Lecture 14: Intelligent Sensor Systems

- **Compensation**
  - Self-diagnostics, self-calibration, adaptation
- **Computation**
  - Signal conditioning, data reduction, detection of trigger events
- **Communications**
  - Network protocol standardization
- **Integration**
  - Coupling of sensing and computation at the chip level
  - Micro electro-mechanical systems (MEMS)
- **Others**
  - Multi-modal, multi-dimensional, multi-layer
  - Active, autonomous sensing

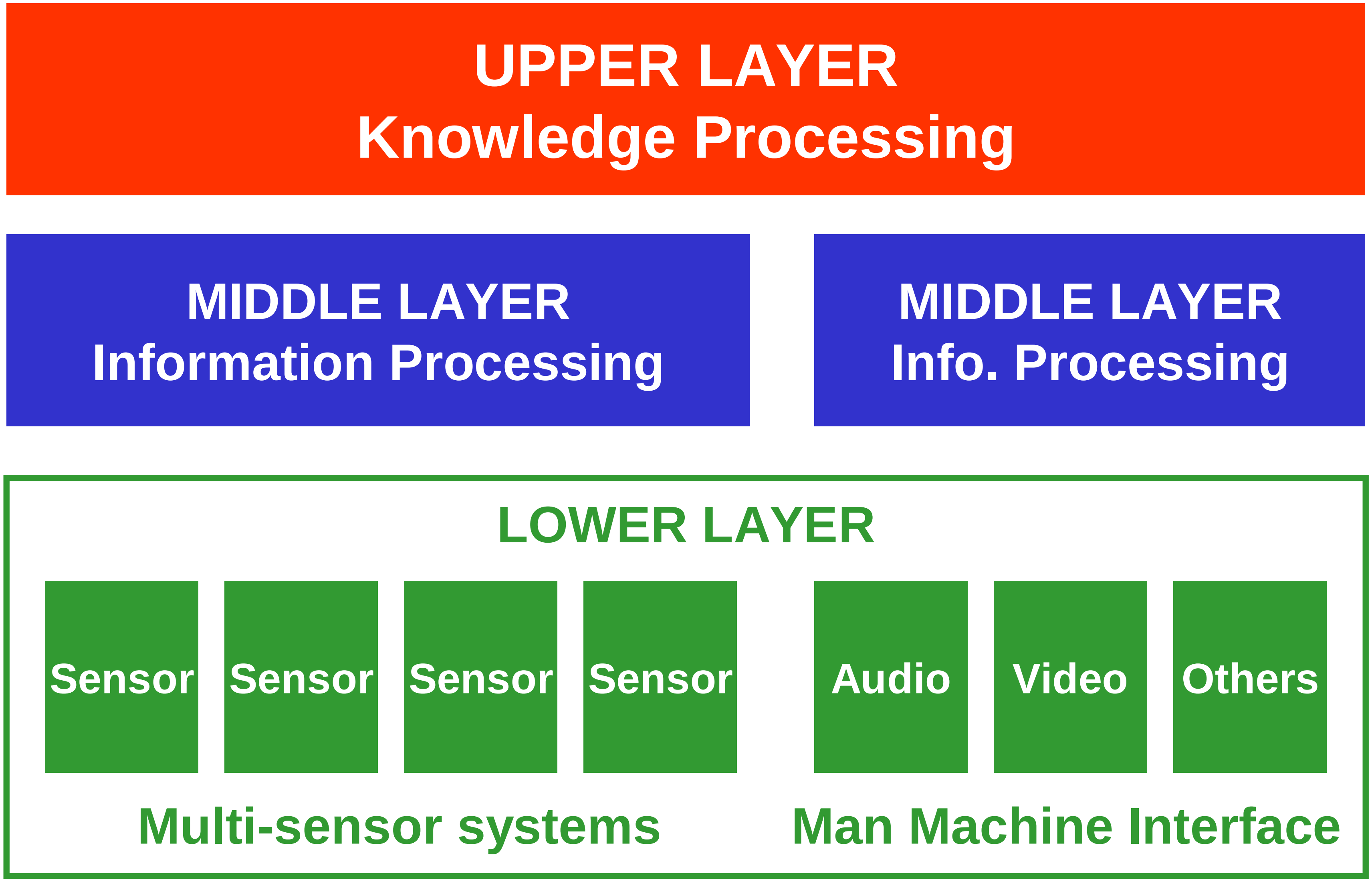
Compensation

- **Self-diagnostics versus self-calibration**
  - An intelligent sensor should be able to answer the following
    - Is the output a reasonable value?
    - Does it agree with the result of an adjacent sensor?
    - Is the rate of change of the output reasonable?
    - Is the output actually changing?
- **Compensation**
  - Offset compensation
    - To fully utilize the dynamic range of ADCs
  - Gain
    - By means of programmable gain amplifiers
  - Linearity
    - By means of look-up tables
  - Cross-sensitivity
    - Temperature control and/or compensation
- **Discussion**
  - How could you incorporate some of these elements into our e-nose?

Computation

- **Various degrees of computation**
  - Signal conditioning (e.g., filtering)
  - Signal conversion (e.g., analog to digital)
  - Logic functions (e.g., triggering events)
  - Data reduction (e.g., feature extraction)
  - Decision making (e.g., classification)
- **Advanced sensing systems have a hierarchical structure with different abstraction layers**
  - LOWER LAYER performs Signal processing
    - Conditioning, filtering, conversion, contrast enhancement
  - MIDDLE LAYER performs Information processing
    - Feature generation, sensor signal fusion and parameter tuning
  - UPPER LAYER performs Knowledge processing
    - Clustering, prediction, classification, decision making, communications
- **Can you identify these layers in our e-nose system?**

Hierarchical system structure



Processing approaches

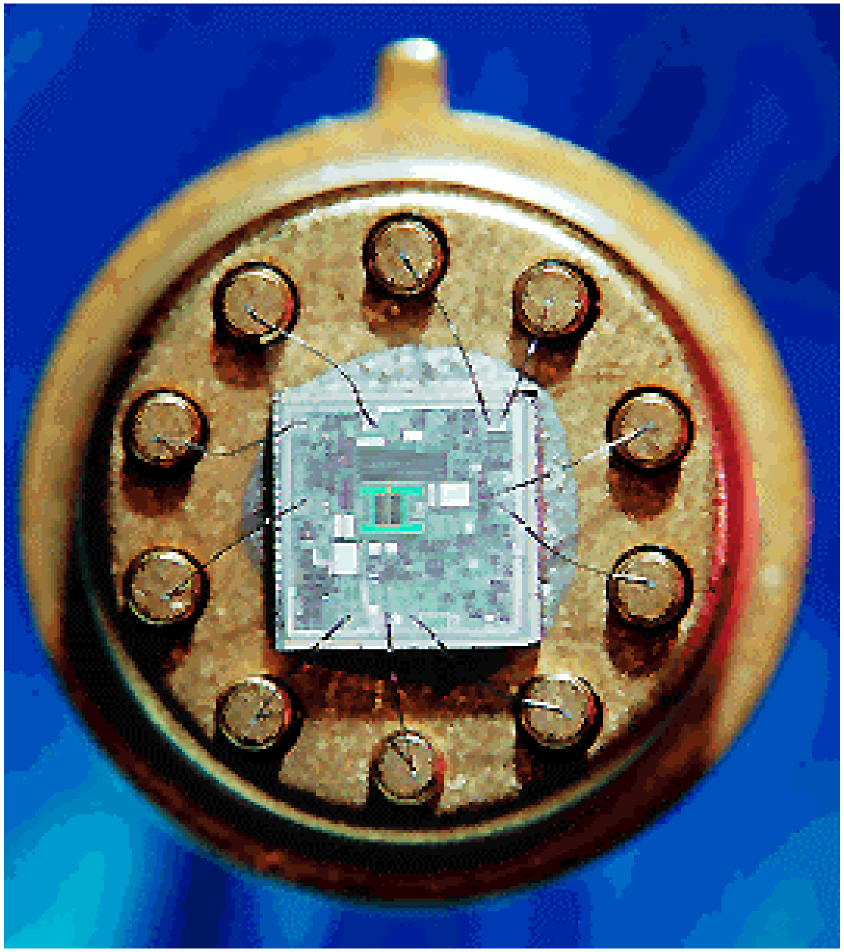
- **Classical**
  - Statistical signal processing
  - Statistical pattern analysis
- **Connectionist**
  - Multilayer feed-forward neural networks
  - Unsupervised learning
- **Fuzzy logic**
  - Fuzzy control
  - Fuzzy signal processing
- **Evolutionary**
  - Genetic algorithms
  - Genetic programming
- **Hybrid approaches**
  - Neuro-fuzzy
  - Neuro-genetic
  - …

Communications

- **Traditionally, each sensor system is custom-designed for specific applications by experience designers**
- **This approach has several limitations**
  - **Complexity**: a limited number of sensors may be installed in each system, imposed by the level of complexity that human designers can deal with
  - **Cost**: system is composed of a small number of highly specialized, relatively expensive sensors
  - **Flexibility**: the resulting system cannot be easily expanded, modified, maintained or repaired. Highly trained personnel is required for these functions
- **Solution**
  - Standardization of transducer interfaces
    - Electrical, mechanical(?), communications protocol
  - Addition of communication capabilities
    - The ideal: Plug-and-play sensors
    - Autonomous, distributed, re-configurable sensors

Integration

- *On-chip signal conditioning and self-diagnostics constitute smartness in the ADXL series of accelerometer ICs from Analog Devices*



Integration

DATA ACQUISITION

- Instrumentation amplifiers
- Filters
- Sample and Hold
- Analog to Digital Converters
- Voltage to Frequency Converters
- Multiplexers
- Oscillators
- Voltage references
- Sensor-specific devices
- Complete DAQ sub-systems

COMMUNICATIONS

- Line drivers
- Line receivers
- Bus transceivers
- Bus controllers

POWER SUPPLY

- AC/DC converters
- DC/DC converters

COMPUTING

- Embedded
  - Micro-controllers
  - Digital Signal Processors
  - 4,8,16,32-bits
- Monitoring devices
- Volatile memories
  - Static RAM
  - Dynamic RAM
- Non-volatile memories
  - ROM
  - EEPROM
  - Flash
  - Disk-on-a-chip

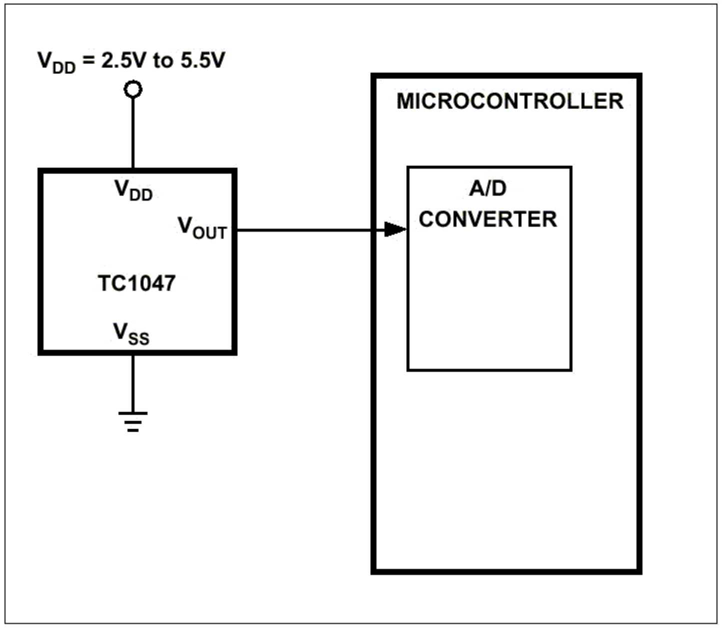
CONTROL

- Digital to Analog Converters
- Frequency to Voltage Converters
- Switches
- Power drivers
- Actuator-specific devices

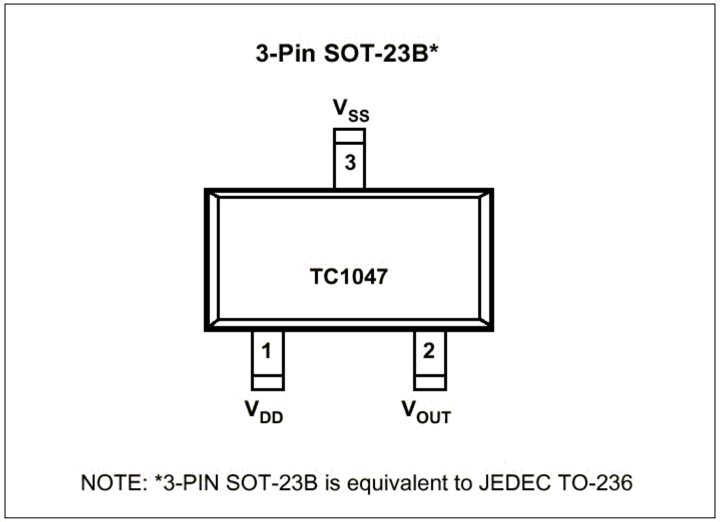
Examples

- **Microchip® temperature to voltage converters (TC1047)**
  - Sensor provides an output voltage directly proportional to measured temperature
    - Temperature range: -40ºC to +125ºC
    - Linear temperature slope: 10mV/ ºC
    - Small 3-pin SOT-23B Package

FUNCTIONAL BLOCK DIAGRAM



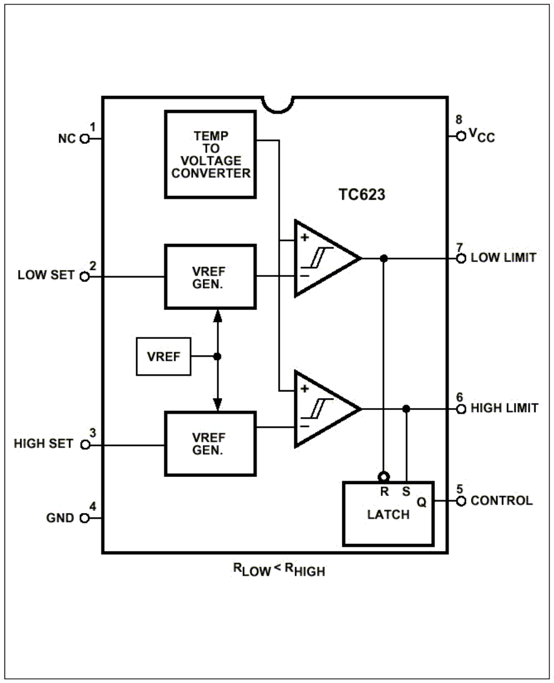
PIN CONFIGURATION



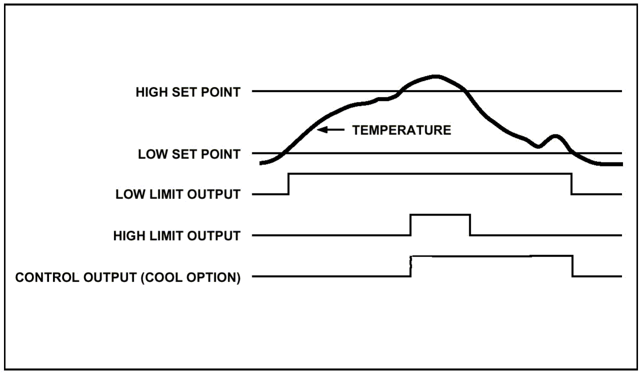
Examples

- **Microchip® dual-trip temperature sensor (TC623)**
  - Integrated temperature sensor and logic threshold
  - 8-pin DIP or SOIC for direct PCB mounting
  - 2 user-programmable temperature set-points (w/ external resistor)
  - 2 independent temperature limit outputs

FUNCTIONAL BLOCK DIAGRAM



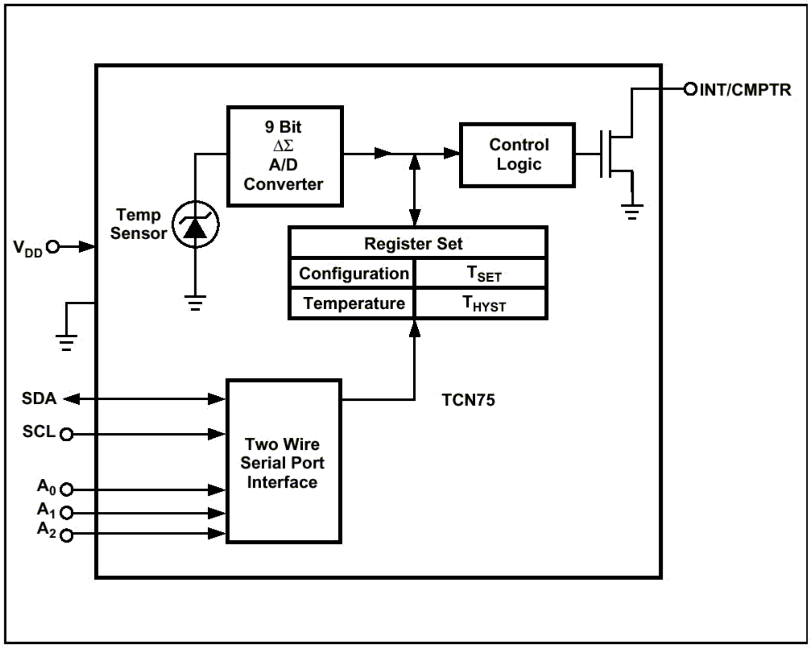
- **Application**
  - Low temp reduces CPU CLK
  - High temp further reduces CPU CLK
  - Control output starts fan



Examples

- **Microchip® 2-wire serial temperature sensor**
  - Standard 2-wire serial interface
    - Programmable trip point and hystheresis
    - Digital readout
    - Device configuration
  - Multiple operation modes
    - Comparator
    - Interrupt
    - Standby (power management)
  - Address lines
    - Up to 8 devices can share the 2-wire bus lines

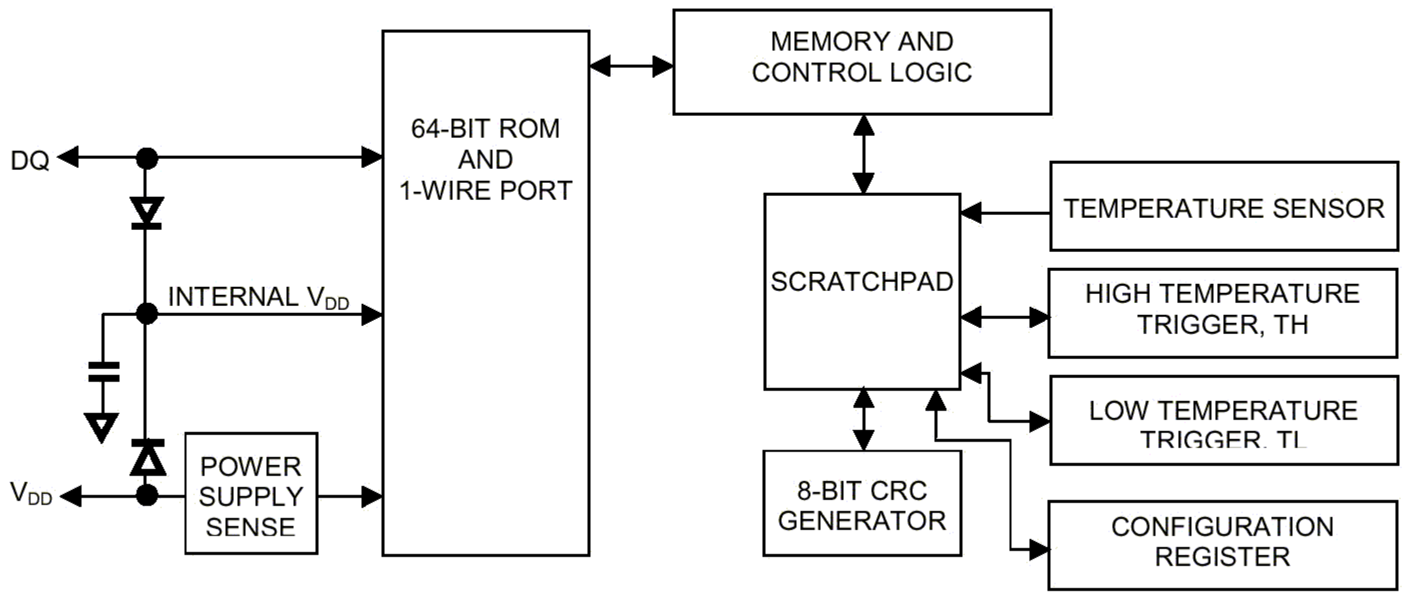
FUNCTIONAL BLOCK DIAGRAM



Example

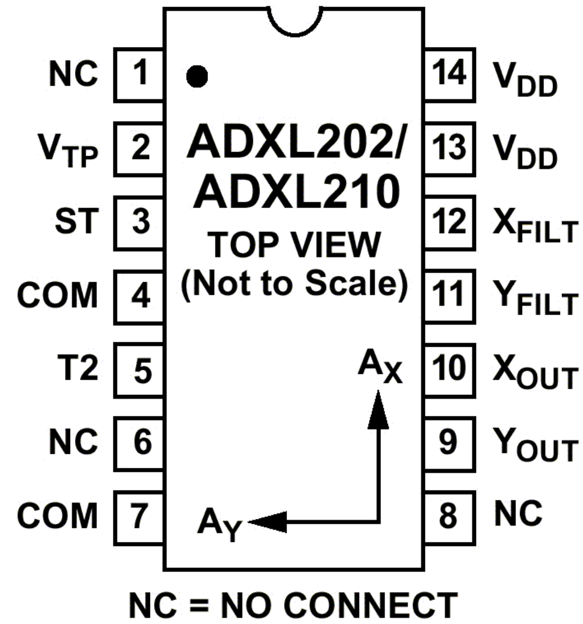
- **Dallas Semiconductor 1-Wire® digital thermometer (DS18B20)**
  - One wire interface requires only one communication pin
  - Can be powered from a data line
  - Programmable thermometer resolution from 9 to 12 bits
  - 2 and 3 wire versions are also available

DS18B20 BLOCK DIAGRAM Figure 1

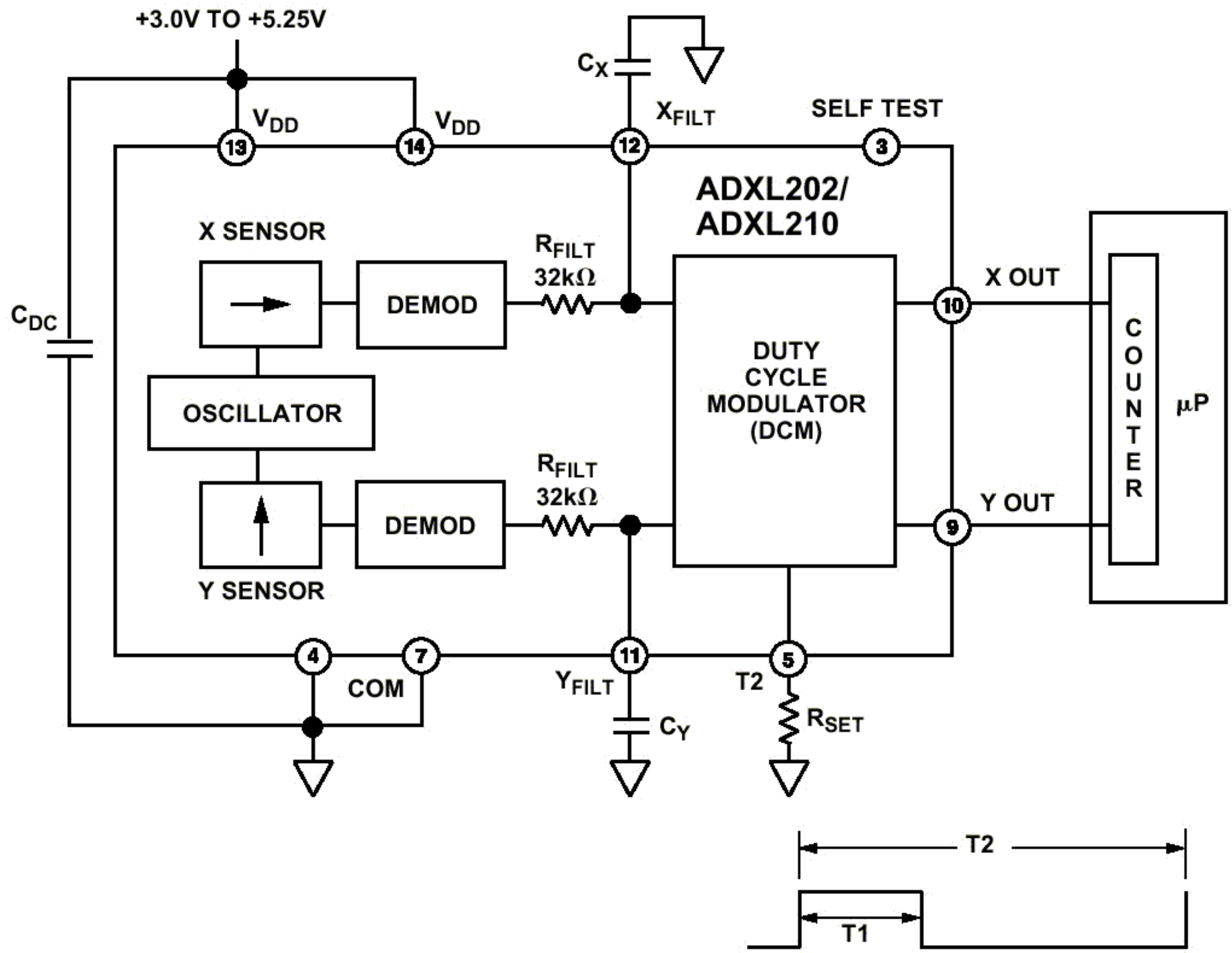


Example

- **Analog Devices 2-axis accelerometer (ADXL202)**
  - Can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity)
  - The outputs are Duty Cycle Modulated (DCM) signals
    - Duty cycles (ratio of pulsewidth to period) proportional to the acceleration in each of the 2 sensitive axe
    - These outputs may be measured directly with requiring no A/D converter or glue logic.
  - If an analog output is desired, an analog output proportional to acceleration is available from the X_{FILT} and Y_{FILT} pins
    - or may be reconstructed by filtering the duty cycle outputs
  - Bandwidth may be set from 0.01 Hz to 6 kHz via capacitors C_X and C_Y



Analog Devices 2-axis accel. (ADXL202)



A(*g*) = (T1/T2 – 0.5)/12.5%
0*g* = 50% DUTY CYCLE
T2 = R_{SET}/125MΩ

Example

- **Analog Devices 2-axis self-test accelerometer (ADXL250)**
  - Low noise (80dB SNR), wide dynamic range (±50g), reduced power consumption…
  - A Logic "1" applied to the **self-test** input will cause an electrostatic force to be applied to the sensor that will cause it to deflect!