Sensors and Transducers

E80 Spring 2014
Erik Spjut
Scientific & Engineering Measurements

• Scientific Measurements
  – What you measure *with* a rocket.
  – What are examples?

• Engineering Measurements
  – What you measure *about* a rocket.
  – What are examples?
Experimental Measurements

- Mass
- Force
- Acceleration
- Velocity
- Position
- Displacement
- Orientation
- Vibration

- EM Intensity
  - Radio
  - Microwave
  - IR
  - Visible
  - UV
  - X-ray
  - Gamma
Experimental Measurements II

• Temperature
• Pressure
• Flow Rate
• Composition
  – Partial Pressure
  – Humidity
  – Mass fraction
  – Mole fraction
  – pH
• Phases
  – Aerosols
  – Suspensions
  – Microstructure
• Sound
• Images
• Video
Experimental Measurements III

- Electrical
  - Voltage
  - Charge
  - Current
  - Resistance
  - Inductance
  - Capacitance
  - Power

- Time
- Frequency
- Phase
- Angular
  - Position
  - Velocity
  - Acceleration
Digikey’s List of Sensors

- Accelerometers (1022 items)
- Accessories (3085 items)
- Amplifiers (277 items)
- Capacitive Touch Sensors, Proximity Sensor ICs (508 items)
- Color Sensors (111 items)
- Current Transducers (1440 items)
- Dust Sensors (11 items)
- Encoders (4042 items)
- Flex Sensors (3 items)
- Float, Level Sensors (313 items)
- Flow Sensors (162 items)
- Force Sensors (50 items)
- Gas Sensors (66 items)
- Gyroscopes (205 items)
- Image Sensors, Camera (313 items)
- Inclinometers (44 items)
- IrDA Transceiver Modules (291 items)
- LVDT Transducers (Linear Variable Differential Transformer) (47 items)
- Magnetic Sensors - Compass, Magnetic Field (Modules) (26 items)
- Magnetic Sensors - Hall Effect, Digital Switch, Linear, Compass (ICs) (2324 items)
- Magnetic Sensors - Position, Proximity, Speed (Modules) (879 items)
- Magnets (95 items)
- Moisture Sensors, Humidity (257 items)
- Motion Sensors, Detectors (PIR) (168 items)
- Multifunction (101 items)
- Obsolete/Discontinued Part Numbers (16 items)
- Optical Sensors - Ambient Light, IR, UV Sensors (561 items)
- Optical Sensors - Distance Measuring (36 items)
- Optical Sensors - Mouse (117 items)
- Optical Sensors - Photo Detectors - CdS Cells (38 items)
- Optical Sensors - Photo Detectors - Logic Output (128 items)
- Optical Sensors - Photo Detectors - Remote Receiver (1104 items)
- Optical Sensors - Photodiodes (925 items)
- Optical Sensors - Photoelectric, Industrial (2861 items)
- Optical Sensors - Photointerrupters - Slot Type - Logic Output (1126 items)
- Optical Sensors - Photointerrupters - Slot Type - Transistor Output (1115 items)
- Optical Sensors - Phototransistors (738 items)
- Optical Sensors - Reflective - Analog Output (323 items)
- Optical Sensors - Reflective - Logic Output (123 items)
- Position Sensors - Angle, Linear Position Measuring (937 items)
- Pressure Sensors, Transducers (25455 items)
- Proximity Sensors (3521 items)
- RTD (Resistance Temperature Detector) (60 items)
- Shock Sensors (11 items)
- Solar Cells (82 items)
- Specialized Sensors (311 items)
- Strain Gages (24 items)
- Temperature Regulators (3285 items)
- Temperature Sensors, Transducers (1374 items)
- Thermistors - NTC (4928 items)
- Thermistors - PTC (1257 items)
- Thermocouple, Temperature Probe (396 items)
- Tilt Sensors (50 items)
- Ultrasonic Receivers, Transmitters (78 items)
- Vibration Sensors (30 items)
What Spec’s Do We Care About?

- Quantity Measured
- Range or Span
- Accuracy
- Precision
- Noise
- Linearity
- Speed of Response

- Voltage Requirements
- Current Requirements
- Output Impedance
- Mounting Requirements
Example – Altimeter

• Measure Absolute Pressure and Calculate Altitude
  – What range of pressures do we need?
  – What accuracy do we expect?
Calculate Altitude from Pressure

[Graph depicting atmospheric layers and parameters such as pressure, density, speed of sound, temperature, etc., with labels for different altitudinal regions like Stratosphere, Troposphere, and thermosphere.]

For the Troposphere

\[ h = \frac{T_0}{-(dT/\,dh)} \cdot \left[ 1 - \left( \frac{P}{P_0} \right)^{-\left(\frac{dT}{dh}\right)\cdot R \over gM} \right] \]

where

- \( h \) = geopotential altitude (above sea level) (in meters)
- \( P_0 \) = standard atmosphere pressure = 101325 Pa
- \( T_0 = 288.15K \ (+15^\circ C) \)
- \( dT/\,dh = -0.0065 \, \text{K/m} \): thermal gradient or standard temperature lapse rate
- \( R = 8.31432 \, \text{Nm/mol K} \) (Current NIST value 8.3144621)
- \( g = 9.80665 \, \text{m/s}^2 \)
- \( M = 0.0289644 \, \text{kg/mol} \)

From 1976 US Standard Atmosphere
### How Does Pressure Vary With Height?

<table>
<thead>
<tr>
<th>Alt. (m)</th>
<th>Alt. (ft)</th>
<th>Alt. (mi)</th>
<th>P (Pa)</th>
<th>dP/dh (Pa/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.000</td>
<td>101325</td>
<td>-12.01</td>
</tr>
<tr>
<td>200</td>
<td>656</td>
<td>0.124</td>
<td>98945</td>
<td>-11.78</td>
</tr>
<tr>
<td>400</td>
<td>1312</td>
<td>0.249</td>
<td>96610</td>
<td>-11.56</td>
</tr>
<tr>
<td>600</td>
<td>1969</td>
<td>0.373</td>
<td>94321</td>
<td>-11.34</td>
</tr>
<tr>
<td>800</td>
<td>2625</td>
<td>0.497</td>
<td>92076</td>
<td>-11.12</td>
</tr>
<tr>
<td>1000</td>
<td>3281</td>
<td>0.621</td>
<td>89874</td>
<td>-10.90</td>
</tr>
<tr>
<td>1200</td>
<td>3937</td>
<td>0.746</td>
<td>87715</td>
<td>-10.69</td>
</tr>
<tr>
<td>1400</td>
<td>4593</td>
<td>0.870</td>
<td>85598</td>
<td>-10.48</td>
</tr>
<tr>
<td>1600</td>
<td>5249</td>
<td>0.994</td>
<td>83522</td>
<td>-10.27</td>
</tr>
<tr>
<td>1800</td>
<td>5906</td>
<td>1.118</td>
<td>81488</td>
<td>-10.07</td>
</tr>
<tr>
<td>2000</td>
<td>6562</td>
<td>1.243</td>
<td>79494</td>
<td>-9.87</td>
</tr>
<tr>
<td>2200</td>
<td>7218</td>
<td>1.367</td>
<td>77540</td>
<td>-9.67</td>
</tr>
<tr>
<td>2400</td>
<td>7874</td>
<td>1.491</td>
<td>75624</td>
<td>-9.48</td>
</tr>
<tr>
<td>2600</td>
<td>8530</td>
<td>1.616</td>
<td>73747</td>
<td>-9.29</td>
</tr>
</tbody>
</table>
Calculate Flight Height
Assume 1 Mile AGL Max Alt

- Lucerne Valley at 3000 ft MSL, Claremont 1200 ft
- $P_{\text{ground}} = 90$ kPa
- $P_{\text{apogee}} = 74$ kPa
- Span = $\Delta P = 16$ kPa
- Need to allow for Barometric Pressure Changes +7% to −13%
- $P_{\text{max}} = \text{MAX}(104$ kPa, 97 kPa)
- $P_{\text{min}} = 64$ kPa
# MPXA6115AC7U

## Operating Characteristics

**Table 1. Operating Characteristics** (*V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2*)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Range</td>
<td>P_{OP}</td>
<td>15</td>
<td>—</td>
<td>115</td>
<td>kPa</td>
</tr>
<tr>
<td>Supply Voltage(1)</td>
<td>V_S</td>
<td>4.75</td>
<td>5.0</td>
<td>5.25</td>
<td>Vdc</td>
</tr>
<tr>
<td>Supply Current</td>
<td>I_o</td>
<td>—</td>
<td>6.0</td>
<td>10</td>
<td>mAdc</td>
</tr>
<tr>
<td>Minimum Pressure Offset(2)(0 to 85°C)</td>
<td>V_{off}</td>
<td>0.133</td>
<td>0.200</td>
<td>0.268</td>
<td>Vdc</td>
</tr>
<tr>
<td>@ V_S = 5.0 Volts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Scale Output(3)(0 to 85°C)</td>
<td>V_{FSO}</td>
<td>4.633</td>
<td>4.700</td>
<td>4.768</td>
<td>Vdc</td>
</tr>
<tr>
<td>@ V_S = 5.0 Volts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Scale Span(4)(0 to 85°C)</td>
<td>V_{FSS}</td>
<td>4.433</td>
<td>4.500</td>
<td>4.568</td>
<td>Vdc</td>
</tr>
<tr>
<td>@ V_S = 5.0 Volts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy(5)(0 to 85°C)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>±1.5</td>
<td>%V_{FSS}</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>V/P</td>
<td>—</td>
<td>45.0</td>
<td>—</td>
<td>mV/kPa</td>
</tr>
<tr>
<td>Response Time(6)</td>
<td>t_R</td>
<td>—</td>
<td>1.0</td>
<td>—</td>
<td>ms</td>
</tr>
<tr>
<td>Warm-Up Time(7)</td>
<td>—</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>ms</td>
</tr>
<tr>
<td>Offset Stability(8)</td>
<td>—</td>
<td>—</td>
<td>±0.25</td>
<td>—</td>
<td>%V_{FSS}</td>
</tr>
</tbody>
</table>

From Freescale Data Sheet
Nominal Values

- $V@P_{\text{min}} = 0.200 \, \text{V} + (64 \, \text{kPa} - 15 \, \text{kPa}) \times 0.045 \, \text{V/kPa} = 2.41 \, \text{V}$
- $V@P_{\text{max}} = 0.200 + (104 \, \text{kPa} - 15 \, \text{kPa}) \times 0.045 \, \text{V/kPa} = 4.21 \, \text{V}$
- Accuracy (Uncalibrated) ±1.5% $V_{\text{FS}} = ±1.5\% \times 4.7 \, \text{V} = ±0.071 \, \text{V} = ±1.57 \, \text{kPa} = ±157 \, \text{m}$
- $t_{R_{10\%-90\%}} = 1.0 \, \text{ms}$, $\tau = t_{R_{10\%-90\%}} / \ln(9) = 0.46 \, \text{ms}$
Output Impedance

• Can drive circuit with 0.5 mA at 4.7 V
• Impedance of driven circuit = \( \frac{V}{I} = \frac{4.7 \text{ V}}{0.0005 \text{ A}} = 9400 \Omega \).
• Actual output impedance determined empirically. How?
Choices on Conditioning

• Data Logger
  – 0 V to 3.3 V
  – Input Impedance ~2200 Ω
  – 16 bit, 1 LSB = 3.3 V/2^{16} = 50 μV

1. Change gain so \( V_{\text{max}} = 3.3 \text{ V} \)
   – 1 LSB = 50 μV = 0.16 m = 6 in

2. Change gain and offset so \( V_{\text{min}} = 0 \text{ V} \) & \( V_{\text{max}} = 3.3 \text{ V} \)
   – 1 LSB = 50 μV = 0.06 m = 2.4 in
Signal Conditioning

• Does it need a buffer amp? How would you know?
• How do you change the gain?
• How do you change the gain and offset?
• What about aliasing?
Single-Sided Circuits

(Will visit again under Flight Hardware)

• Data logger expects 0 V to 3.3 V signals
• Classical op-amp circuit power ±15 V
• Low-voltage op-amp circuit power
  – ±1.4 V to ±3 V
  – 0-to-2.8 V to 0-to-6 V
• Signal offset
• Reference offset
• Virtual ground
Inverting Amps

\[ V_{out} = -\left( \frac{R_f}{R_{in}} \right) V_{in} \]

\[ V_{out} = -\left( \frac{R_f}{R_{in}} \right) V_{in} + 2.5 \left( 1 + \frac{R_f}{R_{in}} \right) \]
Non-Inverting Amps

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

\[
V_{out} = \left( 1 + \frac{R_f}{R_{in}} \right) V_{in} - 2.5 \left( \frac{R_f}{R_{in}} \right)
\]
Can You do Single Sided for:

- Differential Amplifier?
- Integrator?
- Transimpedance Amplifier?
- Sallen-Key Filter?
- Bipolar sensor like piezoelectric vibration?
Example – Gas Sensor

• MQ-2 CH₄ Gas Sensor (Digikey, Parallax, or Pololu)
### Other Specs

**SPECIFICATIONS**

**A. Standard work condition**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter name</th>
<th>Technical condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vc</td>
<td>Circuit voltage</td>
<td>5V±0.1</td>
</tr>
<tr>
<td>V_H</td>
<td>Heating voltage</td>
<td>5V±0.1</td>
</tr>
<tr>
<td>R_L</td>
<td>Load resistance</td>
<td>can adjust</td>
</tr>
<tr>
<td>R_H</td>
<td>Heater resistance</td>
<td>33 Ω ±5%</td>
</tr>
<tr>
<td>P_H</td>
<td>Heating consumption</td>
<td>less than 800mw</td>
</tr>
</tbody>
</table>

**C. Sensitivity characteristic**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter name</th>
<th>Technical parameter</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rs</td>
<td>Sensing Resistance</td>
<td>3K Ω -30K Ω (1000ppm iso-butane)</td>
<td>Detecting concentration scope: 200ppm-5000ppm iso-butane</td>
</tr>
<tr>
<td>α</td>
<td>Concentration Slope</td>
<td>≤0.6</td>
<td>LPG and propane 300ppm-5000ppm butane</td>
</tr>
<tr>
<td>(3000/1000) iso-butane</td>
<td></td>
<td></td>
<td>5000ppm-20000ppm methane 300ppm-5000ppm H₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100ppm-2000ppm Alcohol</td>
</tr>
<tr>
<td>Standard Detecting Condition</td>
<td>Temp: 20℃ ±2℃</td>
<td>Vc:5V±0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humidity: 65%±5%</td>
<td>Vh: 5V±0.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Preheat time: Over 24 hour</td>
<td></td>
</tr>
</tbody>
</table>
Sensitivity

Fig. 2 sensitivity characteristics of the MQ-2
Power Calculations

• 5 V @ 800 mW = 160 mA.
• 5 V @ 33 Ω = 150 mA.
• Standard 9 V battery is ~250 mAh
  – Would last about 1 ½ hours
  – Separate battery for sensor and system.
Signal Conditioning

• Must get air to sensor.
• Resistance changes with gas concentration.
• Designed to work in voltage divider.
• Need R in range of approx. 3 kΩ to 30 kΩ.
• Need buffer amp.
• What is time constant?
• [http://www.parallax.com/catalog/sensors/gas](http://www.parallax.com/catalog/sensors/gas) for more info
Example – Particle Sensor

Internal schematic

GP2Y1010AU0F

1. V-LED
2. LED-GND
3. LED
4. S-GND
5. V₀
6. Vcc
Driving & Reading Circuits

Fig. 1 Input Condition for LED Input Terminal

Fig. 2 Sampling Timing of Output Pulse
Output & Caution

Fig. 3 Output Voltage vs. Dust Density

10 Vibration influence
The sensor may change its value under mechanical oscillation. Before usage, please make sure that the device works normally in the application.
The timer can also be connected as shown in Figure 2B. In this circuit, the frequency is:

\[ f = \frac{1.44}{(R_A + 2R_B)C} \]  
\[ \text{(EQ. 2)} \]

The duty cycle is controlled by the values of \( R_A \) and \( R_B \), by the equation:

\[ D = \frac{(R_A + R_B)}{(R_A + 2R_B)} \]  
\[ \text{(EQ. 3)} \]
Reading Circuit

- Pulse Width 0.32 ms
- Minimum 1 point
- Best 10 points
- Sample rate = \(10/0.32 \text{ ms} = 31.25 \text{ kSPS}\)
Could You Do Better?

- IRED and Driver
- Photodiode & Reading Circuit
- Mechanical & Optical Chamber
- Start at
  http://en.wikipedia.org/wiki/Particle_counter
  for more information
Example – Humidity Sensor

• Check out Digikey
nSort=1000011&page=1&stock=0&pbfree=0&rohs=0&quantity=1&ptm=0&fid=0&pageSize=25](http://www.digikey.com/product-search/en?FV=fff4001e%2Cfff80274&mnonly=0&newproducts=0&Colum
nSort=1000011&page=1&stock=0&pbfree=0&rohs=0&quantity=1&ptm=0&fid=0&pageSize=25)

• Digital, I²C – 18 s response time
• Capacitive – 15 s, 5 s response time
• Linear Voltage – 5 s response time
Digital, I²C

- Need microcontroller, e.g., Arduino Pro Mini 328 - 3.3V/8MHz <Sparkfun>
- Power separately from data logger
- Must synchronize
- Must program
Capacitive

• How do you measure capacitance?
  – Put in a timer circuit
  – Put in an integrator
  – Put in a voltage divider
In a Timer Circuit

ICM7555,

\[ f = \frac{1}{1.4 \cdot RC} \]  
(EQ. 1)
Honeywell HIH-1000-002

HCH-1000 Series

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Condition</th>
<th>Min.</th>
<th>Typ.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal capacitance</td>
<td>at 55 %RH</td>
<td>310</td>
<td>330</td>
<td>350</td>
<td>pF</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>10 %RH to 95 %RH</td>
<td>0.55</td>
<td>0.60</td>
<td>0.65</td>
<td>pF/%RH</td>
</tr>
<tr>
<td>Humidity hysteresis</td>
<td>—</td>
<td>—</td>
<td>±2</td>
<td>—</td>
<td>%RH</td>
</tr>
<tr>
<td>Linearity</td>
<td>—</td>
<td>—</td>
<td>±2</td>
<td>—</td>
<td>%RH</td>
</tr>
<tr>
<td>Response time</td>
<td>30 %RH to 90 %RH</td>
<td>—</td>
<td>15</td>
<td>—</td>
<td>sec</td>
</tr>
<tr>
<td>Temperature coefficient</td>
<td>5 °C to 70 °C [41 °F to 158 °F]</td>
<td>0.15</td>
<td>0.16</td>
<td>0.17</td>
<td>pF/°C</td>
</tr>
<tr>
<td>Long-term stability (drift)</td>
<td>—</td>
<td>—</td>
<td>0.2</td>
<td>—</td>
<td>%RH/year</td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>—</td>
<td>— -40 [-40]</td>
<td>—</td>
<td>120 [248]</td>
<td>°C [°F]</td>
</tr>
<tr>
<td>Operating humidity range</td>
<td>—</td>
<td>— 0%</td>
<td>—</td>
<td>100%</td>
<td>RH</td>
</tr>
<tr>
<td>Operating frequency range</td>
<td>—</td>
<td>— 1</td>
<td>—</td>
<td>100</td>
<td>kHz</td>
</tr>
</tbody>
</table>
### Measurement Calc’s

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>200,000Ω</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>330 pF</td>
<td></td>
</tr>
<tr>
<td>RC</td>
<td>0.000066 s</td>
<td>66 µs</td>
</tr>
<tr>
<td>Angular Freq</td>
<td>15152 s⁻¹</td>
<td></td>
</tr>
<tr>
<td>Freq</td>
<td>2411 Hz</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensitivity 0.6 pF/%RH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0% RH 297 pF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100% RH 357 pF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ΔF 450 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ΔF/F 18.67% Hz/Hz</td>
</tr>
</tbody>
</table>

The sample rate will need to be high enough to discriminate the frequency changes.
Integrator

Issues

• Easiest input is constant voltage
  – Output is then a ramp
  – Calculate $C$ from ramp slope or time to $V_{set}$.
• How control reset switch?
  – Solid State Relay
  – Signal Generator
  – Comparator
Voltage Divider

• Need sinusoidal input

\[
\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{1 + jRC\omega}
\]

\[
\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{1}{j\omega C_2} + \frac{1}{j\omega C_1} = \frac{1}{1 + \frac{C_2}{C_1}}
\]
How Do You Generate a Sine Wave?

## XR-2206
Monolithic Function Generator

### FEATURES
- Low-Sine Wave Distortion, 0.5%, Typical
- Excellent Temperature Stability, 20ppm/°C, Typ.
- Wide Sweep Range, 2000:1, Typical
- Low-Supply Sensitivity, 0.01%V, Typ.
- Linear Amplitude Modulation
- TTL Compatible FSK Controls
- Wide Supply Range, 10V to 26V
- Adjustable Duty Cycle, 1% TO 99%

### APPLICATIONS
- Waveform Generation
- Sweep Generation
- AM/FM Generation
- V/F Conversion
- FSK Generation
- Phase-Locked Loops (VCO)

### GENERAL DESCRIPTION
The XR-2206 is a monolithic function generator integrated circuit capable of producing high quality sine, square, triangle, ramp, and pulse waveforms of high-stability and accuracy. The output waveforms can be both amplitude and frequency modulated by an external voltage. Frequency of operation can be selected externally over a range of 0.01Hz to more than 1MHz.

The circuit is ideally suited for communications, instrumentation, and function generator applications requiring sinusoidal tone, AM, FM, or FSK generation. It has a typical drift specification of 20ppm/°C. The oscillator frequency can be linearly swept over a 2000:1 frequency range with an external control voltage, while maintaining low distortion.
How Do You Generate a Sine Wave?

FEATURES

- Excellent Temperature Stability (20ppm/°C)
- Linear Frequency Sweep
- Wide Sweep Range (1000:1 Minimum)
- Wide Supply Voltage Range (+4V to +13V)
- Low Supply Sensitivity (0.1% /V)
- Wide Frequency Range (0.01Hz to 1MHz)
- Simultaneous Triangle and Squarewave Outputs

APPLICATIONS

- Voltage and Current-to-Frequency Conversion
- Stable Phase-Locked Loop
- Waveform Generation
  Triangle, Sawtooth, Pulse, Squarewave
- FM and Sweep Generation

GENERAL DESCRIPTION

The XR-2209 is a monolithic voltage-controlled oscillator (VCO) integrated circuit featuring excellent frequency stability and a wide tuning range. The circuit provides simultaneous triangle and squarewave outputs over a frequency range of 0.01Hz to 1MHz. It is ideally suited for FM, FSK, and sweep or tone generation, as well as for phase-locked loop applications.

The oscillator of the XR-2209 has a typical drift specification of 20ppm/°C. The oscillator frequency can be linearly swept over a 1000:1 range with an external control voltage.
Linear Voltage

HIH-5030/5031 Series
Low Voltage Humidity Sensors

DESCRIPTION
The HIH-5030/5031 Series Low Voltage Humidity Sensors operate down to 2.7 Vdc, often ideal in battery-powered systems where the supply is a nominal 3 Vdc.

The HIH-5030/5031 Series delivers instrumentation-quality RH (Relative Humidity) sensing performance in a competitively priced, solderable SMD.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Typical</th>
<th>Maximum</th>
<th>Unit</th>
<th>Specific Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interchangeability (first order curve)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0% RH to 10% RH, 90% RH to 100% RH</td>
<td>-7</td>
<td>-</td>
<td>7</td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>11% RH to 89% RH</td>
<td>-3</td>
<td>-</td>
<td>3</td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Accuracy (best fit straight line) 11% RH to 89% RH</td>
<td>-3</td>
<td>-</td>
<td>+3</td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Hysteresis</td>
<td></td>
<td>2</td>
<td></td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Repeatability</td>
<td></td>
<td>±0.5</td>
<td>-</td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Settling time</td>
<td></td>
<td>-</td>
<td>70</td>
<td>ms</td>
<td></td>
</tr>
<tr>
<td>Response time (1/e in slow moving air)</td>
<td></td>
<td>5</td>
<td></td>
<td>s</td>
<td></td>
</tr>
<tr>
<td>Stability (at 50% RH in 5 years)</td>
<td></td>
<td>±1.2</td>
<td></td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Voltage supply</td>
<td>2.7</td>
<td></td>
<td>5.5</td>
<td>Vdc</td>
<td></td>
</tr>
<tr>
<td>Current supply</td>
<td></td>
<td>200</td>
<td>500</td>
<td>μA</td>
<td></td>
</tr>
<tr>
<td>Voltage output (1st order curve fit)</td>
<td>V_{OUT} = (V_{SUPPLY})(0.00636(sensor RH) + 0.1515), typical at 25 °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature compensation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage temp. coefficient at 50% RH, 3.3 V</td>
<td>-2</td>
<td></td>
<td></td>
<td>mV/°C</td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>-40[-40]</td>
<td>See Figure 2.</td>
<td>85[185]</td>
<td>°C[°F]</td>
<td></td>
</tr>
<tr>
<td>Operating humidity (HIH-5030)</td>
<td>0</td>
<td>See Figure 2.</td>
<td>100</td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Operating humidity (HIH-5031)</td>
<td>0</td>
<td>See Figure 2.</td>
<td>100</td>
<td>% RH</td>
<td></td>
</tr>
<tr>
<td>Storage temperature</td>
<td>-50[-58]</td>
<td></td>
<td>125[257]</td>
<td>°C[°F]</td>
<td></td>
</tr>
<tr>
<td>Storage humidity</td>
<td></td>
<td></td>
<td></td>
<td>% RH</td>
<td></td>
</tr>
</tbody>
</table>

**Specific Notes:**
1. Includes stress outside of recommended operating zone.
2. Device is tested at 3.3 Vdc and 25 °C.
3. Non-condensing environment. When liquid water falls on the humidity sensor die, output goes to a low rail condition indicating no humidity.
4. Total accuracy including interchangeability is ±3 %RH.

**General Notes:**
- Sensor is ratiometric to supply voltage.
- Extended exposure to ≥90 % RH causes a reversible shift of 3 % RH.
- Sensor is light sensitive. For best performance, shield sensor from bright light.
Figure 4. Typical Output Voltage (BFSL) vs Relative Humidity (At 0 °C, 70 °C and 3.3 Vdc.)
The challenges are how and where to connect it, how and where to mount it, and how to get airflow over it.
Where to look for sensors

• Digikey: http://www.digikey.com
• Mouser: http://www.mouser.com
• Arrow: http://www.arrow.com
• Sparkfun: https://www.sparkfun.com
• Pololu: https://www.pololu.com
• Parallax: http://www.parallax.com