if (...) {
    \text{print some code;}
    break;
}

Introduction to Sensors

Gabriel Hugh Elkaim
Mechantronic Systems

The world

World to signal
Sensor

Decision Maker

MC

Actuator

Number to world

Armure
World to Signal

Sensor Transducer → convert one physical phenomenon into another.

Signal Conditioning → need to add this to all of our sensors. Most sensors (e.g.,

Example:

Thermal
Pin/IR

CDs light sensor

μV → V
Thermostat

Next → Rotation
Rotation → Magnetic
Magnetic → Continuity

Sensor & Amplification
Sensor Development

Very very expensive to develop ~$1 Billion

- Military (Cost Insensitive)
- Automotive (Cost Sensitive)
- Medical/Pharma (~Development)
- Applied Physics
The Operational Amplifier

**Inverting**

- $V_{(+)} > V_{(-)}$  
  $V_{out}$

**Non-Inverting**

- $V_{(+)} < V_{(-)}$  
  $V_{out}$

**Negation Feedback**

- $V_{(+)} = V_{(-)}$
  - Output
  
**Inputs Draw No Current**

**$V_{out} = G \left( V_{(+)} - V_{(-)} \right)$**

**IDFNL**
Inverting Op-Amp

\[ V = IR \]

\[ i_1 = \frac{V_{in} - 0}{R_1} \]

\[ i_2 = \frac{0 - V_{out}}{R_2} \]

\[ V_{out} = -\frac{R_2}{R_1} V_{in} \]

\[ i_1 = i_2 \]
Non-Inverting Op-Amp

\[ i_1 = \frac{V_{in} - V}{R_1} \]

\[ i_2 = \frac{V_{out} - V_{in}}{R_2} \]

\[ V_{in} = \frac{V_{out} - V_{in}}{R_2} \]

\[ V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in} \]

\[ V_{out} = V_{in} \]

\[ R_1 = \infty \quad \text{and} \quad R_2 = 0 \]
What can the Microcontroller Measure?

Voltage

Analog

(DAC)

$0 - 3.3 \text{V}$

Digital

$(3.3 \text{V}, \text{low})$

$3.3 \text{V}$

$0 \text{V}$

Time - every microcontroller can measure

- Control Cycles
- Time / Cycles
- RTC (Real Time Clock)
Basic Sensors: Light

- Photocell

CdS - resistance varies with light

More light $\uparrow$

Spectral response is very close to the human eye.

Dynamic response is slow (mom)

- Power Reading

[Graph showing photocurrent vs. wavelength for CdTe and CdS with maxima at different wavelengths]
DARK ~ 200 kr

CdS Photocell Spec.'s

\[ R_{1000} = \left( \frac{10}{1000} \right) R_{10} \]

ABSOLUTE MAXIMUM RATING

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER</th>
<th>MIN</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{pk} )</td>
<td>Applied Voltage</td>
<td>150</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>( P_{d,apd/\lambda} )</td>
<td>Continuous Power Dissipation</td>
<td>100</td>
<td>mW/°C</td>
<td></td>
</tr>
<tr>
<td>( T_O )</td>
<td>Operating and Storage Temperature</td>
<td>-30</td>
<td>+75 °C</td>
<td></td>
</tr>
<tr>
<td>( T_S )</td>
<td>Soldering Temperature*</td>
<td>+260</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

* 0.200 inch from base for 3 seconds with heat sink.

ELECTRO-OPTICAL CHARACTERISTICS RATING

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>CHARACTERISTIC</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_D )</td>
<td>Dark Resistance</td>
<td>After 10 sec. @ 10 Lux @ 2856 °K</td>
<td>0.2</td>
<td></td>
<td></td>
<td>MO</td>
</tr>
<tr>
<td>( R_I )</td>
<td>Illuminated Resistance</td>
<td>10 Lux @ 2856 °K</td>
<td>3</td>
<td>11</td>
<td></td>
<td>KΩ</td>
</tr>
<tr>
<td>( S )</td>
<td>Sensitivity</td>
<td>LOG(R100)-LOG(R10)**</td>
<td></td>
<td>0.6</td>
<td></td>
<td>Ω/Lux</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOG(E100)-LOG(E10)**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \lambda_{range} )</td>
<td>Spectral Application Range</td>
<td>Flooded</td>
<td>400</td>
<td>700</td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td>( \lambda_{peak} )</td>
<td>Spectral Application Range</td>
<td>Flooded</td>
<td>520</td>
<td></td>
<td>nm</td>
<td></td>
</tr>
<tr>
<td>( t_r )</td>
<td>Rise Time</td>
<td>10 Lux @ 2856 °K</td>
<td>55</td>
<td></td>
<td>ms</td>
<td></td>
</tr>
<tr>
<td>( t_f )</td>
<td>Fall Time</td>
<td>After 10 Lux @ 2856 °K</td>
<td>20</td>
<td></td>
<td>ms</td>
<td></td>
</tr>
</tbody>
</table>

**R100, R10: cell resistances at 100 Lux and 10 Lux at 2856 °K respectively.**

***E100, E10: luminances at 100 Lux and 10 Lux 2856 °K respectively.***

---

Lux

154 BUCK

1.2 DARK

50 MOON

100 pmu candle

400 ohm

1200 DARK

10,000 HOD
CdS Photocells: How do you use them?

Sourcing:

\[ V_{out} = 5 \left( \frac{R}{I_0 + R} \right) \]

Sinking:

\[ V_{out} = 5 \left( \frac{R_{min}}{R + R_{min}} \right) \]
How else could you use a Photocell?

Linear with resistance

Transresistive circuit
Basic Sensors: Light

Photo transistor

NPN transistor

Base controlled by light

Spectral Response: near IR

Dynamic response ~ 1-5 ms

Come with a built-in lens,

Spectral sensitivity characteristics

Wavelength $\lambda$ (nm)

$V_{CE} = 10\, \text{V}$

$T_e = 25\, ^\circ\text{C}$
10 mW ~ 4 mW/cm²

Photo-transistors

Yellow Dot LED

Red Photo Xen

FIG.4 RELATIVE COLLECTOR CURRENT VS IRRADIANCE

FIG.5 SENSITIVITY DIAGRAM
LTR-301 Data Sheet (1.2)

FEATURES
* WIDE RANGE OF COLLECTOR CURRENT
* LENSED FOR HIGH SENSITIVITY
* LOW COST PLASTIC SIDE LOOKING PACKAGE
* CLEAR TRANSPARENT COLOR PACKAGE

PACKAGE DIMENSIONS

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector</td>
<td>4.40±0.2 mm (0.173 in)</td>
</tr>
<tr>
<td>Emitter</td>
<td>2.20±0.2 mm (0.087 in)</td>
</tr>
<tr>
<td>Base</td>
<td>0.75±0.1 mm (0.030 in)</td>
</tr>
<tr>
<td>Case</td>
<td>1.50±0.2 mm (0.059 in)</td>
</tr>
</tbody>
</table>

(See Notes 3)
### Absolute Maximum Ratings at TA=25°C

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>MAXIMUM RATING</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Dissipation</td>
<td>100</td>
<td>mW</td>
</tr>
<tr>
<td>Collector-Emitter Voltage</td>
<td>30</td>
<td>V</td>
</tr>
<tr>
<td>Emitter-Collector Voltage</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>-40°C to +85°C</td>
<td></td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>-55°C to +100°C</td>
<td></td>
</tr>
<tr>
<td>Lead Soldering Temperature [1.6mm (.063&quot;) From Body]</td>
<td>260°C for 5 Seconds</td>
<td></td>
</tr>
</tbody>
</table>

### Electrical Optical Characteristics at TA=25°C

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
<th>TEST CONDITION</th>
<th>BIN NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector-Emitter Breakdown Voltage</td>
<td>( V_{BRCEO} )</td>
<td>30</td>
<td></td>
<td>V</td>
<td></td>
<td>( I_C = 1mA ) ( E_e = 0mW/cm^2 )</td>
<td></td>
</tr>
<tr>
<td>Emitter-Collector Breakdown Voltage</td>
<td>( V_{BRCEO} )</td>
<td>5</td>
<td></td>
<td>V</td>
<td></td>
<td>( I_E = 100\mu A ) ( E_e = 0mW/cm^2 )</td>
<td></td>
</tr>
<tr>
<td>Collector Emitter Saturation Voltage</td>
<td>( V_{CE(SAT)} )</td>
<td>0.4</td>
<td></td>
<td>V</td>
<td></td>
<td>( I_C = 0.1mA ) ( E_e = 1mW/cm^2 )</td>
<td></td>
</tr>
<tr>
<td>Rise Time</td>
<td>( T_r )</td>
<td>10</td>
<td></td>
<td>( \mu s )</td>
<td></td>
<td>( V_{CC} = 5V ) ( R_L = 1K\Omega )</td>
<td></td>
</tr>
<tr>
<td>Fall Time</td>
<td>( T_f )</td>
<td>15</td>
<td></td>
<td>( \mu s )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collector Dark Current</td>
<td>( I_{CEO} )</td>
<td>100</td>
<td></td>
<td>nA</td>
<td></td>
<td>( V_{CE} = 10V ) ( E_e = 0mW/cm^2 )</td>
<td></td>
</tr>
<tr>
<td>On State Collector Current</td>
<td>( I_{C(ON)} )</td>
<td>0.20</td>
<td>0.60</td>
<td>mA</td>
<td></td>
<td>( V_{CE} = 5V ) ( E_e = 1mW/cm^2 ) ( \lambda = 940nm )</td>
<td>BIN A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.40</td>
<td>1.08</td>
<td></td>
<td></td>
<td></td>
<td>BIN B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.72</td>
<td>1.56</td>
<td></td>
<td></td>
<td></td>
<td>BIN C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.04</td>
<td>1.80</td>
<td></td>
<td></td>
<td></td>
<td>BIN D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.20</td>
<td>2.40</td>
<td></td>
<td></td>
<td></td>
<td>BIN E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BIN F</td>
</tr>
</tbody>
</table>