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# Characterization of a Liquid Crystal Television Display as a Spatial Light Modulator for Optical Processing

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## Abstract

The recent availability of inexpensive, video-addressable liquid crystal displays has generated interest in the use of such devices for optical processing applications. This paper will present some pertinent performance characteristics for a device of this type, the Radio Shack (Tandy Corp.) Pocketvision. Specific characteristics to be considered are screen transmission, linearity, modulation depth, modulation transfer function (MTF), temporal response and optical flatness. Examples of device performance as a coherent and incoherent processing element will be briefly considered.

## Introduction

Display devices using video-addresssed liquid crystal arrays have recently become available at a cost some two orders of magnitude less than devices based on competing technologies, represented by optically-addressed liquid crystal, or electronically-addressed magneto-optic. The video-addressed liquid crystal devices were originally intended for display applications, and hence their performance as optical processing elements is not optimum.

The thrust of this paper is to present some performance characteristics for a representative device, which are pertinent to its use as an optical processing element. Its performance may be sufficient for some applications, and can represent a reasonable compromise for those researchers desiring a means to investigate application areas, without an extensive investment in hardware.

## Basic screen characteristics

The device requires two initial modifications in order to be useful. A diffusing screen must be removed, and the hinge mechanism which holds the display at a 45 degree angle can be modified so that a straight optical path through the device can be configured.

The display consists of 140 pixels horizontal by 120 pixels vertical, which are addressed by a standard RS-170 video input. Modulation of the transmitted light occurs via the twisted nematic effect. The pixels are at the intersection of transparent drive electrode lines, and have dimension .33 mm by .33 mm, with a border of .01 mm around each pixel.

## Measurement of performance characteristics

Many of the parameters to be described herein are dependent on the so-called reference voltage $V_{ref}$, which varies with the brightness control and with the input video signal level. A specification of the reference voltage provides a convenient means to quantify the signal actually impressed upon the display. The particular test point used to measure $V_{ref}$ is shown in the technical service manual[1] as adjacent to the center conductor of the flexible ribbon cable on PCB1. For the measurements to follow, the video level was initially set to correspond to a "white" screen, and $V_{ref}$ was varied using the brightness control.

Measurements were made with a plane-polarized Helium-Neon laser, with the plane of polarization adjusted for maximum transmission through the input polarizer. The specific characteristics to be measured on the device are the following: screen transmission vs. $V_{ref}$, modulation depth vs. $V_{ref}$, modulation transfer function (MTF), temporal response, and optical flatness.

## Screen Transmission

A plot of screen transmission vs. $V_{ref}$ is shown below. The transmission varies between ≈ 1% and 50%. A nearly linear relationship is seen over most of the dynamic range, indicating that the device would be useful as a modulator where a grey scale filter is desired. This measurement was made with an unexpanded laser beam of diameter 2 mm. Recalling that the laser beam was linearly polarized, the 50% value of maximum transmittance indicates an excess loss present in the polarizers.

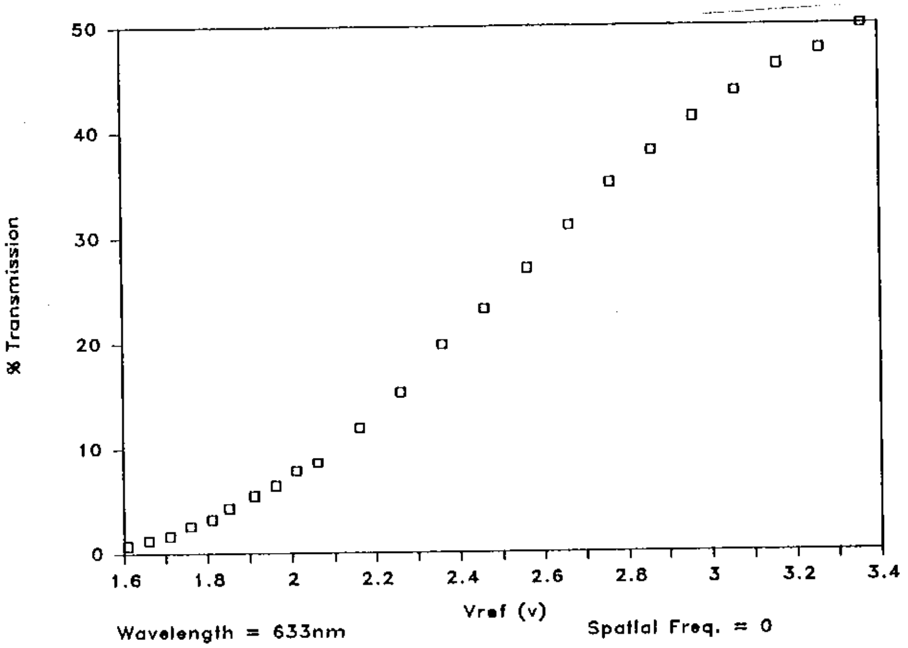

Figure 1. Screen transmittance vs. $V_{ref}$

## Modulation Depth

A plot of modulation depth vs. reference voltage is seen in figure 2. The measurements were made at zero spatial frequency, that is, by comparison of uniform bright and dark screens. An unexpanded, polarized laser beam was used. The usual formula for modulation depth was used:

$$M = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} , \qquad (1)$$

where $I_{max}$ is the transmitted power for a bright screen, and $I_{min}$ is the transmitted power for a dark screen. Note that the peak modulation depth of .67 occurs at $V_{ref}$ = 1.75 volts, where (from figure 1) the overall transmission of the screen is ≈ 2%., so that a compromise between modulation depth and signal level will usually be necessary.

A plot of modulation depth for reflected light vs. reference voltage showed a complementary shape, but was of much smaller magnitude, on the order of $10^{-3}$. This indicates that the primary modulation mechanism is absorptive, and one cannot conveniently use the reflected light, with the present configuration.

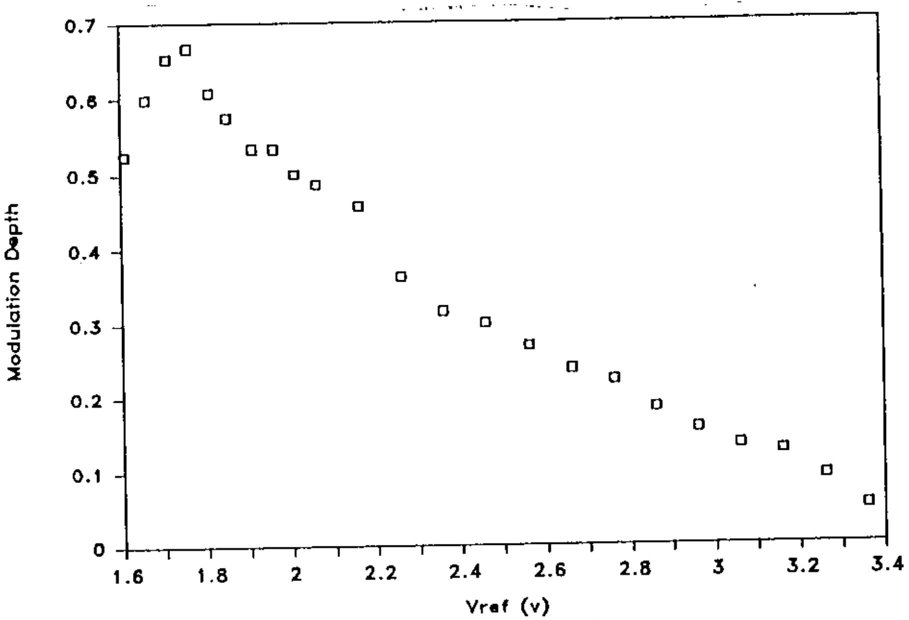

Figure 2. Modulation depth vs. $V_{ref}$

Modulation transfer function

The MTF curve seen in figure 3 was measured by driving the display with an assortment of square wave patterns of increasing spatial frequency. The laser beam was focussed to a spot smaller than the size of a single pixel. The maximum and minimum transmittances were measured, as an inverse video operation was performed on the input signal. This allowed the measurement to be performed without moving the laser spot across the array. The reference voltage was set to 1.75 volts, yielding maximum modulation depth.

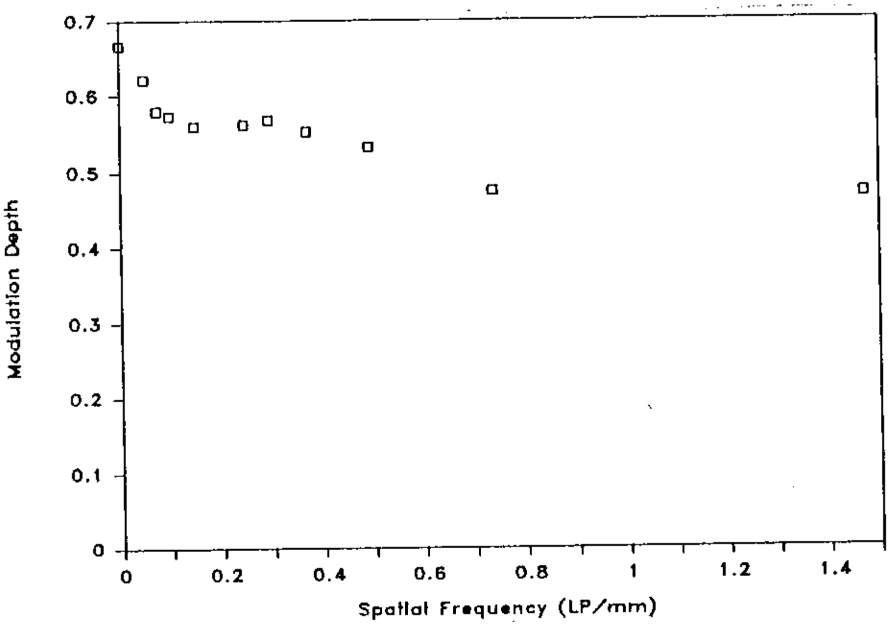

Figure 3. Modulation Transfer Function

The MTF plot shows that the array has a fairly flat transfer function, out to the Nyquist frequency of the array, indicating a minimal amount of cross-talk between pixels. A pixel spacing of .33 mm yields a spatial Nyquist frequency of 1.5 cycles/mm. At that frequency, the value of the transfer function is down by ≈ 25% relative to its value at zero spatial frequency. Thus, the useful resolution of the device is limited by the pixel spacing, rather than the MTF.

## Temporal response

The image on the display is written one line at a time, by pulsing the electrode lines. This makes the individual pixels transmissive, in proportion to the input video signal. The refresh rate is 60 Hz. The curve seen in figure 4 is the transmission of a single pixel, as a function of time. Note that increasing transmission is in the down direction for that curve. For most applications, the transmission averaged over several refresh cycles will be the quantity of interest, since the pixel response is seen to decay until the onset of the next refresh pulse.

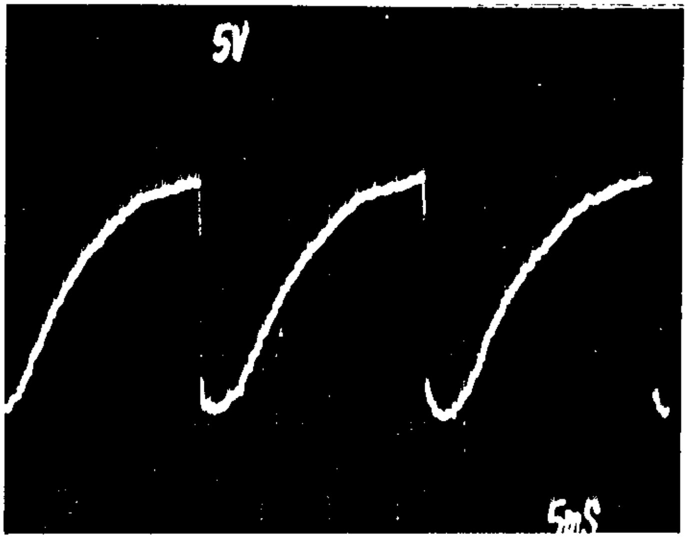

Figure 4. Time dependence of transmission of a single pixel

## Optical flatness

The optical quality of the device "as is" is quite poor, for coherent optical processing applications. This is evidenced by the interferogram seen in figure 5, which tests the display in a double-pass configuration at $\lambda = .633\ \mu m$. There have been recent publications[2,3] which indicate that the major source of degradation of wavefront quality is the plastic film polarizers which are attached to the liquid crystal array, and that improvements are possible by replacing the polarizers, or by the addition of a liquid gate.

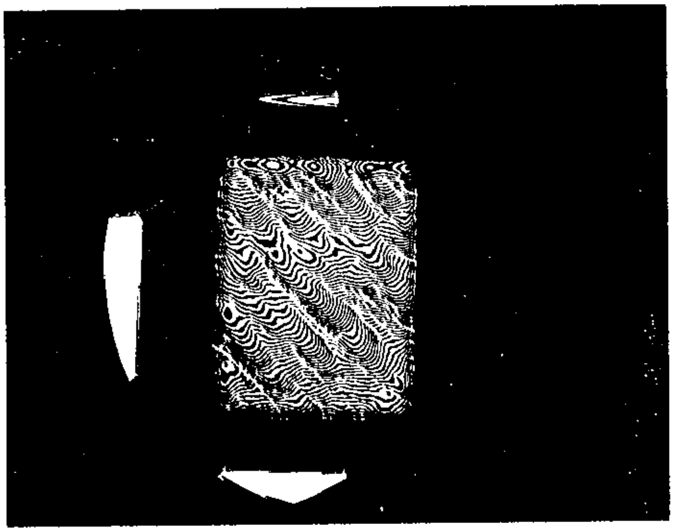

Figure 5. Double pass transmission interferogram

## Example of coherent processing - spatial filtering

The setup seen in figure 6 allows viewing of the Fresnel diffraction pattern of a transparency. This was used to investigate the utility of the display for spatial filtering. The device was placed in the Fourier transform plane, and allowed modification of the Fresnel pattern and of the image. An intermediate observation plane was chosen for this demonstration instead of the image plane, in order to be able to visualize the effect of the large amount of phase distortion on the filtering process. This phase distortion caused images seen in the final image plane to be of unacceptable quality.

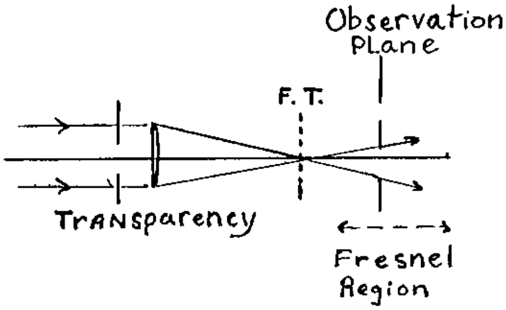

Figure 6. Coherent processing setup

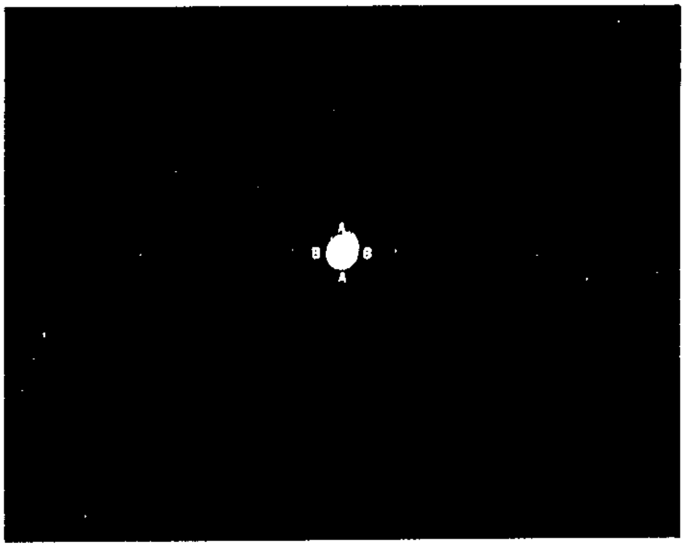

Figure 7. Fresnel pattern without filtering

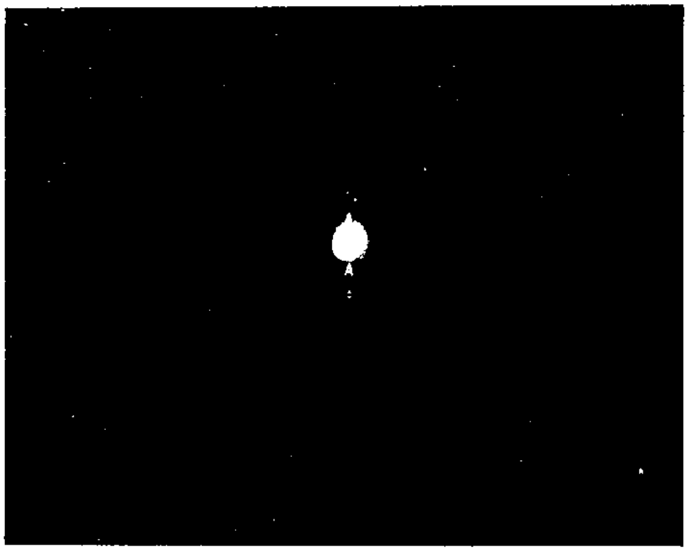

Figure 8. Fresnel pattern with knife edge slit at Fourier plane

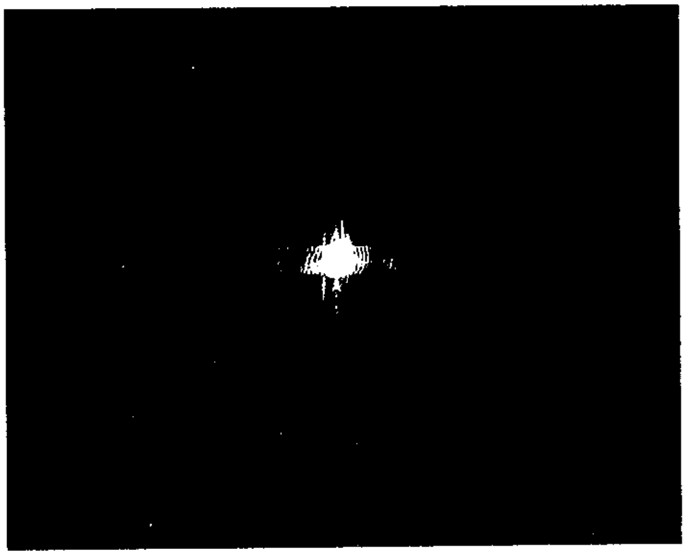

Figure 9. Fresnel pattern with SLM slit at Fourier plane

## Incoherent Processing

These devices may find utility in the context of incoherent processing systems[4], where they could replace a moving slit or reticle and function as a programmable mask. A simple demonstration of such use is provided by the example of image multiplication seen in figure 10. A transparency was placed in contact with the SLM, backlit and photographed.

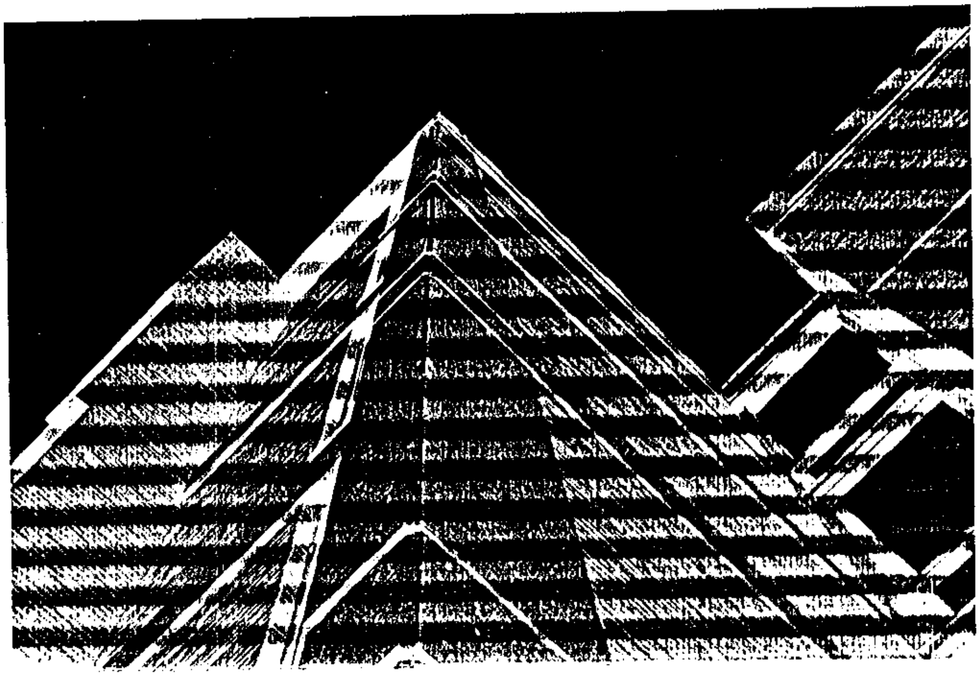

Figure 10. Image multiplication

## Conclusions

Performance characteristics were presented for the Radio Shack Liquid Crystal TV display. Characteristics considered were: transmittance/linearity, modulation depth, MTF, temporal response and flatness. Examples of use of this device in coherent and incoherent processors were shown.

## Acknowledgements

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## References

1. *Technical Service Manual, Model 16-151*, Tandy Corp., Ft.Worth, 1983.
2. Young, M., "Low cost LCD video display for optical processing", *Applied Optics*, Vol. 25, #7, p.1024.
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4. Rogers, G.L., *Noncoherent Optical Processing*, Wiley, 1977.