Arbeitskreis Hardware

Prof. Dr. Michael Rohs, Dipl.-Inform. Sven Kratz

michael.rohs@ifi.lmu.de

MHCI Lab, LMU München

Schedule (preliminary)

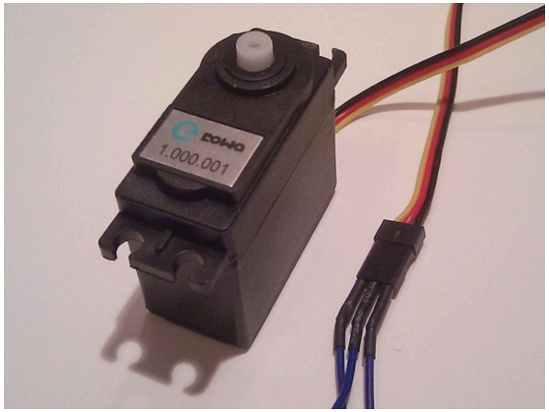
Date	Topic (preliminary)
2.5.	Introduction to embedded interaction, microcontrollers, hardware & software tools
9.5.	*keine Veranstaltung (CHI)*
16.5.	soldering ISP adapter, AVR architecture
23.5.	LED displays, LED multiplexing, transistors, electronics basics
30.5.	AVR architecture, AVR assembler, sensors: light, force, capacity, acceleration, etc.
6.6.	PCB design & fabrication, EAGLE, 3D printing
13.6.	*keine Veranstaltung (Pfingsten)*
20.6.	Actuation: stepper motors, servo motors, I2C: interfacing to other chips (EEPROM, real-time clock, digital sensors)
27.6.	USB to serial chips, storage on memory cards, capacitive sensors
4.7.	Displays (character LCDs, graphics LCDs), audio (speakers, amplification, op-amps)
11.7.	Communication: fixed-frequency RF, ZigBee, Bluetooth
18.7.	Project
25.7.	Project

SERVO MOTORS

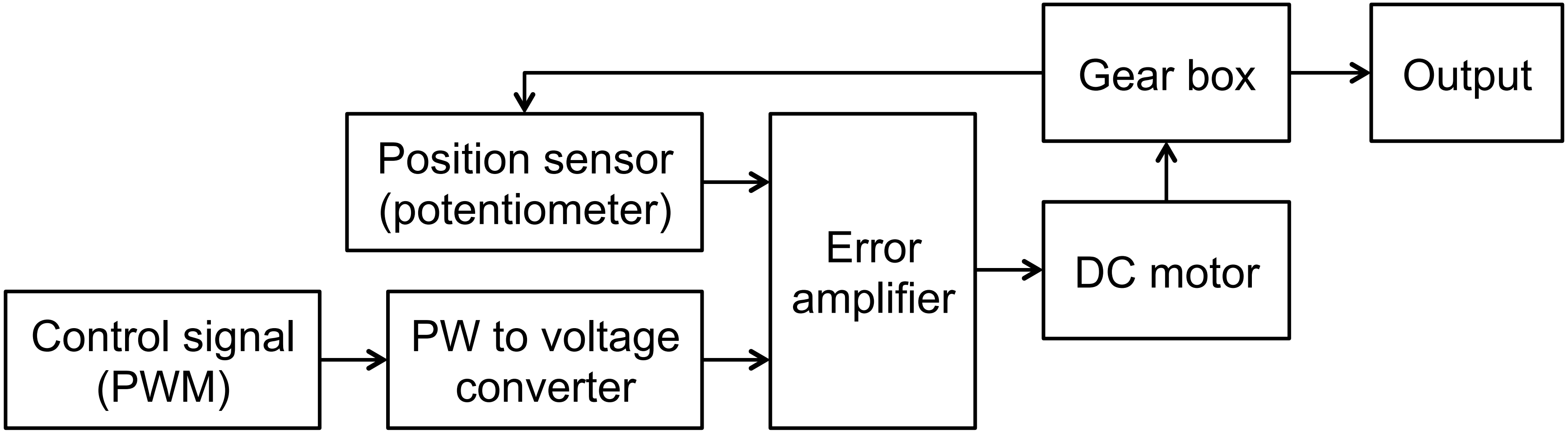
Servomotors

- Precise angular position control
- Limited to ±90° rotation
- Can be modified to unlimited rotation and velocity control
- Used in RC models, robots, sensor positioning, etc.

Operating Principle

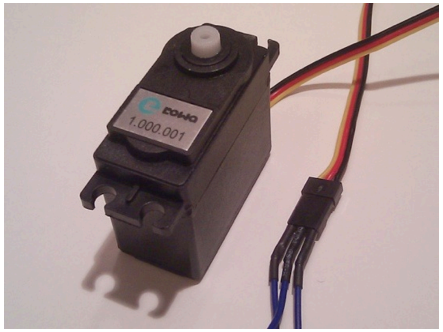


- DC motor with a servo mechanism for precise control of angular position
- Motor + feedback device + control circuit

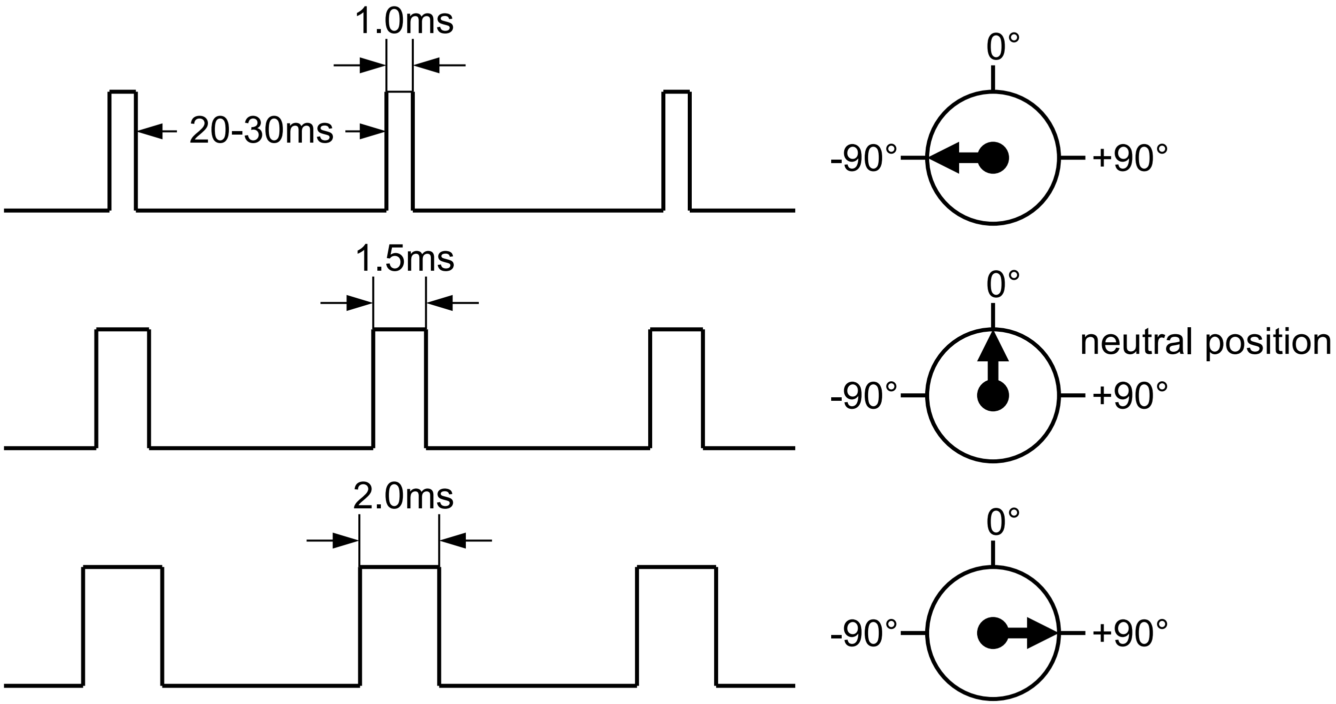


- Motor speed depends on “error”
  - Fast if large difference between sensor and signal
  - Slow if small difference between sensor and signal

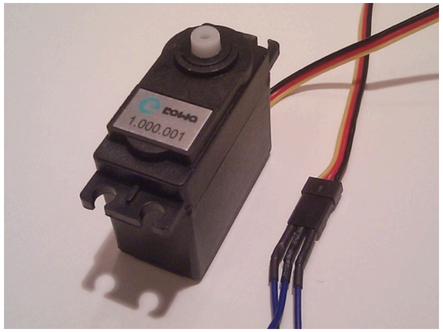
Controlling Servo Motors



- Wiring: red, black, yellow cables
  - red = V_{CC} (4.8-6V), black = GND, yellow = PWM signal
- PWM signal: 1.5ms is always neutral, min/max times and positions may vary



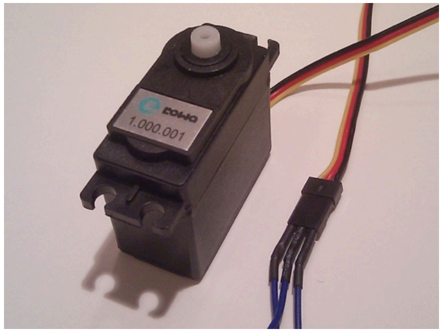
Controlling Servo Motors



- Motor can draw huge amounts of power
  - Use large Elko between red and black wires (≥1000µF)
- High precision requirements for PWM signal
  - External quartz rather than internal RC oscillator (otherwise, motor will jitter)
- Simplest case: busy waiting (not recommended)

```
// yellow wire of motor on PB3
DDRB  |= 0b00001000; // port PB3 output
PORTB &= 0b11110111; // port PB3 low
while (1) {
    PORTB |= 0b00001000; // port PB3 high
    _delay_us(1500);
    PORTB &= 0b11110111; // port PB3 low
    _delay_ms(18); // 1.5 + 18 = 20 ms
}
```

Controlling Servo Motors



- Timer-generated PWM signal
  - Problem, long gaps (20-30ms) between signals (1-2ms)
  - For 8-bit timers (e.g. ATtiny45) this results in very low resolution:
    20ms = 256 counts ⇔ 1ms = 13 counts = -90°,
    2ms = 26 counts = +90° ⇔ resolution = 180°/14 counts = 13°
- Solution: 16-bit timers
  - For 16-bit timers (e.g. ATmega8) resolution is better:
    20ms = 65536 counts ⇔ 1ms = 3277 counts = -90°,
    2ms = 6554 counts = +90° ⇔ resolution = 180°/3278 counts = 0.05°
- Solution: Combine PWM with timer interrupts
  - Use shorter timer period to optimally use 1-2ms
  - Deactivate signal generation (but not timer) during gaps
  - Tradeoff between interrupt rate and angular resolution

Timer-generated PWM + Interrupts

```
GTCCR = (1 << TSM) | (1 << PSR0); // halt timer, reset prescaler
DDRB  |= 0b00000001; // port PB0 (OC0A) output
PORTB &= 0b11111110; // port PB0 (OC0A) low
TCCR0A = (2 << COM0A0) | (0 << COM0B0) | (3 << WGM00); // Clear OC0A on Compare Match, set OC0A at BOTTOM (non-inverting mode); Fast PWM, TOP = 0xFF
TCCR0B =  (0 << WGM02) | (4 << CS00); // prescaler: clkIO/256
TCNT0 = 0; // reset conter
OCR0A = 94; // should be 93.75 for 1.5ms
TIMSK = (1 << OCIE0A); // Timer0 Output Compare Match A Interrupt Enable
sei(); // enable interrupts
GTCCR = (0 << TSM) | (0 << PSR0); // start timer

while (1) { …}
```

16 MHz external quartz

ATtiny45 datasheet, ch. 11: 8-bit Timer/Counter0 with PWM, 11.9 Register Description

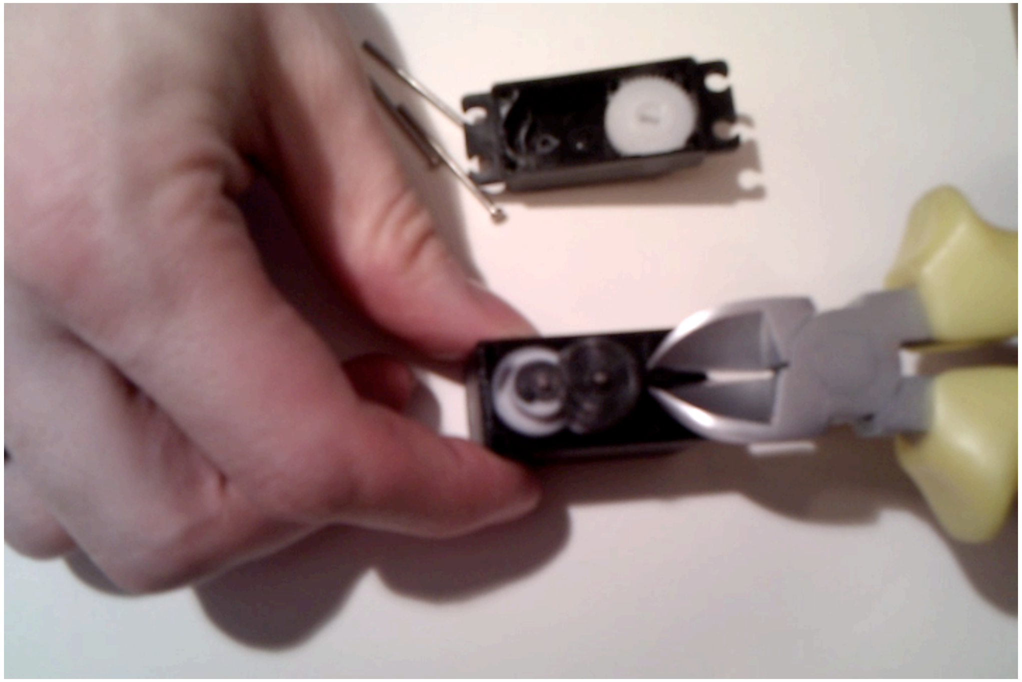
Timer-generated PWM + Interrupts

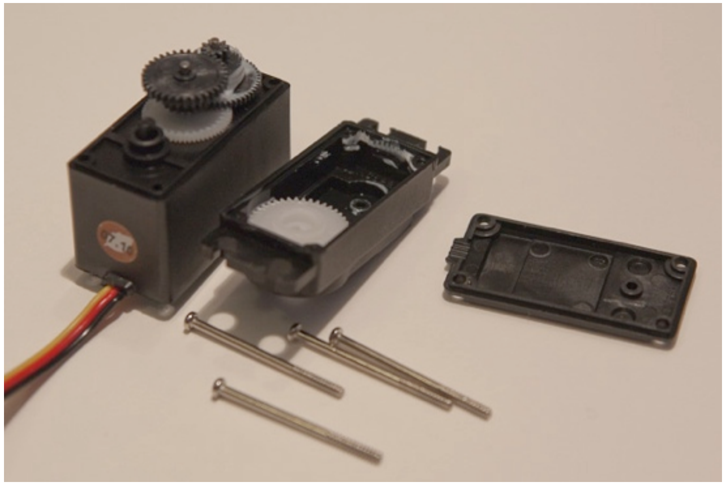
16 MHz external quartz, prescaler 256, 256 counts

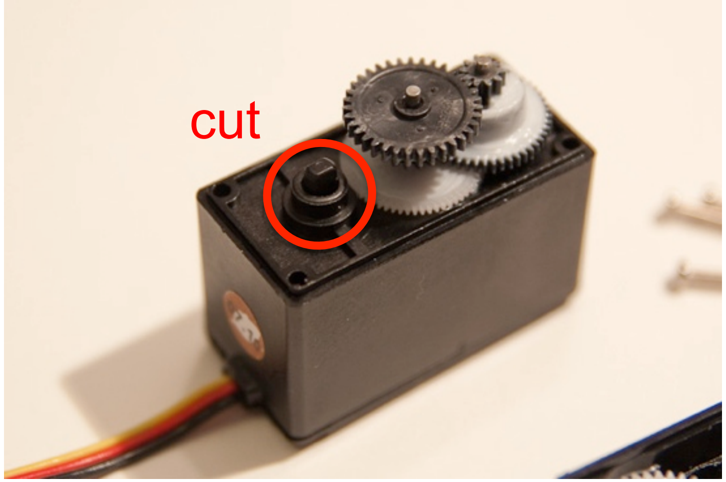
```
#include <avr/interrupt.h>
int interruptCount = 0;
ISR(TIMER0_COMPA_vect) // interrupts occur at a frequency of 244.14Hz
{
    interruptCount++;
    if (interruptCount == 1) { // switch off OC0A output
        // Normal port operation, OC0A/OC0B disconnected; Fast PWM
        TCCR0A = (0 << COM0A0) | (0 << COM0B0) | (3 << WGM00);
    } else if (interruptCount >= 5) { // produce OC0A output
        // Clear OC0A on Compare Match, set OC0A at BOTTOM; Fast PWM
        TCCR0A = (2 << COM0A0) | (0 << COM0B0) | (3 << WGM00);
        interruptCount = 0;
    }
    // set OCR0A: 63 = -90°, …, 94 = 0°, …, 125 = +90° (2.9° resolution)
}
```

Unlimited Rotation and Velocity Control

- Useful for robot wheels
- Servo needs to be modified by cutting off link to potentiometer





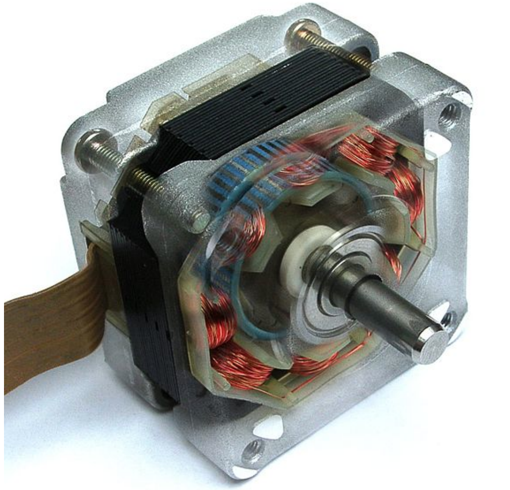


- Steps: remove mechanical stop on gear, cut/file off potentiometer axis, glue potentiometer to neutral position

STEPPER MOTORS

Stepper Motors

- Rotates fixed number of degrees per step
  - Typically 15° or 30°
- Lower maximum speed than DC motor
- High torque at low speeds
- Used in printers, plotters, sensor positioning
- Do not need feedback device, but control circuit (“translator”)
- Different wiring schemes
  - Unipolar, biploar, etc.



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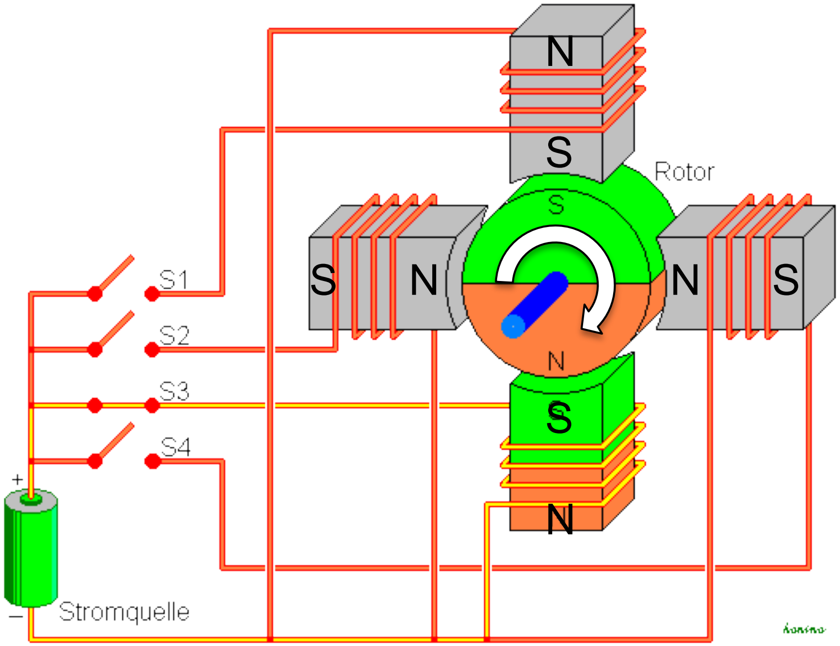

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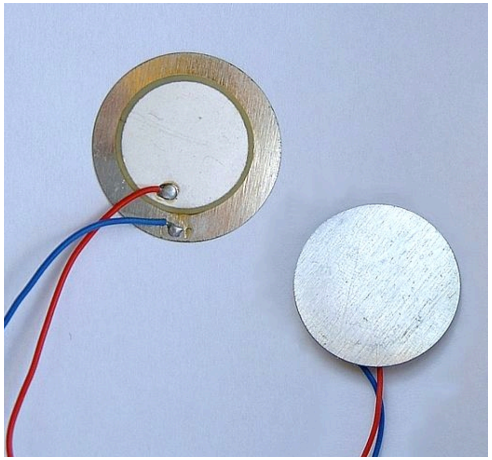
SENSORS (CONTINUED)

Piezo Elements as Sensors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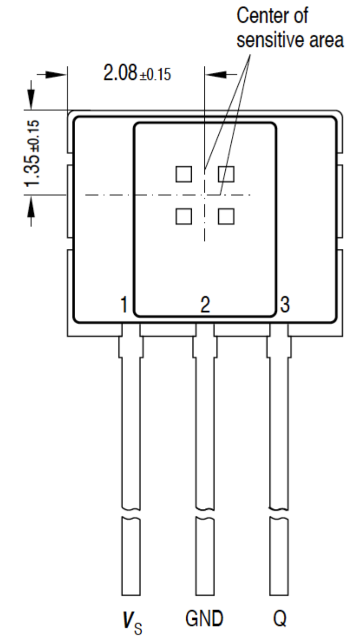
- Piezo elements can be used for output, but also for sensing vibration, e.g. knocks
  - Generates voltage when deformed by vibration, sound wave, mechanical strain
  - Generates vibration (a sound), when voltage is applied
- Directly usable as sensor by reading analog value with AVR's ADC
- Piezos are polarized (red = V_{cc}, blue= ground)
- Need a current-limiting resistor (1MΩ)
- Glue against sensing surface

Hall Sensor (TLE 4905)



- Senses magnetic field:
  switch on, when magnet nearby
- Used in bike computers to count wheel revelations
- Principle: Magnetic field perpendicular to Hall sensor induces voltage
- V_S = 3.8..24V
- I_{out} = 100mA

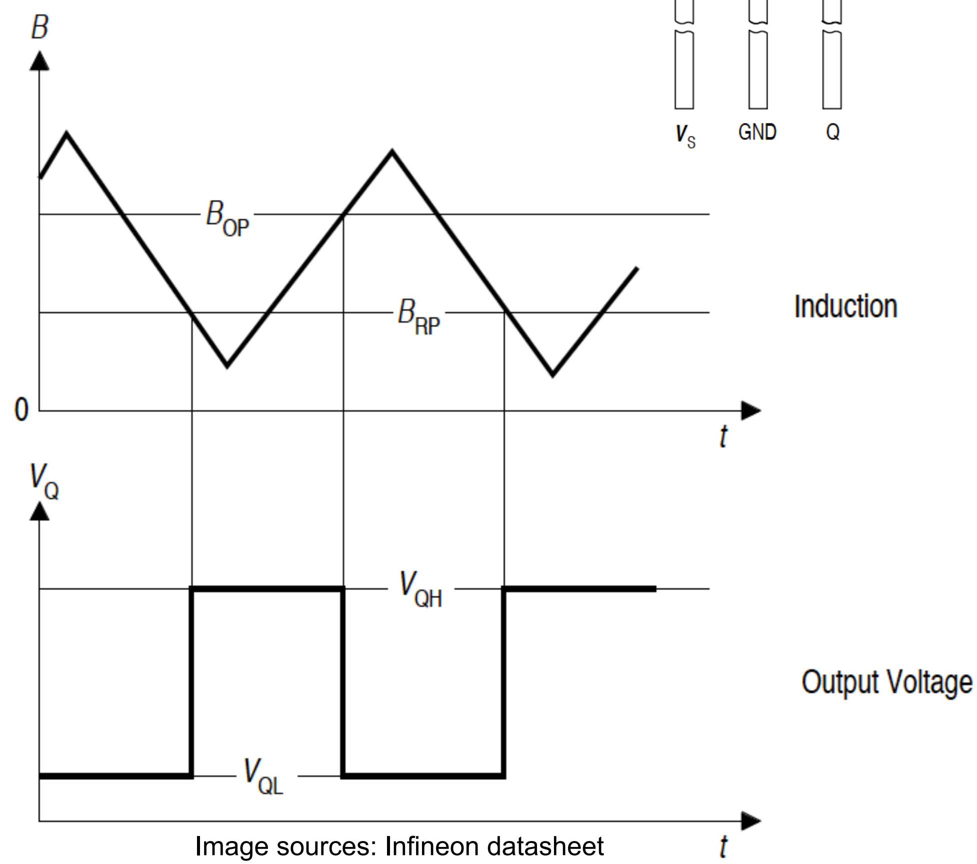
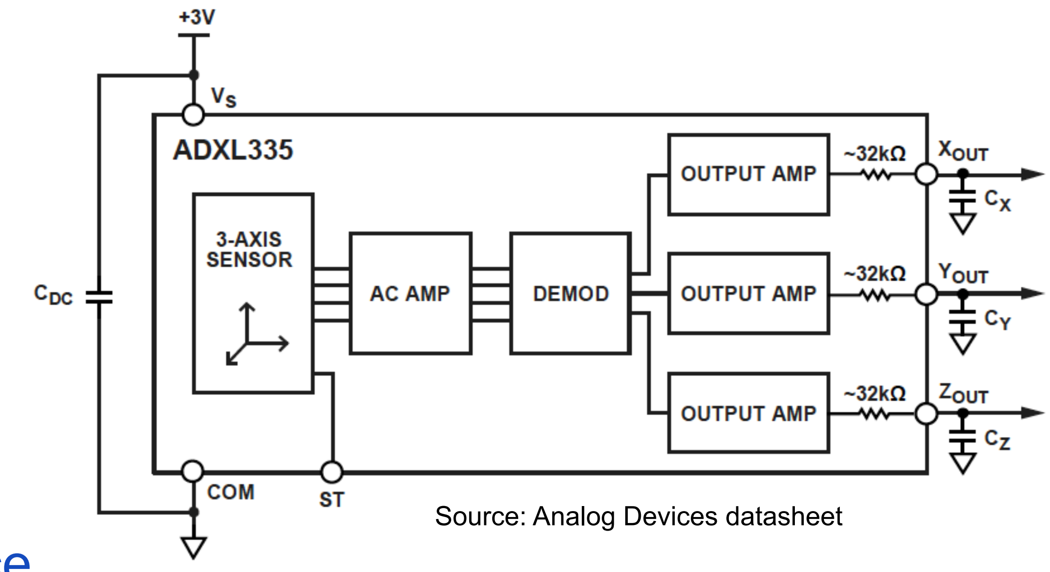


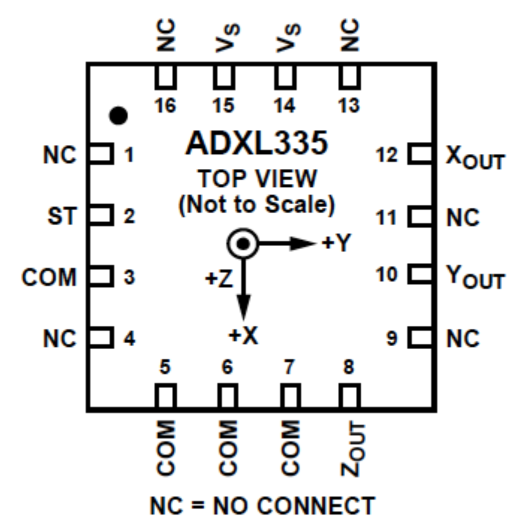
Image sources: Infineon datasheet

Accelerometer ADXL335



Source: Analog Devices datasheet

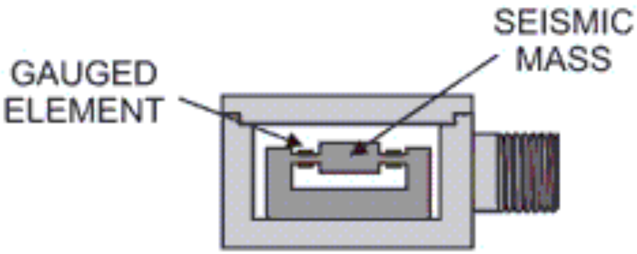
- Polysilicon surface-micromachined sensor
- 3-axis sensing, ±3g
  - Gravity as static reference
- Low power (350µA @ V_{cc} = 3V)
- Output voltages X_{out}, Y_{out}, Z_{out} proportional to acceleration
- Selectable bandwidth / filtering
  - Capacitors C_X, C_Y, C_Z
  - F_{-3} dB = 1 / (2π (32kΩ) $C_{(X, Y, Z)}$)
  - Max: 1600 Hz (x,y axes), 500 Hz (z axis)



Source: Analog Devices datasheet

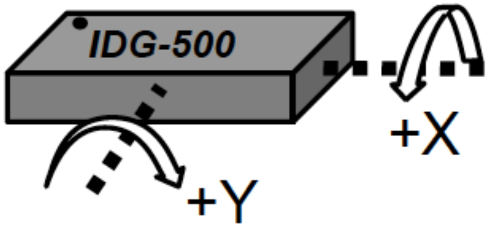
How do Accelerometers work?

- Causes of acceleration
  - Gravity, vibration, human movement, etc.



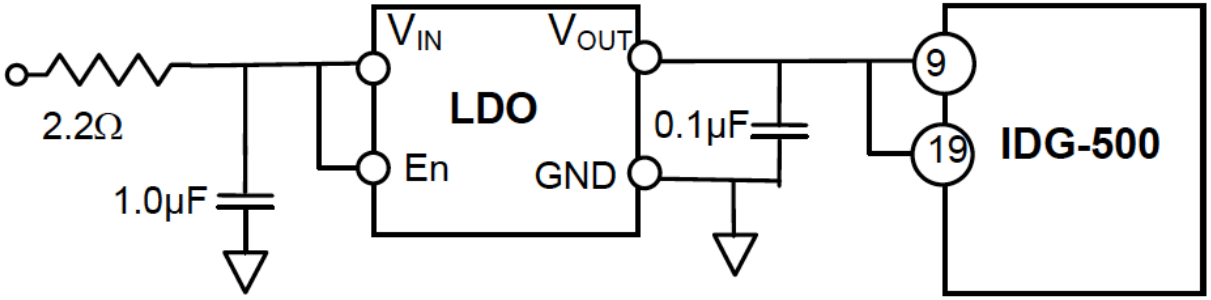
- Operating principle
  - Conceptually: damped mass on a spring
  - Typically: silicon springs anchor a silicon wafer to controller
  - Movement to signal: Capacitance, induction, piezoelectric etc.
- For ADXL335
  - Polysilicon surface-micromachined structure containing mass
  - Polysilicon springs suspend mass
  - Deflection of mass measured with differential capacitor: one plate fixed, other attached to moving mass
  - Square waves drive plates
  - Deflection unbalances differential capacitor

Gyroscope IDG500



Source: InvenSense datasheet

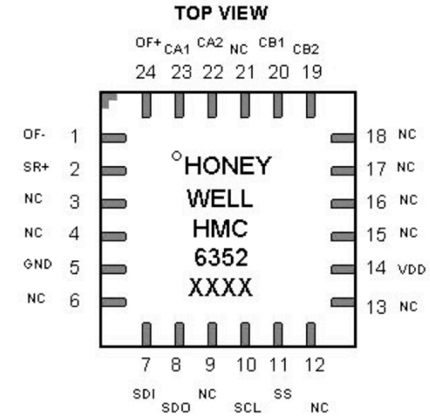
- Dual-axis angular rate sensor (gyroscope)
  - Senses rate of rotation about X- and Y-axis (in-plane sensing)
  - Factory-calibrated
  - Low-pass filters
- V_{CC} = 3V



Source: InvenSense datasheet

- Output voltage proportional to the angular rate
- Separate outputs for standard and high sensitivity
  - X-/Y-Out Pins: 500°/s full scale range, 2.0mV/°/s sensitivity
  - X/Y4.5-Out Pins: 110°/s full scale range, 9.1mV/°/s sensitivity

I2C Magnetometer / Compass Honeywell HMC6352



Source: Honeywell datasheet

- Compass module
  - 2-axis magneto-resistive sensors
  - Support circuits
  - Algorithms for heading computation
- Parameters
  - V_{CC} = 2.7..5.2V, typ. 3.0V
  - Update rate: 1..20Hz
  - Heading resolution: 0.5°
  - I2C interface

used for complex sensors (e.g., allows sending configuration commands)

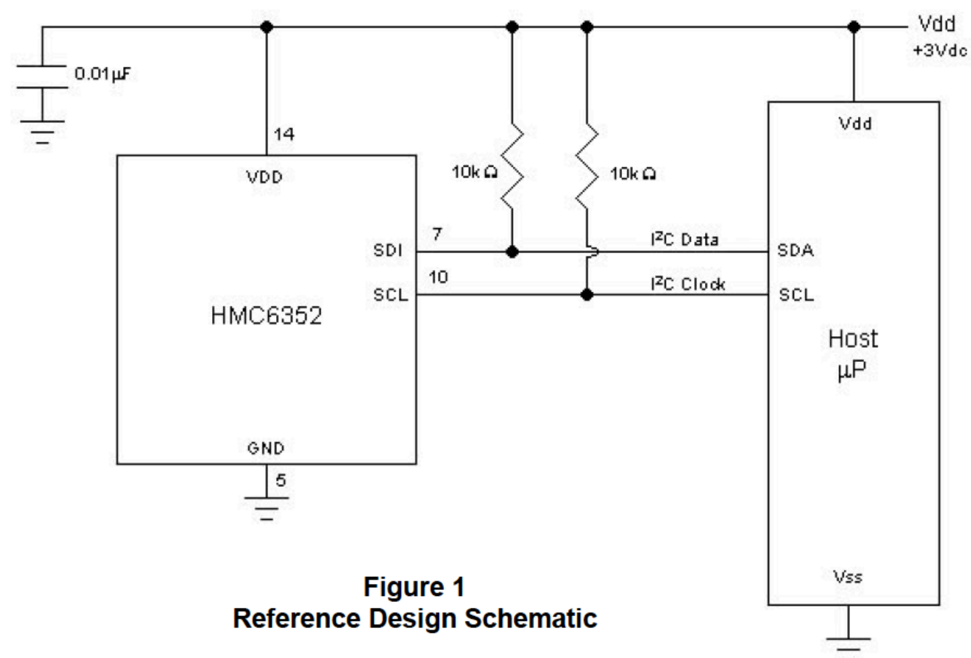


Figure 1
Reference Design Schematic

Source: Honeywell datasheet

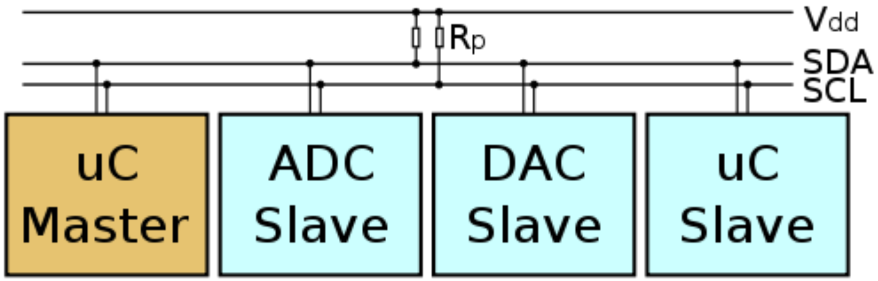
Sparkfun Sensors

- Many more sensors…
- http://www.sparkfun.com/categories/23?page=all

INTERFACING HARDWARE

Inter-Integrated Circuit (I^2C)

- Low-speed data bus developed by Philips to interconnect components, aka. “two-wire interface”
  - Requires only two wires, connected to all devices on bus
- Two bidirectional open-drain lines, pulled up with resistors
  - Serial Data (SDA)
  - Serial Clock (SCL)



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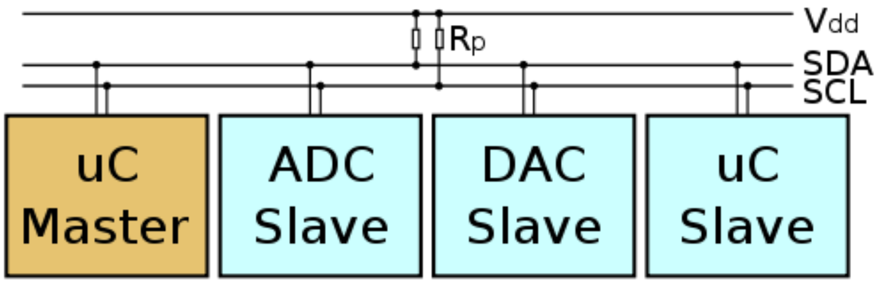
- 7-bit address space with 16 reserved addresses
  - up to 112 nodes on one bus
- Bus speeds
  - arbitrarily low clock non-uniform frequencies possible
  - typical: 100 kbit/s standard mode, 10 kbit/s low-speed mode

Inter-Integrated Circuit (I^2C)

- Node roles: master and slave
  - Master node: issues clock signal and addresses slaves
  - Slave node: receives clock signal and own address
  - Multiple masters can be present,
    master and slave roles can be changed

- Operation modes
  - Master transmit
  - Master receive
  - Slave transmit
  - Slave receive



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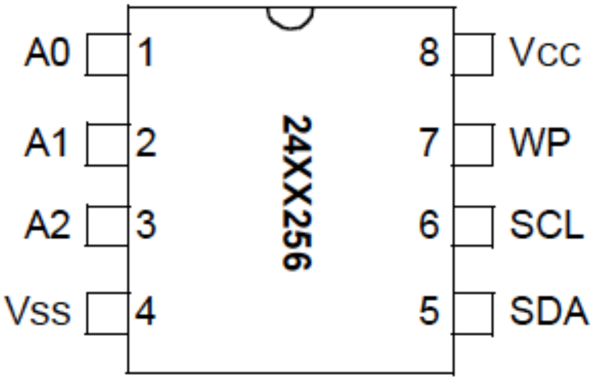
Inter-Integrated Circuit (I^2C)

- Protocol
  - Master node (in master transmit mode) sends start bit, followed by slave address, followed by read(1)/write(0) bit
  - Slave responds with ACK-bit (0)
  - Master continues in master transmit / receive mode; slave continues in slave receive / transmit
  - Master sends stop bit to finish transmission (or repeats start)
- Conventions
  - Bytes are sent MSB first
  - Start bit: SDA high-to-low transition with SCL high
  - Stop bit: SDA low-to-high transition with SCL high
  - Bytes sent/received are ACKed by other node
  - Master can read bytes repeatedly: ACKs every byte but the last one

I2C EEPROM 24LC256

- Features
  - 256 Kbit, V_{CC} = 2.5-5.5V
  - Max. write current 3mA at 5.5V
  - Max. read current 400µA at 5.5V
  - Standby current 100nA
  - 64-byte pages

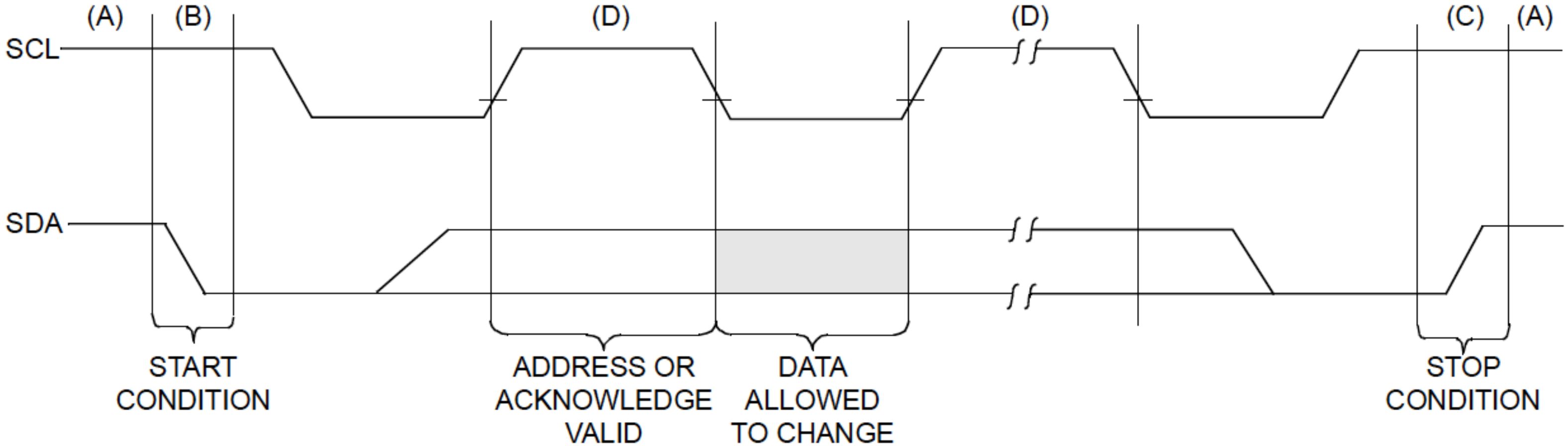


Source: Microchip datasheet

- Pins
  - A0..A2 connected to GND or V_{CC}
  - Write protect if WP connected to V_{CC}
  - Pullup resistors on SCL, SDA lines: R_{PU} = 10kΩ for SCL 100kHz

I2C EEPROM 24LC256: Sequence

- Data transfer sequence
  - SCL and SDA high on inactive bus (pulled up to V_{CC})



- Acknowledge bit timing

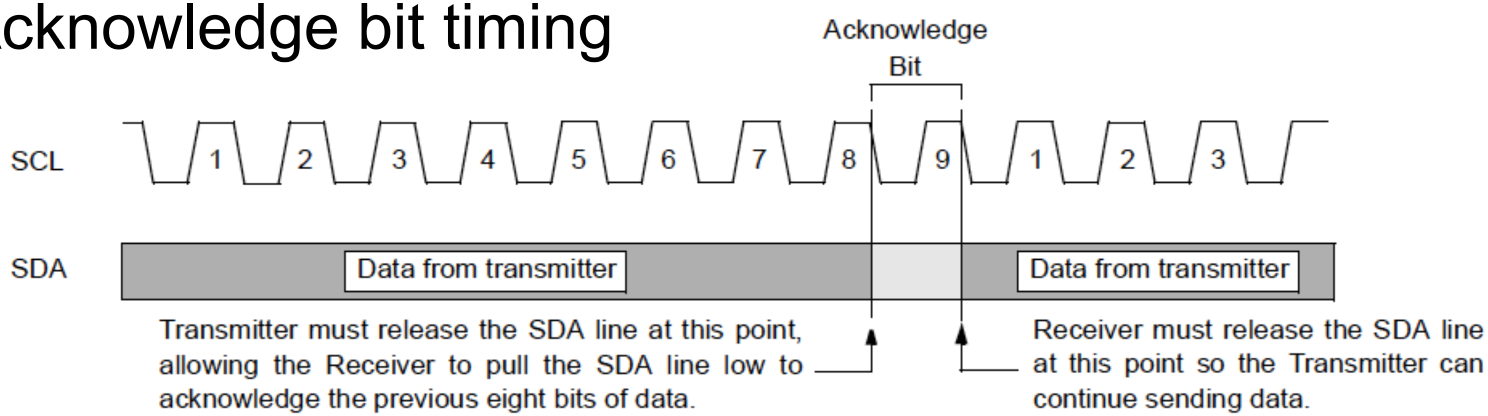


Figure sources: Microchip datasheet

I2C EEPROM 24LC256: Control Byte

- Control byte (first byte after start bit)

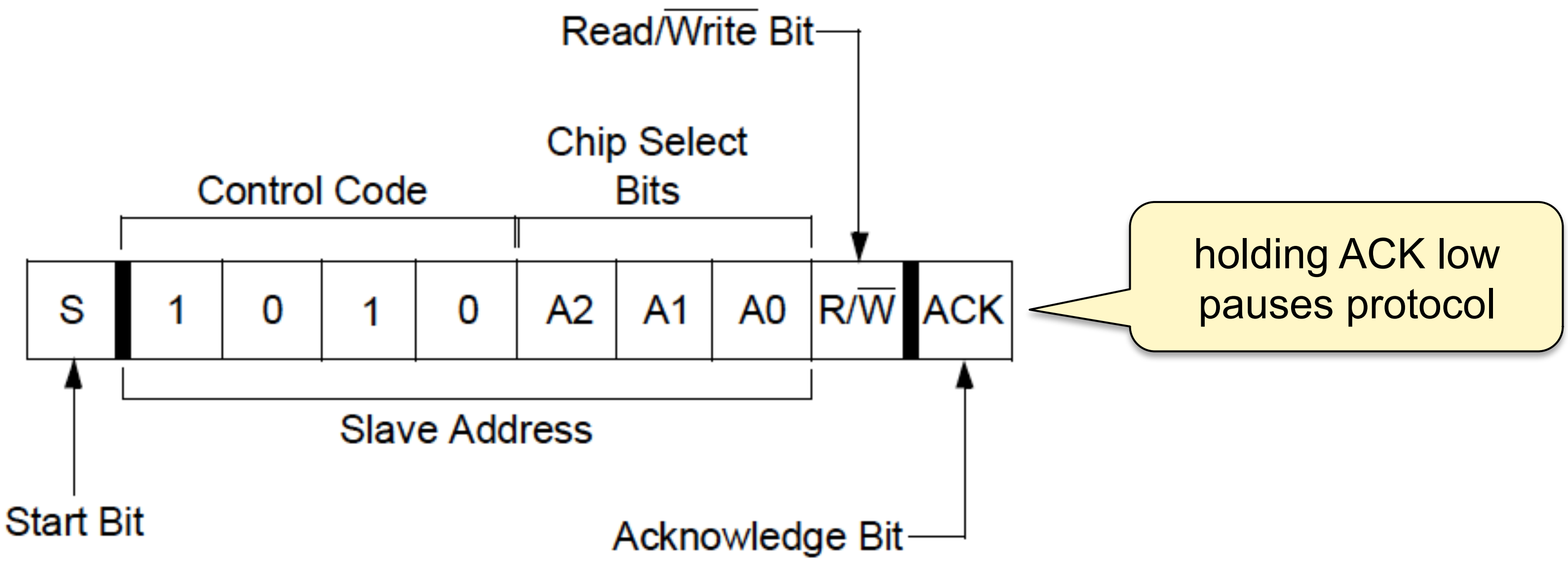
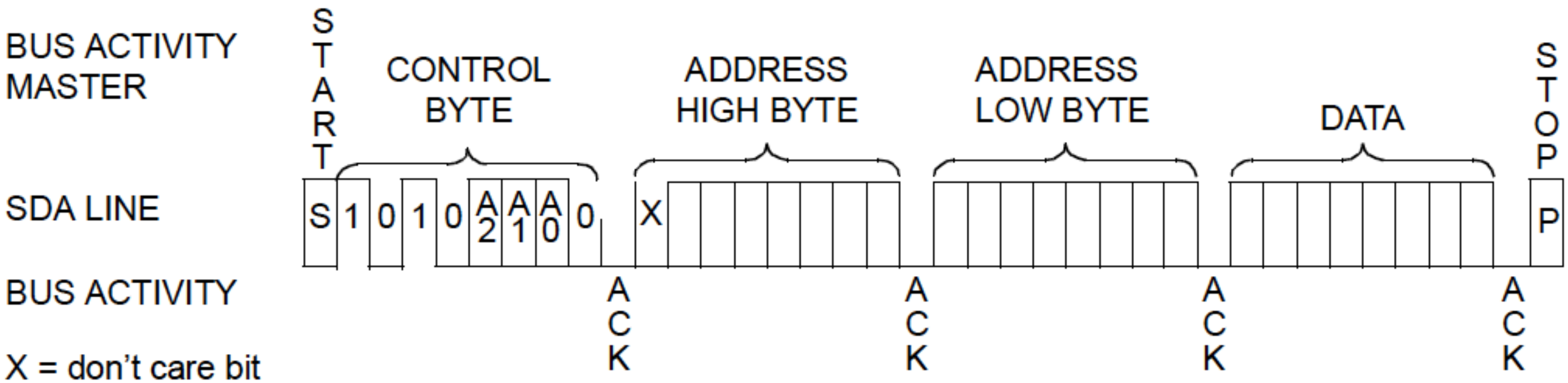


Figure sources: Microchip datasheet

- Control code (1010) reserved for 24LC256
- A2..A0 assigned according to pin wiring
- Up to 8 24LC256s on one bus

I2C EEPROM 24LC256: Write

- Byte write



- Page write (up to 64 bytes)

master continues to send more bytes, finally STOP

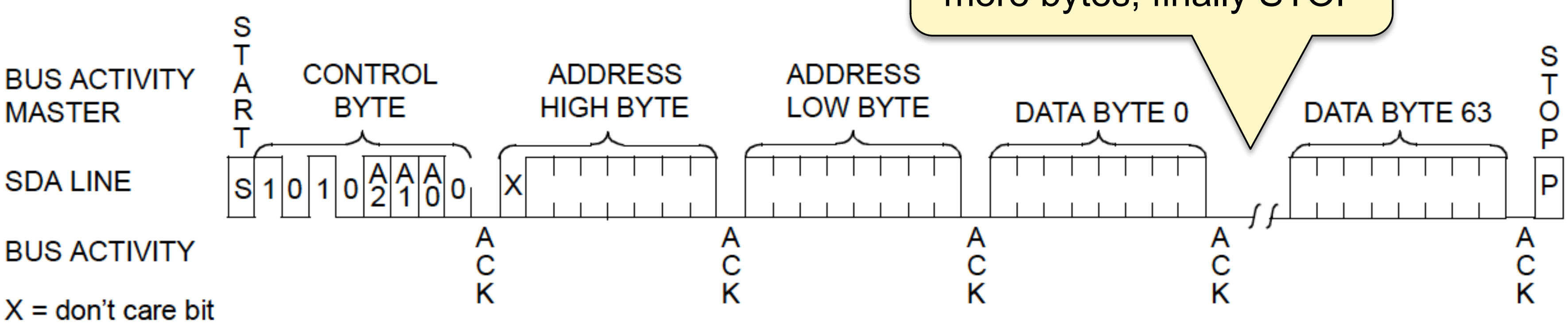
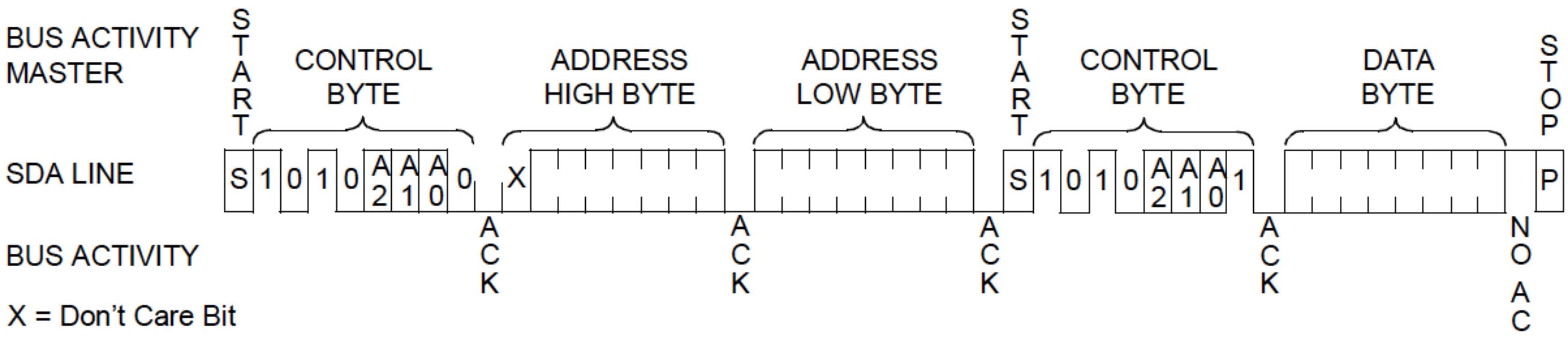


Figure sources: Microchip datasheet

I2C EEPROM 24LC256: Read

- Byte read



- Sequential read

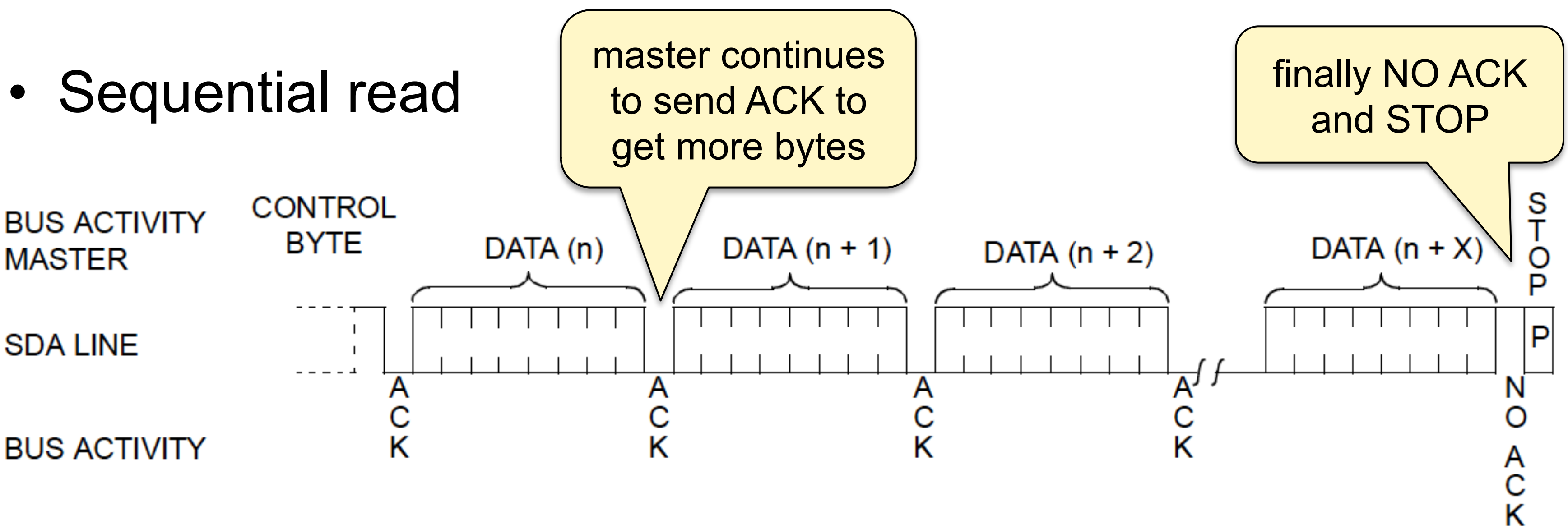
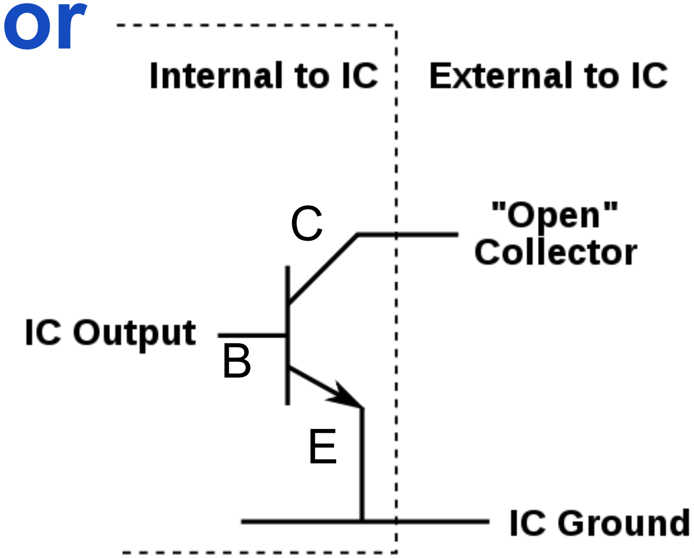


Figure sources: Microchip datasheet

Open Drain / Open Collector



Sources: Omegatron, public domain

- IC output applied to base (B) of (internal) transistor,
  collector (C) is output to IC pin,
  emitter (E) is connected to GND

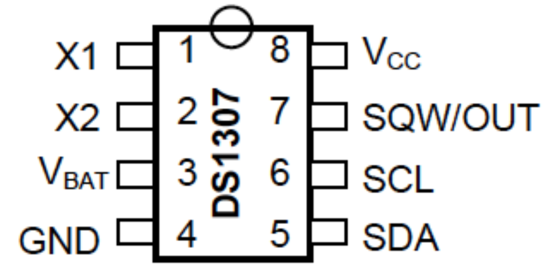
- If base (B) is low C is at high impedance
  - Pull-up resistor required to put C to defined state
- If base (B) is high C is close to E (GND)

- Multiple open collector drain/outputs connected
  - Logical AND

I2C Physical Layer

- Start/stop bits vs. data bits
  - Start/stop: SDA transitions while SCL is high
  - Data: SDA transitions while SCL is low
- Channel access
  - Start/Stop delimit bus transactions
  - Masters continuously monitor the state of bus (Start/Stop conditions and state of SDA/SCL lines)
  - Masters drop transmission if SDA/SCL other than expected, retries after sensed STOP message
- Clock stretching: slave keeps SCL low
  - Example: EEPROM needs time to save a byte
- What happens if two masters initiate a transfer at the same time? …to the same device? … same message?

Real-Time Clock
DS1307 with I2C interface



- Highly stable time/date, battery buffered
  - Clock/calendar: provides seconds, minutes, hours, day, date, month, and year information
  - Leap year handling, 12-/24-hour format
  - Power-sense circuit to switch to backup supply
  - 500nA in Backup Mode (e.g. button cell battery)
  - Normal operation: 5V
- Useful for long-term sensing applications that need time-/date-stamps
- I2C commands to set/read time/date

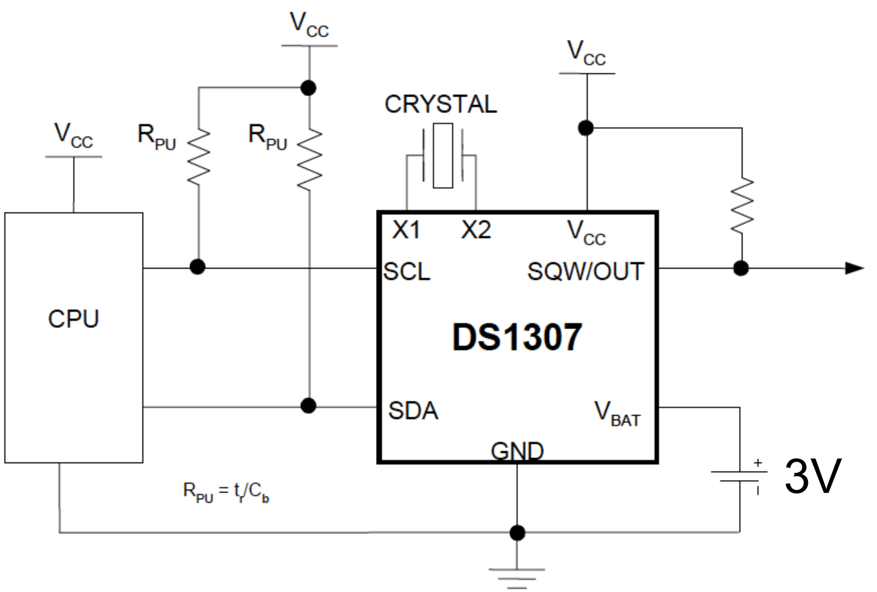


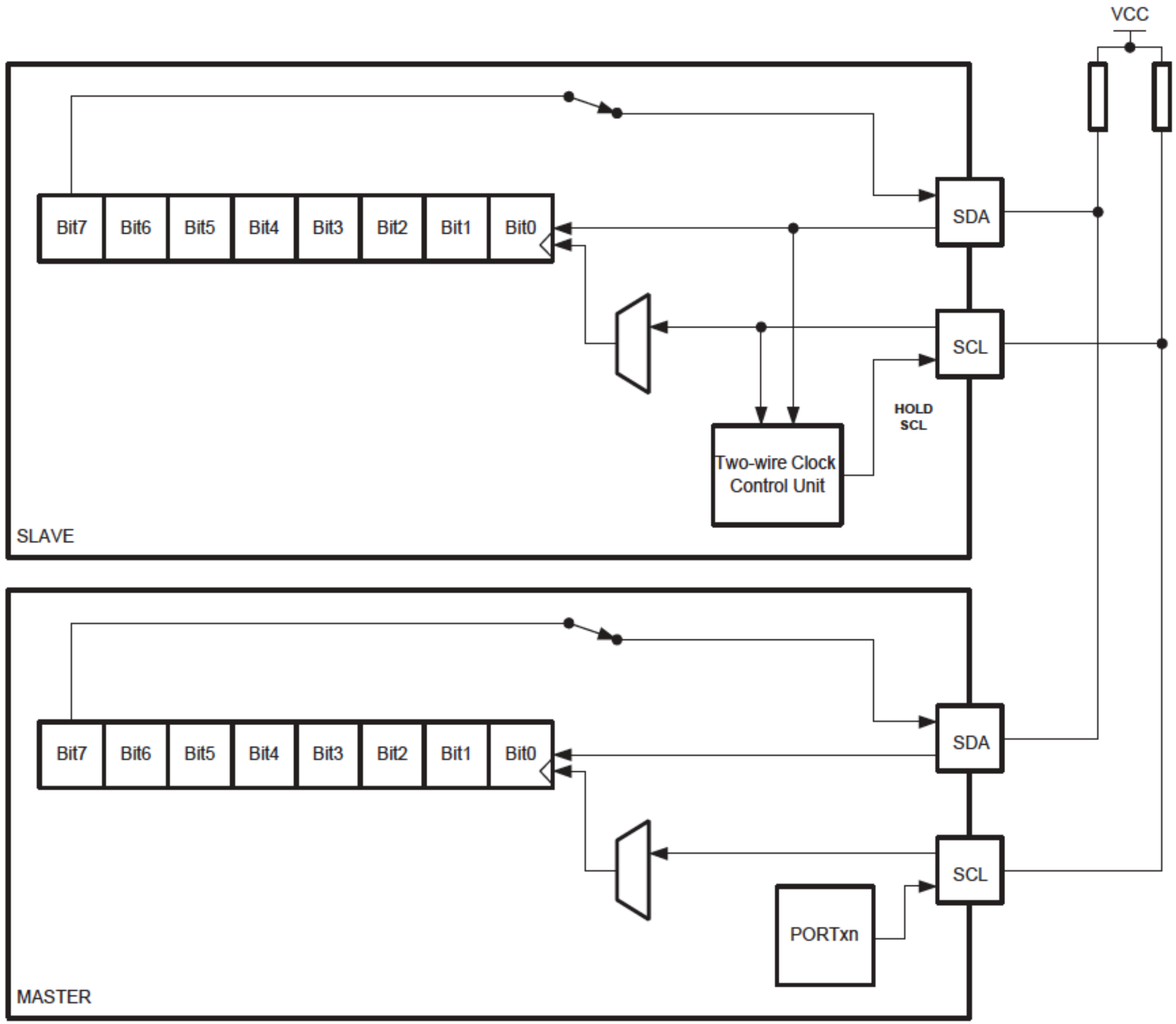
Figure sources: MAXIM datasheet

AVR Universal Serial Interface

- Two-wire interface (I2C)
- Three-wire interface (e.g. for programming)

- ATtiny45 and ATmega8, not ATtiny13

Universal Serial Interface: I2C, TWI



Source: Atmel Datasheet

Universal Serial Interface: I2C, TWI

- Interrupt on detected start condition
  - 14 0x000D USI_START USI START
- Interrupt on sent/received byte
  - 15 0x000E USI_OVF USI Overflow
- Registers (ATtiny45 datasheet, ch. 15.5)
  - USIDR – USI Data Register
  - USIBR – USI Buffer Register (buffers data register)
  - USISR – USI Status Register (interrupt, collision, stop, counter)
  - USICR – USI Control Register (interrupt enable, wire mode, clock strobe)