Introduction to Sensors

Gabriel Hugh Elkaim
World to Signal

Sensor Transducer $\rightarrow$ converts one physical phenomenon into another

Sensor Conditioning $\rightarrow$ need to add this to all of our sensors $(\mu V \sim mV \rightarrow V)$

Examples

Thermocouple

PIR/IR

CDS light sensor
Thermostat

Bang Bang Control

Sensor and Amplification

Heat → Rotation → Magnet → Continuity
Sensor Development

Very very very expensive to develop ~ $1 Billion

- Militarily (cost insensitive)
- Automotive (cost sensitive)
- Medical/Research (~ development)
- Applied Physics
- Cell Phone
The Operational Amplifier (OpAmp)

Inverting

Non-Inverting

$V_{(+)} > V_{(-)}$, $V_{out} \uparrow$

$V_{(+)} < V_{(-)}$, $V_{out} \downarrow$

Output

$V_{out} = G(V_{(+)} - V_{(-)})$

$\infty, 10^3$

Input draw no current.
K.C.L.: \( i_1 = i_2 \)

Inverting Op-Amp

\[ V = iR \]

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

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

\[ \frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_2} \]

\[ \frac{-V_{out}}{R_2} = -\frac{R_2}{R_1} \]
Non-Inverting Op-Amp

\[ V_{in} = \frac{V_{ou1} - V_{in}}{R_2} \]

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

\[ i_2 = \frac{V_{ou1} - V_{in}}{R_2} \]

\[ \boxed{\frac{V_{ou1}}{V_{in}} = \left(1 + \frac{R_2}{R_1}\right)} \]

- \( R_1 = \infty \)
- \( R_2 = 0 \)

Buffer
What can the Microcontroller Measure?

Voltage

- Analog (ADC)
  - 0 - 1023
  - 0 - 3.3V

- Digital
  - 0/1 (3.3V or 0V)

Time - Every microcontroller can measure time

- Count clock cycles
- Timer/Counters
- RTC (Real Time Clock)
Basic Sensors: Light

- Photocell

- CdS: More resistance varies w/ light

- Spectral Response is very close to the human eye

- Dynamic response is slow (~10 ms)

- CdTe

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\[
R_{1000} = \left(\frac{10}{1000}\right)^5 R_{10}
\]

**CdS Photocell Spec.'s**

<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></td>
<td>V</td>
</tr>
<tr>
<td>(P_{d, \text{amp}})</td>
<td>Continuous Power Dissipation</td>
<td>100</td>
<td></td>
<td>mW/°C</td>
</tr>
<tr>
<td>(T_o)</td>
<td>Operating and Storage Temperature</td>
<td>-30</td>
<td>75</td>
<td>°C</td>
</tr>
<tr>
<td>(T_s)</td>
<td>Soldering Temperature*</td>
<td>+260</td>
<td></td>
<td>°C</td>
</tr>
</tbody>
</table>

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

**ABSOLUTE MAXIMUM RATING** (TA = 23°C UNLESS OTHERWISE NOTED)

**ELECTRO-OPTICAL CHARACTERISTICS RATING** (TA = 23°C UNLESS OTHERWISE NOTED)

<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>MΩ</td>
</tr>
<tr>
<td>(R_I)</td>
<td>Illuminated Resistance</td>
<td>10 Lux @ 2856 °K</td>
<td></td>
<td></td>
<td>11</td>
<td>KΩ</td>
</tr>
<tr>
<td>(S)</td>
<td>Sensitivity</td>
<td>(\log(R_{100}) - \log(R_{10}))***</td>
<td>0.6</td>
<td></td>
<td></td>
<td>Ω/Lux</td>
</tr>
<tr>
<td>(\lambda_{\text{range}})</td>
<td>Spectral Application Range</td>
<td>Flooded</td>
<td>400</td>
<td>700</td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>(\lambda_{\text{peak}})</td>
<td>Spectral Application Range</td>
<td>Flooded</td>
<td>520</td>
<td></td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>(t_r)</td>
<td>Rise Time</td>
<td>10 Lux @ 2856 °K</td>
<td>55</td>
<td></td>
<td></td>
<td>ms</td>
</tr>
<tr>
<td>(t_f)</td>
<td>Fall Time</td>
<td>After 10 Lux @ 2856 °K</td>
<td>20</td>
<td></td>
<td></td>
<td>ms</td>
</tr>
</tbody>
</table>

**R_{100}, R_{10}: cell resistances at 100 Lux and 10 Lux at 2856 °K respectively.**

**E_{100}, E_{10}: luminances at 100 Lux and 10 Lux 2856 °K respectively.**
CdS Photocells: How do you use them?

$V_{out} = 3.3 \left( \frac{R}{R + R_{m}} \right)$

$V_{out} = 3.3 \left( \frac{R_{m}}{R + R_{m}} \right)$
How else could you use a Photocell?

- Constant current
- Linear w/ resistance
- Transresistive
Basic Sensors: Light

Photo transistor

New transistor, base is controlled by light.

Spectral Response: NEAR IR

Dynamic Response: ~1-5 μs

Come with a built-in lens.

Spectral sensitivity characteristics

$V_E = 10$V

$T_e = 2.5^\circ$C

Wavelength $\lambda$ (nm)
10 Wx = 1 mw/cm²

Photo-transistors

FIG. 4 RELATIVE COLLECTOR CURRENT VS IRRADIANCE

Vce = 5V

FIG. 5 SENSITIVITY DIAGRAM

CMPE 118/218 – Intro. to Mechatronics
LTR-301 Data Sheet (1.2)

NPN Transistor

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

PACKAGE DIMENSIONS
### 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</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></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></td>
<td></td>
</tr>
<tr>
<td>Collector Emitter Saturation Voltage</td>
<td>$V_{CESAT}$</td>
<td>0.4</td>
<td></td>
<td>V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rise Time</td>
<td>$T_r$</td>
<td>10</td>
<td></td>
<td>µs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall Time</td>
<td>$T_f$</td>
<td>15</td>
<td></td>
<td>µs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collector Dark Current</td>
<td>$I_{CEO}$</td>
<td>0.20</td>
<td></td>
<td>0.60</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On State Collector Current</td>
<td>$I_{(ON)}$</td>
<td>0.40</td>
<td></td>
<td>1.08</td>
<td>mA</td>
<td>$V_{CE} = 5V$</td>
<td>BIN A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.72</td>
<td></td>
<td>1.56</td>
<td>mA</td>
<td>$E_e = 0mW/°C$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.04</td>
<td></td>
<td>1.80</td>
<td>mA</td>
<td>$R_L = 1KΩ$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.20</td>
<td></td>
<td>2.40</td>
<td>mA</td>
<td>$V_{CE} = 10V$</td>
<td>BIN B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.60</td>
<td></td>
<td></td>
<td></td>
<td>$E_e = 0mW/°C$</td>
<td></td>
</tr>
</tbody>
</table>

$\lambda = 940nm$
Phototransistors: How do you use them? (1.2)

\[ V_{CE} = 3.3 - V_{Sat} \]

Source

\[ V_{Sat} \]

Sinking

\[ V_{Sat} \]
How do I choose R

\[ 10 \Omega \]

1 kΩ

10 MΩ

10 mV

Too small

1 V

\( \bigcirc \)

Too big

10 kV

Non-linear response
Phototransistors: How do you use them? (2.2)

1. Linear w/ light
2. Buffered
Quit Today!!

Announcement: INCREMENTAL DEVELOPMENT!

During lecture - Lab is closed!!

No animals in lab either!

Queries are at beginning of class
$1.5kW_3 \times 600mA$

$2kW_3$

$2.5kA_3$
Basic Sensors: Magnetic Field (1.4)

**REED SWITCH**
- Fragile
- Low current

![Diagram of a reed switch](image)

**Figure 1:** Two-reed (top) and three-reed (bottom) reed switches
Basic Sensors: Magnetic Field (2.4)

Hall Effect Sensor
- Semiconductor device

Two Flavors
- Switch (on/off)
- Analog 3-5x

Input Signal → Sensor → Output Signal
- Magnetic Flux
- Hall Voltage
- Current
- HAL
- $V_{OUT}$
Basic Sensors: Magnetic Field (3.4)

Unipolar

Analog

Bipolar
Basic Sensors: Magnetic Field (4.4)

Rotation $\rightarrow$ Magnetic Field $\rightarrow$ Voltage $\rightarrow$ ECM

Rotation $\rightarrow$ Modulated Magnetic Field $\rightarrow$ ECM
Measuring Position

Convert motion to voltage

Sound \( v \) ultrasonic 2-5 m

Time of Flight

\[ \frac{1 \text{ m}}{\text{msec}} \]

\[ 1 \text{ ft} / \text{msec} \]

TX

RX

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10 nF

1 s/s

$\text{V}_{\text{in}}$ to $\text{V}_{\text{out}}$

$5k \sim \$3k - \$12k$

$12k \sim \$120k$

$K \rightarrow \$300$

80m ± 2mm

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Optical Sensors for Position (1.2)

Reflective Optical Sensor with Transistor Output

FEATURES
- Package type: leaded
- Detector type: phototransistor
- Dimensions (L x W x H in mm): 10.2 x 5.8 x 7
- Peak operating distance: 2.5 mm
- Operating range within > 20% relative collector current: 0.2 mm to 15 mm
- Typical output current under test: I_C = 1 mA
- Daylight blocking filter
- Emitter wavelength: 950 nm
- Lead (Pb)-free soldering released
- Compliant to RoHS directive 2002/95/EC and in accordance to WEEE 2002/96/EC

APPLICATIONS
- Position sensor for shaft encoder
- Detection of reflective material such as paper, IBM cards, magnetic tapes etc.
- Limit switch for mechanical motions in VCR
- General purpose - wherever the space is limited

DESCRIPTION
The TCRT5000 and TCRT5000L are reflective sensors which include an infrared emitter and phototransistor in a leaded package which blocks visible light. The package includes two mounting clips. TCRT5000L is the long lead version.

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Collector current vs. $V_{CE}$

(Showed in diagrams)

Fig. 7 - Collector Emitter Saturation Voltage vs. Collector Current
Optical Sensors for Position (2.2)

Photo Interruptor
Encoders for Position Sensing (1.2)

- Odometry
- Rotation, rotation rate

Absolute Encoder

"Gray" 10-12 bits
Encoders for Position Sensing (2.2)

**QUADRATURE PHASE-ENCODED (QPE)**

\[ A \wedge B, \neg \neg \neg \neg \times 4 \]
Encoders: Where Do You Find Them?

Printers

Have — might scroll wheel.

Robots — everywhere

$5

AUTOMA microphones
14 Bit A/DE
12 Bit AES

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Basic Sensors: Temperature (1.2)

Thermistor

Temperature Sensitivity

Large $R_0$ for $R_T$

Non-linear - 4th or 5th order polynomial

$-90^\circ C$ to $200^\circ C$
Basic Sensors: Temperature (2.2)

RTD — Resistive thermal device (Platinum)

High temp range ~ 200°C - 600°C
Very linear ~ 0.1% of linear across full range

- Extremely stable
- Expensive
- Not very sensitive ~ small ΔT or Δx
$15/ device

$-0.0006$

$R^2 = 0.99998$

**RTD vs. Temp**

\[ y = -0.0006x + 3.8103x + 999.99 \]

\[ R^2 = 1 \]
# Platinum RTD Datasheet

## RTD Thin Platinum

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Resistance Ohms @ 0°C</th>
<th>DIN 43760 Class</th>
<th>Resistance Tol ±% @ 0°C</th>
<th>Temp. Dev. ±°C @ 0°C</th>
<th>TCR ppm/°C</th>
<th>Dim &quot;W&quot; (±0.007)</th>
<th>Dim &quot;L&quot; (±0.008)</th>
<th>View R-T Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG101A1</td>
<td>100</td>
<td>A</td>
<td>0.06</td>
<td>0.15</td>
<td>3850</td>
<td>0.067</td>
<td>0.110</td>
<td></td>
</tr>
<tr>
<td>PPG101B1</td>
<td>100</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3850</td>
<td>0.067</td>
<td>0.110</td>
<td></td>
</tr>
<tr>
<td>PPG101C1</td>
<td>100</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3850</td>
<td>0.067</td>
<td>0.110</td>
<td></td>
</tr>
<tr>
<td>PPG501A1</td>
<td>500</td>
<td>A</td>
<td>0.06</td>
<td>0.15</td>
<td>3850</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>PPG501B1</td>
<td>500</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3850</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>PPG501C1</td>
<td>500</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3850</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>PPG102A1</td>
<td>1000</td>
<td>A</td>
<td>0.06</td>
<td>0.15</td>
<td>3850</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>PPG102B1</td>
<td>1000</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3850</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>PPG102C1</td>
<td>1000</td>
<td>C</td>
<td>0.24</td>
<td>0.60</td>
<td>3850</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>PPG102B2</td>
<td>1000</td>
<td>B</td>
<td>0.12</td>
<td>0.30</td>
<td>3750</td>
<td>0.079</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td><strong>PPG102C2</strong></td>
<td><strong>1000</strong></td>
<td><strong>C</strong></td>
<td><strong>0.24</strong></td>
<td><strong>0.60</strong></td>
<td><strong>3750</strong></td>
<td><strong>0.079</strong></td>
<td><strong>0.118</strong></td>
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Basic Sensors: Light (1.2)

Photo diode

Silicon diode

940 nm

Near IR

Fast ~ 5 ns

Communication/modulation

Much less sensitive to light

Fig. 5 RELATIVE SPECTRAL SENSITIVITY VS WAVELENGTH
Basic Sensors: Light (2.2)

- Very wide dynamic range
- No saturation
- Less useful than a Photo XToy

Fig. 6: Photocurrent vs Irradiance $\lambda = 940$ nm
Photodiode Datasheet (1.2)

LITEON

Black Plastic Photodiode
LTR-516AD/LTR-526AD/LTR-536AD/LTR-546AD

Features
• High photo sensitivity.
• Suitable for infrared radiation.
• Low junction capacitance.
• High cut-off frequency.
• Fast switching time.

Description
The LTR-516AD/LTR-526AD/LTR-536AD/LTR-546AD are special dark plastic package that cut the visible light and suitable for the detectors of infrared applications.

Package Dimensions
LTR-516AD

[Diagram of package dimensions]
### Photodiode Datasheet (2.2)

#### Absolute Maximum Ratings at $T_a=25 \, ^\circ C$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Dissipation</td>
<td>150</td>
<td>mW</td>
</tr>
<tr>
<td>Reverse Break Down Voltage</td>
<td>30</td>
<td>V</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>-55 °C to +100 °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</td>
<td>260 °C for 5 Seconds</td>
<td></td>
</tr>
</tbody>
</table>

#### Electrical Optical Characteristics at $T_a=25 \, ^\circ C$

<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>
</tr>
</thead>
</table>
| Reverse Break Down Voltage        | $V_{BR}$| 30   | 30   |      | V    | $\lambda\,=940\,nm$  
|                                   |        |      |      |      |      | $E_r=0.5\,mW/cm^2$  
| Reverse Dark Current              | $I_{D}$ |      | 30   |      | nA   | $V_n=10\,V$  
|                                   |        |      |      |      |      | $E_r=0\,mW/cm^2$  
| Open Circuit Voltage              | $V_{OC}$ | 350  |      |      | mV   | $\lambda\,=940\,nm$  
|                                   |        |      |      |      |      | $E_r=0.5\,mW/cm^2$  
| Rise Time                         | $T_r$  | 50   |      |      | nsec | $V_n=10\,V$  
|                                   |        |      |      |      |      | $\lambda\,=940\,nm$  
| Fall Time                         | $T_f$  | 50   |      |      | nsec | $R_L=1\,\Omega$  
| Light Current                     | $I_s$  | 1.7  | 2    |      | $\mu A$ | $V_n=5\,V$  
|                                   |        |      |      |      |      | $\lambda\,=940\,nm$  
| Total Capacitance                 | $C_t$  | 25   |      |      | pF   | $R=3\,\Omega$  
| Wavelength of the Max Sensitivity | $\lambda_{SMAX}$ | 950  |      |      | nm   | $V_r=1\,MHz$  
|                                   |        |      |      |      |      | $E_r=0\,mW/cm^2$  |
Photodiodes: How Do You Use Them?

\[ V_{at} \]

\[ I_{in} \]

\[ 3.3V \]

\[ U_{LCT} \sim f(U_{LCT}) \]
String Pot

GPS
Position ($\sim 3-5 \text{ m}$)
Velocity ($\sim 0.1 \text{ m/s}$)
Time ($\sim 3 \text{ hours}$)

C/H = code
10 meter
L1 1.25 cm

P/H = code - encrypted
2-3 m - (L2 1.67)
Questions?
Interventions: Early and often

Lab Kits: Parts you will need.
Event Checker → TRUE (Posts an EVENT)
FALSE otherwise

Services — Runs when there is an EVENT in its queue

Start

Timeout
Reset Timer

Post EVENT
Es_TIMEOUT → Param (which one)