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SEMINAR M-3:

ACTIVE-MATRIX LCDs

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Summary

This seminar will describe the principles of matrix-addressing techniques and the evolution of AMLCDs which has resulted in the broad availability of personal information displays. Technology innovations which are expected to futher broaden the market for AMLCD-based products will also be described.

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NOTES

AMLCDs

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Introduction

Over the last 25 years we have witnessed the emergence and evolution of a new class of high technology products, which we can generally describe as personal information displays. Very shortly the net revenue attributed to the display component of this product class will exceed 20 billion dollars, yet at the onset of this evolution, the extent of this product was wrist watches utilizing Light Emitting Diodes, LEDs. As is the case today, the objective was to provide the maximum information content within the constraints of a portable product. To illustrate the magnitude of this evolution the LED watch display circa 1970 may have utilized some 28 display elements operating in a binary monochrome mode with a data update rate of one minute and a power consumption which prohibited continuous viewing for more than a few minutes. In comparison today's portable display screens may provide more than one million full color elements with an update rate of 60 Hz, and it can be used continuously for a few hours.

If one is allowed to use the product of these metrics to gauge the technology growth that has taken place, it results in the remarkable factor of 10^{10} over a 25 year span. The contribution of Active Matrix LCD to this evolution has been most pronounced over the last decade as illustrated in Figure 1 and 2.

LCD Evolution

The single technology which facilitated this evolution was the utilization of the twisted nematic, TN, configuration of liquid crystal, LC, materials. Initial exploitations of LC utilized the Dynamic Scattering mode of operation but was disadvantaged due to limited contrast, temperature dependency, and poor lifetime performance. It subsequently emerged that the TN mode would become the foundation for virtually all subsequent portable display products and continues to remain so. This is not to say that there have not been major advances and alternative configurations which have also emerged during this period of time and this topic will be addressed within this seminar.

To begin with, LC technology offers the opportunity to mechanize a light valve and in itself is non-emissive. It simply and to a sufficient degree by the influence of an electric field is able to vary the transmission of light (Figure 3). If it were an ideal light valve it would provide

100% transmission in the on-state and zero transmission in the off-state and would thus provide infinite contrast.

$$Contrast = \frac{T_{ON}}{T_{OFF}} \tag{1}$$

The TN mode is based on the properties of polarized light and the ability to rotate the plane of polarization as it propagates through the cell. The source of polarized light is created by an input polarizer which will have overall through-put of about 42% and since the output polarization state has to be analyzed in an output polarizer which will have a maximum transmission of about 85%, the T_{on} level is limited to 36%. In a practical display transparent electrodes of Indium Tin Oxide, ITO, are used to create the field effect thus reducing the transmission by at least 8%. This then limits the overall throughput, T_{ON} to about 30%.

The off-state transmission is somewhat more difficult to precisely quantify since first order models indicate that for monochromatic light a genuine zero condition can be achieved. In practice, this does not occur due to a number of causes such as, non-ideal polarizer operation and LCD molecular alignment, fringe fields at the edge of the active area and leakage contributed by the presence of spacers within the structure. The consequence is that:

Contrast (Normally Black - Parallel Polarizers) is typically

$$\frac{0.3}{0.01} = 30 \tag{2}$$

whereas Contrast (Normally White - Orthogonal Polarizers) is typically

$$\frac{0.3}{0.003} = 100 \tag{3}$$

to more than $$\frac{0.3}{0.001} = 300\,. \tag{4}$$

These values apply normal to the display and we are all aware that they are not sustained when viewed off-axis. They also rationalize why the vast majority of TN displays are configured in the Normally White mode. In the twisted state, the attainment of precisely 90° rotation requires that the cell spacing be in a specific relationship with respect to the birefringence of the LC fluid and in any event is wavelength dependent. This understanding was provided by Gooch and Tarry and explains the reason for the limited contrast of NB as well as the familiar purple coloration encountered in the off-state[4] (Figure 4).

A similar situation prevails in the NW mode but in this case it corresponds to the on-state and a slight imbalance in the relative transmission of green with respect to blue/red is not noticeable (Figure 5).

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