Norman L. Johnson

Born in Sioux Falls, South Dakota, Norm Johnson received his BSEE and MSEE degrees from the South Dakota School of Mines and Technology in 1966 and 1967 respectively. His PhD degree in electrical engineering is from Oregon State University (1974). With HP since 1977, he worked on several of the HP-41C CMOS integrated circuits, including the CPU and display driver. Before coming to HP he was a process development engineer working on MNOS, N-channel SOS, and N-channel silicon gate integrated circuits. Married with two sons and living in Corvallis, Norm and his family enjoy outdoor activities and camping in the beautiful Oregon countryside. He also does woodworking.

CORRECTION

Sharp eyed readers may have noticed in last month's issue that the drawing of the 8450A optical system (Fig. 1, page 17) contained some linework errors that escaped even the authors' proofreading. The reference and sample beams actually reflect off all three of their respective cube corner mirrors instead of passing through the third one as shown. And the return beam from the reference cube corner mirrors actually goes under the fence window, not through it as shown.

Vijay V. Marathe

A native of Hyderabad, India, Vijay Marathe received his B.Tech degree in electrical engineering from the Indian Institute of Technology, Bombay, in 1964. He earned his MSEE degree from the University of California at Berkeley in 1966, and the following year came to HP. Since then he has worked in nearly all of HP's IC operations, including those at Santa Clara, Cupertino, the Desktop Computer Division and the integrated circuit laboratory of HP Laboratories. He was responsible for setting up the CMOS operation at the Corvallis Division and is now working in the components operation there. Vijay also holds an MBA degree, received in 1976 from Santa Clara University, and a DEE degree from the same university (1973). He is named inventor on two patents related to the HP-01 Calculator/Watch project. A member of the American Management Association and a first generation emigrant to the United States, Vijay has spent the past few years researching the various religions of the world, a subject he finds fascinating. He's an avid tennis and ping pong player and has been a stamp collector for 25 years. He and his wife and two children make their home in Corvallis, Oregon.

The First HP Liquid Crystal Display

by Craig Maze

LIQUID CRYSTAL DISPLAYS are used in calculators largely because of their inherent low power dissipation and low voltage requirements. Other factors contributing to their expanding use in calculators and portable instruments are the ease with which different character sizes and shapes can be produced inexpensively and LCDs' good visibility under conditions of high ambient lighting.

The display used in the HP-41C is a multiplexed, twisted nematic LCD with a twelve-character alphanumeric capacity. It operates from 0 to 45°C with electrical compensation of the drive voltage to correct for LC property variations with temperature.

LCDs are optically passive in that they do not generate light to produce contrast. Operation of the device depends on the ability of the LC to rotate plane polarized light relative to a pair of crossed polarizers attached to the outside of the display. Rotation of the plane of polarization is a function of the applied field and decreases with increasing field or voltage. The following brief discussion of LC properties and display construction will serve to explain how a twisted nematic LCD works.

Nematic Liquid Crystal

Nematic liquid crystals are ordered fluids whose molecules lie parallel to each other with their centers of mass randomly distributed. They are organic compounds and their molecules are rod-like in overall shape. The word "nematic" comes from the Greek "nema", meaning "thread-like." A thread-like pattern is observed when nematics are viewed through a microscope under polarized light. The difference between nematic and ordinary fluids

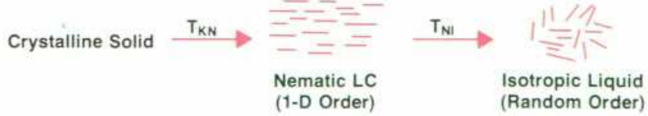


Fig. 1. *Nematic liquid crystals are ordered fluids whose molecules lie parallel to each other. "Nematic" means "thread-like."*

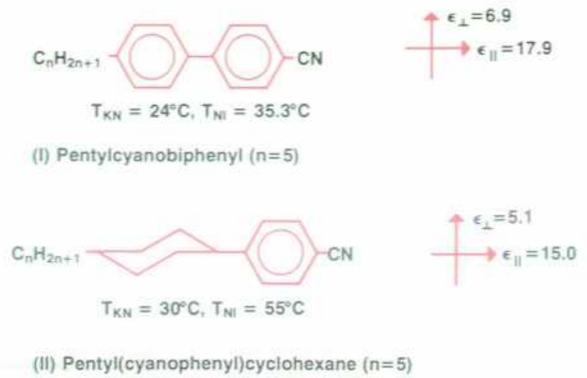


Fig. 2. *Structures and properties of two commercially available nematic liquid crystal materials. The HP-41C display uses four compounds similar to type I.*

is illustrated in Fig. 1.

Nematic liquid crystals are formed by melting otherwise ordinary crystalline solids. Unlike most solids, which transform into isotropic liquids upon melting, a nematic liquid crystal passes into an ordered phase at temperature T_{KN}. Additional heating, to T_{NI}, the clearing temperature, will cause the nematic to undergo another phase transformation where molecular order becomes random. To an observer, the solid will transform into a milky, light-scattering fluid at T_{KN} and then become clear at T_{NI}. Cooling reverses the sequence of transformations.

Nematic liquid crystals have one-dimensional, long-range order, are uniaxial crystals, behave like liquids, and possess elastic properties. Two examples of commercially available liquid crystals along with transition temperatures and dielectric properties are shown in Fig. 2.

The HP-41C uses a mixture of four liquid crystals similar to type I of Fig. 2. Multicomponent mixtures are necessary because no single compound has an appropriate nematic temperature range for use in products. In the case of the HP-41C, the nematic range is −10 to 60°C. Specified display operating temperature limits are always well within the nematic range. The ability of a display to perform at low temperature is usually limited by increasing viscosity and attendant slower on-off response, and not by freezing of the liquid. The upper bound results from highly nonlinear variations in LC properties with temperature, making compensation in the drive circuitry too complex.

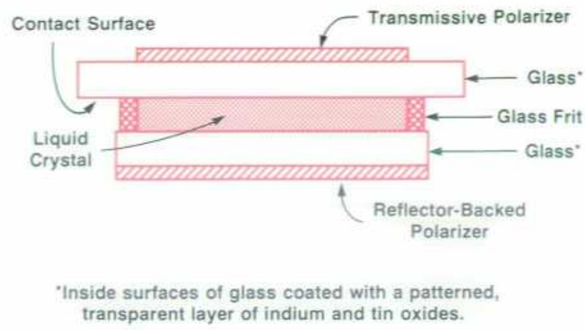


Fig. 3. *Construction of the HP-41C liquid crystal display.*

To facilitate further discussion it is convenient to define a unit vector, called the director, which is parallel to the long molecular axis. LC structure and molecular orientation in a liquid crystal display can be discussed in terms of director orientation.

Dielectric anisotropy ($\epsilon_\parallel - \epsilon_\perp$) is positive for LC materials of types I and II and for mixtures used in twisted nematic displays. The largest component, $\epsilon_\parallel$, is parallel to the director. Three elastic constants can be defined for nematic substances and used to describe the forces required to displace the director from its equilibrium position. These constants are many orders smaller than elastic moduli of ordinary solids. Even though small, a static balance between elastic and dielectric torques arises when a field is applied to an LCD. This balance produces a well-defined molecular structure that determines the degree to which the plane of polarization is rotated in a display.

Display Construction and Operation

Construction of the HP-41C display is depicted in Fig. 3, and Fig. 4 is the process flow sheet. The display is a parallel plate capacitor with polarizers bonded to the external surfaces. The two glass plates are separated by about ten micrometres and sealed with a vitreous glass frit. Liquid crystal fills the space between the plates, and the molecules are oriented with their directors in the plane of the substrate. The directors are also aligned parallel to the axis of the polarizer attached to the outside of the adjacent glass. A 90-degree director twist results with nematic order producing a uniform change across the liquid crystal layer. This structure is shown in Fig. 5a.

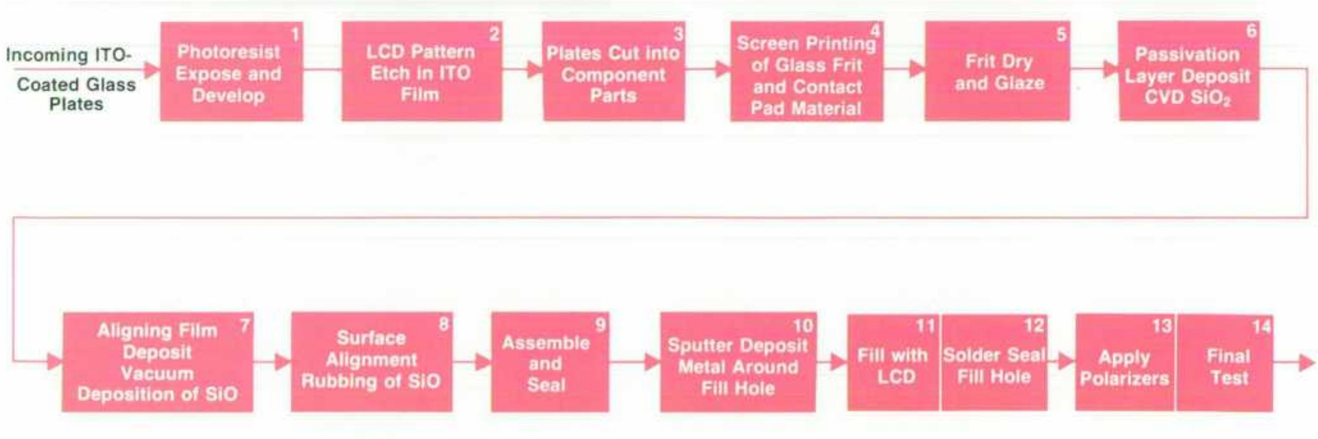
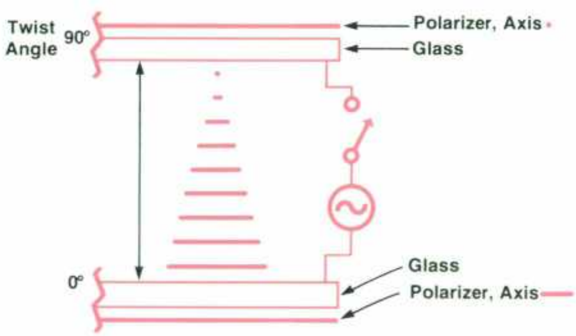


Fig. 4. *HP-41C liquid crystal display manufacturing process.*

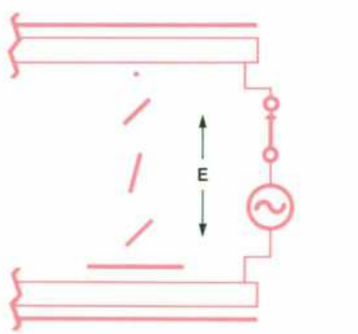
Light passing through the first polarizer rotates 90 degrees as it passes through the LC layer. As a consequence it is aligned with the second polarizer, passes through, reflects, and propagates out unattenuated. The entire display appears light gray as a result of polarizer and reflector tints. Application of a voltage across the LC causes the directors to rotate so they are parallel to the applied field. At a sufficiently high voltage, alignment is nearly parallel as shown in Fig. 5b. The 90-degree director twist is eliminated, for all practical purposes, and light propagating through the LC is absorbed by the second polarizer. Dark digits appear in the active areas.

Director tilt increases with increasing voltage, and as a consequence, contrast develops first at lower voltages at shallow viewing angles. As shown in Fig. 6, brightness decreases at lower voltages at a 40-degree viewing angle compared to the curve representing zero-degree behavior.

Multiplexed displays operate with voltage applied at all times. To be off, nonselected elements must be above 90-percent brightness, and for the HP-41C, this is required to extend over a 40-degree angle. These two factors define the rms off voltage, as shown in Fig. 6. Good viewing also dictates that brightness be 50 percent or less for selected elements over the same 40-degree angle, and this voltage is also shown in Fig. 6.



(a)LCD off, molecules oriented by surface forces and twisted 90 degrees



(b)LCD turned on, molecules tend to align with directors parallel to E-field.

Fig. 5. *Liquid crystal display behavior in the on and off states. (a) When the display is off, the molecules are oriented by surface forces and twisted 90° from the top of the display to the bottom. The display appears light gray. (b) When a voltage is applied, the molecules tend to align parallel to the applied electric field. Light is absorbed by the bottom polarizer and the display turns dark in the active areas.*

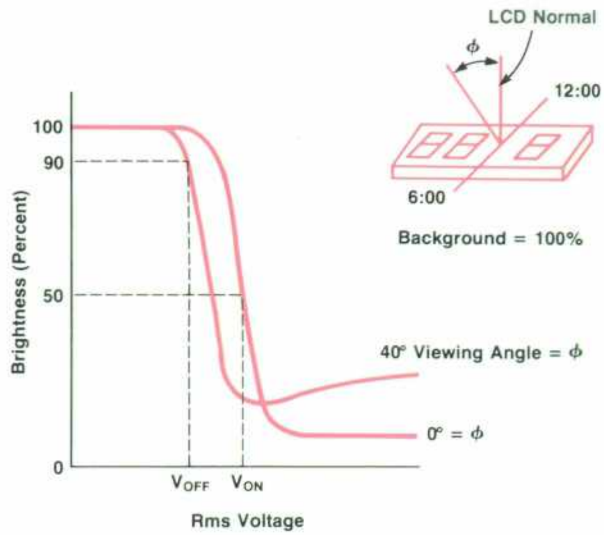


Fig. 6. *Electro-optical response of a twisted-nematic LCD at two viewing angles.*

A small V_{on}/V_{off} ratio is desirable for good optical performance for an LCD operating in the multiplexed mode. Proper selection of the LC material, care in LC surface alignment, and care in maintaining proper cell spacing all serve to maximize viewing angle and contrast for a given application.

Acknowledgments

Two separate groups have been involved in the development of LCD technology at HP. First, in Corvallis, thanks to Curt Sheley, Ed Heinsen, Paul Van Loan, Pat Shelley, and Earl Garthwait. At HP Labs credit goes to Fred Kahn, Hsia Choong, and Henry Birecki for their technical assistance over the past several years. Ed Kanazawa of Data Terminals Division and Sun Lu, formerly of HP, were also major contributors.

Craig Maze

A midwesterner from Galveston, Indiana, Craig Maze took his BS degree in chemical engineering from Purdue University in 1959, and later attended Iowa State University, where he earned his MS degree in 1967 and his PhD in 1970, both in chemical engineering. He joined HP in 1978 as a product engineer on the HP-41C liquid crystal display program. Author of 18 papers and named inventor on two patents, he worked in the fields of liquid crystals, polymer science, thermal analysis, surface chemistry, and computer modeling before joining HP. His professional memberships include the American Chemical Society and the American Institute of Chemical Engineers. He has spent two years in the U.S. Army and taught thermodynamics and chemical instrumentation at Arizona State University. Now a resident of Corvallis, Oregon with his wife and three children, two of whom are in college, Craig spends his spare time gardening, trying his hand at photography, and generally enjoying outdoor activities.