Building Interactive Devices and Objects

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Today

- Servo Motors
- DC Motors
- Stepper Motors
- Motor Drivers
- PWM
- WLAN module
- Exercise 4

Schedule

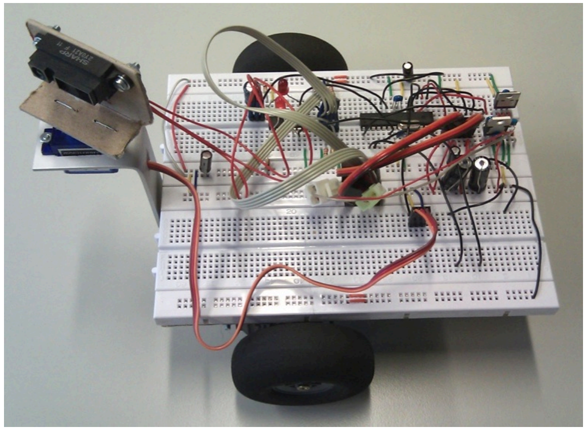
#	Date	Topic	Group Activity
1	19.4.2012	Session 1: Introduction	Team building
2	26.4.2012	Session 2: Microcontrollers & Electronics	
3	3.5.2012	Session 3: Sensors	Concept development
4	10.5.2012	CHI	Concept development
5	17.5.2012	Christi Himmelfahrt	Concept development
6	24.5.2012	Session 4: Actuators	Concept presentation, Hardware requ.
7	31.5.2012	Session 5: Physical Objects (Sven)	
8	7.6.2012	Frohnleichnam	Project
9	14.6.2012		Project
10	21.6.2012		Project
11	28.6.2012		Project
12	5.7.2012		Project
13	12.7.2012		Evaluation
14	19.7.2012		Evaluation, Presentation

Sessions 4: Actuators, Concept Presentation, Hardware Requ.

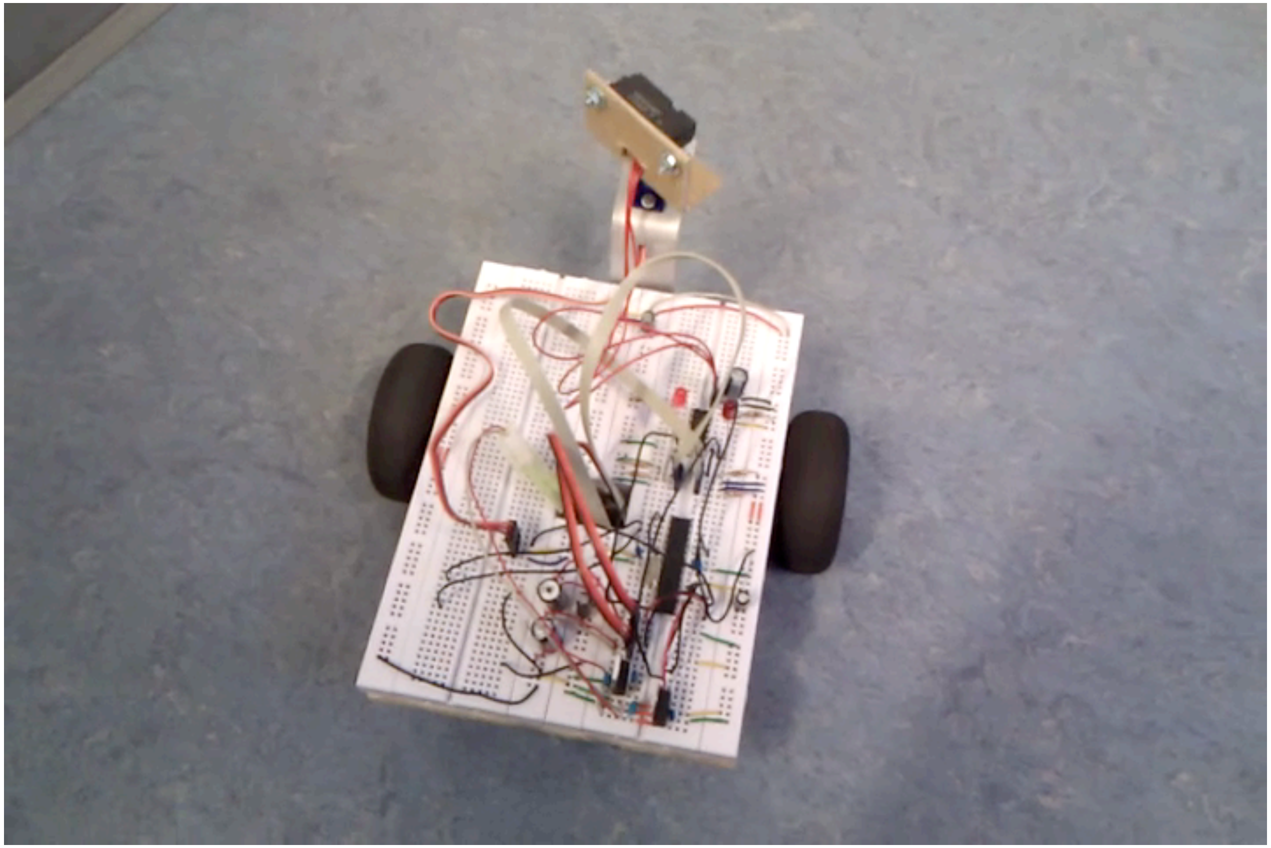
- Servo motors, DC motors, PWM
- Exercises
  1. Control servo motor, attach pointer to motor and move to predefined positions
  2. H bridge for DC motor

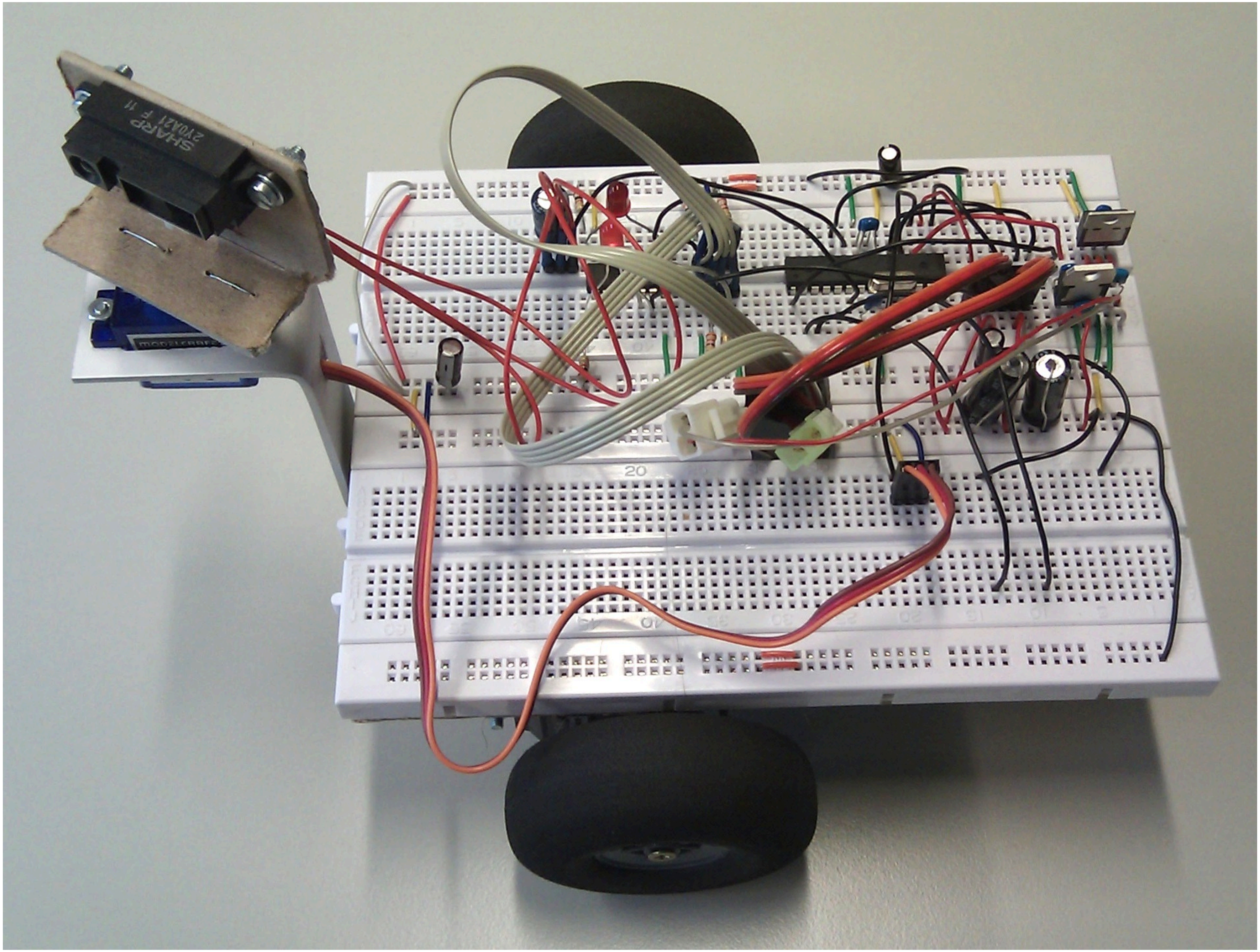
http://www.wimp.com/pointlessmachine/

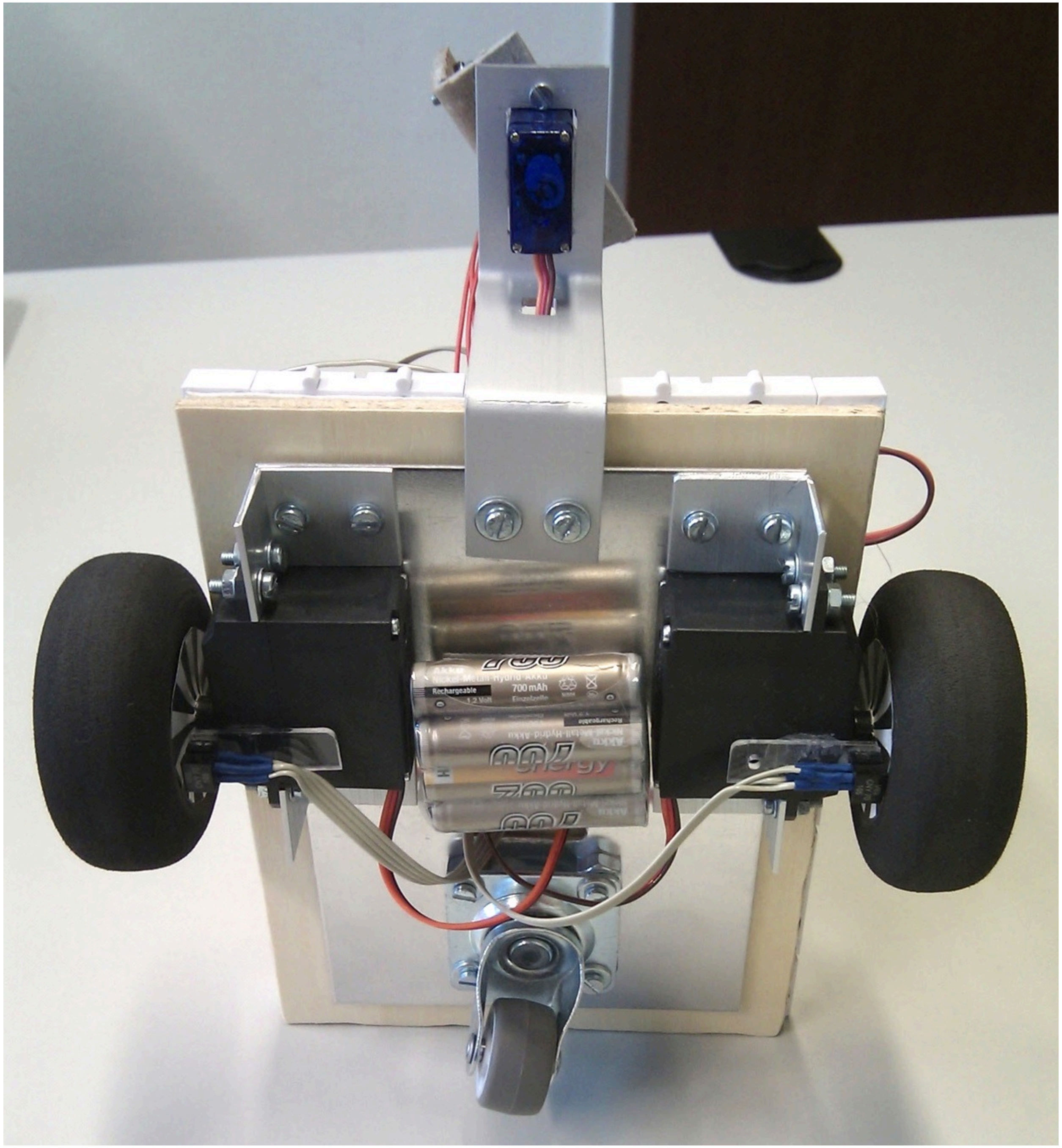
Mobile Robots

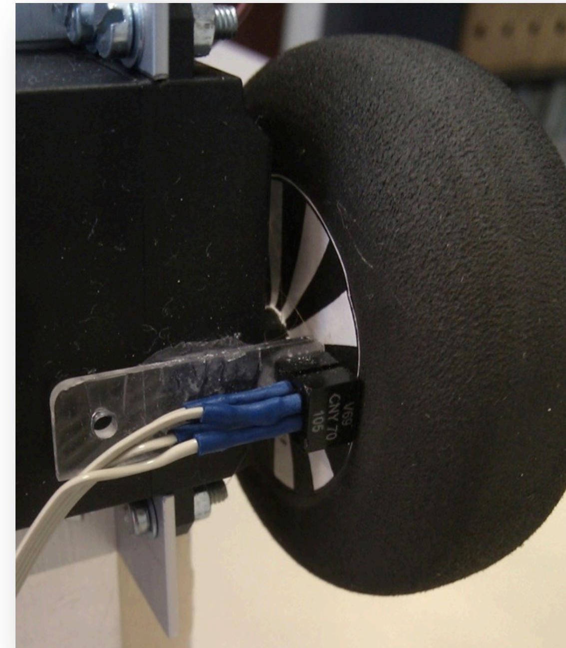


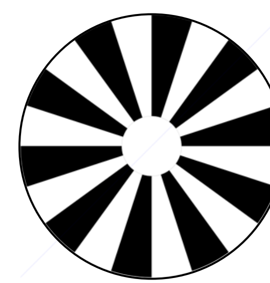
- Human-robot interaction hot topic
- Robot tasks
  - manual tasks
  - cleaning
  - communicate
  - observe




SHARP
2Y0A21 F 11
20

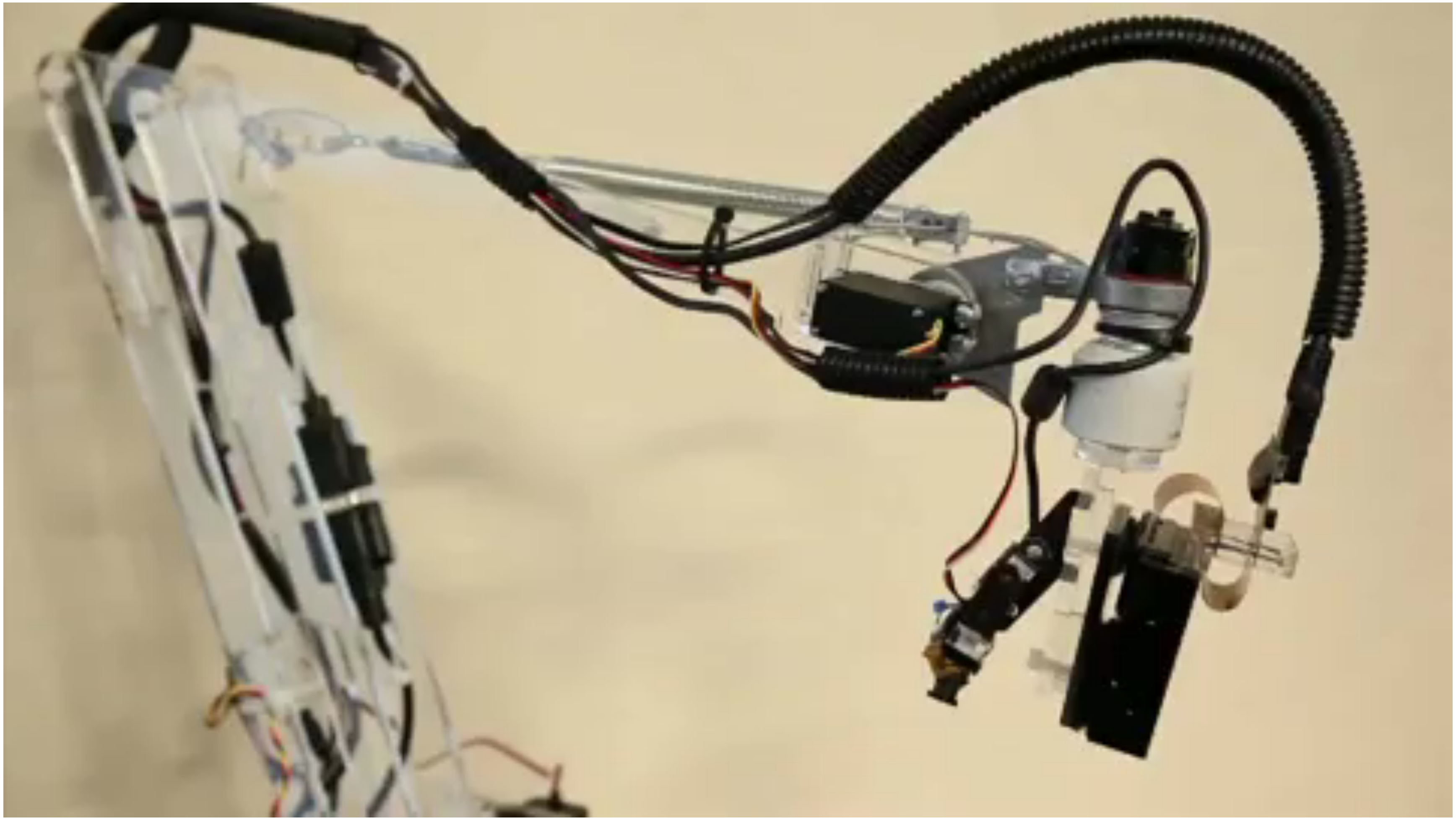






Rotary Encoder

MIT LuminAR: Actuated Desk Projector



http://www.youtube.com/watch?v=XV5V-dQW8CI

Robotized Objects

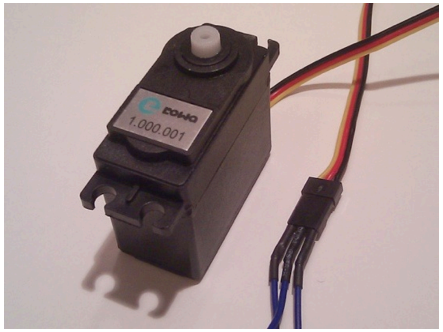
http://www.youtube.com/watch?v=sYutehhGknI

SERVO MOTORS

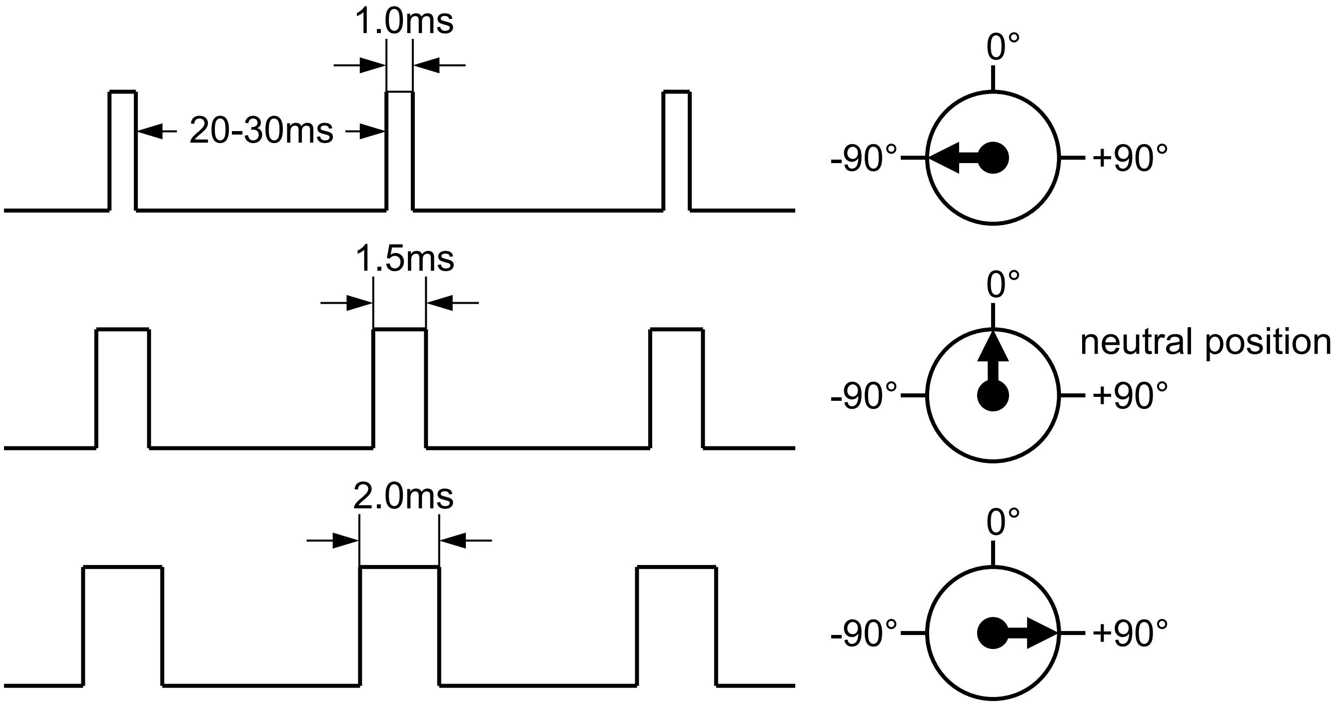
Servomotors

- 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.

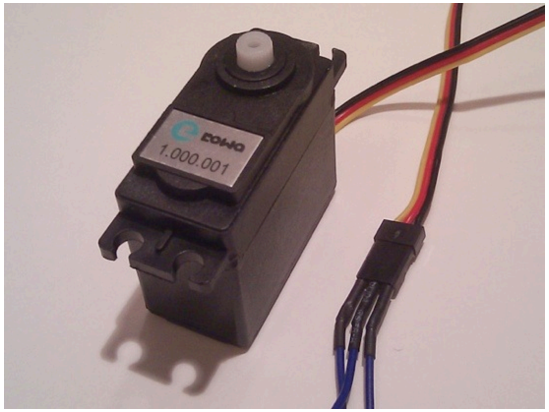
Controlling Servo Motors



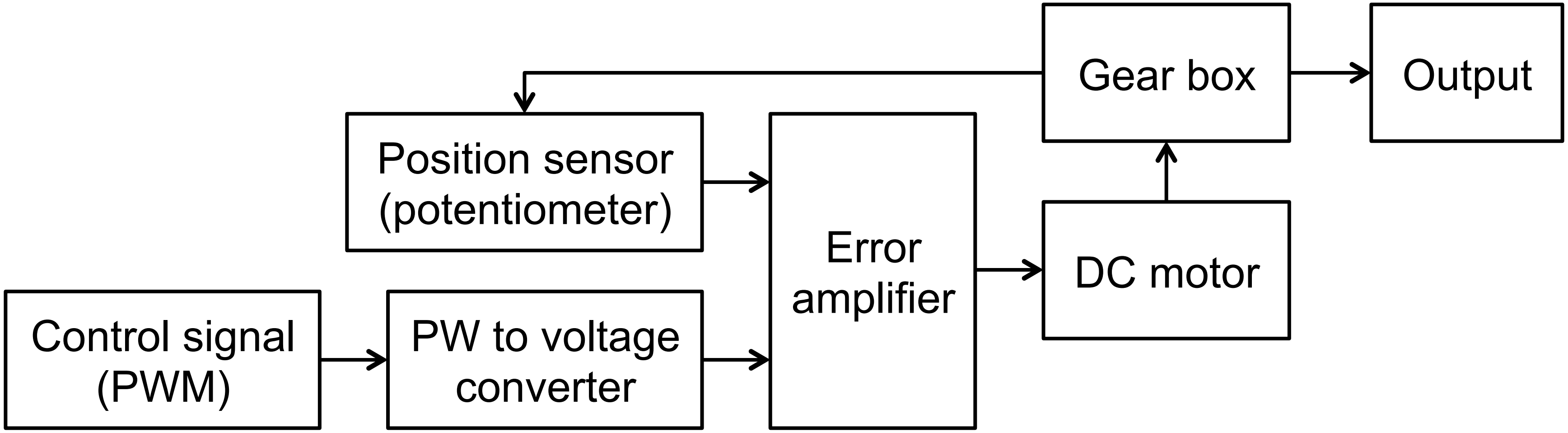
- Wiring: red, black, yellow cables
  - red = V_{CC} (4.8-6V), black = GND, yellow = PWM signal
- PWM signal: 1.5ms is always neutral, min/max times and positions may vary



Operating Principle

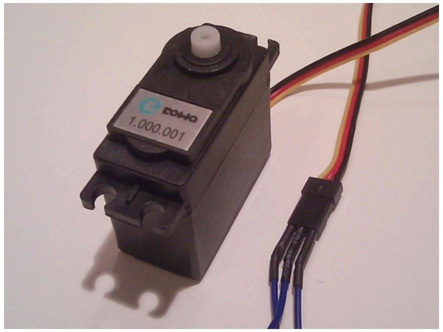


- DC motor with a servo mechanism for precise control of angular position
- Motor + feedback device + control circuit



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

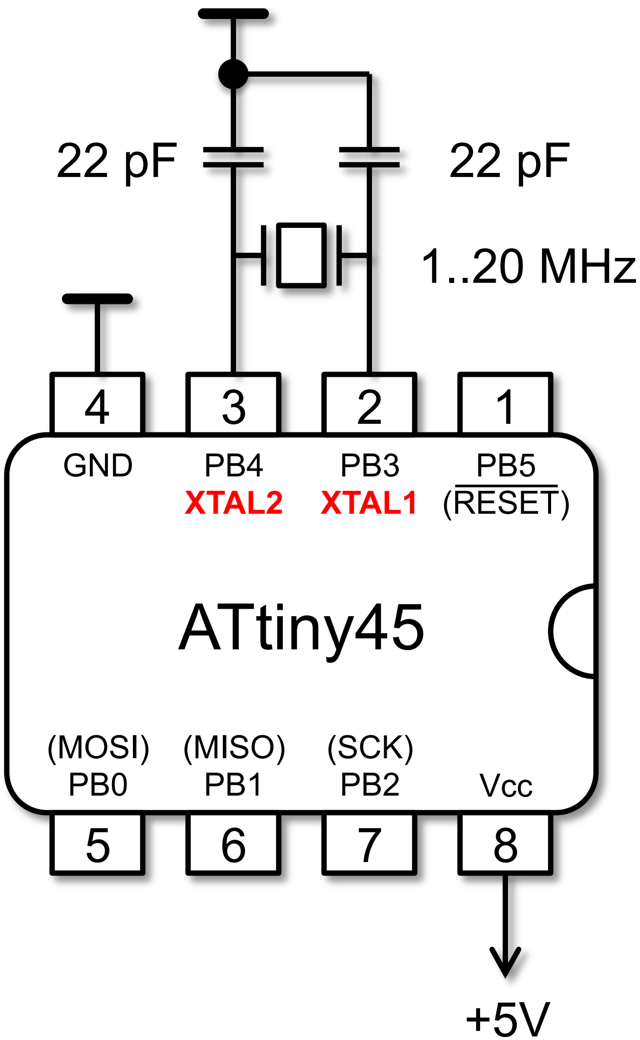
Controlling Servo Motors



- Motor can draw huge amounts of power
  - Use large Elko between red and black wires (≥100µF)
  - Separate power supplies / voltage regulators recommended
- High precision requirements for PWM signal
  - External quartz rather than internal RC oscillator (otherwise jitter)
- Simplest case: busy waiting (not recommended)

```
// yellow wire of motor on PB3
DDRB  = 0b00001000; // port PB3 output, all others input
PORTB = 0b11110111; // port PB3 low
while (1) {
    PORTB |= 0b00001000; // port PB3 high
    _delay_us(1500); // 1.5 ms = neutral position, high precision required
    PORTB &= 0b11110111; // port PB3 low
    _delay_ms(18); // 1.5 + 18 = 20 ms, low precision between pulses
}
```

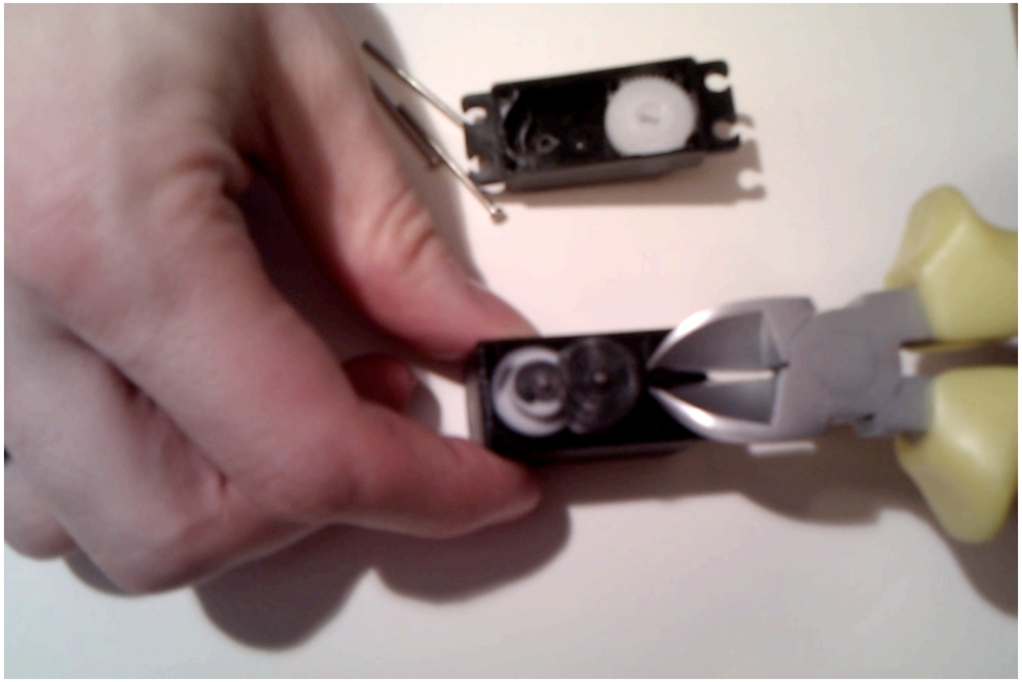
External Clock: Quartz Crystal Oscillators

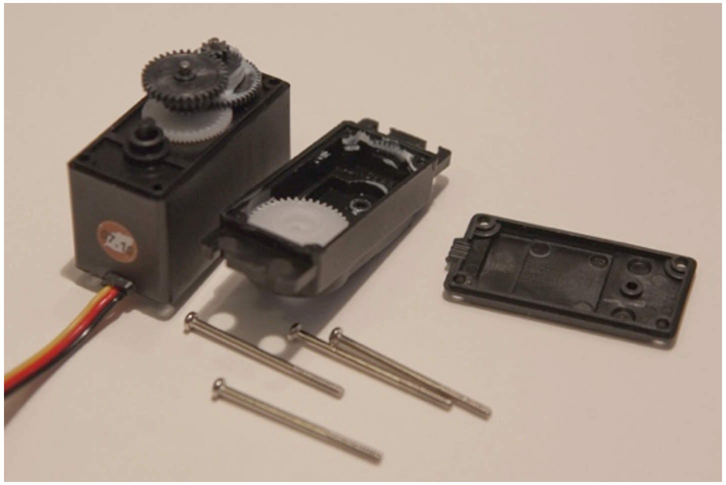


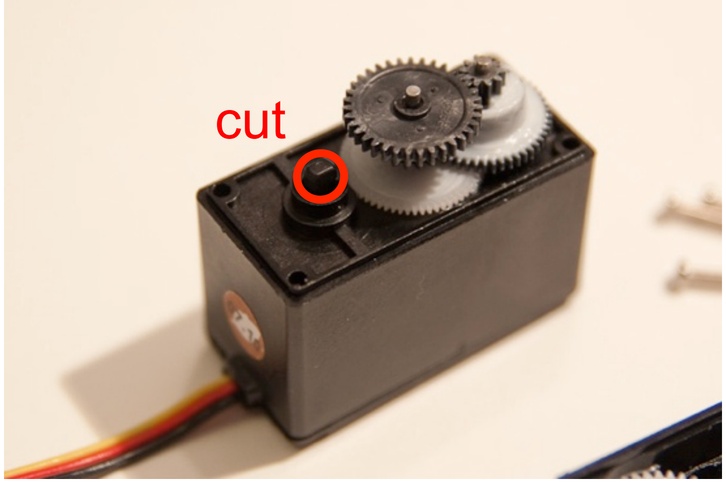
- More precise than internal oscillators
- Quartz 1..20 MHz
- Ceramic capacitors 12-22pF
  - Can be omitted
- Place quartz and capacitors close to AVR pins
- Change CLKSEL fuse bits

Unlimited Rotation and Velocity Control

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





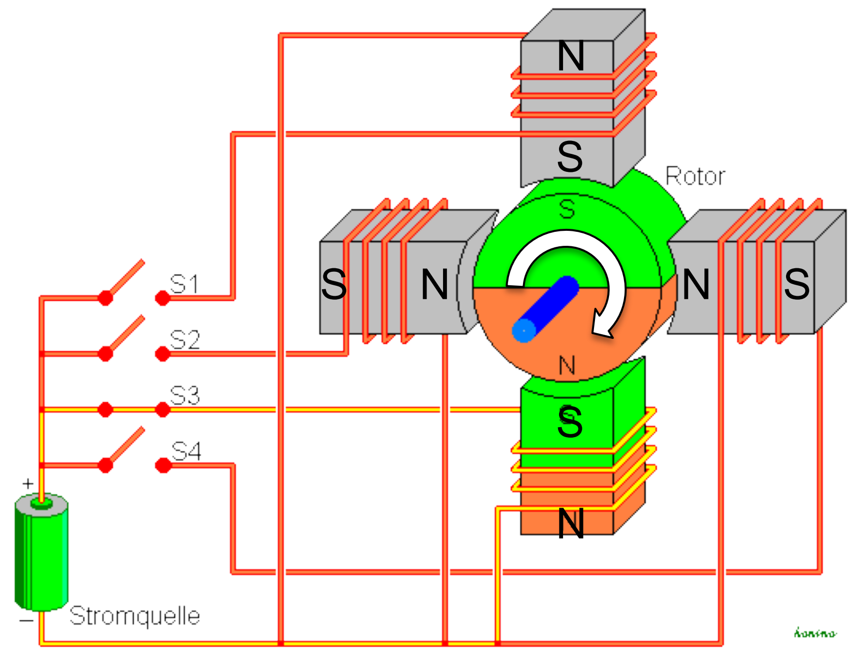


- Steps: remove mechanical stop on gear, cut/file off potentiometer axis, glue potentiometer to neutral position

STEPPER MOTORS

Stepper Motors

- Rotates fixed number of degrees per step
  - Typically 15° or 30°
  - No need for feedback device
- Lower maximum speed than DC motor
- High torque at low speeds
- Used in printers, plotters, sensor positioning
- Requires control circuit
- Different wiring schemes
  - Unipolar, biploar, etc.



Smaller Steps: Hybrid Stepper Motor

- Rotor contains two disks of magnets

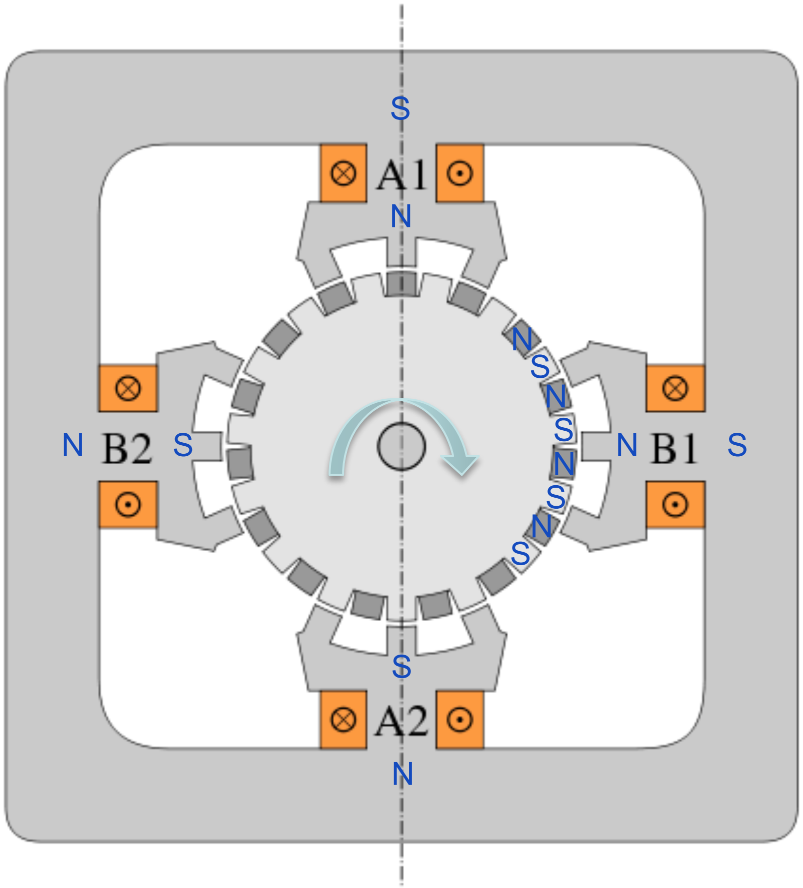
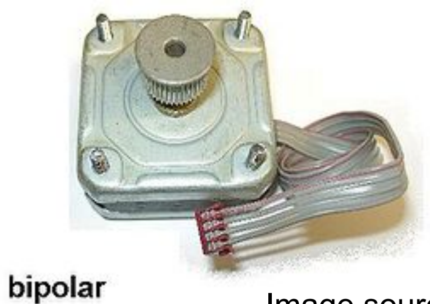


Image source: Stündle, Public Domain

Image source: Coyote83, cc-by-sa

Bipolar and Unipolar Motors

Bipolar Motor



Unipolar Motor

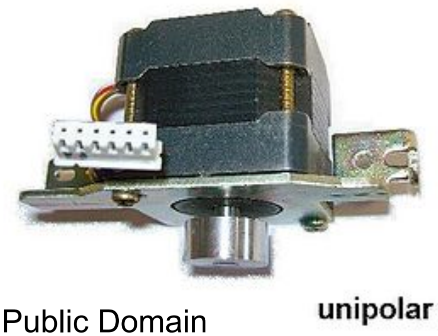
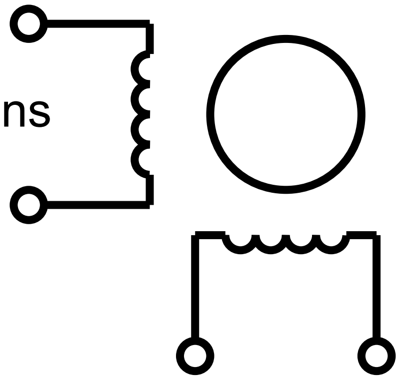
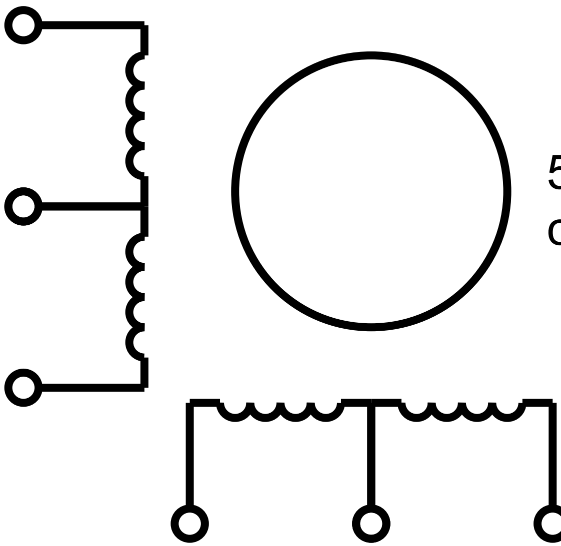


Image source: Ulfbastel, Public Domain

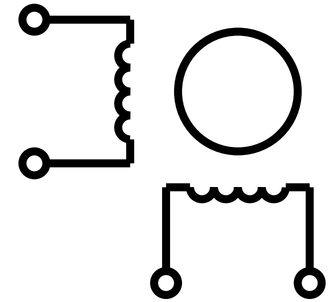
4 connections

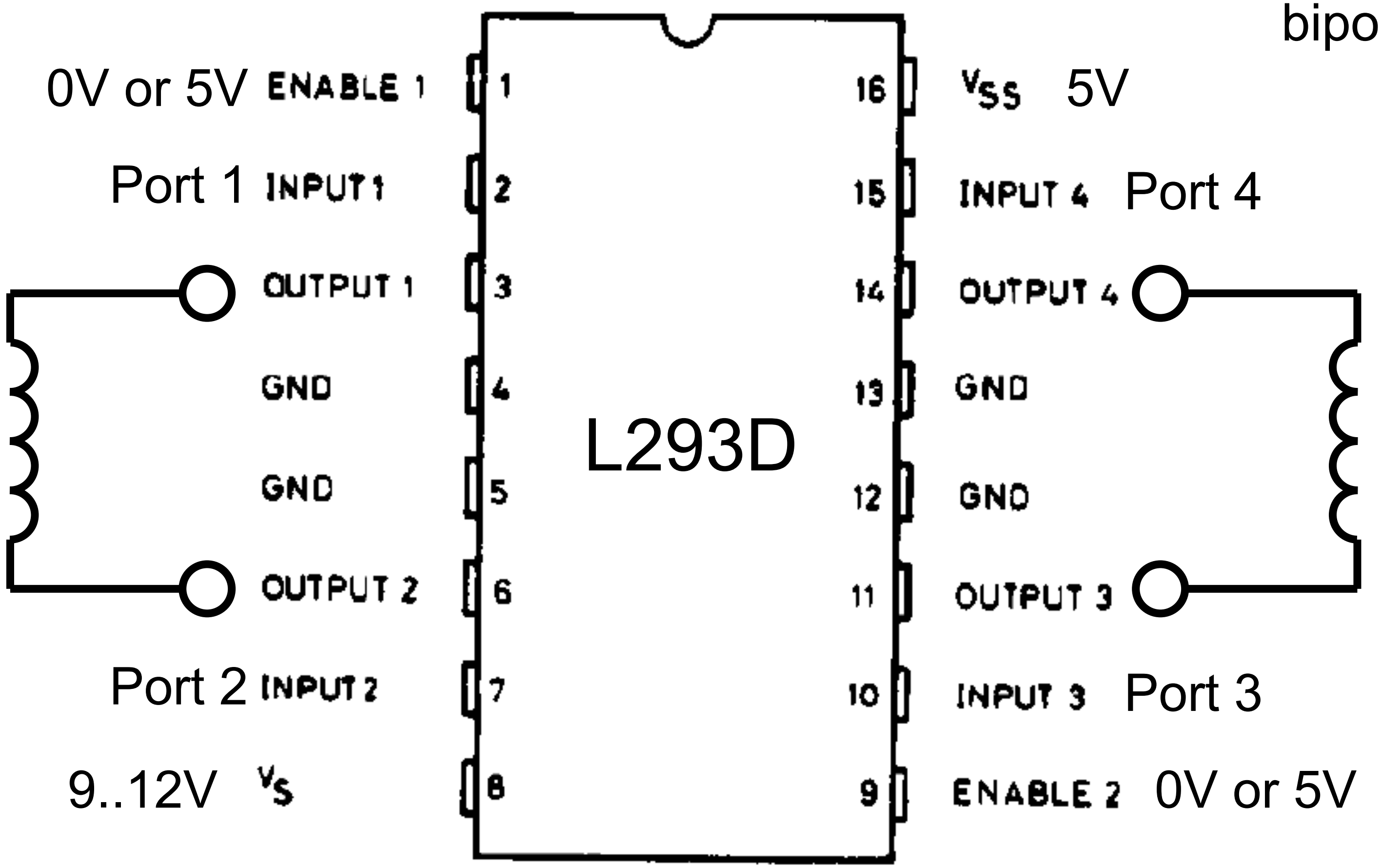




5 or 6 connections

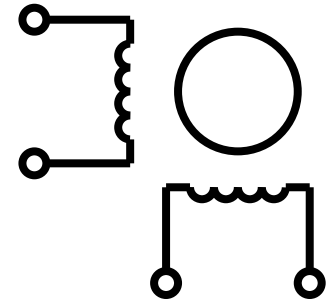
Driving Stepper Motors (basic)



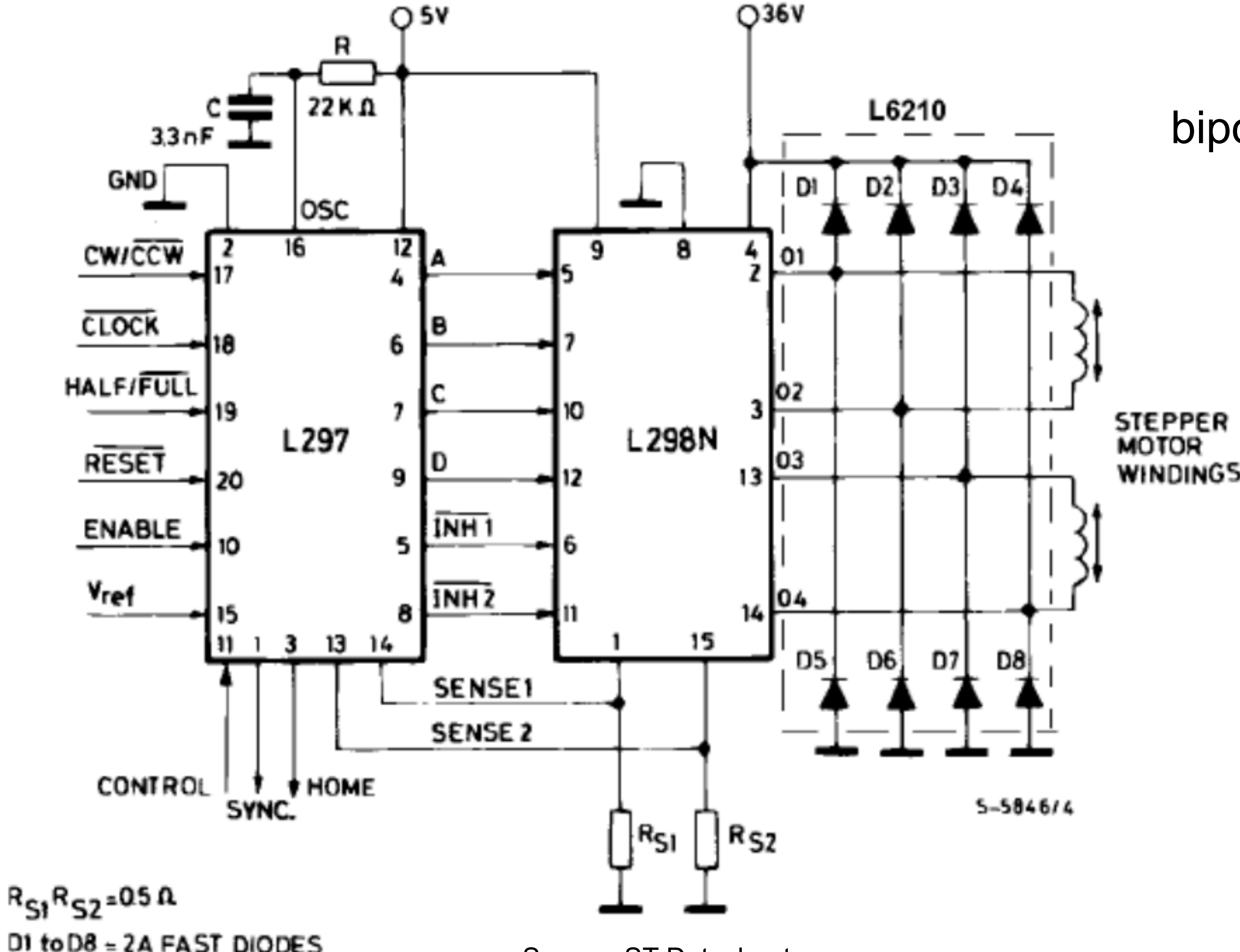


Source: ST Datasheet

Driving Stepper Motors (advanced)



bipolar motor



Source: ST Datasheet

H-BRIDGE

H-Bridge for Controlling DC Motors

- Let motor run in forward or reverse direction
  - S1, S4: forward
  - S2, S3: reverse
  - S1, S3: brake
  - S2, S4: brake

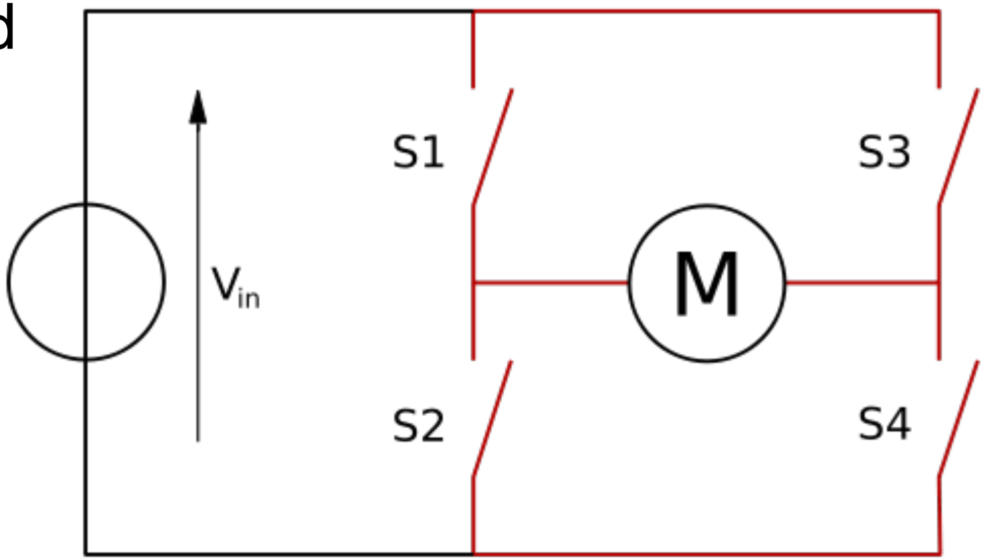


Image source: Cyril Buttay, cc-by-sa

H-Bridge for Motor Control

- Let motor run in forward or reverse direction
  - S1, S4: forward
  - S2, S3: reverse
  - S1, S3: brake
  - S2, S4: brake
- Protection diodes for reverse voltage

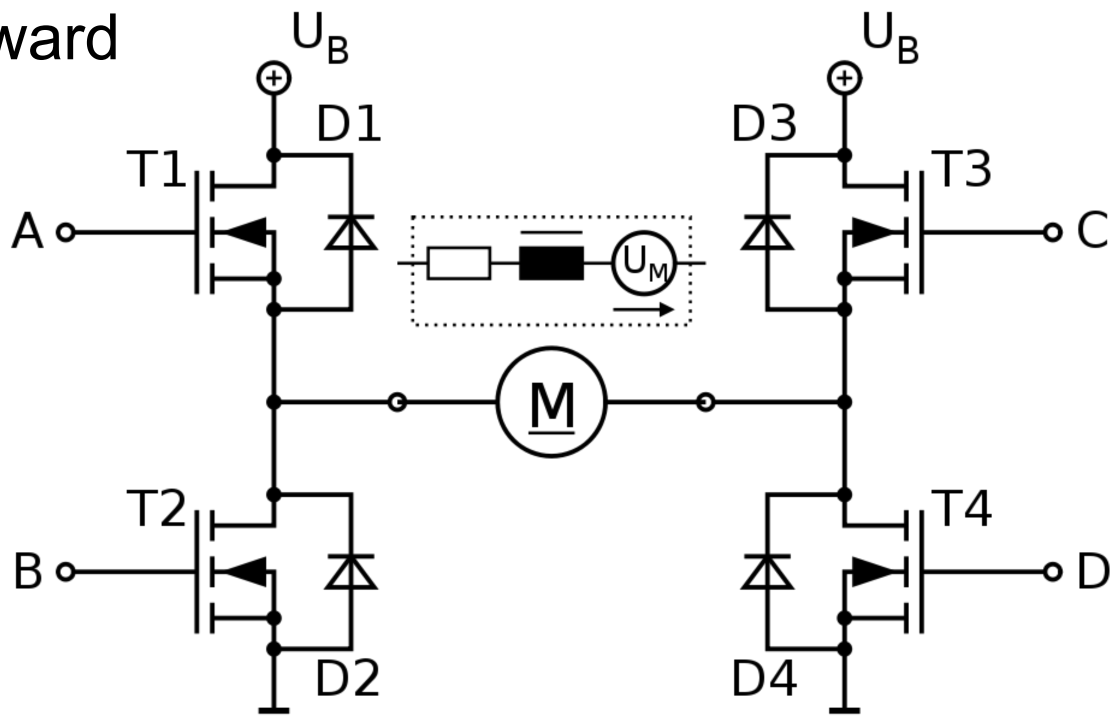
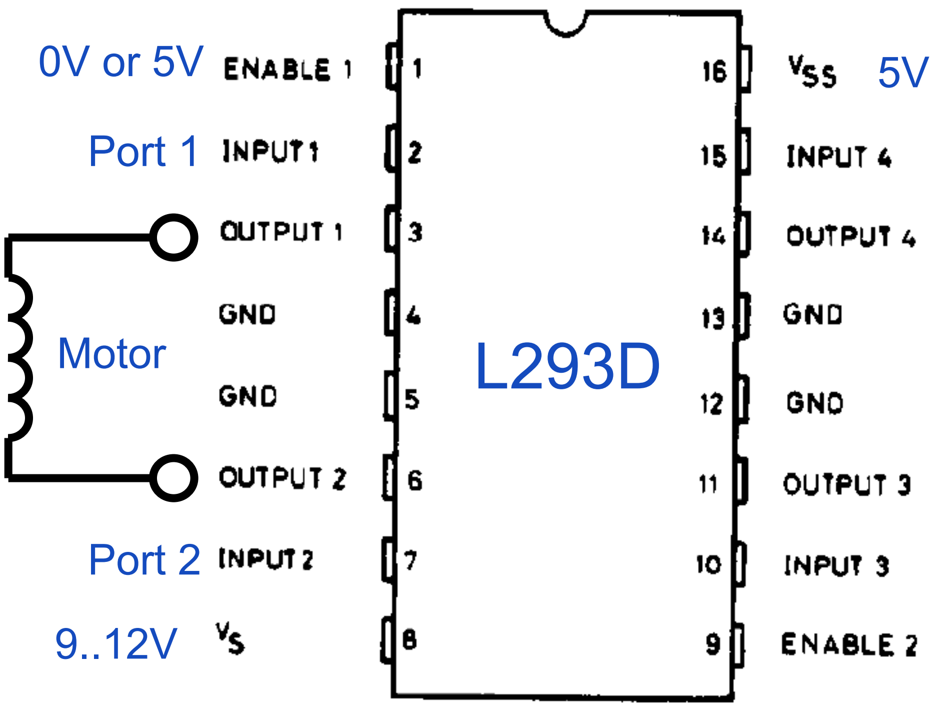


Image source: Biezl, Public Domain

L293D Motor Driver

- 600mA per motor
- Control speed via PWM signal



Source: ST Datasheet

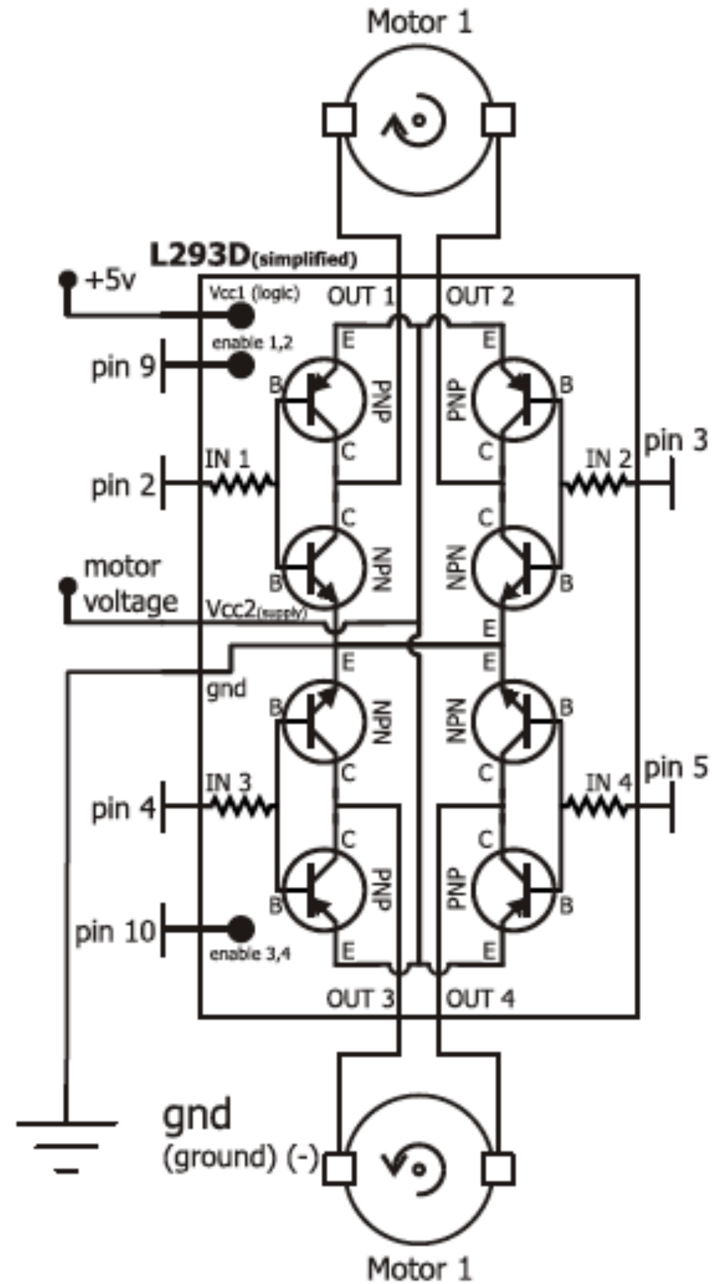
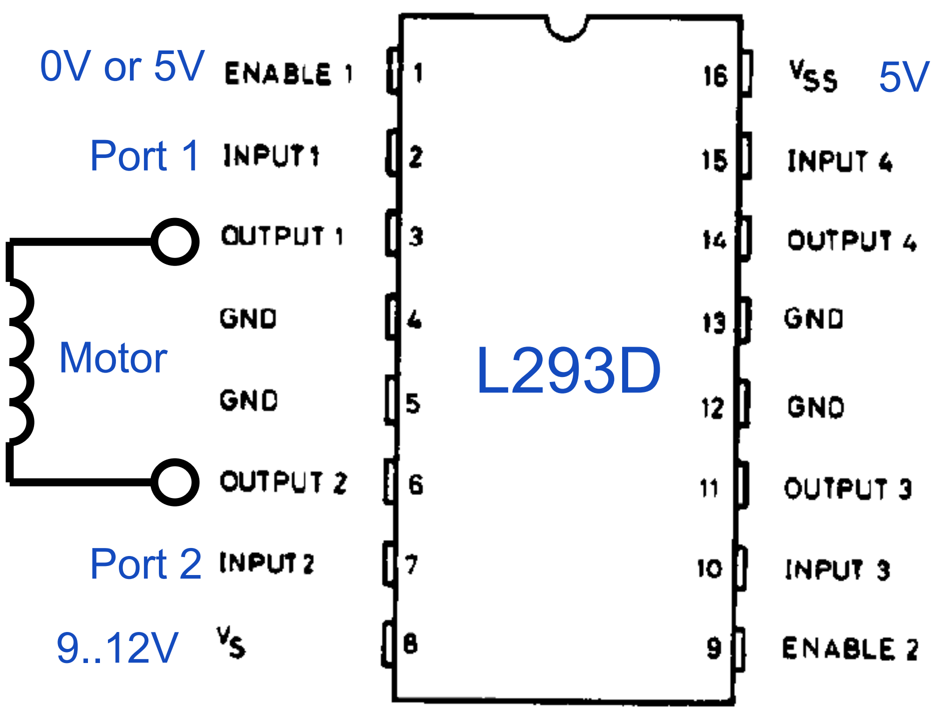
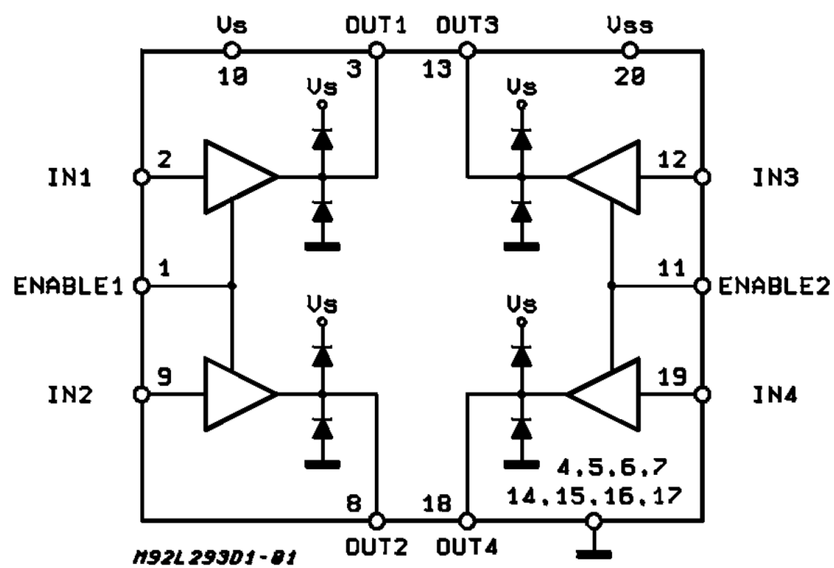


Image source: http://oomlout.com/L293/L293-Guide.pdf

L293D Motor Driver

- 600mA per motor
- Control speed via PWM signal



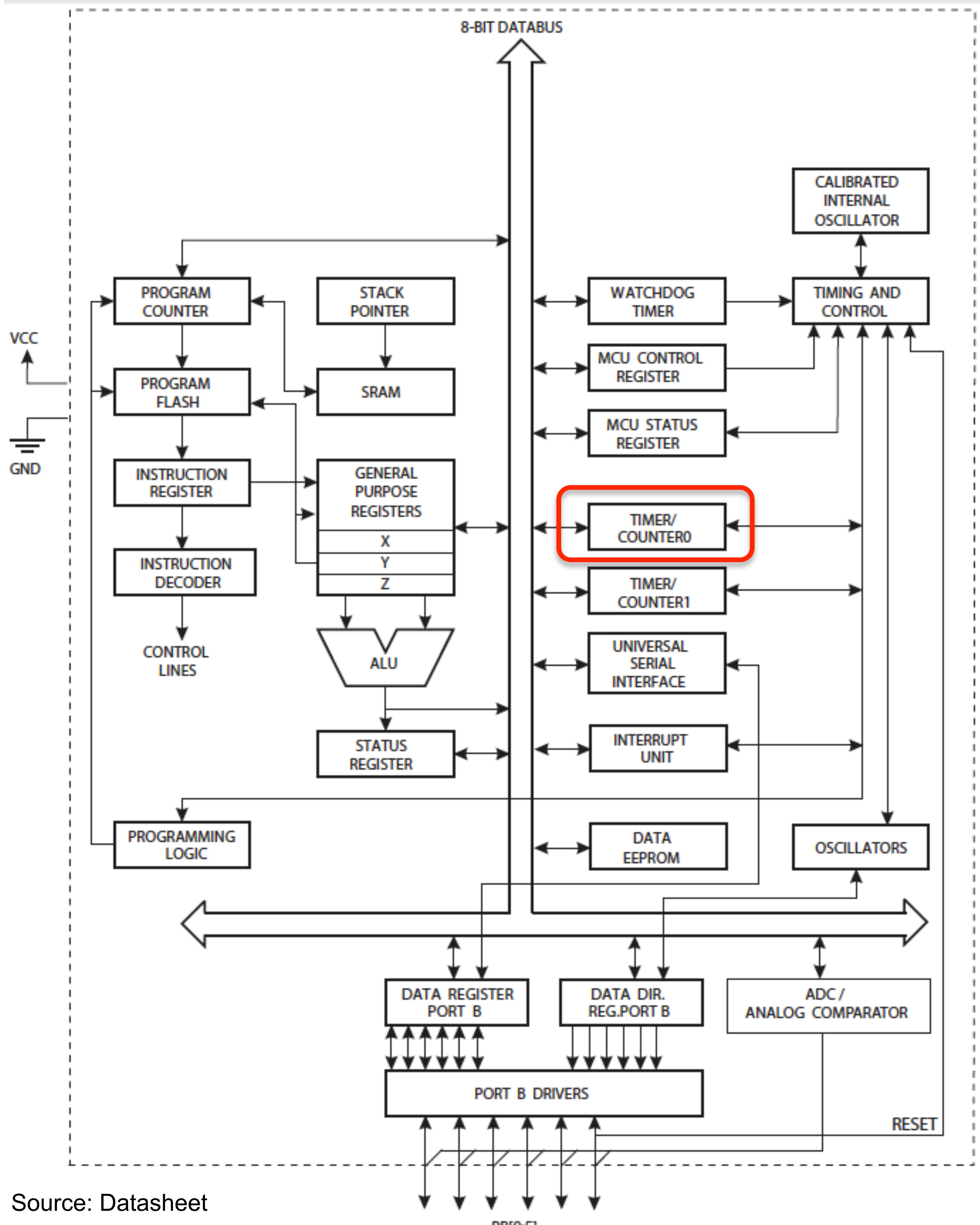


Source: ST Datasheet

PULSE WIDTH MODULATION (PWM)

AVR ATtiny45 Architecture

- Timer / Counter 0



Source: Datasheet

AVR Timers

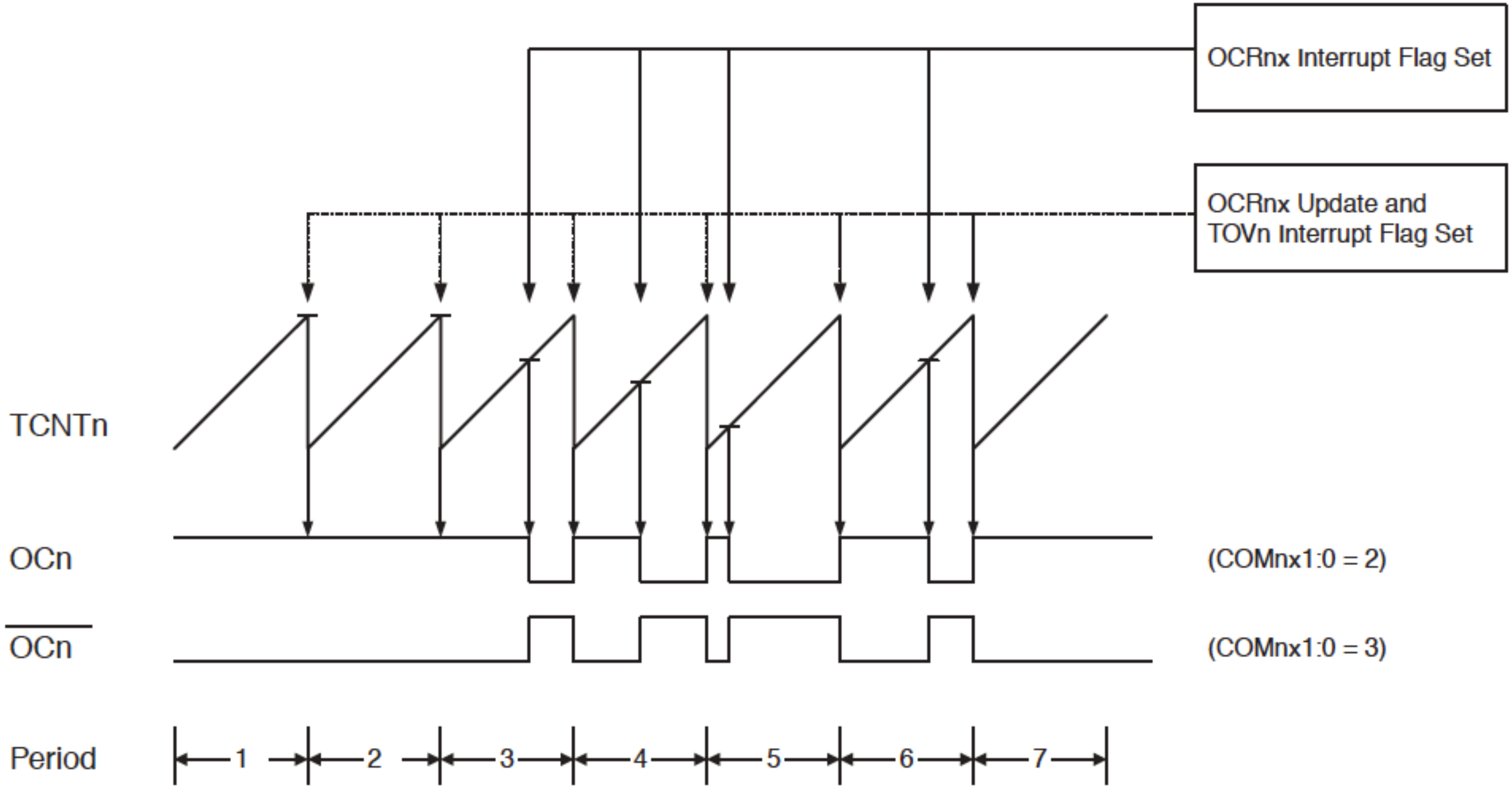
- Tasks: Generating periodic events, PWM
  - Pulse-width modulation (PWM) on I/O pins
  - Timers can generate interrupts

PWM with 25% duty cycle

- Synchronous clock source: device clock
  - divided by prescaler, if necessary
- Asynchronous clock source: external clock
- Modes
  - normal: count to 2^8-1 = 255, generate interrupt, continue at 0
  - clear-timer-on-compare: count to value
  - fast PWM: single slope, count to 255 or value, set/clear pin on match
  - phase-correct PWM: dual slope, 50% speed of fast PWM

Fast PWM (single-slope operation)

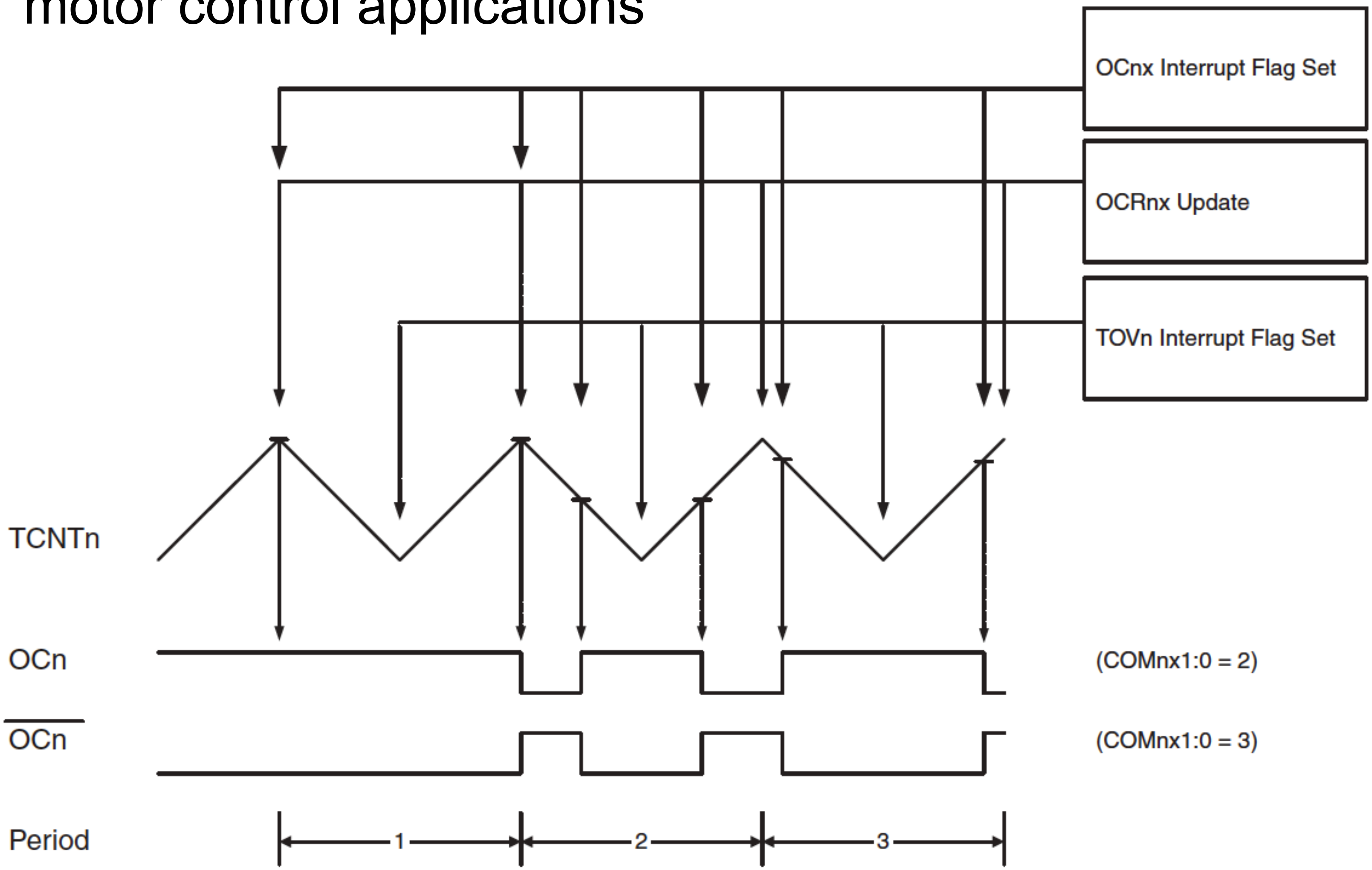
- power regulation, rectification, and DAC applications



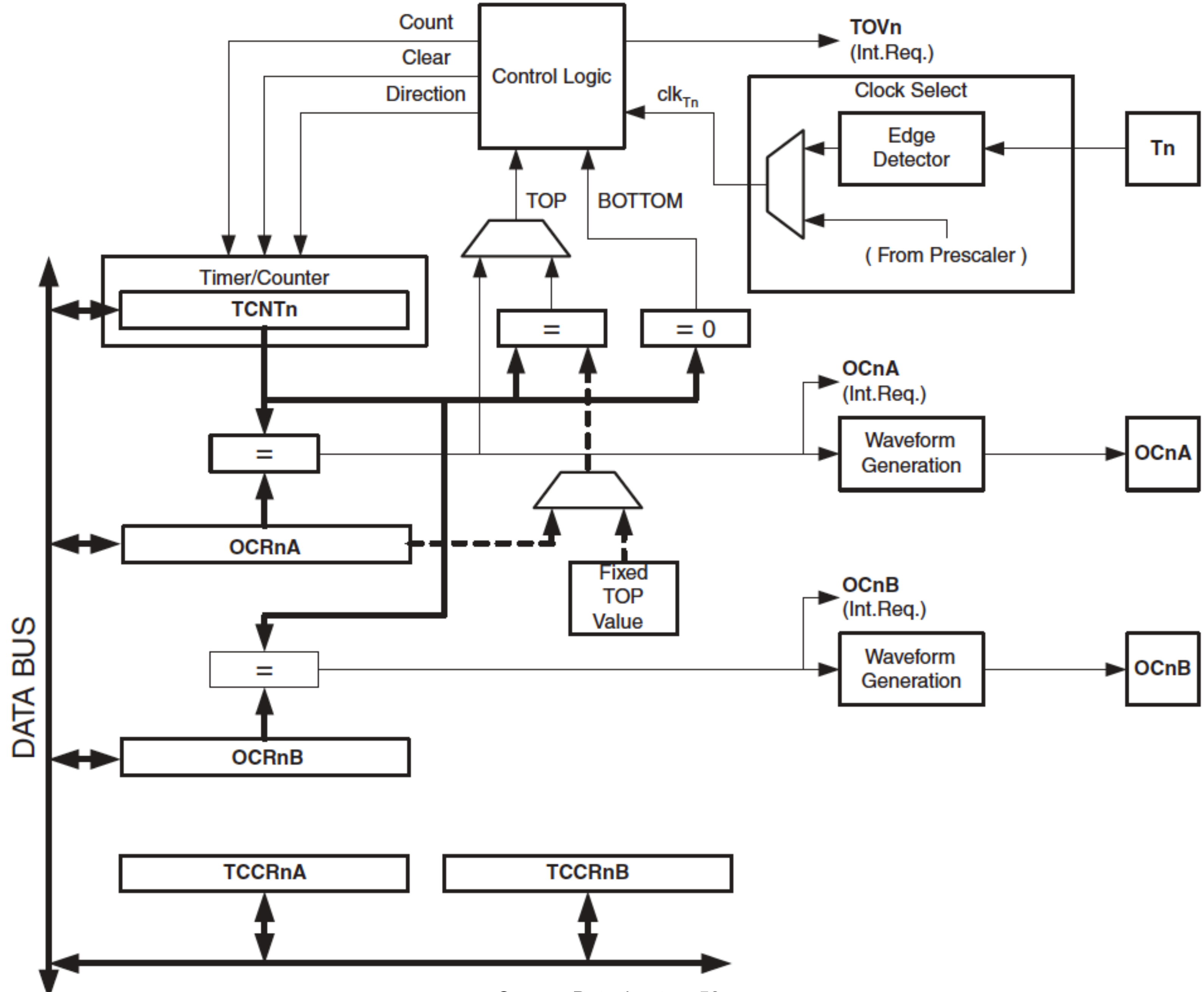
Source: Datasheet

Phase-Correct PWM (dual-slope operation)

- motor control applications

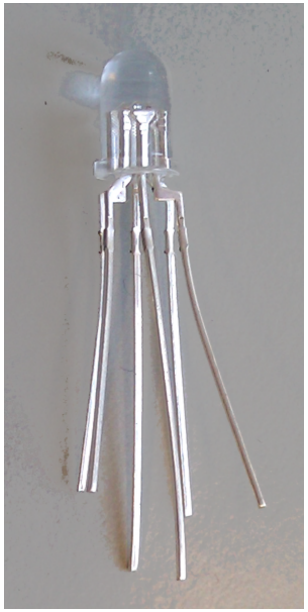


Source: Datasheet

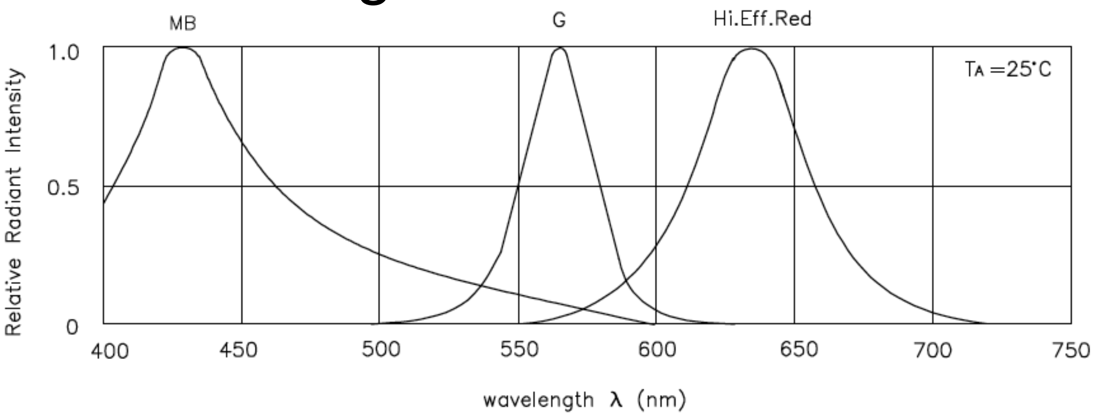


Source: Datasheet, p. 58

RGB LEDs

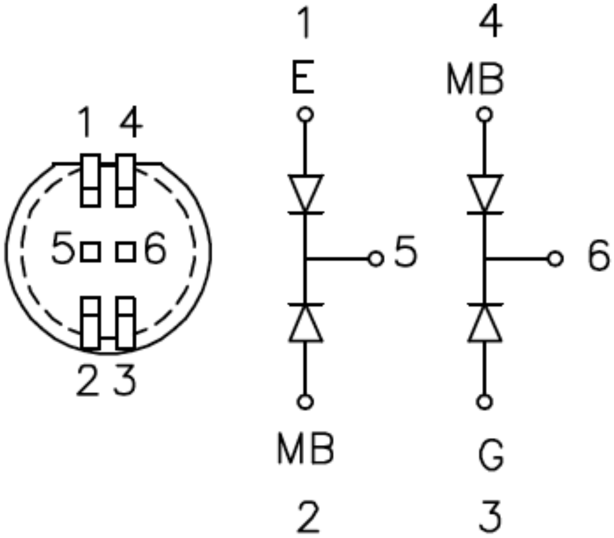


- Red, green, and blue in one package
- Different forward voltages (I_f = 20mA):
  - $U_{f,red}$ = 2.0V
  - $U_{f,green}$ = 2.2V
  - $U_{f.blue}$ = 3.8V
- Example (right): 30° angle, 2x blue
- Control brightness via PWM



Source: Kingbright Datasheet

RELATIVE INTENSITY Vs. WAVELENGTH

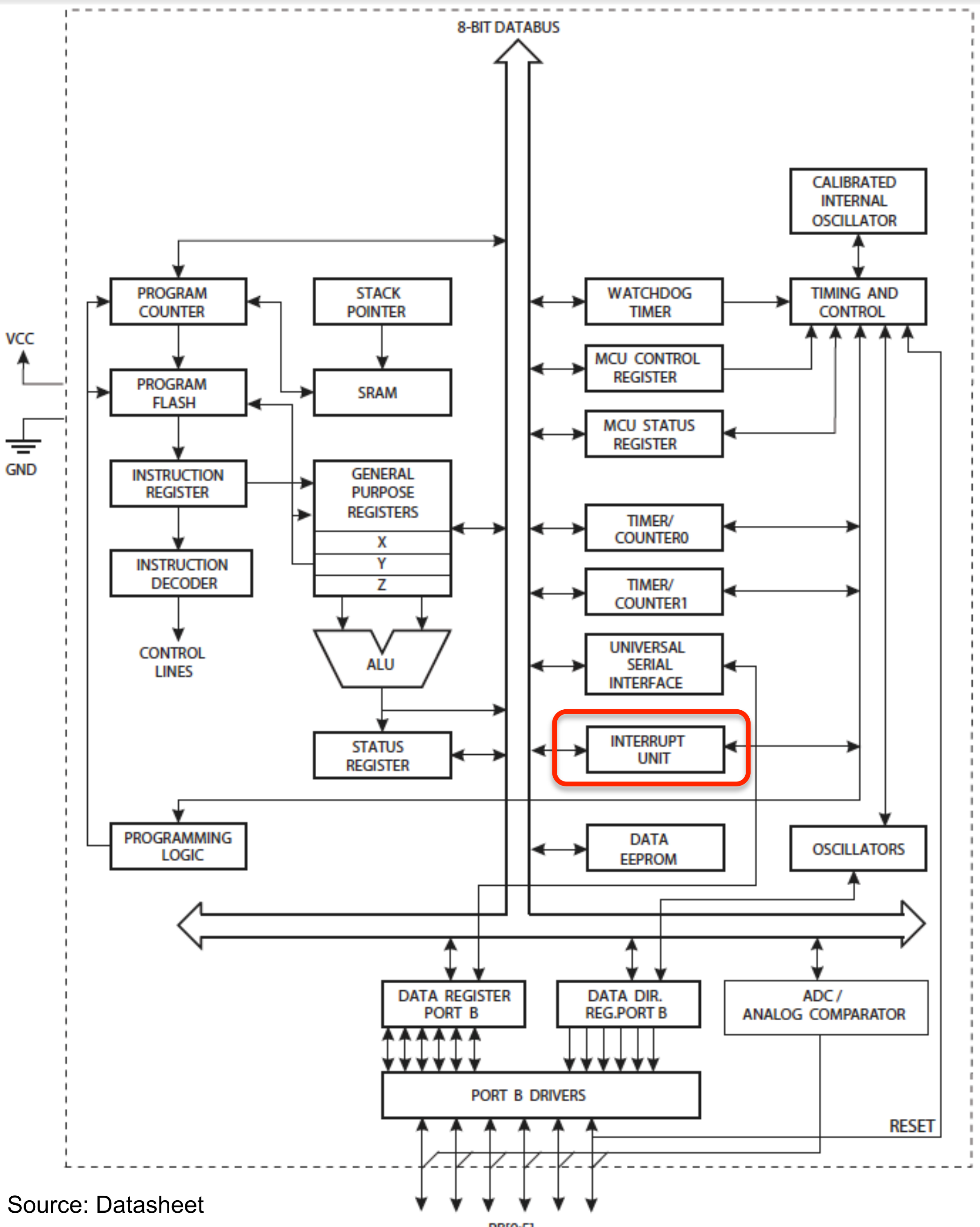


Source: Kingbright Datasheet

INTERRUPTS

AVR ATtiny45 Architecture

- Interrupt Unit



Source: Datasheet

AVR Interrupts

- Interrupt normal execution, jump to interrupt service routine (ISR), resume normal execution
- Interrupt vectors at start of program memory space (Flash)
  - intr. vectors = jump instructions to interrupt services routines
  - Lower address = higher priority
- Memory layout

```
0x0000 rjmp RESET ; Reset Handler
0x0001 rjmp EXT_INT0 ; IRQ0 Handler
0x0002 rjmp PCINT0 ; PCINT0 Handler
0x0003 rjmp TIM0_OVF ; Timer0 Overflow Handler
0x0004 rjmp EE_RDY ; EEPROM Ready Handler
0x0005 rjmp ANA_COMP ; Analog Comparator Handler
0x0006 rjmp TIM0_COMPA ; Timer0 CompareA Handler
0x0007 rjmp TIM0_COMPB ; Timer0 CompareB Handler
0x0008 rjmp WATCHDOG ; Watchdog Interrupt Handler
0x0009 rjmp ADC ; ADC Conversion Handler
```

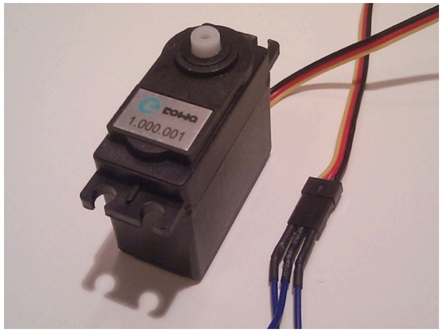
```
0x000A RESET: ldi r16, low(RAMEND); Start
0x000B out SPL,r16 ; Stack Pointer to RAM end
0x000C sei ; Enable interrupts
0x000D <instr> xxx
```

AVR Interrupts

- Timers, ADC, analog comparator, etc. generate interrupts
  - No need for busy waiting
  - Multitasking
- Interrupts must be enabled
  - Global interrupt enabling, disabling: sei(), cli()
  - Various registers enable/disable interrupts (e.g. timer overflow, timer compare, ADC ready, etc.)
  - Flag register shows interrupt states
- External interrupts
  - INT0 pin or PCINT5..0 pins
  - Even if configured as outputs (software interrupt)
  - Pin change interrupts: trigger if PCINT5..0 pin toggles
  - Level interrupt: triggers as long as INT0 pin low

CONTROLLING SERVO MOTORS WITH TIMERS AND INTERRUPTS

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

- Code

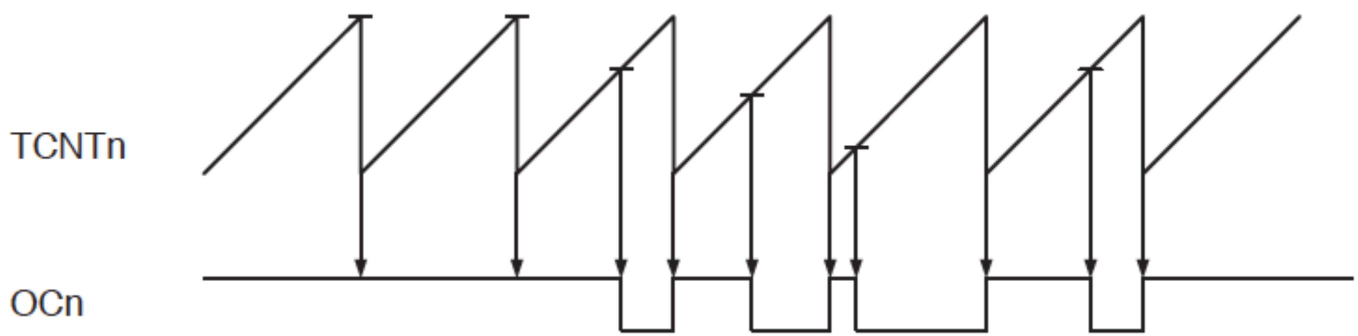
```
TCCR0A = (2 << COM0A0) | (0 << COM0B0) | (3 << WGM00);
```

- Explanation
  - TCCR0A = Timer/Counter 0, Control Register A

7	6	5	4	3	2	1	0
COM0A**1**	COM0A**0**	COM0B**1**	COM0B**0**	–	–	**WGM01**	**WGM00**

Source: AVR Datasheet

  - COM0A1..0 = 2: Clear OC0A pin on compare match, set OC0A pin at counter = 0 (non-inverting mode)
  - WGM01..0 = 3: Fast PWM, TOP = 0xFF



Timer-generated PWM + Interrupts

- Code

```
TCCR0B =  (0 << WGM02) | (4 << CS00);
```

- Explanation
  - TCCR0B = Timer/Counter 0, Control Register B

7	6	5	4	3	2	1	0
FOC0A	FOC0B	–	–	**WGM02**	**CS02**	**CS01**	**CS00**

Source: AVR Datasheet

  - CS02..0 = 4: divide clock by 256, at 16 MHz clock
  - 16 MHz / 256 = 62.5 kHz per counter step
    = 16 μs per counter step
  - one cycle (256 counter steps) = 4.096 ms = 244.14 Hz

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)         }
```

WLAN MODULE

Roving RN-XV WLAN Modules

- Simple communication via WLAN
  - Roving RN-171 WiFi chip
  - UDP, TCP, HTTP, FTP
  - rovingnetworks.com/products/RN_XV
- Serial I/O to WLAN module
- Requires 3.3V power supply
- Connections
  - Pin 1: 3.3V power supply (use 3.3V voltage regulator)
  - Pin 2: TX (connect to RX of ATmega8, direct)
  - Pin 3: RX (connect to TX of ATmega8, **via voltage divider!**)
  - Pin GND: connect to common ground

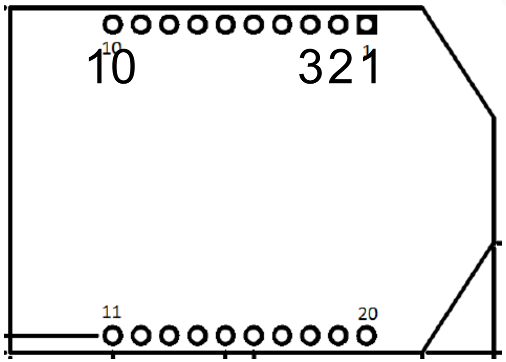


Image Sources: Roving Datasheet

Roving RN-XV WLAN Modules

- Pin 3 of RN-XV (RX): connect to TX of ATmega8
  - **via voltage divider!**
  - TX of ATmega8 uses +5V
  - RX of RN-XV expects +3.3V
- Example: $R_1 = 3000\ \Omega$, $R_2 = 1500\ \Omega$
  - $U_1 = 5V * R_1 / (R_1 + R_2) = 3.33V$

Roving RN-XV Commands

- Start terminal: screen /dev/tty.usbserial-A100XZ 9600
- Enter command mode: $$$
- Initialize

  factory RESET

  reboot

  set wlan ssid MYSSID

  set wlan pass 12345678

  set wlan join 1

  save

  reboot

Details:
rovingnetworks.com/products/RN_XV

- Get information

  ver, get ip, get adhoc, get com, get dns, etc.