Embedded Systems

Ch 13A
Analog Interface & Codec

Byung Kook Kim
Dept of EECS
Korea Advanced Institute of Science and Technology

Overview

- *1. Introduction*
- *2. A/D Conversion*
- *3. ADC Interface*
- *4. Sensor Interface*
- *5. D/A Conversion*
- *6. PWM*

- *References*
  - *Steve Heath, "Embedded Systems Design", 2nd Ed., Newnes, 2003.*

1. Introduction

- How to sample external voltages and convert them into digital values
  - Sources
    - Sensors
      - Convert physical quantity into electrical quantity
      - Represent light levels, temperature, vibration
    - Analog signals
      - Output of microphone or audio system
  - Conversion
    - Analog-to-digital converter

ADC

- How to turn digital data into an analog output voltage
  - Destinations
    - Speaker, motor
  - Conversion
    - Digital-to-analog converter

DAC

2. A/D Conversion

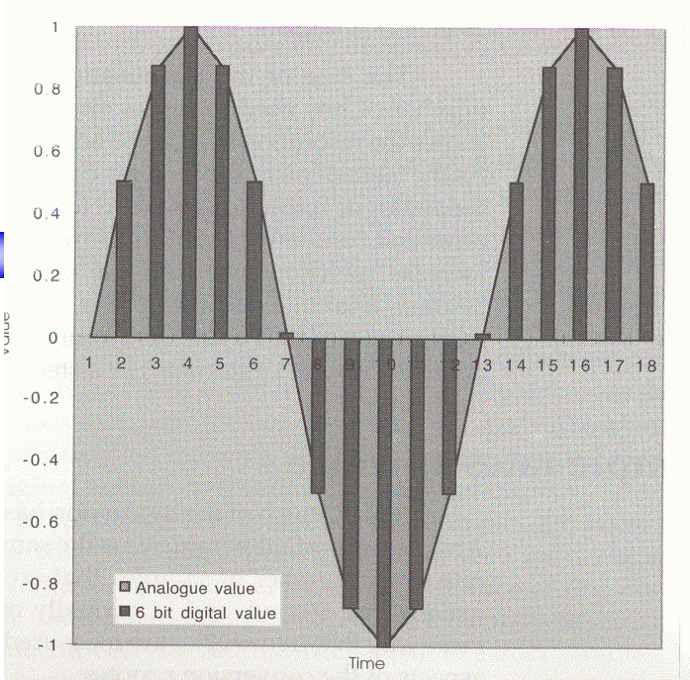
- **Amplifier**
  - Increases a given input voltage
    - Ex: Sensor output amplification from 5mVpp to 5Vpp

      Gain = V_out / V_in = 1000
  - Implementation
    - Using vacuum tubes, transistors, or OP amps
      - Inverting amplifier
      - Non-inverting amplifier
      - Differential amplifier
    - Restrictions
      - Frequency response
        - Home stereo: 20 Hz – 20 kHz
        - Sensor: flat (ideally)
      - Distortion
        - Total Harmonic Distortion (THD) in audio amp.

A/D Conversion (II)

- **Analog-to-Digital converter (ADC)**
  - A device that converts an analog input voltage to a digital number
  - Coder part of codec (Coder-DECoder)
  - Used in maaaaaany areas
    - Microphone in PC
    - CD mastering
    - DVD mastering
    - Sensor processing
  - Types
    - Integrating ADC: Counter, DAC, Comparator. 2^(n-1) clocks average.
    - Successive-approximation ADC: Binary search. n clocks.
    - Flash ADC (parallel ADC): (2^n – 1) comparators, encoding logic.

A/D Conversion (III)



- **Sampling**
  - Sample rate: samples per second
    - >2x signal bandwidth to avoid aliasing: Nyquist sampling theory
    - Faster: expensive ADC required
- **Quantization**
  - Accuracy of each sample (resolution)
  - Number of bits in digital data
  - Quantization level: Full_scale_voltage/(2^n)
    - 8-bit ADC: 1/256
    - 12-bit ADC: 1/4096
    - 16-bit ADC: 1/65536. More expensive
    - Ex: Temperature sensor with a range 0 to 100 deg.C, 0.5 deg. Resolution: 8-bit ADC is sufficient.
    - Ex2: CD - 16-bit, 44.1 kHz, stereo. 600 MB/h.
- Conversion equation
  - Analog signal = (digital sample / max value) * reference voltage.

3. ADC Interface

- **Wide range of ADCs**
  - Low-cost, low-speed ADCs: Simple voltage conversion
  - High-speed, precise (and expensive) ADCs: Sampling video streams
  - Built-in ADCs in microcontrollers: Simple interface

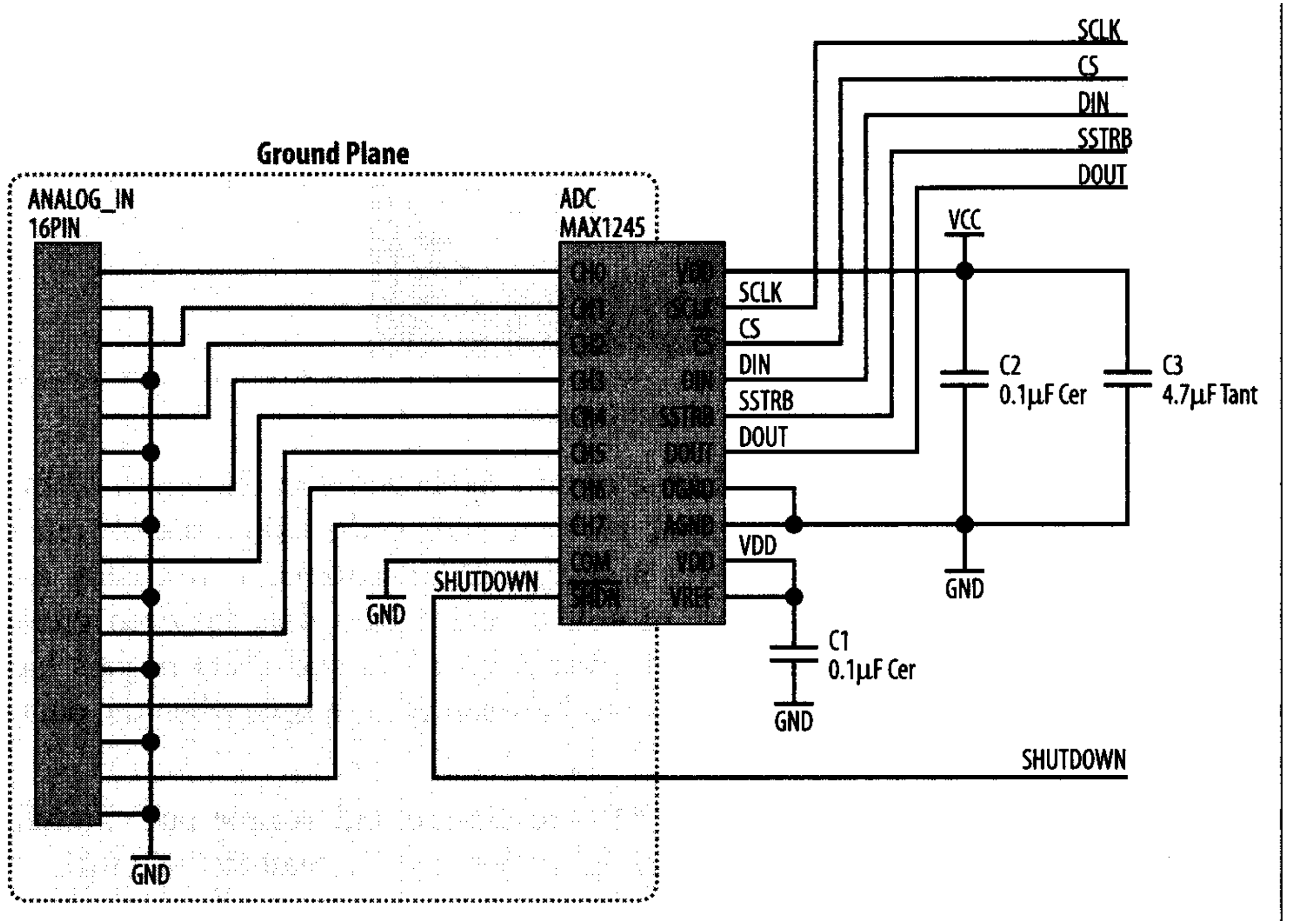
- **Considerations**
  - Number of bits (resolution): 8/12/14/16
  - Conversion rate (speed)
  - Interface: Parallel, serial, SPI, I2C
  - Analog multiplexer, Sample-and-hold: Internal or external
  - Package
  - Cost

ADC Interface (II)

- **Maxim MAX1245**
  - A good general-purpose ADC for sensor applications
    - 8 channels of analog input
    - 100K samples/sec
    - 12-bit resolution
    - Internal track-and-hold
    - Interface: SPI, microwire, serial (TI DSP)
      - DOUT: MISO, DI: MOSI, SCLK: SCLK
  - Operation
    - Start command to ADC via the SPI interface
      - Specifies the channel and other ADC settings
    - Internal/external clocks
      - SPI SCLK can be used as ADC clock

ADC Interface (III)

- MAX1245 Interface ->



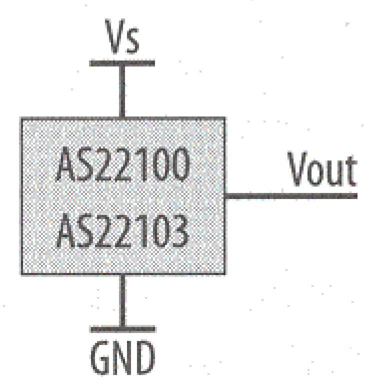
ADC Interface (IV)

- MAX1245
  - Ability to enter low-power mode
    - Hardware: SHDN' pin. Low: low-power operation

      Also specifies the clock frequency (1: 1.5 MHz, 0: 225 kHz)
    - Software:
      - If the two least-significant bits of the start command are both 0, then the MAX1245 is placed in shutdown.
      - Conversion and shutdown possible: Conversion and then shut-down.
- Power
  - In the range 2.7V to 3.3V
- Grounds
  - COM: Ground reference for analog inputs
  - DGND: ground for digital section
  - AGND: ground for analog section
    - -> Connected together at a single point near AGND.

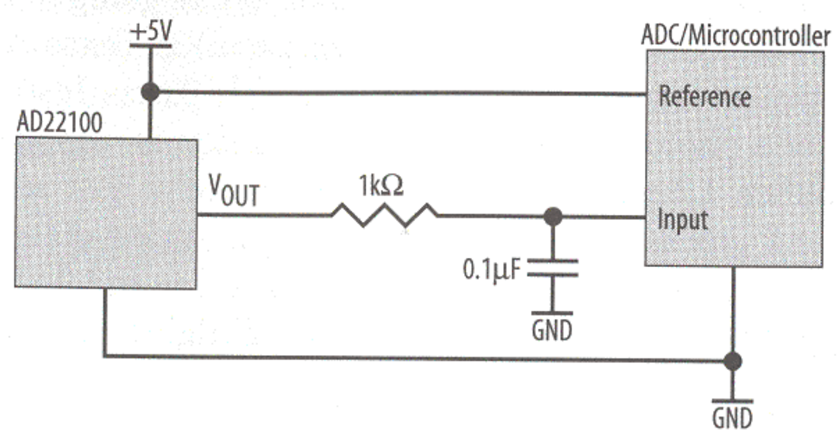
4. Sensor Interface

- **A. Temperature Sensor**
  - Applications
    - Room temperature: heating & cooling systems
    - Temperature recorder: shipment of fruits, vegetables, frozen foods, and flowers
  - AD22100/22103 temperature sensors by Analog Devices
    - Easy to use
    - 3-pin device: power, GND, and Vout ->
    - 5V (AD22100), 3.3V (AD22103)



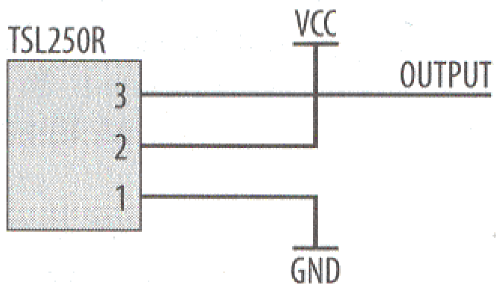
Sensor Interface (II)

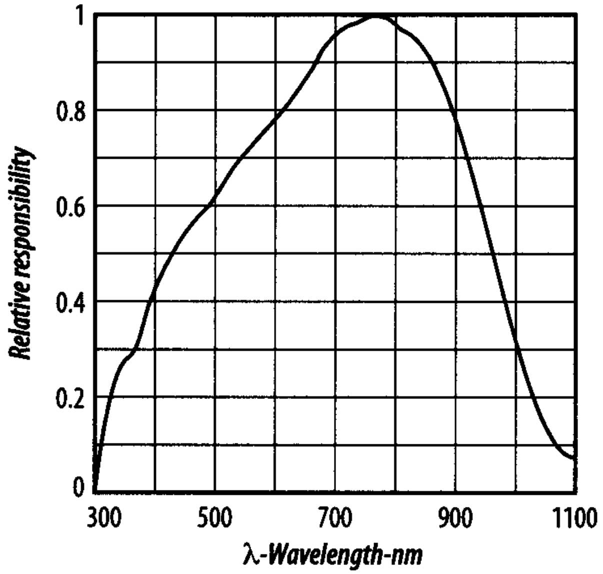
- *Temperature sensor (Cont'd)*
  - AD22100/22103
    - Temperature range: -50 deg.C to 150 deg.C
    - 22.5 mV/deg.C for AD22100
      - Vout = (Vs/5)*(1.375 + 0.0225*TA)
      - TA = (((Vout*5)/Vs) – 1.375) / 0.0225
    - 28 mV/deg.C for AD22103
      - Vout = (Vs/3.3)*(0.25 + 0.028*TA)
      - TA = (((Vout * 3.3) / Vs) / 0.028
  - Interfacing ->



Sensor Interface (III)

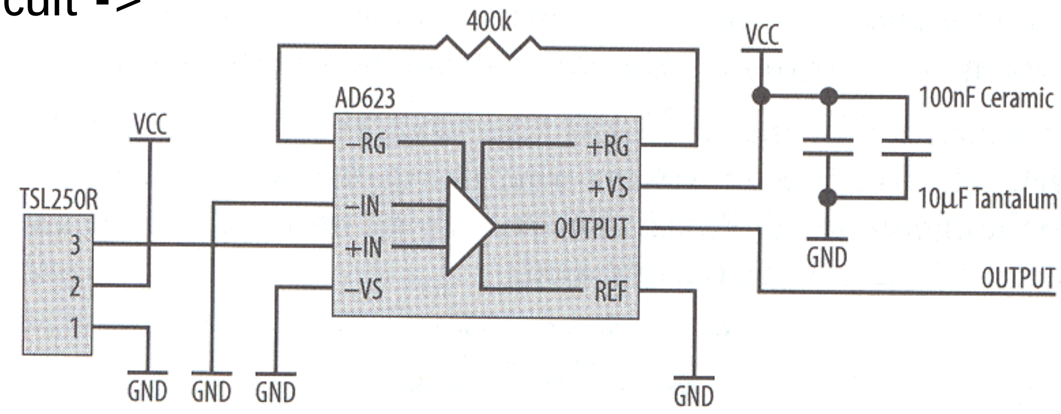
- **B. Light Sensor**
  - Applications
    - Artificial lighting systems
    - Security detector: Checks light interruption
  - TAOS TSL250R
    - Texas Advanced Optical Solutions Inc. http://www.taosinc.com
    - Consists of a photodiode and an integrated amplifier
    - Simple 3-pin device:
      - Vcc, GND, Output ->
    - Spectral response ->
    - Supply voltage between 2.7V to 5.5V
    - Consumes typically only 1.1 mA
    - Output: 0 to 4V





Sensor Interface (IV)

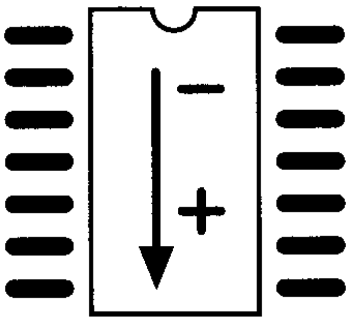
- *Light sensor (Cont'd)*
  - Amplifying the light sensor
    - 4V to 5V. Gain: 1.25
    - AD623: A good general-purpose op amp
      - Rail-to-rail operation, Single supply voltage
      - Requires very little current, Easy to use
      - Single external resistor to set gain
        - R_G = 100 kohm / (Gain – 1)
        - 1% accurate R req'd
    - Amplifier circuit ->

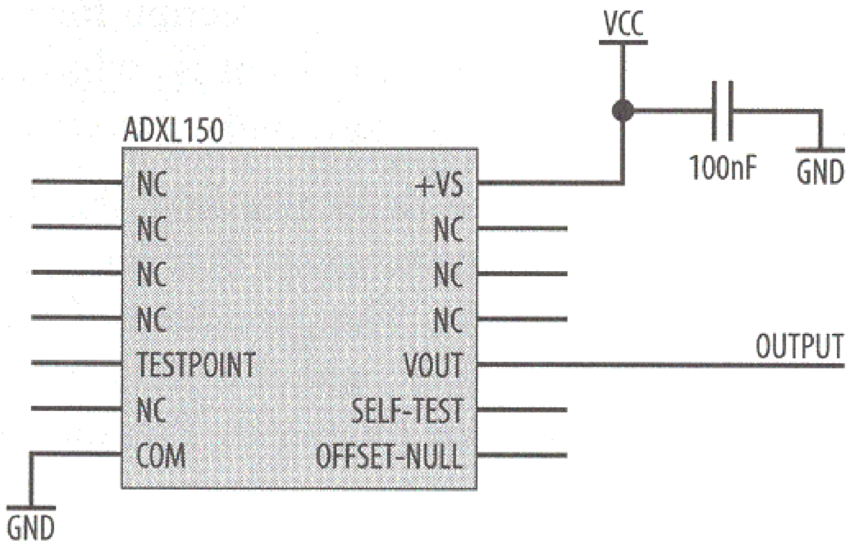


Sensor Interface (V)

- **C. Accelerometer**
  - ADXL150 (Analog Devices)
    - Single-axis (one-dimensional) accelerometer
    - Resolution 10 mg (1 g = 9.8 m/s^2)
    - Full-scale range +-50g
  - ADXL250
    - Dual-axis (two-dimensional) accelerometer
  - Applications
    - Measure linear acceleration of vehicles
    - Gentle vibrations and shifts
    - Seismometer
    - Vibrations of ground shift in mines, in tunnels, or at building sites
    - Monitor motion.

Sensor Interface (VI)





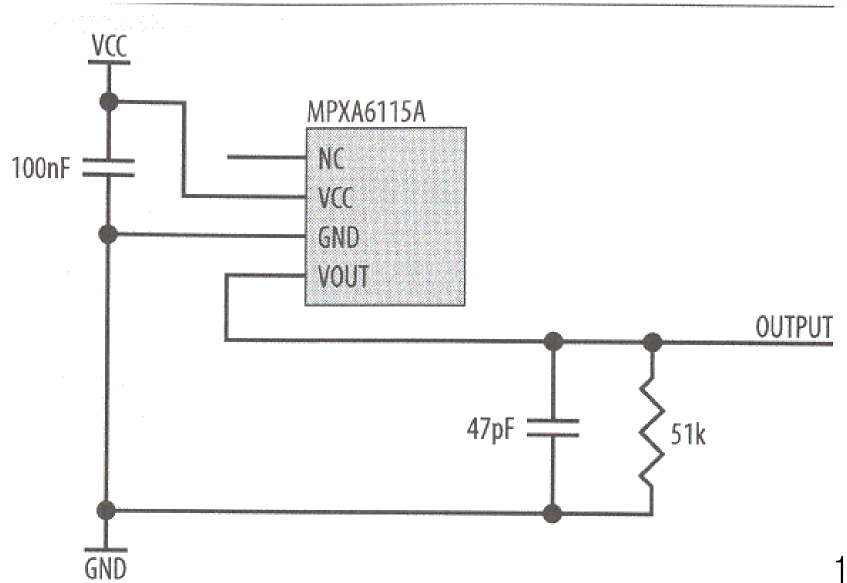
- *Accelerometer (Cont'd)*
  - Axis of sensitivity for ADXL150 ->
    - Use strong glue under the chip
  - ADXL150 circuit ->
    - No external components except power supply
    - Incorporates sensor, signal conditioning, and amplification
    - Output directly interfaced to an ADC
    - TESTPOINT: Used during manufacturing process
    - Power supply 4 – 6 V (5 V exact desirable)
    - V_out = Vs/2 – (sensitivity * Vs/5 * acceleration)
      - Sensitivity: 33.0 to 43.0 (38.0 nominal) for range +-50g
      - Sensitivity doubling
        - Connect output to the OFFSET_NULL pin (+-25g)
    - SELF-TEST: Verify correct operation (artificial force)

Sensor Interface (VI)

- **D. Pressure sensors**
  - Applications
    - Air pressure for weather monitoring and prediction
    - Cars: manifold pressure
    - Washing machine: water level
    - Biomedical: blood pressure
    - Measure altitude (air pressure dep. on height above sea level)
    - Ocean depth
  - Sensing methods
    - Deflection of a diaphragm separating two chambers
      - Absolute, differential, gauge (wrt atmosphere)

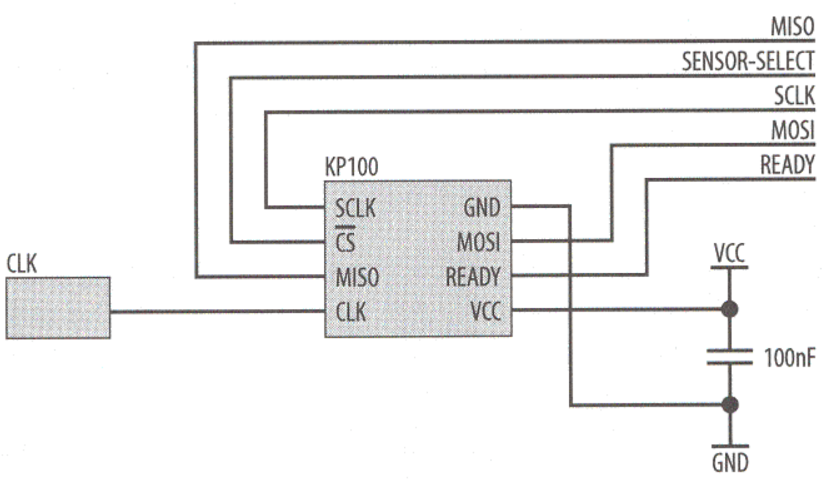
Sensor Interface (VIII)

- *Pressure sensors (II)*
  - **Motorola MPXA6115A**
    - Absolute pressure sensor ->
    - 5 V supply
    - Output voltage 0.2V to 4.8V (15kPa to 115kPa)
    - Integrates signal conditioning, temperature compensation
    - Requires
      - External power supply and decoupling capacitor only
      - RC filter at the output



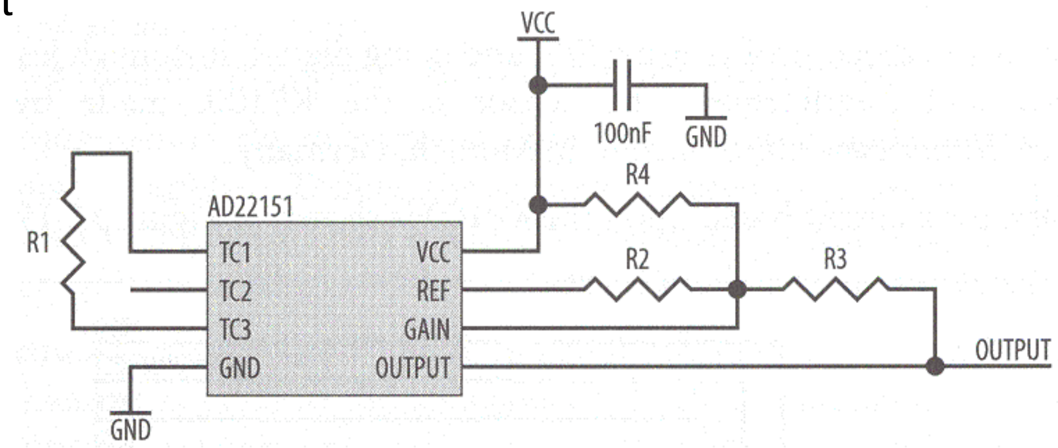
Sensor Interface (IX)

- *Pressure sensors (III)*
  - **KP100 by Infineon**
    - Absolute pressure sensor
    - Incorporates a built-in ADC
    - Much less susceptible to noise and interference
    - SPI interface ->
    - 5V supply and decoupling capacitor
    - READY output: may interrupt the processor
    - Separate CLK input: 4MHz or 8MHz



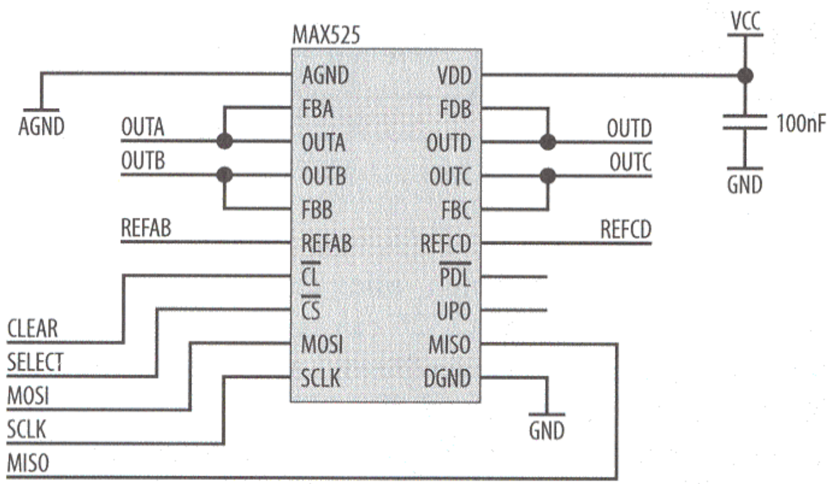
Sensor Interface (X)

- **E. Magnetic field sensor**
  - AD22151 by Analog Devices
    - Measure position and proximity
      - Magnetic source as a reference point
    - Built-in temperature compensation and amplification
    - Sensor circuit ->
      - R1: Temperature compensation resistor
      - R2, R3: Gain
      - R4: Voltage offset



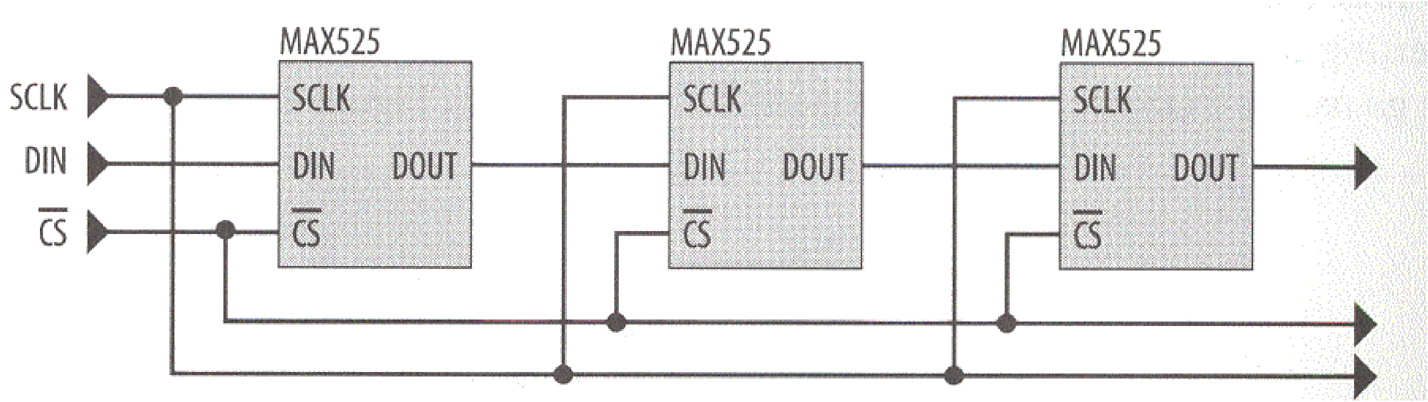
5. D / A Conversion

- **Digital-Analog Converter**
  - Take digital data and convert it into an analog signal
  - Digital input
    - Bus, SPI, or I^2C
  - **MAX525 by Maxim**
    - 12bit DAC with SPI interface ->
    - 4 channels of analog output
      - OUTA, OUTB, OUTC, OUTD
    - Output amplifiers on-chip
      - Feedback inputs: FBA, FBB, FBC, FBD
    - Voltage reference inputs: REFAB, REFCD
      - At least 1.4V or more below VCC
    - Output voltage
      - Vout = (Vref * code / 4096) * gain



D/A Conversion (II)

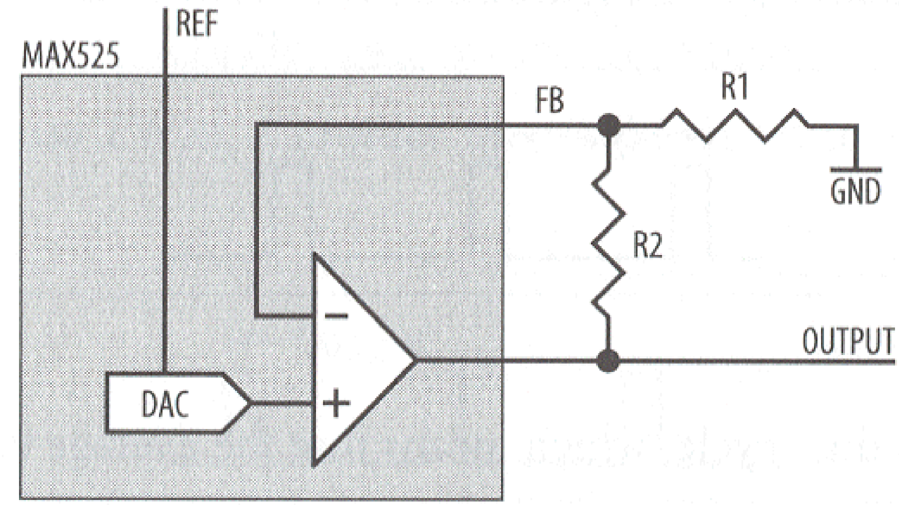
- *MAX525 (Cont'd)*
  - Daisy chaining multiple MAX525s ->



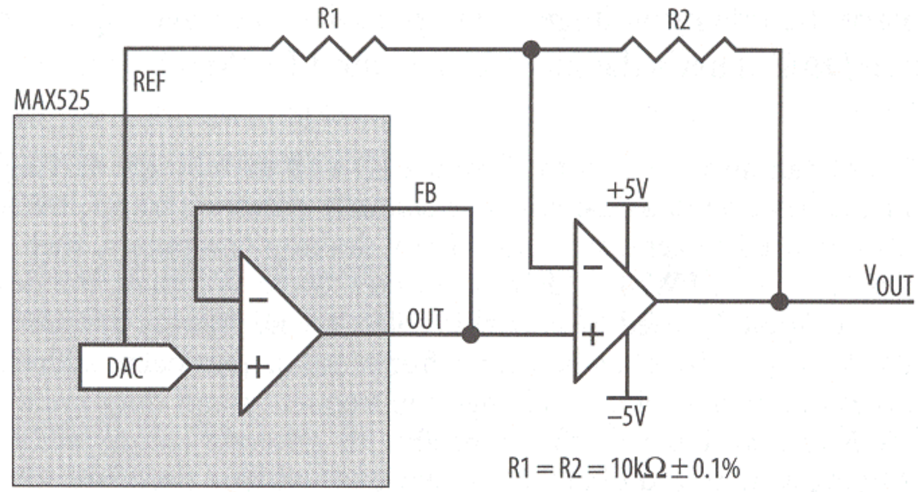
  - CLb input: All outputs to lowest value
  - Low-power mode under software control
  - PDLb input: power-down lockout
  - UPO: User Programmable Output
    - General-purpose

D/A Conversion (III)

- *MAX525 (Cont'd too)*
  - Nonunity gain amplifier ->
    - Gain = 1 + R2 / R1



  - Bipolar output
    - Use external amplifier with bipolar supplies ->

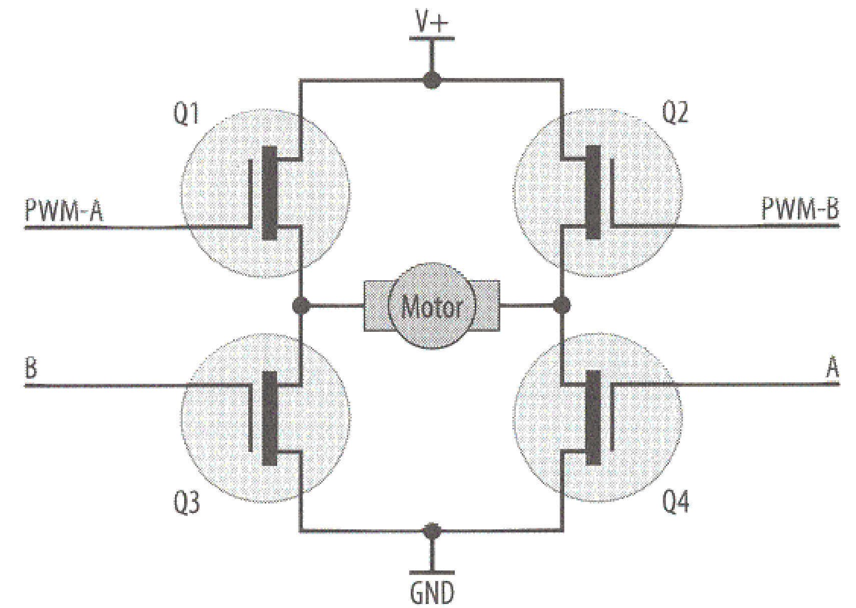


6 PWM

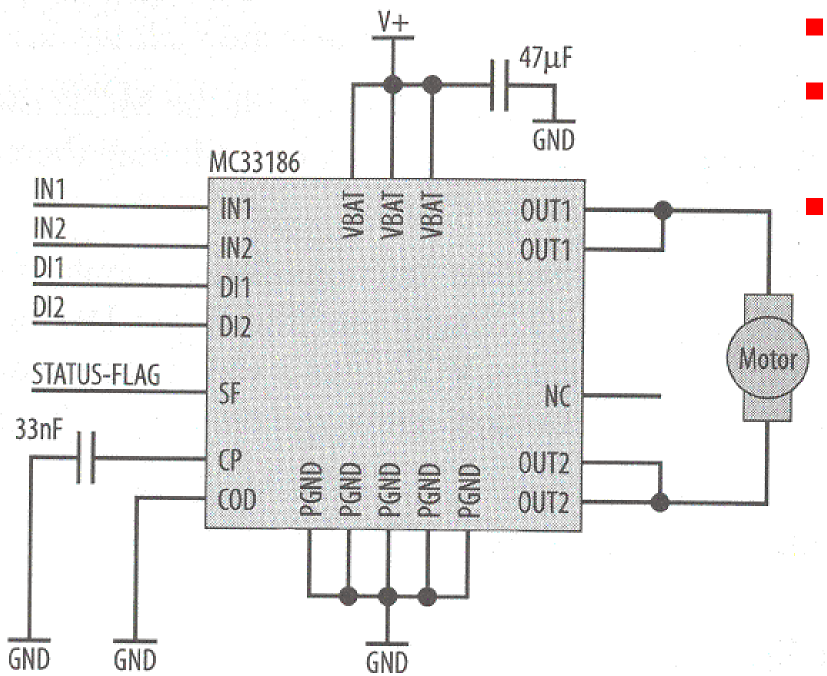
- **Pulse Width Modulation**
  - Use one digital output to generate analog output
    - Use a constant frequency (or period)
    - Change the duty cycle
    - Average value of the output is proportional to the duty cycle
  - Low-pass filter
    - Averaging
    - Convert the pulse to an analog voltage
  - Applications
    - Drive LEDs
    - Drive a speaker
      - Frequency and duty -> pitch and volume

PWM (II)

- Motor Control: DC motor drive
  - DAC + linear amplifier
    - Poor low-speed operation
    - Low power efficiency
  - PWM + switching amplifier
    - Better low-speed operation
    - High power efficiency
  - H-bridge ->
    - Bidirectional drive with single power supply
    - Q1, Q3 simultaneous ON: short circuit!



PWM (III)



- MC33186 by Motorola ->
  - More functionality
  - Easier to control
  - V+: 5 to 28V
  - TTL compatible inputs
  - Switch continuous current up to 5A
  - Built-in short-circuit and over-current protection
  - Pins
    - CP: Charge pump
    - Forward: DI1=0, DI2=1, IN1=1, IN2=0
    - Backward: DI1=0, DI2=1, IN1=0, IN2=1
    - Freewheeling: DI1=0, DI2=1, IN1=IN2
    - Disabled: DI1=1 or DI2=0
    - SF output: Status Flag.