a solid, yet they can move in response to heat and electric current, like a liquid. Predictable responses to electric current control light and create images. Existing LCDs were still slow, with a limited ability to present shades of gray. They were limited in size as well. Moreover, manufacturing the LCDs required a large up-front capital investment, because it is difficult to produce large flawless LCD panels. Producing large LCD direct-view displays was considered unsuitable for monitors or high-definition televisions (HDTVs) due to a high defect rate in manufacturing.

CRT screens have serious drawbacks: they are heavy, bulky, and inherently analog rather than digital.

At the time, all LCDs for laptop displays were manufactured outside the United States. If Kopin and Philips' proposed project could make the necessary advances in speed, grayscale resolution, and optics/color, LCD projection technology could provide an entrée for U.S. manufacturers to compete in the global high-definition market.

Kopin and Philips Propose to Collaborate

Kopin Corporation is a small, innovative U.S. company of scientists and engineers that focuses on developing personal, portable communication products. Philips Electronics North America is part of a leading global electronics firm that focuses on consumer electronics, with a strong research and development program in New York. The subcontractor, Massachusetts Institute of Technology (MIT), was brought into the project because they specialize in designing digital signal-processing methods (translating electronic signals into images). However, after the first year of the project, MIT dropped out and Philips took over MIT's task.

The joint venture applied and was awarded ATP funding support in 1994 in order to pursue an aggressive technology development path. ATP awarded three years of funding to advance LCD projection display technology and to build a U.S. infrastructure to manufacture the technology. This infrastructure would support high-definition projection displays for future HDTV and computer applications. The technology required integrating the optical and color system (such as lenses, mirrors, and light guides), digital signals, and LCDs. The team needed the ATP award in order to support collaboration between Philips and Kopin; to speed up the development; and to break into a newly expanding global market.

To accomplish the joint venture's goals, fundamental advances were needed in high-resolution LCD grayscale images, speed, optical/color filter systems, light manipulation, screens, electronics, and digital signal processing. The team needed to produce shades of gray first, in order to display image detail and richness. Kopin was producing Smart Slide, an LCD technology for small projection systems that projected like a photographic slide (at 640 x 480 pixels). Philips had developed color high-definition display systems with three panels, one for each color. Philips hoped to integrate systems and produce color projection HDTVs and computer monitors at a lower cost. The joint venture's goal was to combine Kopin's image quality with Philips' optics and color technologies.

Joint Venture Defines Specific Tasks to Meet Challenging Objectives

If Kopin and Philips' technologies could be combined successfully, the proposed projection displays would save production expenses:

- HDTV components could be manufactured on existing production lines.
- Reducing pixel size would reduce cost. If the size of each pixel could be reduced, the manufacturer could either provide more pixels in a given space, providing more detail, or else reduce the size of the image with the same image quality and lower cost.
- Production of small components would cost less than large, direct-view LCDs, which could not be produced in large sizes at the time, due to a high defect rate.

The team set challenging system requirements: over a million pixels (high resolution); full color; bright, sharp, and pleasing images; and a fast display that was capable of video speeds. The team's five specific tasks were the following:

1. Kopin would improve LCD speed (from 30 milliseconds (ms) to 2 ms). The basis of the technology was a cost-effective glass panel on which an overlying layer of liquid crystal is rapidly controlled with an underlying thin film of silicon-based circuitry.

2. Philips would integrate electronics into the display (projecting images using standard digital video formats).

3. Philips would design and develop the optical and color system, minimize light loss, and generate full color by filtering three colors on a single panel.

4. Philips would design external electronics for a test bed monitor and HDTV.

5. Philips would construct a prototype system and would evaluate image quality.

The entire system needed to be designed so that manufacturing costs would be low enough to open the technology to the large consumer markets expected in projection display for monitors, multimedia applications, and HDTV. The team anticipated that Philips or a third-party label would produce the displays that could interface with computer software, HDTV signals, or other image sources. Anticipated spillover products included home entertainment systems, business presentation graphics, printing, and graphic arts.

Projection Technology Makes Great Strides

By the end of the ATP-funded project in 1998, the joint venture had successfully developed and demonstrated the key components to support high-definition color projection display products. Kopin and Philips accomplished 95 percent of their five technical goals:

1. Kopin reached target LCD image refresh speeds of 2 ms (improved by a factor of 15). The company developed an active matrix liquid crystal display (AMLCD) and some electronics with a resolution of 1280 x 1024 pixels. Kopin developed proprietary methods to redesign circuits so that the foundry could manufacture AMLCD displays with fewer defects, thus increasing the yield and lowering production costs.

2. Philips integrated electronics into the display and achieved high-speed image transfer (1.8 gigabits per second). They developed and demonstrated high-speed image microprocessors using TM-1000 chips. Faster TM-2 chips were being developed, but were not expected to be available until 1999, after project conclusion. These new chips would accommodate parallel operation of all image enhancement and correction programs simultaneously. Philips intended to perform additional research using the faster TM-2 chips after the completion of the ATP-funded project.

3. Philips designed and developed the optical and color system (see illustration, below). Steps included controlling and processing light passing through the liquid crystal; developing the lenses; and demonstrating real-time correction of color, contrast, and resolution. The system scans sequential stripes of red, green, and blue light down the display panel. Simultaneous color data loading into the pixel array run ahead of the respective scanning color stripes. These parallel operations maximize the time that each color is displayed and increase brightness.

Magnified view of Philips' color optics. Mirrors separate and recombine the red, green, and blue colors.

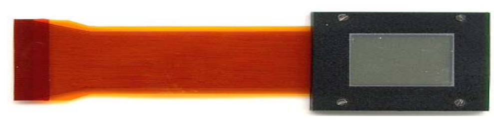
4. Philips designed the display drive electronics to take television-format video signals and display a picture, while controlling the picture's brightness and color saturation. The electronics module receives digital video signals and scales the image to match the display resolution (size).

5. The final color display demonstration was not performed at project conclusion, because the LCD technology was still too slow for commercial use. Philips demonstrated a prototype system to evaluate image quality. The company completed an operational TM-1000-based system in a personal computer (PC). Philips constructed 12 screen samples, which compared well with the design goals. The proof-of-concept implementation verified the algorithms and evaluated image quality (formatting, brightness, color, and contrast were demonstrated individually). While the demonstration system approached, but did not achieve, the resolution and speckle goals, the system did validate the viability of the technology.

Philips and Kopin's key accomplishments during the ATP-funded project included the following: achieving a 1280 x 1024 pixel display operating at 180 Hertz frame rate; correcting color in real-time; and demonstrating high color brightness. Philips received two patents for this technology. Philips and Kopin shared their advances with industry through publications and presentations. While these accomplishments encouraged the two companies to continue with additional investment and research into the technology, later changes in the industry led the companies to redirect their efforts. The computer monitor market changed as direct-view LCD manufacturing yield improved, as flat panels were being produced with fewer defects. This eliminated the need for projection technology in high-definition computer monitors. Therefore, Philips focused on HDTV only; Kopin applied its technology to other miniature near-to-eye displays (e.g., cell phones, viewfinders for camcorders, and eyewear viewers that allow wearers to view the display screen with one eye). Thus, the ATP-funded technology was successfully applied to other markets.

Kopin Moves toward Miniature Display Development

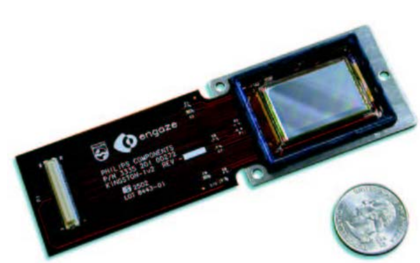
Kopin moved away from projection HDTV development, because the company could not reduce the manufacturing cost of LCD screens for large projections. Instead, it focused on miniature displays and commercialized its first CyberDisplay product in 1997 (see illustration below). This product includes a color sequential display, based on the technology developed during this ATP-funded project, that uses a 0.25-inch diagonal AMLCD. At the conclusion of the internally funded research, Philips developed its own project in October 1998, Kopin was marketing 10,000 AMLCD displays per month to U.S. original equipment manufacturers (OEMs) for miniature near-to-eye viewing (e.g., eyeglass attachments for medical and research applications) and military applications (e.g., helmet-mounted displays for pilots).



Example of a Kopin CyberDisplay LCD, with 0.25-inch diameter, used for a microdisplay.

Philips Continues HDTV Display Development after Project Concludes

After the conclusion of the ATP-funded project, Philips realized that Kopin's LCD technology was still too slow to meet commercial needs for HDTV. Continuing with faster miniature internal reflective display system (less than 0.2 ms image refresh speed) that relied on liquid crystal on silicon (LCoS), which would replace LCD for this product by 2000. LCoS devices have the crystals coated over the surface of a silicon chip. Electronic circuits are etched into the chip, which is coated with a reflective surface. LCoS devices are even smaller than LCDs, are easier to manufacture, and have a higher resolution (see illustration below). Philips had completed a full high-definition demonstration of the front-end electronics using the TM-2 chip by the end of 1999. Using the faster TM-2 chip showed full high-definition processing functionality in real time. Philips published several articles about its research and continued to pursue projection displays for HDTV.



Example of a Philips LCoS device used for a microdisplay.

High-Definition Technology Booms

Both Philips and Kopin were successful in marketing technology developed during this ATP-funded project.

In 1996, projection display was one of the fastest growing areas of the display industry, with sales increasing at 25 percent per year. Sales were driven by home-theater applications, which also included CRT projectors, light-amplifier systems for large audiences and theaters, electronic overhead projectors, and helmet-mounted systems for personal viewing. Demand for institutional applications for presentations and data projectors was growing by 15 percent per year.

The joint venture had successfully developed and demonstrated the key components to support high-definition color projection display products.

After conducting a business analysis in 2000, Philips decided to commercialize its projection HDTV, which it had initiated during this ATP project. Philips demonstrated its first commercial prototypes in January 2003 and began to market them in August 2003. Illustrated below, this 44-inch LCoS-based projection HDTV system later won the Consumer Electronics Show's "Best Innovation" award.

Philips' prototype 44-inch LCoS-based projection HDTV system, demonstrated in January 2003, won Consumer Electronics Show's "Best Innovation" award.

Philips' model has a short depth and a low weight, when compared with CRT technology. Because of its small components, Philips' projection HDTVs can be manufactured at 50 to 70 percent lower cost than direct-view displays (plasma and LCD), with higher quality images than CRTs. For example, in 2003, Philips' projection HDTVs ranged in price from $1,700 for a 43-inch screen to $2,700 for a top-end 60-inch screen. In comparison, a CRT analog TV up to 36 inches, with 1024 x 768 resolution, sold for $2,100, and super-thin 42-inch plasma HDTVs cost from $3,000 to $11,500.

Philips plans to offer more models of LCoS-based projection short-depth, low-weight HDTVs. The company believes it will continue to gain a price advantage over time, as sales grow and LCoS manufacturing costs drop.

Kopin also achieved success with the project-related technology. By September 2003, Kopin was selling more than 400,000 AMLCD units per month, up from 10,000 per month in 1998. Company employment had increased from 80 employees at the beginning of the project to 379 in 2003.

Kopin currently markets several near-eye display products, called CyberDisplay (see illustration below). Products include monochrome and color options with varying resolutions. The CyberDisplay is 1,000 times smaller and consumes 100 times less power than a conventional PC monitor. Kopin sells these displays to a variety of OEMs for applications including viewfinders for digital cameras and camcorders, miniaturized view screens for cellular telephones, personal digital assistants, computerized writing instruments, virtual reality games, belt-wearable computers, and eyewear viewers (the viewer is attached to eyeglasses or a helmet and allows wearers to view the CyberDisplay screen with one eye), as well as low-volume, specialty military products. Demand for these products is driven by consumers' desire for smaller, less expensive, more compact electronic devices, which display ever-increasing amounts of data and visual information.

Examples of OEM products that use the Kopin CyberDisplay. From left: IBM BodyWorn ThinkPad, JVC Camcorder, Oriscape Personal DVD Viewer, and Navitrak Hand-Held GPS.

Also in 2003, Kopin was developing a rear-screen dashboard projector for automobiles, which builds on the ATP-funded technology. This dashboard will include instruments and programmable formats and colors. Prototypes of the dashboard have been used since 2002 in Formula 1 race cars. However, because the dashboard is subjected to engine heat and high environmental temperatures, Kopin must develop methods to permit higher temperature tolerances for the display.

Regulations Stimulate Demand for HDTV

The Federal Communications Commission (FCC) is responsible for regulating and enforcing communications standards; therefore, they are interested in standardizing HDTV broadcasting. In April 1997, the FCC adopted rules for digital television broadcasting. The agency has been trying to accelerate the slow rollout to HDTV. In 2002, Congress set a target date for completing the transition to HDTV signals by December 31, 2006. These requirements encourage more broadcasters to offer HDTV, which stimulates consumer demand. As of May 2003, more than 1,000 U.S. stations were on the air with HDTV signals, including at least one in every major market. (Analog TVs will still receive a signal; however, they will not be able to pick up the HDTV signal.) Philips expects to increase sales of its ATP-funded projection HDTVs as a result of increased consumer demand.

U.S. Manufacturing Gains Entry into Display Market

Philips provided an entry for U.S. manufacturing into a market that was previously dominated 100 percent by foreign manufacturers. Philips manufactures key components and assembles the HDTV units in the United States. Kopin designs and manufactures its miniature displays in the United States and is the largest exporter of displays to Japan.

The ATP-funded technology was successfully applied to other markets.

By early 2003, more than 5 million U.S. consumers owned HDTV sets (less than 5 percent of U.S. homes). It is estimated that the market for projection HDTV will reach $6 to $10 billion by 2005. Worldwide shipments of electronic display materials were estimated at $8.5 billion in 2000 and $66 billion in 2002, with sales projected to continue to grow by 12 percent per year and to reach $115 billion by 2007. In addition to HDTVs, LCD projection technology advances from this ATP-funded project have contributed to improved resolution, speed, and color, as well as reduced prices in cellular phones, camcorders, and digital cameras.

Conclusion

This pioneering technology facilitated a paradigm shift in high-definition display technology. From 1995 to 1998, Kopin and Philips combined existing monochrome liquid crystal displays (LCDs), which were used in watches and radios, with color, signal processing, and high-definition technology. During the project, the team accomplished 95 percent of its technical goals, received two patents, and shared knowledge with the industry through presentations and publications. The team members independently continued their development efforts after the conclusion of the project and achieved all of the project goals. Philips successfully developed and commercialized a liquid-crystal-on-silicon-based high-definition projection technology for high-definition televisions (HDTVs), providing prototypes by January 2003 and retail products by August 2003. Screens are now lighter, with improved color and speed, and consume less power. Projection HDTVs have lowered the entry price for consumers into the HDTV market. They are priced 50 to 70 percent less than comparable-sized plasma HDTVs, which is stimulating sales. The market for projection HDTVs is anticipated to expand to $6 to $10 billion by 2005, growing at approximately 11 percent per year. Philips expects to benefit from this sales increase.

After the conclusion of the ATP-funded project, Kopin further developed LCD technology and provided the foundation for enhanced miniature color screens for multiple uses. Original equipment manufacturers use the screens in cellular phones, personal digital assistants, camcorder and still digital camera viewfinders, virtual reality games, wearable computers, and military applications. Kopin’s monthly sales increased from 10,000 active matrix liquid crystal displays in October 1998 to more than 400,000 units in September 2003. The outlook for additional new applications as well as growth in sales is excellent.

PROJECT HIGHLIGHTS
Kopin Corporation

Project Title: Miniature LCDs Enhance High-Definition Displays (High-Information Content Display Technology)

Project: To develop next-generation liquid-crystal projection display technology capable of producing the high-quality, high-resolution images needed for monitors, multimedia applications, and high-definition TV.

Duration: 4/15/1995–6/14/1998
ATP Number: 94-01-0304

Funding (in thousands):

ATP Final Cost	$6,097	49%
Participant Final Cost	6,407	51%
Total	$12,504	

Accomplishments: Kopin and Philips accomplished 95 percent of their technical goals:

- Developed and demonstrated high-speed image microprocessors using TM-1000 chips
- Designed and developed the optical and color system
- Designed the display drive electronics to take television-format video signals and display a picture
- Demonstrated a prototype system to evaluate image quality

Philips continued research and ultimately developed and successfully commercialized high-definition projection televisions (HDTVs) in 2003, which relied on liquid-crystal-on-silicon (LCoS) displays. Philips manufactures components and assembles the HDTV units in the United States.

ATP support allowed Kopin to develop a knowledge base that later made its CyberDisplay product series possible; CyberDisplay's color sequential display is based on this technology. Kopin produces U.S.-made liquid crystal displays (LCDs) for miniaturized color screens used in cellular phones, personal digital assistants, camcorder and still digital camera viewfinders, virtual reality games, wearable computers, and military applications. Kopin was selling more than 400,000 units per month by September 2003 and was the largest exporter of displays to Japan.

In addition, Philips and Kopin received patents and awards, and they disseminated knowledge through presentations and publications.

Philips filed and was awarded the following two patents resulting from this project:

- "Rear projection screen with reduced speckle" (No. 6,147,801: filed August 18, 1997, granted November 14, 2000)
- "Dichroic filters with low nm per degree sensitivity" (No. 5,999,321: filed June 19, 1998, granted December 7, 1999)

The Philips projection HDTV won an award for innovation:

- "Best Innovation for Consumer Electronics Show 2003" for the 44-inch LCoS HDTV

The ATP-funded project contributed to the knowledge base that made development of Kopin's CyberDisplay product series possible in an accelerated timeframe. Kopin's CyberDisplay won the following awards for innovation:

- "Product of the Year," for expanding functionality of portable devices including PDAs, cell phones, and pagers, 1998, Electronic Products magazine
- "25 Technologies of the Year," 1998, IndustryWeek magazine
- "25 Most Technically Innovative Products," 1999, for the CyberDisplay 320C, Photonics Spectra magazine

Commercialization Status: Philips successfully brought the short-depth, low-weight projection HDTVs to market in August 2003. The award-winning LCoS picture provides "the next level…[of] unsurpassed natural colors and picture sharpness," according to the Consumer Electronics Show 2003. Philips was able to price the models 50 to 70 percent lower than comparable-sized plasma HDTVs and anticipates that production costs will become even more cost competitive as LCoS production increases. Sales are expected to be brisk.

Kopin's projection display products are being marketed for many applications. Kopin products include the CyberDisplay 320 Monochrome, CyberDisplay 320 Color, CyberDisplay 640 Color, CyberDisplay 1280 Monochrome, and custom displays. These are used by original equipment manufacturers for many applications, including camcorder viewfinders, digital still camera viewfinders, hand-held global positioning system devices, wireless cellular telephones, personal digital assistants and pagers, personal computers, wearable computers, and military applications. Near-to-eye head-mounted displays (attached to eye glasses or a helmet) connect with any device that provides video output (e.g., digital camera, camcorder, portable TV, or laptop).

Outlook: The outlook for this technology is excellent. Worldwide sales of electronic display products were estimated at $66 billion in 2002. Shipments were projected to continue to grow by 12 percent per year to reach $115 billion by 2007. The market for projection HDTVs is anticipated to reach $6 to $10 billion in 2005. In addition, sales of miniature near-to-eye applications (e.g., viewfinders for camcorders and digital cameras, wearable computers, and military applications) are growing.

Composite Performance Score: * * * *

Number of Employees: 80 at project start, 379 as of September 2003

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Publications and Presentations:

Philips and Kopin's presentations and publications include the following:

- Stanton, D. A., J. A. Shimizu, and J. E. Dean. "Three-Lamp Single-Device Projector." Proceedings of SID 1996, San Diego, CA, pp. 839-42, May 12-17, 1996.
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