An exciting new technology may make it possible to offer color displays in applications where previously they have been impractical or impossible. In this article we'll look at that technology, and its first commercial application.

OSCILLOSCOPES IN COLOR

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MOST READERS OF **RADIO-ELECTRONICS** are familiar with shadow-mask CRT's. Those CRT's are used in the vast majority color display applications, including the most familar of all, the color TV. But several breakthroughs in color-display technology have recently occurred, breakthroughs that could eventually make the shadow-mask color CRT obsolete.

One of the most recent of those breakthroughs is the new liquid-crystal color shutter (or switch) from Tektronix (PO Box 500, Beaverton, OR 97077). The color shutter is used in combination with a high-resolution *monochrome* CRT and allows the monochrome CRT to display *color* images. The system developed by Tektronix offers the advantage of high-resolution color—much higher than possible with shadow-mask CRT's—at a reasonable cost. We'll take a closer look at the color shutter in a moment, but first let's take time to review some important LCD basics.

LCD basics

A liquid crystal is an organic compound; that means that it is a compound that consists of carbon, hydrogen, oxygen, and nitrogen. What is different about a liquid-crystal compound is that it is fluid like a liquid, but has the optical properties of a solid.

Another interesting property of a liquid crystal is that its molecules, which are shaped like long rods, act like dipoles in the presence of an electric field. That means that the alignment of molecules in a liquid crystal can be controlled by applying and removing an electric field.

Liquid-crystal displays differ from other types of displays in that they scatter rather than generate light. The type of LCD used in watches and calculators, as well as in the color shutter, consists of a vertical polarizer, a liquid-crystal cell (the cell used in the shutter will be described below), and a horizontal polarizer. When there is no electric field present, the liquid-crystal material is in its relaxed state. In that state, the liquid-crystal molecules nearest the polarizers have their long axes parallel to the polarizers with subsequent layers twisting through the 90° between horizontal and vertical (see Fig. 1-a). Light from the light source passes through the horizontal polarizer, is twisted 90° by the liquid crystal, and passes out through the vertical polarizer. Someone looking at the LCD will see light.

When an electric field is applied, the liquid-crystal material is in its driven state. In that state, the liquid-crystal molecules are oriented parallel to the direction of the field (see Fig. 1-b). Because of that, the natural twist is destroyed, and hence, the light is not rotated by the LCD. Therefore the light is absorbed by the vertical polarizer and a viewer would see a dark area.

The π cell

Tektronix' major accomplishment in developing the color shutter was in devising a liquid-crystal device, called a π cell, with a fast-enough switching time. Most liquid crystals switch (change between a relaxed and a driven state) at rate of 20 to 100 milliseconds. The π cell has a switching time of 1.7 milliseconds.

The π-cell consists of two glass plates coated with indium-tin-oxide, a thin layer of silicon-dioxide (which serves as an insulator), and a special alignment layer. It has a special structure in which the liquid-crystal molecules are arranged so that when the applied electric field is removed, the liquid flow within the cell does not oppose the natural rotation of the liquid-crystal molecules into their relaxed (twisted) orientation. That is the key to the fast switching times.

Another factor in developing the π-cell was the thin cell spacing that Tektronix has achieved. The cell spacing must be very accurate because the switching characteristics described above depend on the cell being very thin and uniform. If the cell is made too thin, however, it will not have the required optical properties. The company has developed techniques for cell spacings of 3 to 10 micrometers with a tolerance of 300 nanometers. Cells with that spacing have been manufactured in sizes ranging from 5 to 40 centimeters, although the actual viewing area is only about 90% of the cell size; that limited viewing area is due to mounting considerations.

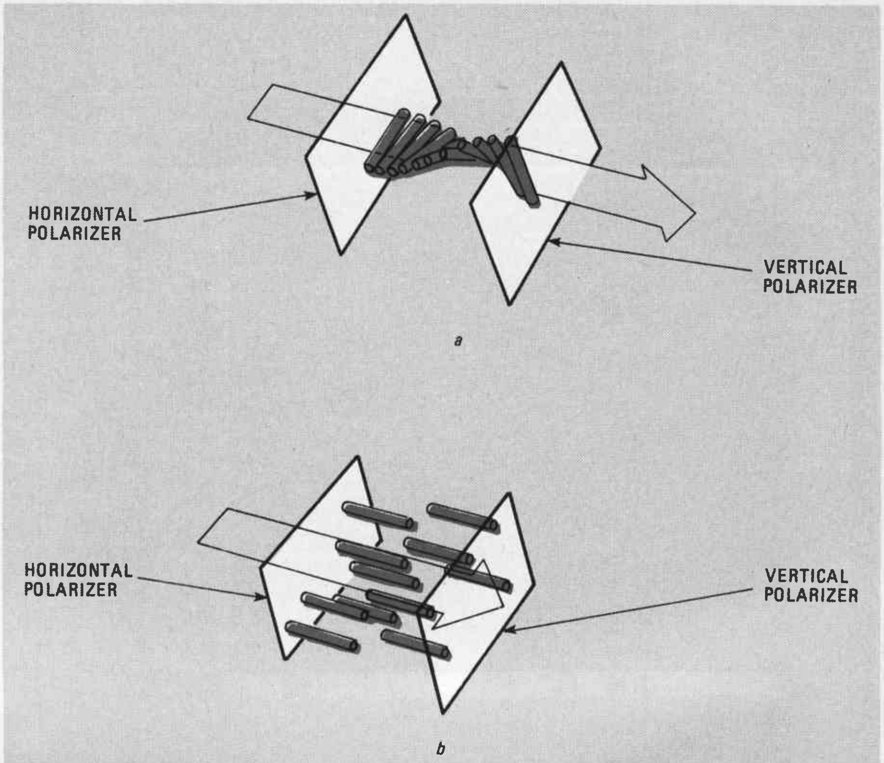


FIG. 1—WHEN NO ELECTRIC FIELD IS PRESENT, as is the case in *a*, an LCD rotates light 90°, allowing it to be seen. When an electric field is present, as is the case in *b*, light is not rotated so it is absorbed by the polarizer.

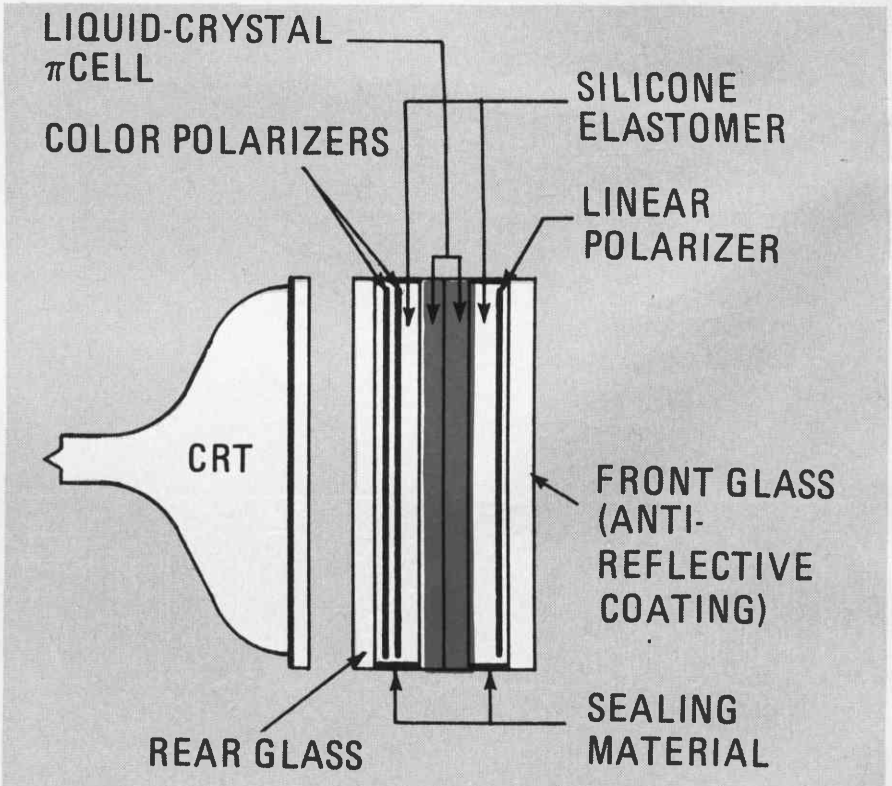


FIG. 2—TO MAKE THE COLOR SHUTTER, the π- cell is sandwiched between, and optically coupled to, a pair of orthogonal color polarizers and a linear polarizer.

The color shutter

To make the color shutter, the π cell is sandwiched between, and optically coupled to, an orthogonal set of color polarizers (orange and blue-green) and a horizontal linear polarizer (see Fig. 2). The "sandwich" is then placed in front of a CRT that uses a phosphor whose emission peaks are in the orange and blue-green portions of the spectrum (see Fig. 3).

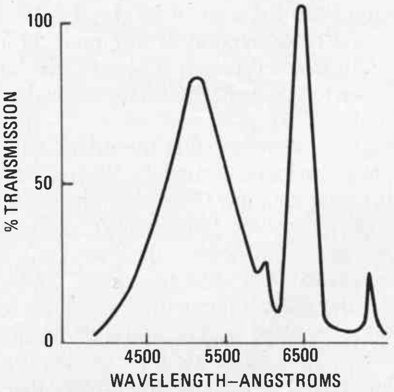


FIG. 3—IN THE CURRENT TEKTRONIX SYSTEM, a CRT with a phosphor whose emission peaks lie in the orange and blue-green regions is used.

To generate a multi-color display, both the screen and the shutter are switched synchronously. A block diagram of the system is shown in Fig. 4. In one frame, all of the information that should appear in orange is displayed. In the next frame, all of the information that should appear in blue-green is displayed.

The role of the π cell in this system is to be sure that only light of the appropriate color will be passed. Orange light entering the shutter is vertically polarized by the orange polarizer; blue-green light entering the shutter is horizontally polarized by the blue-green polarizer. (Note that the color polarizers also polarize white light as indicated in Fig. 4.) During the "orange" frame, the liquid-crystal is in its undriven state. Orange light is thus rotated 90° by the liquid-crystal and passes through the horizontal linear polarizer. The horizontally polarized blue-green light is also rotated, but it is rotated out of the transmission axis of the linear polarizer and is thus absorbed.

During the "blue-green" frame, the liquid-crystal molecules are oriented so that they do not twist light. Thus, the horizontally polarized blue-green light is passed by the horizontal linear polarizer while the vertically-polarized orange light is absorbed.

As the alternate frames are viewed, the eye integrates them to produce a multicolored image. With the phosphor/polarizer combination used in this system, any color that can be created by combining orange and blue-green can be displayed by varying the intensity of the scanning beam. To achieve flicker-free operation, each color (frame) is repeated at a rate of 60 Hz; thus, the two field system will run at a rate of 120 Hz.

Although orange and blue-green are the colors chosen by Tektronix, any two colors could be used through the proper selection of color polarizers and phosphors. For instance, early versions of the color shutter used red and green. The colors chosen for the current shutter were selected because they, and neutral (a color formed by the combination of the two primary colors and used in the first commercial application of the new technology—more on that later), are spectrally separated enough to be easily distinguishable, but close enough to minimize the eye's need to refocus.

As indicated above, only colors that can be generated by combinations of two primary colors can be displayed. Tektronix is continuing with its research in order to develop a shutter capable of displaying colors that could be produced by three primary colors. Such a shutter would be capable of producing a full gamut of colors, with results comparable to, or better than, conventional color displays.

Advantages

The development of the liquid-crystal color shutter is important for a number of reasons. Perhaps most significant is its high resolution. Because a monochrome CRT is used in place of a shadow mask (or other type, such as penetration-phosphor) color CRT, much better resolution is possible than with any other type of color display. That means, of course, much better graphics, and clearer, easier-to-read text.

The use of a monochrome CRT is also a key to a number of other advantages offered by the display. For one thing, adding color capability to a monochrome instrument will not require repackaging the instrument to accommodate the longer color CRT. Also, due to the absence of a fragile shadow-mask or complex electron-gun, monochrome CRT's are inherently more rugged than color CRT's. Use of a monochrome CRT also eliminates the color-convergence problems that plague other types of color displays.

One potential problem with the display arises from the fact that the system is field sequential. In the system, the brightness of a given color will be reduced to a maximum of 25% of the brightness of that color on a continuously rastered CRT. That is due to two factors. One is that since the system is field-sequential, the two colors have a 50% duty cycle (since the frames alternate, each color is displayed only half of the time). The second factor is that an ideal polarizer has a transmission factor of about 50%. We are dealing with real devices here, however. Taking into account factors such as the non-ideal nature of the polarizers, the brightness level of the display is only about 12%–14% of the brightness level of a continuously rastered display.

What offsets that potential problem is a high and controllable contrast-ratio. The combination of color and linear polarizers used in the Tektronix system allows for contrast ratios that can exceed 20:1. The contrast ratio of the display can be varied by varying the intensity of the scanning beam. That high contrast ratio allows the display to be satisfactorily viewed under high ambient-light conditions, even in full sunlight.

Applications

There are, of course, a number of applications where the new Tektronix technology can provide color capability where it has not been practical before. Examples of that include small instrument displays such as oscilloscopes, logic analyzers, and spectrum analyzers. Those instruments require high-resolution displays to adequately convey waveform information. Another area where color would be useful is in system-control displays. In that application, color could be used for highlighting special situations or warnings.

In fact, the display could be used in any application where color is desired, but high-resolution is required. It would be ideal, for example, for word processing. In addition, the display's high contrast is a

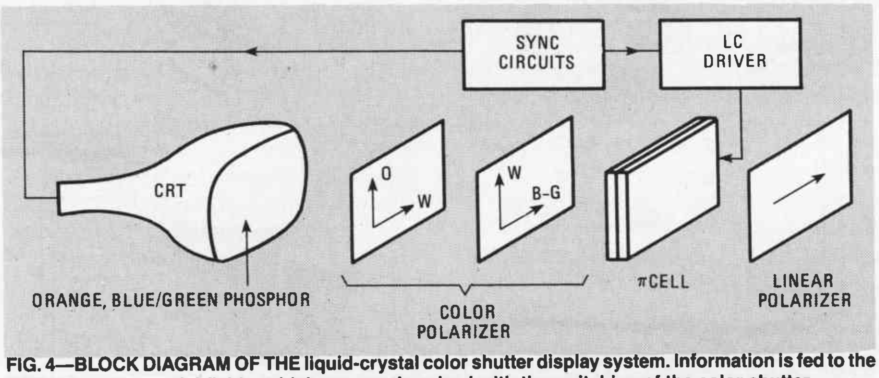


FIG. 4—BLOCK DIAGRAM OF THE liquid-crystal color shutter display system. Information is fed to the CRT in two sequential fields, which are synchronized with the switching of the color shutter.

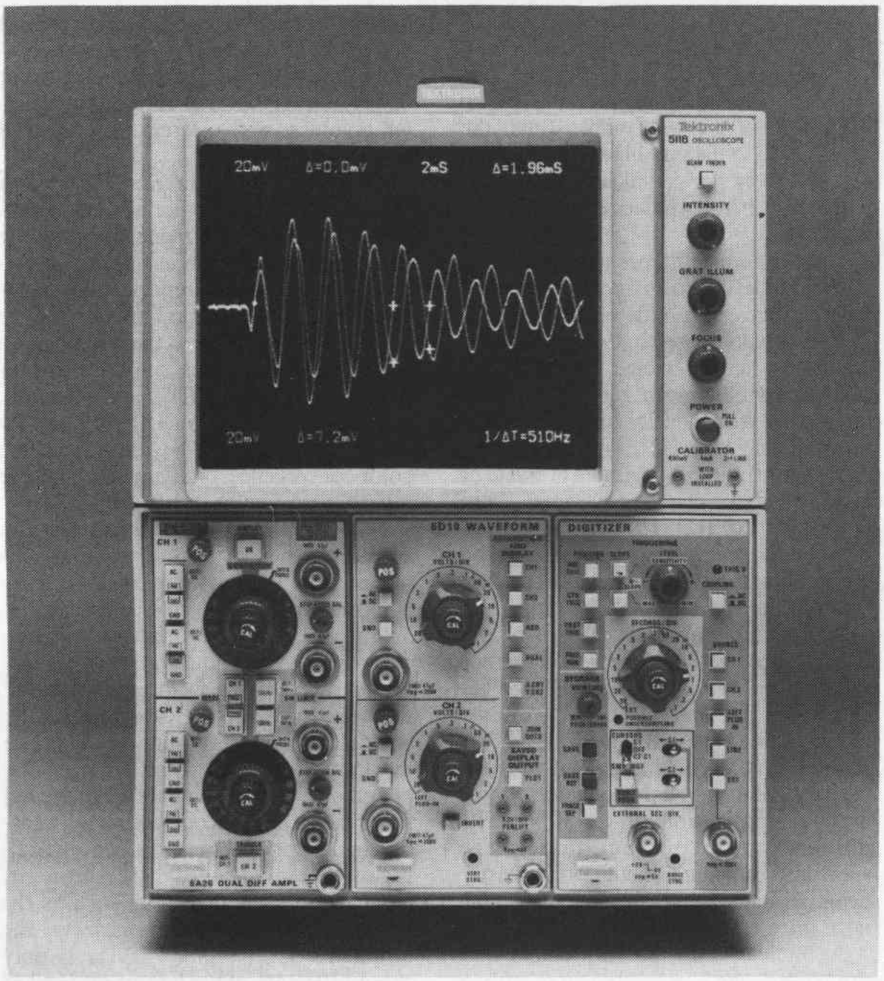


FIG. 5—THE MODEL *5116* from Tektronix. That oscilloscope is the first commercial application of Tektronix' liquid-crystal color shutter technology.

great advantage in the high ambient light of the typical office.

The *5116*

Textronix' first commercial application of the liquid-crystal color shutter was in its *5116* color-display oscilloscope. The usefulness and practicality of the color shutter is clearly illustrated by that device.

In that scope (see Fig. 5), the color traces are used to make it easy to distinguish between channels, for emphasizing certain types of important information, and in general to make the scope easier and more efficient to use.

In the past, oscilloscopes have used a variety of schemes to make them easier to use. Those schemes include highlighting, cursors, and alphanumeric readouts. The addition of color merely takes those schemes one step farther. In the *5116*, for instance, channel 1 data is displayed in blue-green while the channel 2 data is displayed in orange. Further, the alphanumeric readouts are color coded by channel, while the X-Y and time-base measurements are displayed in neutral (off-white).

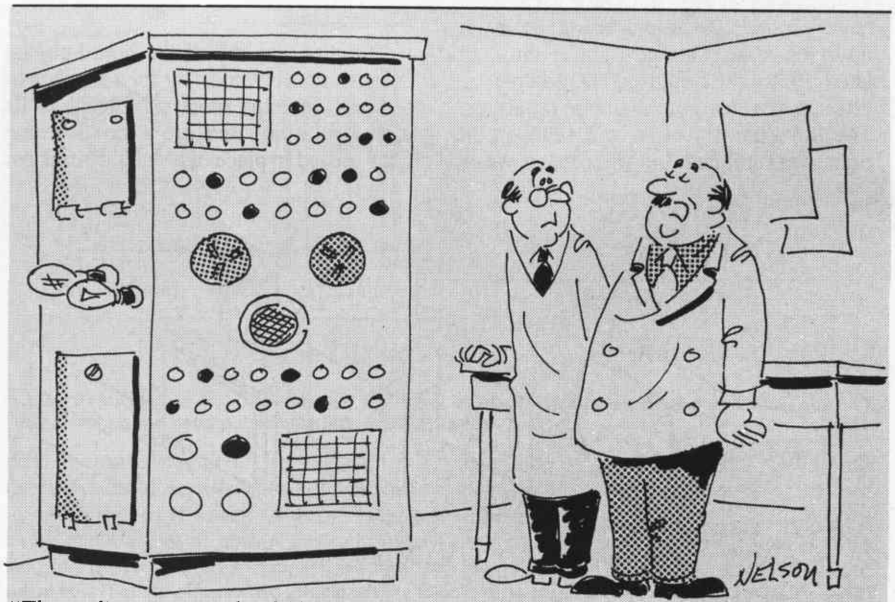
The use of color allows users to overcome many of the shortcomings of traditional oscilloscopes. For instance, in the past, one problem has been how to display multiple traces while taking advantage of the full vertical resolution of the oscilloscope. When the traces are of one color, confusion often arises when those traces are overlaid. In the *5116*, the use of color eliminates that problem. The channel-1 and channel-2 traces are, of course, displayed in their designated colors; with the areas of the waveform overlap shown in neutral.

Of course, one of the key factors in the eventual success or failure of liquid-crystal color shutter technology is its cost to implement. Right now, the only indication of that cost is found in the *5116*. The basic *5116* color oscilloscope carries a suggested list price of $2335. That scope is the color version of the monochrome *5110*, which is priced at $1505. That boils down to a cost of $830 for the color shutter alone.

Note, however, that the prices quoted above are for basic models. When the *5116* is mated with the *5D10* waveform digitzer (which turns the *5116* into a color digital-storage-oscilloscope) the total cost becomes $5185. At that price level, the $830 for the color shutter does not represent quite as large a percentage of the total cost. Just as with any technology, however, it is reasonable to assume that as production picks up, costs will drop, making the color shutter an extremely attractive display option.

As time goes on then, it is reasonable to assume that the color shutter will be used in a wide variety of products and applications. In addition, it is likely that it will be used in a variety of non-Tektronix products. That's because the manufacturer has recently announced that it intends to sell the new technology to other companies for use in their products.

In summary, the liquid-crystal color shutter, with its dual properties of color and high resolution, offers instrument manufacturers an attractive alternative to other types of color displays. It is reasonable to assume that we'll be seeing them in a great number of products before too long. **R-E**



"The audio response should have a deeper—John Barrymore—voice."