You can now buy liquid crystal displays off the shelf as well as get the chemicals and parts for them separately. These devices have micropower supply requirements, extreme thinness, high brightness, and a bunch of other advantages. Here's how they work, what's available, how they stack up to led's, what you can do with them, and where to get materials for your own displays.

LIQUID CRYSTAL DISPLAYS

by DON LANCASTER

A LIQUID CRYSTAL IS A CHEMICAL THAT FLOWS LIKE A LIQUID, yet retains an orderly molecular structure within that flow. Many chemicals behave this way over a limited temperature range. Some of these also have unique electrical or thermal properties that make them attractive for a wide variety of electronic uses. For instance, *cholesteric* liquid crystals have a very interesting property—they change color wildly for a very small temperature change. These have been available for several years and are used widely for thermal and heat studies microwave power field analysis, medical diagnosis, and even in dime-store novelties.

A more recent development is the *nematic* liquid crystal, whose properties were first described extensively by RCA engineers in 1968. Nematic crystals are clear, but whenever you apply an electric field, they turn milky or cloudy. Chemically, the process is called *dynamic scattering* and the cloudiness or milkiness is caused by the external field interacting with the ordered liquid structure.

An obvious use for something that turns white whenever you apply voltage is an electronic display. To make things more interesting, liquid crystals are also poor conductors, which means they draw practically no current when they're in the milky state and zero current when clear. This makes liquid crystals particularly attractive for watches, clocks, miniature computers, and pocket calculators. We can also use them as *Nixie* tube replacements on electronic instruments, particularly on battery-powered versions. Liquid crystals offer quite a bit as a possible route to flat-screen TV displays. The computer people are also interested, because certain combinations of nematic and cholesteric liquid crystals can also exhibit *storage* and *memory,* important features in a terminal or computer output display where the information need only be provided once by the computer instead of having to be refreshed 60 times a second as in ordinary TV.

Liquid crystal displays do not *generate* light. They either *reflect* it or *transmit* it, depending on how you use

OPTEL MODEL 1003 liquid crystal displays are in photo above them. This means that there is no contrast problem with high ambient light levels—the brighter the room lights, the brighter the display. Normally the liquid crystal material is only a mil or two thick, making for an extremely thin display. It can be made into a display of any size, and we could even imagine room partitions or windows using liquid crystals for controllable privacy or light transmission. And, you can make liquid crystals into any color display you want—white for maximum contrast, red to alert or warn, yellow or green for easy reading, blue for attractive appearance.

Right now, you can't go out and buy liquid crystal displays for 50¢ a digit, but the potential is certainly there. Several manufacturers now offer composite displays and individual digits. These are still rather expensive in small quantities, although their quantity (1000-10,000) prices are competitive with *Nixie* and Light Emitting Diode (LED) displays, particularly if large digits or alphanumerics are needed.

Materials

One of the first nematic materials studied by RCA is an organic jawbreaker going by the name of Anisylidene-Para-Aminophenylacetate. A half-mil (0.0005-inch) thick layer of this was placed between two pieces of conductive, transparent glass and heated to its nematic operating range of 83° to 100° C. When 60 volts was applied, (an equivalent *field strength* of 120,000 volts per inch), the test cell turned milky, blocking transmitted light and reflecting incident light. With no voltage applied, the cell was clear. The best brightness of this early display was around half that of a good piece of writing paper.

Things have improved considerably since those early tests. Research by such people as RCA, Kent State University, Penn State University, Vari-Light Corp., Optel, Ilixco, and Liquid Crystal Industries has made a wide variety of room temperature operating liquid crystals available. One of these is p-Methoxy-Benzylidine, p-n-Butyl-Aniline 4-Methoxy, 4'n-Butyl-Benzylidene-Aniline. While this isn't the sort of chemical you'll be able to mix up in your kitchen sink, the stuff is readily available and ranges in price from $4 per gram in 5-gram lots to under $1 per gram in kilogram lots. Depending on the character size, a gram is enough for a hundred or so characters or digits. Thus the price per digit is around 4¢ each. Other nematics are similarly priced, ranging up to $15 per gram in small lots.

Fig. 1 shows four popular liquid crystal configurations. In Fig. 1-a, we have a simple *transmissive* display. Here the liquid crystal is sandwiched between two layers of conductive glass or any suitable transparent, rigid material with a conductive path on its *inside* surfaces. With a modern liquid crystal compound, 12 to 15 volts is needed to block light transmission through the display, while 0 volts allows light to pass through freely. Thus, this type of display is directly compatible with MOS or COSMOS integrated circuits, but will not give acceptable contrast when driven with 5-volt TTL (at least not with presently available materials). Fig. 1-b shows a *reflective* display, where the back conductor becomes a reflector that returns scattered light to the observer. This is the most popular form, because only external room lighting is needed to view the display.

To improve the contrast and to get by on lower operating voltages, we can use other optical properties of liquid crystals, as shown in the *bi-level* displays of Figs. 1-c and 1-d. Some liquid crystals have an optical property called birefringence. *If the birefringence is voltage-controllable, we can use it to selectively rotate polarized light. In 1-c we have two light polarizers that are parallel in orientation. With no voltage applied, the liquid crystal does not significantly affect the plane of polarization of the light. The first polarizer polarizes the light and the second one passes it freely. This is called a* normally open *display. When voltage is applied, the liquid crystal rotates the plane of polarization 90°* and the second polarizer blocks *the light transmission. To get the* normally closed *display of Fig. 1-d, we use* crossed *polarizers. Here, in the absence of a voltage, the first polarizer polarizes the light, the liquid crystal does nothing to it, and the second one blocks the transmission. Fancier forms of bilevel displays can be used in the reflective mode and some can even produce selectable colors.*

Some problems

Liquid crystals still have some problems and disadvantages. The cell holding the liquid must be dimensionally stable, clear, and a conductor,

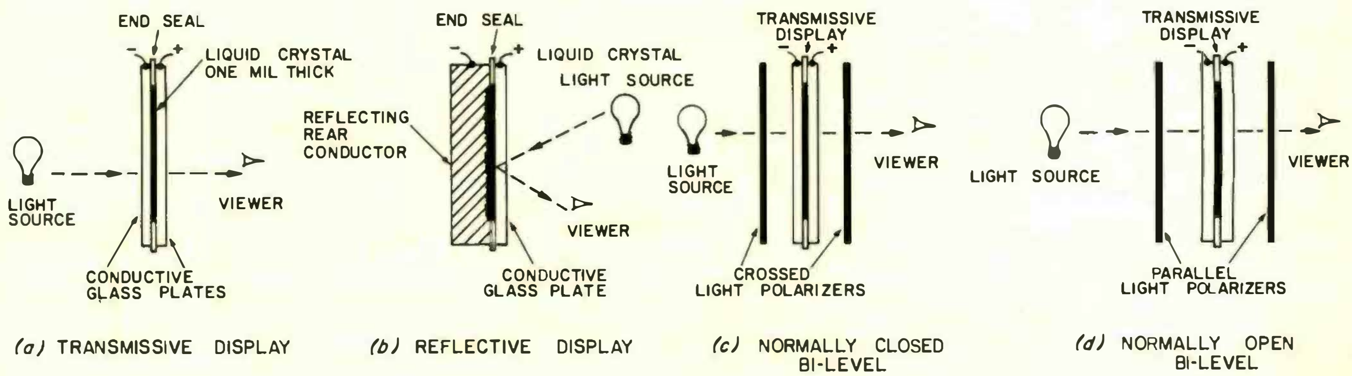
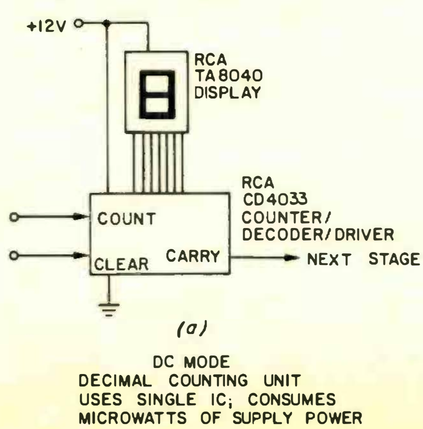
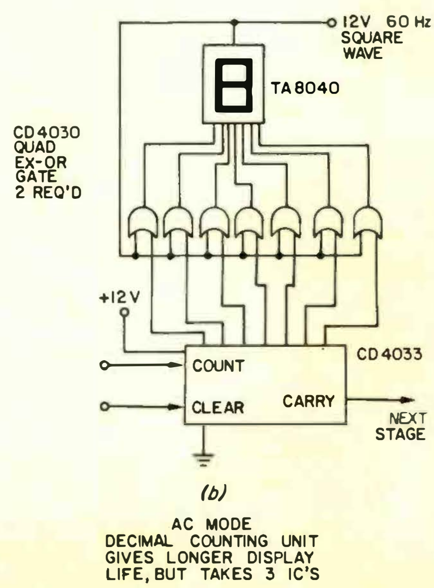


FIG. 1—FOUR COMMON CRYSTAL displays, showing transmissive and reflective effects.

FIG. 2—DECIMAL COUNTERS using liquid crystal devices. 2-a, working with dc, uses a single IC; the ac version in Fig. 2-b has a longer display life but is more complex.





at least on its inner surfaces. There is presently no ultra-low-cost material that fits these standards, and you have to go to a fairly fancy coated glass to meet the requirements. One widely used glass is the *Nesatron* N-2 manufactured by *Pittsburgh Plate Glass Industries.* The process puts a metallic oxide on the glass surface and does it at low temperatures, preventing any stress or annealling effects from hurting the flatness of the glass. Coated glass of this type runs around $14 per square foot, dropping to $10 per square foot in quantity. This is seven to ten cents a square inch, so it turns out that the glass you look through costs twice as much as the liquid crystal material itself. The *Vari-Light* people offer a 2 x 2½-inch piece of electrically conductive glass with a busbar edge for $1.50 each in single quantities. This should be enough for either one transmissive four-digit display or two reflecting ones.

The liquid crystals are sensitive to impurities, so reliable displays must be hermetically sealed. Bubbles must obviously be avoided—they will degrade the display appearance. Capillary and edge effects present a problem with any thin liquid film. Obviously the display must not leak. Small impurities can alter the dynamic scattering drastically, and mechanical stress on the conductive glass faces can alter the optical birefringence properties dramatically.

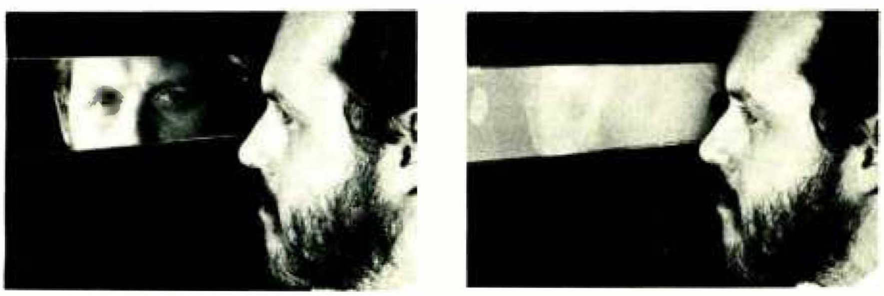
If you apply a dc voltage continuously to a liquid crystal, it loses contrast after a 2000 to 10,000-hour operating lifetime. To get around this, the displays should be run from an ac source if long lifetimes are needed. Fig. 2a shows how we might build a decimal counting unit by connecting a MOS decimal counter-decoder to a 7-segment liquid crystal display. Note that we only need two parts for the complete count-decode-display operation. We can run this on *ten microwatts* at a 1 Hz counting rate for the counter, and around 20 *microwatts* or so for the display on the average.

The trick is to run the IC's on dc, yet convince the display it is running on ac, without going to any fancy Triac drivers or anything like that. To get long life ac operation, we use the circuit of Fig. 2-b. Here seven EXCLUSIVE OR gates are added between the counter and the display, which is driven off a 60-Hz square wave. The exclusive OR gate turns the square wave upside down (inverts it) whenever you want to light a segment, and simply passes it on whenever you want the segment off. An *off* segment sees the same signal on both ends and doesn't light. An *on* segment sees 15 volts across it all the time, alternating polarity 120 times a second. Thus we get ac display operation with dc on the integrated circuits at reasonable cost and complexity.

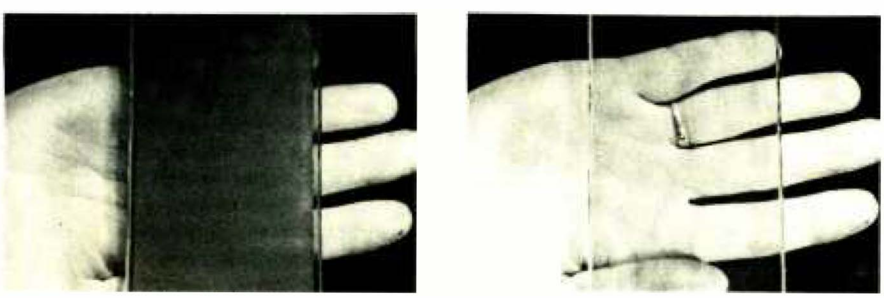
Liquid crystal displays are somewhat slow. Normally they turn on in 10 milliseconds or so and off in 100 to 200 milliseconds. While we can speed them up a bit with "quenching" techniques, they are inherently slow devices. They're great for people, but cannot generally be used in such high-speed applications as electronic shutters, film annotation, and anywhere else a fast turnoff is needed. They *can* be used at television vertical rates, and TV displays using liquid crystals have been demonstrated. Considerable effort will be needed before a flat screen liquid crystal TV or computer display becomes a commercial reality.

A final problem with liquid crystals is that LC displays do not *multiplex* very well. Multiplexing is a trick you use to share one decoder-driver with many digits, thus holding down system costs and the number of interconnections. For instance an eight-digit display done normally would take 57 connections and eight decoder-drivers. If we multiplex, we get by with one decoder-driver, one eight-point scanner, and 15 connections, assuming you're using 7-bar displays. To multiplex, you run each digit at eight times normal brightness for one-eighth of the time, and switch them fast enough that the human eye can't follow. The eye sees a continuously lit display of normal brightness. The breakeven point on multiplexing is four digits; the more digits, the more you gain.

Neon lamps, *Nixie* tubes and light emitting diodes multiplex very well since they can be overdriven for short times, and more important, since they are inherently diodes that block current in the reverse direction or below a threshold value. Liquid crystals cannot reflect more light than they receive, and they do not have a well defined off-on threshold. Thus, at the very least, series diodes are needed for each segment of each digit to prevent sneak paths and ghost images. Good multiplexing techniques will eventually develop, but right now liquid crystals are not overly attractive for multiplex use.



REFLECTION FROM A MIRRORED SURFACE is minimized with nematic liquid crystals. Future applications may include an automatic dimming rear-view car mirror.



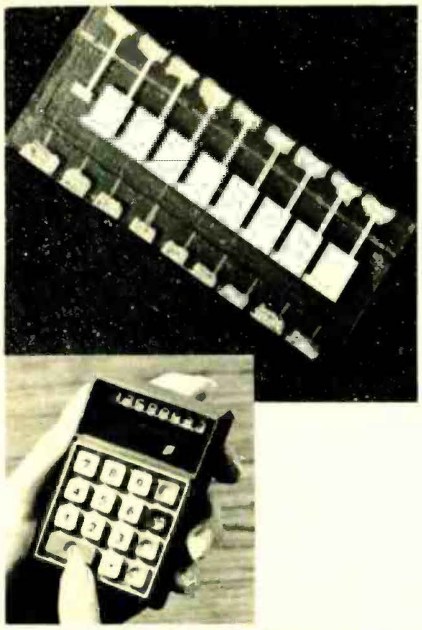
CONTROLLING THE TRANSMISSION OF OBJECTS opposite a viewing surface using nematic liquid crystals, makes display overlays, optical shunters and automatic dimming windows possible.

Liquid crystals *versus* LED's

The light emitting diode, or LED, is rapidly becoming the dominant type of readout used today, replacing the now obsolete *Nixie* type with its high voltage requirements. LED's combine a long life, very attractive appearance, TTL 5=volt compatibility with a wide availability, and, recently, low cost. How do they stack up against liquid crystals?

The obvious answer is that both LEDs and liquid crystals have unique advantages and they can each serve an important segment of the display market. Where you want to *produce* light, you must go the LED route. For good multiplexing, high-speed operation, complex alphanumerics, and custom arrays, LED's are the way to go. They also have very much of a head start in the marketplace and right now are more attractive than the liquid crystal displays in appearance.

On the other hand, it always takes more power to produce light than to guide it, and liquid crystal technology is inherently simpler than semiconductor



EIGHT DIGIT liquid-crystal display (larger photograph) forms the readout of a new pocket size electronic calculator made by Ragen. The calculator will retail for about $100.

TABLE I

LIQUID CRYSTAL DISPLAYS OFF-THE-SHELF SUPPLIERS

ILIXCO
Box 184
Kent, Ohio, 44240

OPTEL CORPORATION
Box 2215
Princeton, N.J., 08540

RCA SOLID STATE
Central and Terminal Avenues
Clark, New Jersey, 07066

TABLE II

MATERIALS FOR BUILD-YOUR-OWN LIQUID CRYSTAL DISPLAYS

CHEMICALS

Liquid Crystal Industries
460 Brown Avenue
Turtle Creek, Penna., 15145

Vari-Light Corporation
9770 Conklin Road
Cincinatti, Ohio, 45242

CONDUCTIVE GLASS

P.P.G. Industries
New Products Development
One Gateway Center
Pittsburgh, Penna., 15222

Vari-Light Corporation
9770 Conklin Road
Cincinatti, Ohio, 45242

POLARIZERS, OPTICS, MISC.

Edmund Scientific Corp
101 East Glouchester Pike
Barrington, New Jersey, 08007

technology. So for lots of digits, low power, low cost, the liquid crystals are very much the better choice. We could envision eventually some gel form of liquid crystal that is silk-screened onto displays by the mile at a cost of pennies per digit. Important first applications of liquid crystals will be in pocket calculators and electronic clocks, particularly miniature, battery-powered ones. Liquid crystals generally interface with high density MOS integrated circuits without needing any high current driver stages. It doesn't take too much imagination to see a pocket add-subtract-multiply-divide-store calculator thats nothing but a keyboard, a single LSI chip and a display combined with a battery. You end up with a device that's far less complex and far simpler to manufacture than a $2.50 AM transistor radio.

What's available now?

Table I lists the manufacturers of liquid crystal displays. Commercially available units are offered by RCA, OPTEL, and ILIXCO.

RCA initially offers six units. Two are single-numeral 0.75-inch high versions that plug into a PC connector. The TA8032 is a transmissive style while the TA8034 is reflective. Total display power is 35 microwatts at a supply voltage of 12 to 15 volts. The operating temperature range is 5° to 55° Centigrade. (22° C is "room" temperature). Introductory single quantity price is $25, dropping to prices competitive with LED displays in quantity. Since, as we'll see below, the ILIXCO prices in single quantities run $8 per digit, we can expect these introductory prices to drop to reasonable levels very shortly, perhaps by the time this is in print.

The other four RCA units are four-digit ones, two with decimal points for instrument use and two with colons in the middle for clock use. One of each type is reflective and one is transmissive. This is their TA8040-43 series. These are initially offered at $75 each, dropping in quantity to competitive prices with LEDs. The characters are 0.6-inch high and the unit plugs into a conventional PC socket. Total power for four digits is around a milliwatt with all segments energized on 15 volts.

OPTEL has two units, a three-digit 1003 and a 3½-digit model 1053. The 1003 comes with decimal points, while the 1053 has a colon and is intended for clock use. The characters are 0.450 inches high and the power dissipation is 40 microwatts per segment at 20 volts. The operating temperature range is 0 to 50° C, and, as with the others, prices are competitive with LED devices in quantity.

ILIXCO presently offers the lowest prices and widest variety in stock displays. They have ten displays available, ranging from 3½ digits to 8 digits and in both 0.4-inch and 0.8-inch sizes. The 3½-digit versions are offered for clocks, while the intermediate sizes are suitable for digital instruments, and the 8-digit version is intended for pocket calculator use. The prices range from $8 per digit in single quantity down to $5 per digit in 50 lots. The ILIXCO units are bilevel and operate clear down to 5 volts, although operation is best between 7 and 15 volts. Their display appears as a dark blue character on a clear background.

Other stock liquid crystal displays should soon be available from a wide range of manufacturers and it is reasonable to expect the per-digit prices to drop dramatically once serious competition and production economies set in.

Building your own

With commercial units still somewhat expensive for an experimenter's budget, you might like to try building your own liquid crystal display. Sources of materials are listed in Table II. This should be a hot science fair, school, or university project as it is a rather exotic technology that you can still work with yourself on a lab bench or a kitchen table and still come up with a working device.

Probably for openers, 5 grams of *Vari-Light* VL462N at $12.80 and a CG-75 gold coated glass at $1.50 might be a good starting point. You can use one or two mil drafting Mylar (25¢ a sheet at any drafting or photocopy store) for spacing, and might try first building up a simple transmissive system that turns cloudy whenever you apply 15 or 20 volts. You could then try printing an invisible message on the glass with PC photoresist and turning the message on and off with the control voltage. From that point on you should be able to work up your own 7-segment readout, eventually ending up with a leakproof, bubble-free version you can stand on end. There are all sorts of possibilities.

Liquid crystals aren't particularly toxic, but their long-term effects aren't really known and some of them do penetrate the human skin very easily. SO,—

(continued on page 90)

LIQUID CRYSTAL

(continued from page 36)

treat them with respect! Don't get any on your hands, eyes, or mouth. Clean up thoroughly when finished, and keep the chemicals away from children. Avoid getting any fumes (highly unlikely) in your eyes or mouth. In short—in spite of the fact that liquid crystal chemicals appear harmless—treat them as dangerous chemicals. Better safe than sorry.

Before you start your display work, get as much printed information as you can, starting with manufacturer's literature from Tables I and II. Then read *Dynamic Scattering: A New Electrooptic Effect in Certain Classes of Nematic Liquid Crystals* by Heilmeier, et al., in the July 1968 *Proceedings of the IEEE.* Vol 56, no 7, pp 1162-1171. You might also find pages 2146-2148 (December 1968) of interest, as well as pages 34-38 (January 1969) of volume 57. For more information beyond this, check the *Engineering Index* in your local library under *Crystals, Liquid.* This will generate a hundred or so papers, some of which you'll be able to pin down. Remember that nematic liquid crystals are most often the ones used in displays, while half the papers will deal only with thermal effects and cholesteric materials. **R-E**

TRANSISTOR TESTING IS A CINCH

(continued from page 39)

sistor now shows good. No leakage, and npn (and, as you can see in Fig. 4-c, the "almost-standard" TO-5 basing or E-B-C counting clockwise around from the locator lug on the case.)

There was evidently too much shunt resistance somewhere to let the transistor test good in-circuit. This was in a little "gadget" I had picked up; I thought the transistors were good, and this one was.

In another test, on an all-channel TV booster, there was a definite suspicion that the transistor was bad. (I don't know what made me think that; maybe because it had been hit by lightning, and wouldn't work!) At any rate, there were a lot of low-resistance things hooked across the transistor; baluns, small resistors, and so on. Resistance readings were way off. However, I did note that the ohmmeter showed no diode-effect between base and emitter.

I took the transistor out and checked it on the tester, no good. The ohmmeter showed that the base-emitter junction was open. The collector-emitter junction still showed a diode-effect. From the low resistance indicated, this note that the ohmmeter showed no the ohmmeter was on the emitter. So, this was a pnp. I did note that what I was using as the collector lead was connected to the case.

The assumption turned out to be correct. Plugging the booster in, and checking the open-circuit dc voltage from the power supply showed 25 volts. So I chose a pnp germanium transistor, collector-voltage rating of 35 V. 800 MHz high-frequency cutoff, and tried it. It worked.

So even if the transistor is a complete stranger, with one junction completely open, you can still use these tests to get enough data to make a ball-park diagnosis of what it was, and select a replacement that has a chance of working. As a matter of fact, if you turn out to be wrong (as demonstrated by the indisputable fact that the thing *won't* work!), it doesn't seem to do any harm to a modern junction transistor to be installed *backward.*

Summation: I have only one suggestion now. Be sure to *try* these tests yourself, with your own equipment, and compare results. At first, use new (checked) transistors, and keep notes. Watch for the peculiar reactions of the two types of bipolar transistors, and remember them. I believe this will be very helpful!

Possibly some of you have your own methods of identifying and testing unknown transistors. If so, I'd like to hear from you. Perhaps we can get together and develop a "standard" test. **R-E**