Recap ADC

- Dithered samples: how are they corrected?
- How is random noise generated during dithering

Noise level: P-P value of 1/3-to-1 LSB voltage level

- What is a priority encoder

<table>
<thead>
<tr>
<th>x3</th>
<th>x2</th>
<th>x1</th>
<th>x0</th>
<th>y1</th>
<th>y0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>X</td>
<td>X</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>X</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>X</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

5. The two forms of dithering are standard or non-subtractive dithering (a) and subtractive dithering (b).
• What do the op-amps do in the ADC/DAC
• Specifics of circuit calculations and stuff
• How do ADCs work
• Specifics of ADC/DAC architecture
• Quantization error

Let’s build an ADC!

• ADC unit conversion
Sensor Types

- Acoustic, sound, vibration
- Automotive, transportation
- Chemical
- Electric current, electric potential, magnetic, radio
- Environment, weather, moisture, humidity
- Flow, fluid velocity
- Ionising radiation, subatomic particles
- Navigation instruments
- Position, angle, displacement, distance, speed, acceleration
- Optical, light, imaging, photon
- Pressure
- Force, density, level
- Thermal, heat, temperature
- Proximity, presence
Typical Sensor Circuits: Voltage

ADC Input Range: GND to VCC (at most, often smaller)

Voltage Division
- 0-100 V → 1/30 → 0-3.3 V

Voltage Amplification
- 0-0.1 V → x 33 → 0-3.3 V

Voltage Shifting
- -1.5 - 1.5 V → + 1.5 → 0-3 V
Voltage Division

- Voltage Divider

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

Dangers? Problems?
Voltage Amplification

- E.g. Negative Feedback Amplification (non inverting)
- \( V_{out} = (1 + \frac{R_f}{R_g}) \times V_{in} \)

- Kirchoff's current law
  - \( I_{in} = I_{out} \)
  - \( I_g = \frac{V_{in}}{R_g} \)
  - \( V_{out} = I_g \times (R_f + R_g) \)

There are volumes of books written on Operational Amplifiers!
Typical Sensor Circuit: Frequency

- Current to frequency (e.g. AD 537)
- Light to frequency (e.g. TI TSL235)
- Voltage to frequency (e.g. AD 537)

How do we measure frequency?

Figures from AD537 datasheet
### Example Freescale MMA7361

- **±1.5g, ±6g Three Axis Low-g MEMS Accelerometer**

![Device Diagram](image)

**Table 1. Maximum Ratings**

<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>Output Signal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero-g ( T_A = 25°C, V_{DD} = 3.3 \text{ V} )(^{(5)},(6))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero-g(^{(4)})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity ( T_A = 25°C, V_{DD} = 3.3 \text{ V} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity(^{(4)})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth Response</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Impedance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0g-Detect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Timing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( V_{OFF} \) is the output voltage for zero acceleration. 
\( V_{OFF}, T_A \) is the output voltage for zero acceleration at a specific temperature. 
\( S_{1.5g} \) and \( S_{6g} \) are the sensitivities for 1.5g and 6g, respectively. 
\( S, T_A \) is the sensitivity at a specific temperature. 
\( f_{0.3dBXY} \) and \( f_{0.3dBZ} \) are the bandwidths for XY and Z axes, respectively. 
\( Z_O \) is the output impedance. 
\( 0g_{\text{detect}} \) is the sensitivity for the 0g-Detect feature.
Example: MEMS Accelerometer ADXL345

- 3-Axis, ±2 g/±4 g/±8 g/±16 g Digital Accelerometer

Figure 1.
Example: Light Sensor TSL230RD

- High-Resolution Conversion of Light Intensity to Frequency With No External Components
- Programmable Sensitivity and Full-Scale Output Frequency
- Communicates Directly With a Microcontroller
- High Irradiance Responsivity ... 790 Hz/(μW/cm²) Typical at 640 nm
- Single-Supply Operation ... 2.7 V to 5.5 V
- Power-Down Feature ... 5 μA Typical
- Nonlinearity Error Typically 0.2% at 100 kHz
- Stable 200 ppm/°C Temperature Coefficient
- Low-Profile Lead (Pb) Free and RoHS Compliant Surface-Mount Package
TSL230RD, TSL230ARD, TSL230BRD

PROGRAMMABLE LIGHT-TO-FREQUENCY CONVERTERS

TAOS054P

OCTOBER 2007

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The LUMENOLOGY Company

www.taosinc.com

TYPICAL CHARACTERISTICS

Figure 1

OUTPUT FREQUENCY vs IRRADIANCE

Output Frequency (fo - fD) — kHz

0.001 0.01 0.1 1 10 100 1k 10k 100k 1M

0.001 0.01 0.1 1 10 100 1k 10k 100k 1M

Ee — Irradiance — µW/cm²

VDD = 5 V

λp = 640 nm

TA = 25°C

S2 = S3 = L

S0 = H, S1 = H

S0 = L, S1 = H

S0 = H, S1 = L

Figure 2

PHOTODIODE SPECTRAL RESPONSIVITY

Normalized Responsivity

0 0.2 0.4 0.6 0.8 1.0 1.2

0 300 400 500 600 700 800 900 1000 1100

λ — Wavelength — nm

Figure 3

Figure 4

TEMPERATURE COEFFICIENT OF OUTPUT FREQUENCY vs WAVELENGTH OF INCIDENT LIGHT

Temperature Coefficient of Output Frequency — ppm/°C
Example: Fastrax UP-501 GPS

- 66 Channel UP-501 GPS Receiver
- NMEA protocols

Table 4  Connections

<table>
<thead>
<tr>
<th>Contact</th>
<th>Signal name</th>
<th>I/O</th>
<th>Signal description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RXD</td>
<td>I</td>
<td>UART Port 0 async. input. Internal pull high resistor 75kΩ.</td>
</tr>
<tr>
<td>2</td>
<td>TXD</td>
<td>O</td>
<td>UART Port 0 async. output.</td>
</tr>
<tr>
<td>3</td>
<td>GND</td>
<td>-</td>
<td>Ground</td>
</tr>
<tr>
<td>4</td>
<td>VDD</td>
<td>I</td>
<td>Main power supply</td>
</tr>
<tr>
<td>5</td>
<td>VDD_B</td>
<td>I</td>
<td>Backup supply</td>
</tr>
<tr>
<td>6</td>
<td>PPS</td>
<td>O</td>
<td>Pulse per second output.</td>
</tr>
</tbody>
</table>

Notes:

Figure 1. Pin numbering in the Fastrax UP501 module.

Low power consumption: 75mW @ 3.0V

Image: Sparkfun.com
Example: Electrical Metering ADE7759

- Active Energy Metering IC with di/dt Sensor Interface

![Functional Block Diagram](image)

**Test Circuit 1. Performance Curve (Integrator OFF)**

**Test Circuit 2. Performance Curve (Integrator ON)**
Example: Flex Sensor

Features
- Angle Displacement Measurement
- Bends and Flexes physically with motion device

Possible Uses
- Robotics
- Gaming (Virtual Motion)
- Medical Devices
- Computer Peripherals
- Musical Instruments
- Physical Therapy

Simple Construction
Low Profile

Mechanical Specifications
- Life Cycle: >1 million
- Height: 0.43mm (0.017"
- Temperature Range: -35°C to +80°C
- Flat Resistance: 10K Ohms
- Resistance Tolerance: ±30%
- Bend Resistance Range: 60K to 110K Ohms
- Power Rating: 0.50 Watts continuous. 1 Watt Peak

Dimensional Diagram - Stock Flex Sensor

6.35 [0.250"

95.25 [3.750"

112.24 [4.419"

From: Flexsensor Datasheet

Following are notes from the ITP Flex Sensor Workshop

From: Flexsensor Datasheet
Force Sensing Resistors

An Overview of the Technology

Force Sensing Resistors (FSR) are a polymer thick film (PTF) device which exhibits a decrease in resistance with an increase in the force applied to the active surface. Its force sensitivity is optimized for use in human touch control of electronic devices. FSRs are not a load cell or strain gauge, though they have similar properties. FSRs are not suitable for precision measurements.

Force vs. Resistance

The force vs. resistance characteristic shown in Figure 2 provides an overview of FSR typical response behavior. For interpretational convenience, the force vs. resistance data is plotted on a log/log format. These data are representative of our typical devices, with this particular force-resistance characteristic being the response of evaluation part # 402 (0.5" [12.7 mm] diameter circular active area). A stainless steel actuator with a 0.4" [10.0 mm] diameter hemispherical tip of 60 durometer polyurethane rubber was used to actuate the FSR device. In general, FSR response approximately follows an inverse power-law characteristic (roughly 1/R).

Figure 2: Resistance vs. Force

Example: Force sensitive resistor

V+ = 5V
RM = 30k
Vout: 100g? 1000g?
• \( V_{OUT} = \frac{(-RG \cdot V_{REF})}{R_{FSR}} \)
• Need negative \( V_{REF} \) to get positive \( V_{OUT} \)
Actuator Types

- Solenoids, valves, cylinders
- Hydraulics, pneumatics
- Motors
- Heaters
- Lights
- Sirens/Horns (audio)

- Most need significant power!
Memory Shape Alloy
Linear Actuators (Motorized Potentiometer)
Servos

Usually take 5+ V

Typical:
- $T = 20$ ms
- $t = 1$ ms to 2 ms

From: http://www.pololu.com/blog/15/servo-servo-motor-servomotor-definitely-not-server
Controlling Brushed Motor: The H-Bridge

- **Pro:**
  - Simple, cheap
  - Two wires

- **Con:**
  - Not too efficient
  - Periodic maintenance
  - Noisy (arching)

See [http://homepages.which.net/~paul.hills/SpeedControl/SpeedControllersBody.html](http://homepages.which.net/~paul.hills/SpeedControl/SpeedControllersBody.html)
**Pro:**
- position sensing for commutation
- no brushes -> low maintenance
- higher speed
- less noise

**Con:**
- more complex control (ESC)
- higher cost

Microchip Application Note AN885:
Brushless DC (BLDC) Motor Fundamentals
**TABLE 3:** SEQUENCE FOR ROTATING THE MOTOR IN CLOCKWISE DIRECTION WHEN VIEWED FROM NON-DRIVING END

<table>
<thead>
<tr>
<th>Sequence #</th>
<th>Hall Sensor Input</th>
<th>Active PWMs</th>
<th>Phase Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 0 0 1</td>
<td>PWM1(Q1) PWM4(Q4)</td>
<td>DC+ Off DC-</td>
</tr>
<tr>
<td>2</td>
<td>0 0 0 0</td>
<td>PWM1(Q1) PWM2(Q2)</td>
<td>DC+ DC- Off</td>
</tr>
<tr>
<td>3</td>
<td>1 0 0 0</td>
<td>PWM5(Q5) PWM2(Q2)</td>
<td>Off DC- DC+</td>
</tr>
<tr>
<td>4</td>
<td>1 1 0 0</td>
<td>PWM5(Q5) PWM0(Q0)</td>
<td>DC- Off DC+</td>
</tr>
<tr>
<td>5</td>
<td>1 1 1 1</td>
<td>PWM3(Q3) PWM0(Q0)</td>
<td>DC- DC+ Off</td>
</tr>
<tr>
<td>6</td>
<td>0 1 1 1</td>
<td>PWM3(Q3) PWM4(Q4)</td>
<td>Off DC+ DC-</td>
</tr>
</tbody>
</table>
Stepper Motors

- Converts electrical pulses into discrete mechanical movement
- Shaft rotates in discrete step increments
- Full torque at standstill
- Precise positioning and repeatability
- No brushes
- Low-speed possible

Con
- Resonance can occur
- Not easy to control at high speed

See [http://library.solarbototics.net/pdflib/pdf/motorbas.pdf](http://library.solarbototics.net/pdflib/pdf/motorbas.pdf)
Where to Buy Sensors?

- Digikey: Major electronic supply house
- Jameco: Many components but significantly cheaper than many vendors.
- Sparkfun: Great electronics hobby source
- Acroname: Robot hobby oriented. Lots of components
- Pololu: Electronic hobby oriented. Lots of sensors.
- Servo City: Lots of servos and actuators
- There are lots of alternate suppliers. Search the web!!

- Local Surplus: RaElco Electronics
  - 2780 S Main St, South Salt Lake, UT 84115