A System LCD with Integrated Infra-Red Sensing Optical Touch Panel

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ABSTRACT

We describe a System LCD with integrated infra-red sensitive optical touch panel. The touch panel function is achieved by an image sensor containing a novel pixel circuit with in-pixel amplification and temperature compensation. The high sensitivity and robustness of this circuit enable adoption of the touch panel in mobile devices.

1. INTRODUCTION

The recent trend towards touch-enabled portable multimedia devices has led to the development of a diverse range of touch panel technologies aimed at meeting the ideal requirement of robust multi-point, arbitrary object detection in a low-cost and mechanically compact display module. In addition to the standard resistive and capacitive type overlays, notable touch panel technologies reported to date include optical waveguide [1] and “in-cell” micro-switch [2] or capacitance [3] sensors. Optical touch panels using image sensor arrays integrated onto the TFT substrate of LCDs [4] have the potential to outperform all other competing technologies (Fig.1) although commercial products using this technology have to date not materialized in number due to the difficulty of achieving robust detection of touch events under all environmental conditions.

In this paper we present a System LCD with integrated optical touch panel suitable for battery powered mobile products in which robust operation is achieved through the use of a TFT-based image sensor that is sensitive to infra-red illumination. The image sensor overcomes its inherently low sensitivity to infra-red (IR) light with a novel 1-transistor active pixel sensor (1T APS) circuit which uses a voltage-dependent capacitor structure to perform in-pixel amplification. The sensor also includes a temperature compensation circuit enabling it to operate under a wide range of environmental conditions.

2. ACTIVE PIXEL SENSOR CIRCUIT

2.1 1-Transistor APS

The basic building block of the image sensor is the 1T APS comprising: a single TFT, M1; a thin-film lateral PIN photodiode, D1; and an integration capacitor, CINT. The operation of this 1T pixel circuit has been previously reported [4] and is now briefly described with reference to the circuit diagram of Fig. 2(a) and the waveform diagram of Fig. 3. During a first reset period, the reset signal RST is pulsed high and the integration capacitor is reset to its initial value via the forward biased photodiode. When RST is pulsed high and the integration capacitor is reset to its initial value via the forward biased photodiode. When RST is pulsed high and the integration capacitor is reset to its initial value via the forward biased photodiode. When RST is pulsed high and the integration capacitor is reset to its initial value via the forward biased photodiode.

Fig. 1 Comparison of selected touch panel technologies

<table>
<thead>
<tr>
<th>Overlay Type</th>
<th>Optical Waveguide Type</th>
<th>In-Cell Type</th>
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<tbody>
<tr>
<td>Added Thickness</td>
<td>Resistor</td>
<td>Projected Capacitance</td>
</tr>
<tr>
<td>Transparancy</td>
<td>×</td>
<td>Δ</td>
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<tr>
<td>Flat Surface Design</td>
<td>Δ</td>
<td>Δ</td>
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<tr>
<td>Input Method</td>
<td>Finger</td>
<td>×</td>
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<td></td>
<td>Glove</td>
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<td></td>
<td>Image</td>
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<td></td>
<td>Input Accuracy</td>
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<td></td>
<td>Multi-Point</td>
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<td></td>
<td>Response Speed</td>
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<td>Cost</td>
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Fig. 2 Schematic diagrams of (a) standard 1T APS (b) new 1T APS with voltage-dependent capacitor
the threshold voltage of the source follower transistor M1 turning it off.

The advantages of this 1T APS include an increased aperture ratio and reduced pixel sample time compared to a standard three transistor (3T) APS. However, due to its dual purpose, the size of the integration capacitor becomes a trade-off between sensitivity to incident illumination and pixel output voltage range: a small capacitor gives a large voltage drop on the integration node during the integration period but reduces the voltage rise in the sample period.

For robust operation, not only must the touch panel operate under a wide range of ambient illumination conditions but any dependency between the image detected by the sensor and the image shown on the display must be avoided. It is therefore necessary to illuminate the sensor with IR light to which the display is substantially transparent and does not modulate – see Fig.

4. To this end, IR LEDs are added to the display module backlight and a high-pass IR filter is added over each photodiode.

However, whilst the use of IR illumination solves the problem of display image dependency, the thin-film lateral photodiode D1 is relatively insensitive to IR illumination (Fig. 4) and, with the trade-off described above, the integration capacitor cannot be scaled to compensate for this reduced signal. This low sensitivity can be overcome - and a large output range achieved - by increasing the intensity of the IR source illumination but, for mobile products, this leads directly to a significant reduction in battery lifetime. Accordingly, a method of increasing the pixel sensitivity to infra-red illumination without sacrificing other performance parameters is required.

2.2 In-Pixel Amplification

An effective method of achieving high sensitivity whilst maintaining the benefit of the other advantages of the 1T APS is to provide a voltage amplification function within each pixel. Such an amplification function can be achieved by replacing the standard integration capacitor with a voltage-dependant MOS capacitor structure which acts to “gate” the charge injected on the rising edge of RWS. This voltage-dependant integration capacitor may be embodied as a p-type TFT (Fig. 5) and arranged to form a new 1T APS circuit as shown in the schematic diagram of Fig.2 (b). The operation of this circuit is now described with reference to this schematic and to the waveform diagram of Fig 6. During the integration period the potential difference between the integration node and the row select signal RWS, \( V_{\text{CAP}} \), exceeds the threshold voltage of the voltage-dependent MOS capacitor structure M2, \( V_{\text{TC}} \). The MOS capacitor structure is therefore turned on at the start of the sample period, \( t_0 \), and, as RWS begins to rise, charge is injected onto the integration node at a rate proportional to \( C_{\text{INT}} \) which is equal to the capacitance of the entire structure. However, since the integration node rises at a slower rate than RWS, at some
point during the rise time of RWS $V_{\text{CAP}}$ will fall below $V_T$ and the MOS capacitor structure will turn off. At this point, charge will continue to be injected onto the integration node but at a significantly lower rate proportional to only the overlap and parasitic capacitance of the structure, $C_{\text{INT}}'$. In the case of low incident light intensity, $V_{\text{CAP}}$ is large at the start of the sample period and a large amount of charge is injected onto the integration node before the active capacitor turns off at $t_2$. However, in the case of a high incident light intensity, $V_{\text{CAP}}$ is closer to $V_T$ at the start of the sample period and relatively little charge is injected before turn off at $t_1$. This difference in injected charge is the source of the amplification effect: the difference in $V_{\text{INT}}$ due to incident light intensity during the sample period, $\Delta V_{\text{INT}}@t_3$, is larger than during the integration period, $\Delta V_{\text{INT}}@t_0$.

### 2.3 Compensation for Temperature Effects

An undesirable side effect of increasing the sensitivity of the pixel to infra-red illumination as described above is that the sensitivity of the pixel to thermally induced dark current in the photodiode is also increased. As a result, the effective output voltage range is reduced as a large proportion of the output signal is simply the dark current offset. In order to maximize the output voltage range, a second photodiode, $D_2$, which is shielded from incident light is added to the pixel circuit. The current of this reference photodiode, $I_{\text{DARK2}}$, is subtracted from that of the first sensing photodiode, $I_{\text{PHOTO1}}$, such that, if well matched and $I_{\text{DARK1}} = I_{\text{DARK2}}$, the integrated current is simply the photocurrent of the sensing photodiode, $I_{\text{PHOTO1}}$. This compensation method may be combined in a display pixel and with the voltage-dependent integration capacitor in a novel arrangement, as shown in Fig 7. Here, p-type TFTs $M_{2a}$ and $M_{2b}$ form the integration capacitor and provide the in-pixel amplification effect. In addition, $M_{2b}$ acts as a switch to prevent the forward biasing of the reference photodiode during the sample period.

### 3. SYSTEM LCD MODULE

The complete block diagram of the module incorporating the System LCD with optical touch panel is shown in Fig. 8. The active matrix incorporates the combined sensor display pixel described above and this is integrated along with the display and sensor row driver circuits onto the TFT substrate of the LCD panel. The display source driver and sensor read-out circuits (including analogue-to-digital converter) are contained in a chip-on-glass which is bonded directly to this TFT substrate. The panel itself is connected to a flexible circuit board containing ICs to drive the LCD and backlight and to process the raw sensor output data. This latter ASIC executes an algorithm to recognize touch events and extract the touch point location data and communicates this data to the host.

### 4. RESULTS

A 4in WVGA System LCD incorporating the pixel circuit described above has been fabricated and the performance improvements experimentally verified. The system exhibited a 5x increase in sensitivity compared to a similar system using the standard 1T APS. For operation over an environmental temperature range of 10 to 70°C, the maximum deviation in output voltage range was reduced from greater than 80% - in the case of no compensation - to less than 5% (Fig. 9). In addition, by careful pixel layout design, there was no reduction in pixel aperture ratio compared to the standard 1T APS circuit due to the inclusion of the additional TFTs $M_{2a}$ and $M_{2b}$ and signal line VC.

### 5. CONCLUSION

The success of increasing the sensitivity of the image sensor without deleterious side-effects enables the use of low power infra-red illumination sources suitable for battery operated devices. As such, it is now possible to realize the full benefits of the optical touch panel and achieve an input device with robust multi-point, arbitrary object detection capability in a low-cost and mechanically compact mobile display module.
6. REFERENCES


Fig. 8 Block diagram of System LCD module

Fig. 9 Experimental results showing effect of temperature compensation circuit