

56.3: Active Matrix LCD with Integrated Optical Touch Screen

Willem den Boer, Adi Abileah, Pat Green, Terrance Larsson,

Scott Robinson and Tin Nguyen
Planar Systems, Inc., Beaverton, Oregon

Abstract

A 2.4 in. by 2.4 in. TFT LCD is presented with an embedded 60x60 array of a-Si photo sensors, for use as a high performance touch-enabled LCD with low cost. In the shadow mode the optical touch screen operates with finger or stylus input under ambient lighting conditions from 50 lux to 50 klux.

1. Introduction

TFT LCDs with touch screens have become popular in displays for industrial and retail applications, as well as in PDAs and emerging tablet PC products.

The majority of touch-enabled AMLCDs are based on resistive, capacitive or inductive touch technology. All these solutions require externally added components or screens, which add cost and reduce optical performance. For example, the most commonly used and currently lowest cost approach is based on resistive touch panels, which reduce display transmittance by about 20 %, increase reflectance and have a limited lifetime.

There is a need for a more integrated touch screen technology that does not significantly degrade the optical performance and will further reduce cost and improve lifetime.

In this paper, we present a prototype 2.4 in. x 2.4 in TFT LCD with an integrated array of optical sensors, which, after image processing, provides the XY location of a shadow cast by a stylus or finger touch.

2. Photocurrent in a-Si TFTs

It is well known that a-Si TFTs exhibit a high photocurrent when exposed to visible light (see figure 1). For the pixel switches in AMLCDs a low OFF current is required to retain charge on the pixels during the frame time. The channel of the a-Si TFT is, therefore, shielded from the backlight by the gate metal and from ambient light by the black matrix on the color plate. In this paper a method is shown to take advantage of the photosensitivity of a-Si TFTs and integrate an optical sensor array into the AMLCD, for example for touch detection.

The photocurrent in a-Si TFTs is proportional to the channel width/length ratio W/L , as verified by measurements on TFTs with different W/L . A reduction of channel length L , which reduces the photosensitive area and number of absorbed photons in the channel, actually leads to an increase in the photocurrent. This observation is counterintuitive, but can be explained by the fact that the photocurrent in the a-Si TFT is a secondary photocurrent with a gain that can exceed unity. The photogenerated electrons in the channel are replenished from the ohmic n+ contacts at the source and drain. Therefore, more than one charge carrier per absorbed photon contributes to the photocurrent when the lifetime of the photogenerated electrons exceeds their transit time from source to drain. For channel length less than about 20 μm the gain

exceeds unity. This is in contrast with the primary photocurrent in a-Si PIN photodiodes, which always has a gain less than one.

The measured photocurrent in back-channel-etched a-Si TFTs with $L = 6 \mu\text{m}$ exceeds the maximum possible photocurrent in a-Si PIN photodiodes with the same photosensitive area by more than an order of magnitude.

This high photosensitivity of the a-Si TFT makes it possible to obtain enough signal from a small photo TFT in a corner of the LC pixel, without sacrificing much pixel aperture.

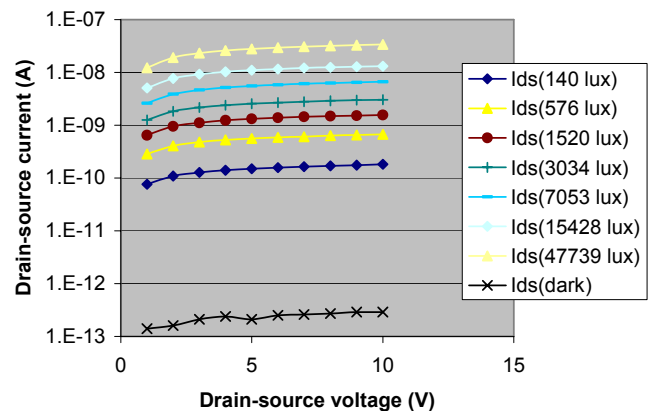


Figure 1. Measured photo-current under varying light intensity for an a-Si TFT with gate shorted to source and $WL = 36 \mu\text{m} / 6 \mu\text{m}$

3. TFT LCD with embedded sensor

A 240x240 pixel TFT LCD was built with sensors interspersed between the pixels at every 8th row select line and every 8th column data line (figure 2). The display is based on an existing avionics LCD platform with an RGBW (Red, Green, Blue, White) quad pixel format. The optical sensors are located at every 4th white subpixel. Each sensor circuit consists of an a-Si phototransistor with gate shorted to source, a storage capacitor C_{st} and a readout TFT. The readout TFTs are connected to added readout lines running parallel to the column data lines.

The phototransistors are connected to a photocircuit bias line which is common for all sensor elements and is held at 0 to -10 V. The photo transistor discharges the storage capacitor when exposed to ambient light through a hole in the Black Matrix (figure 3). The sensor circuits share the same select line with each 8th row of display pixels. Therefore, the row and column drivers are identical to those in a TFT LCD without the optical sensor array.

The photosensitive TFTs and readout TFTs are manufactured in the same process as the addressing TFTs for the AMLCD, so that

the processing is identical to that for a conventional TFT LCD without sensor array. The added photo circuit requires only a fraction of the subpixel area and has therefore a minor impact on the pixel aperture and transmittance of the display.

The 60 readout lines for the 60x60 photo sensor array are connected to a readout chip with 60 channels of charge amplifiers as inputs. This chip converts the readout charges to voltages that are multiplexed to a serial signal for output to an A/D converter and subsequent image processing. The timing for the signal acquisition and data output of the readout chip is derived from the display controller and synchronized with the display driving at a frame rate of 60 Hz.

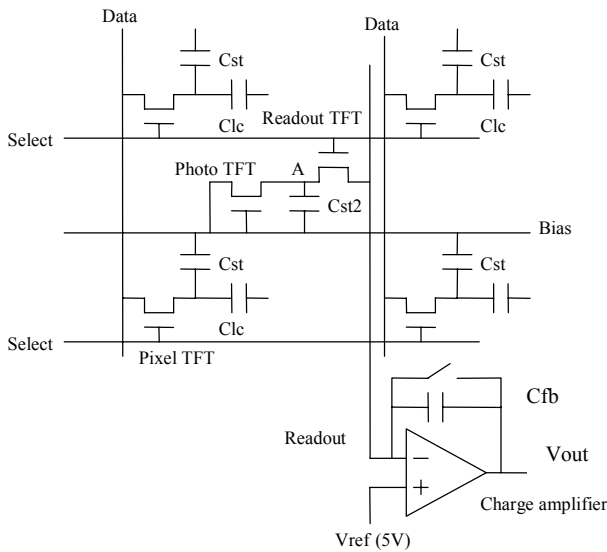


Figure 2. Circuit diagram of four display pixels and one sensor circuit

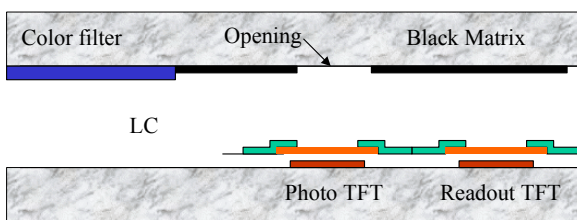


Figure 3. Cross-section of readout and photo a-Si TFT with opening in black matrix

When the display is touched, the ambient light is locally blocked at one or a few of the photo sensors (figure 3). The surrounding photo sensors are exposed to the ambient light through the opening in the black matrix. Their storage capacitors will be partially or completely discharged. Each time a row of photo sensor circuits is read out, a current flows through the readout lines that is proportional to the integrated light exposure on the phototransistor during the preceding frame period.

4. Operation of the sensor circuit

The sensor circuit design was optimized with SPICE simulations. Its basic operation can be understood from the plot of voltage vs. time on node A between the readout transistor and phototransistor (figure 4). While the charge on the capacitor C_{st2} is read out, its voltage is reset to the original value. For example, when the voltage on the photo circuit bias line is -5 V and the reference voltage for the charge amplifier is 5 V , the voltage across the capacitor C_{st2} will be reset to 10 V .

The full well capacity or saturation charge Q_{sat} is given by:

$$Q_{sat} = C_{st2} * (V_{ref} - V_{bias}),$$

where V_{ref} is the reference voltage of the charge amplifier and V_{bias} is the voltage on the photocircuit bias line.

The output voltage V_{out} of the charge amplifier is:

$$V_{out} = \frac{\int_{t_0}^{t_0+T_f} I_{ph}(t) dt}{C_{fb}},$$

where $I_{ph}(t)$ is the photocurrent in the photo TFT, t_0 is the readout time, T_f is the frame time and C_{fb} is the feedback capacitor in the charge amplifier. Normally, the photocurrent is constant during the frame time, but in some applications with a fast moving stylus, such as handwriting, I_{ph} can vary during the frame time. The maximum readout voltage V_{outmax} depends on the full well capacity:

$$V_{out\ max} = \frac{C_{st} * (V_{ref} - V_{bias})}{C_{fb}}$$

In our design C_{st} was 0.22 pF and C_{fb} was variable between $1, 2, 4$ and 16 pF .

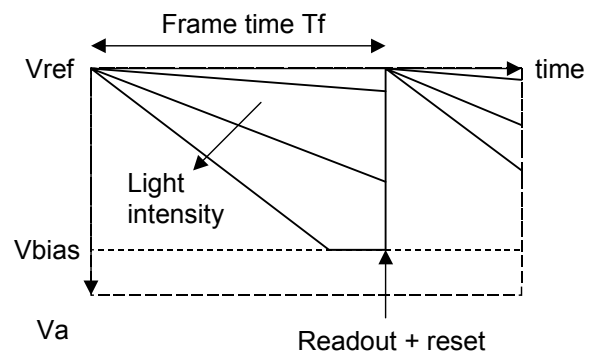


Figure 4. Voltage vs. time at node A of figure 2

5. Performance of the touch panel

The analog sensor signals from the readout chip are digitized in a National Instruments data acquisition card controlled by a LabVIEW™ program. The sensor image is processed in the LabVIEW™ environment according to the flow diagram in figure 5. The captured image is first corrected for the possible presence of defective sensors, followed by a normalization using stored light reference and dark background calibration maps. The processed image is then smoothed and edge detection is used to enhance the location of touch by finger, stylus, light pen or laser pointer. When the signal exceeds a threshold, a touch event occurs, a center of gravity analysis determines the XY location of the touch and the display screen is updated. Figure 6 shows a typical measured map of sensor signals with a touch input from a stylus. Figure 7 shows the color LCD with input from a finger touch and the notebook computer with the LabVIEW™ images.

We have also implemented the algorithms into a standard low cost Digital Signal Processor.

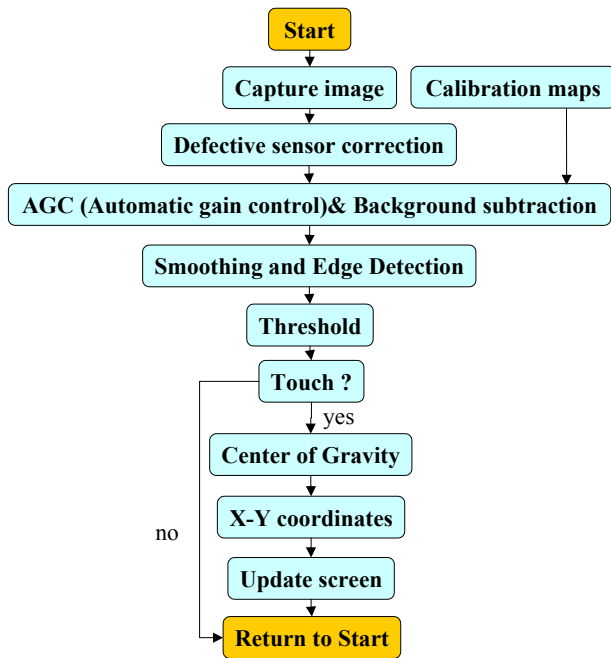


Figure 5. Image processing flow for touch detection

We verified that the touch panel operates in the shadow mode by blocking ambient light locally, as well as in the excess light mode with a laser pointer or light pen. A summary of specifications is listed in Table I.

Since this type of touch panel is actually a low resolution image sensor, simultaneous input at two or more locations is possible, a unique feature not seen in other touch technologies. Another benefit of the array of photo sensors is that their average or individual signal can be used as a measure of the ambient light intensity and can therefore control the back-light intensity without adding an external photo-sensor.

Table I. Specifications of prototype AMLCD with integrated optical touch screen

Display size	2.4 x2.4 in.
Pixel count	240x240 RGBW pixels (480x480 subpixels)
Integrated optical sensor count	60x60
Sensor pitch	0.96 mm
Touch Input modes	Shadow mode: Stylus, finger Excess light mode: Laser pointer, light pen
Ambient light operating range	50 lux to 50 klux in shadow mode 0 to 1000 lux in excess light mode
Resolution	> 500 dpi (with interpolation between sensors)

In dark or very low ambient lighting conditions the optical touch screen can not operate in the shadow mode. In this case a controlled light source, such as a light pen, is needed. When the touch targets on the display transmit sufficient light, it is also possible to utilize the light reflected from the backlight by the finger or stylus to detect the touch location.

6. Conclusions

The integrated optical touch screen improves the optical performance of touch-enabled AMLCDs, lowers their weight and volume, simplifies their construction with a reduced number of components and potentially lowers their cost significantly. We calculated that, when the sensor circuit occupies 15 % of the blue sub-pixel area, the overall reduction in transmittance is less than 3 %. Since the Active Matrix array including the sensors can be processed on a standard TFT LCD line without a change in the process, the added cost to the AMLCD manufacturer is minimal, while the touch function adds value to the LCD module.

For small handheld applications current touch solutions are already low cost. To further reduce cost of optical touch in small displays the charge amplifiers for sensor readout could be integrated into the column data driver and image processing functions may be implemented in the main processor. As a result, the added cost of touch functionality can be minimized.

7. Acknowledgements

The authors express their appreciation to AU Optronics for manufacturing the TFT LCD backplanes with embedded sensor array and to Kirk Hargreaves of Synaptics, Inc. for his contributions to the electronics design. We are also grateful to Tom Baker, Peter Kurahashi, Brent Leback and Matt Spiegelberg for their support in software and algorithm development and to Chris Fey for measurements of photocurrents in a-Si TFTs.

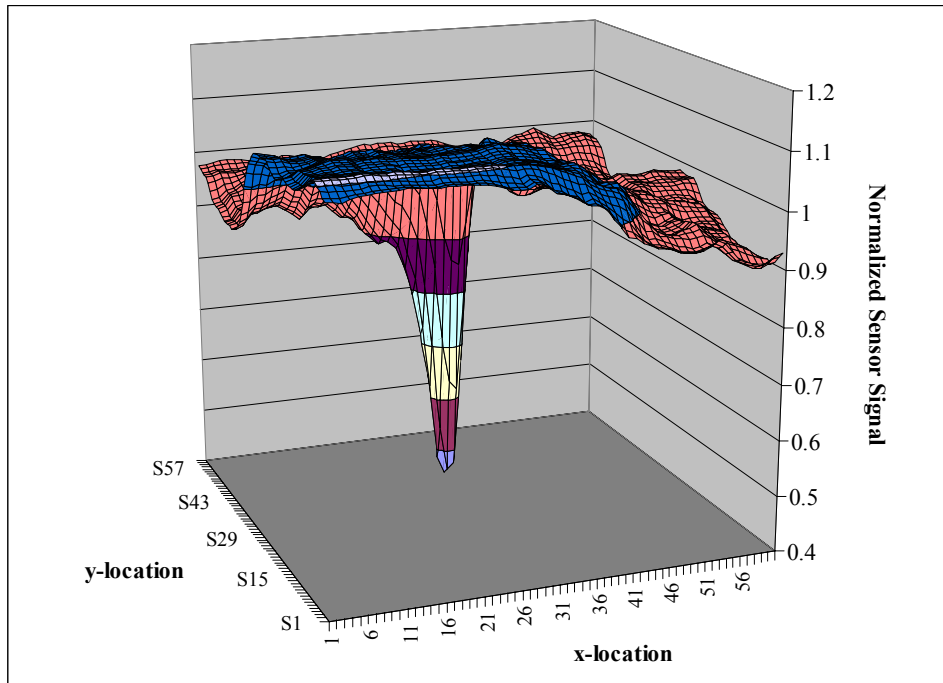


Figure 6. Measured signal map with stylus input after background subtraction and AGC

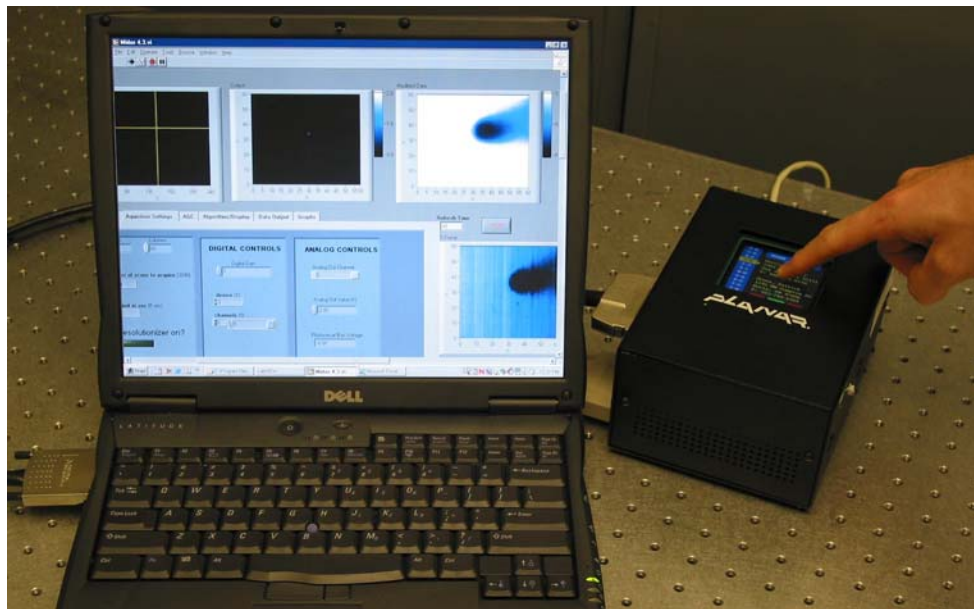


Figure 7. Photograph of prototype TFT LCD with Integrated Optical Touch Screen at the right side. The LabVIEW plots on the notebook show the image of a finger touch and a cross-hair indicating location of touch.