EECS 192: Mechatronics Design Lab
Discussion 3: Motor Driver and Servo Control

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1 & 2 Feb 2017 (Week 3)

- Motor Driver Circuits
- Wiring
- Servomotors
- Summary
Motor Driver Circuits
This simple driver design gives you on/off control while only needing one transistor.
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When the switch is off, no current can flow and the motor freewheels.
Single-Transistor Recap (for your reference)

- This simple driver design gives you on/off control while only needing one transistor.
- When the switch is off, no current can flow and the motor freewheels.
- When the switch is on, current flows through the motor, causing it to spin.
This driver design gives you drive and braking control using two transistors. When both switches are off, no current can flow and the motor freewheels. When the bottom switch is on, current flows through the motor, causing it to spin. When the top switch is on, the motor's voltage is applied back across itself, applying braking force. Never turn on both transistors on at once - this shorts the supply across the transistors, which is called shoot-through.
This driver design gives you drive and braking control using two transistors.

When both switches are off, no current can flow and the motor freewheels.

When the bottom switch is on, current flows through the motor, causing it to spin.

When the top switch is on, the motor's voltage is applied back across itself, applying braking force.

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This condition is called shoot-through.
- This driver design gives you drive and braking control using two transistors
- When both switches are off, no current can flow and the motor freewheels
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Motor on
This driver design gives you drive and braking control using two transistors.

- When both switches are off, no current can flow and the motor freewheels.
- When the bottom switch is on, current flows through the motor, causing it to spin.
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Half-Bridge Recap (for your reference)

- This driver design gives you drive and braking control using two transistors.
- When both switches are off, no current can flow and the motor freewheels.
- When the bottom switch is on, current flows through the motor, causing it to spin.
- When the top switch is on, the motor's voltage is applied back across itself, applying braking force.
- Never turn on both transistors on at once - this shorts the supply across the transistors.
  - This condition is called shoot-through.

 Shoot-through
H-Bridge Recap (for your reference)

- This driver design gives you forward, reverse, and braking using four transistors.
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When all switches are off, no current can flow and the motor freewheels.

Motor off
H-Bridge Recap (for your reference)

- This driver design gives you forward, reverse, and braking using four transistors
- When all switches are off, no current can flow and the motor freewheels
- With an opposing pair of top and bottom switches on, current flows through the motor causing it to spin

Forward
H-Bridge Recap (for your reference)

- This driver design gives you forward, reverse, and braking using four transistors.
- When all switches are off, no current can flow and the motor freewheels.
- With an opposing pair of top and bottom switches on, current flows through the motor causing it to spin.
- Turning on the opposite switches causes the motor to spin in the other direction.
H-Bridge Recap (for your reference)

- This driver design gives you forward, reverse, and braking using four transistors.
- When all switches are off, no current can flow and the motor freewheels.
- With an opposing pair of top and bottom switches on, current flows through the motor causing it to spin.
- Turning on the opposite switches causes the motor to spin in the other direction.
- Braking is accomplished by turning on both the top or both the bottom switches.
A Single Transistor MOSFET Motor Driver

- I’ve got a demo circuit set up:
  - All running off benchtop power supplies
  - NMOS switch on the low side (source to GND, drain to the motor)
  - Function generator drives MOSFET gate
- A logic-level signal (microcontroller or computer) controls a huge current source (to the motor)
  - Logic pins source around 10 mA; not enough for motors
PWM Input Waveform

- PWM “interpolates” between on and off
  - Use highly efficient digital switches to approximate analog signal
- Function generator creates a 1kHz PWM signal (square wave) at 20% duty cycle
  - When MOSFET is on, forward current goes through the motor, creating torque
  - When MOSFET is off, no current through the motor, so just spins from inertia
- Do this really fast and you control speed between “full-on” and “full-off”
  - Note that an H-bridge should PWM between forwards and coast or backwards and coast but not forwards and backwards
Check your Understanding (Live Demo Edition!)

- I can adjust these PWM parameters: frequency (period) and duty cycle

- What should I do to ...
  - ... make the motor faster?
  - ... make the motor slower?

- What happens if ...  
  - ... I reduce the frequency?
  - ... I increase the frequency?

Motor Driver Circuit

Gate Waveform
I can adjust these PWM parameters: frequency (period) and duty cycle.

What should I do to ...
- ... make the motor faster?
  - Increase duty cycle (more time in accel)
- ... make the motor slower?

What happens if ...
- ... I reduce the frequency?
  - Motor chatter, danger of producing high motor currents
- ... I increase the frequency?
  - Smoother operation, but thermal effects (switching puts MOSFET through low-efficiency region) and slew
Check your Understanding (Live Demo Edition!)

- I can adjust these PWM parameters: frequency (period) and duty cycle.
- What should I do to ...
  - ... make the motor faster?
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  - ... make the motor slower?
    - Decrease duty cycle (more friction time)
- What happens if ...
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- ... I increase the frequency?
  - Smoother operation, but thermal effects (switching puts MOSFET through low-efficiency region) and slew
- Recall: a spinning motor produces voltage
  - ... which can be measured to sense speed!
- The scope is connected to the motor leads
  - Green probe on the positive motor lead (connected to the positive supply)
  - Purple probe on the negative motor lead (connected to the MOSFET drain)
- I want the voltage across the motor
  - Use math mode (red) to get green - purple
Sensing speed with back-EMF

- Recall: a spinning motor produces voltage
  - ... which can be measured to sense speed!
- The scope is connected to the motor leads
  - Green probe on the positive motor lead (connected to the positive supply)
  - Purple probe on the negative motor lead (connected to the MOSFET drain)
- I want the voltage across the motor
  - Use math mode (red) to get green - purple
- ... now what about on a microcontroller?
  - Sample both pins and subtract in software (if sampling speed $\gg$ motor time constant)
A High-Side Motor Driver

- Consider a MOSFET driving the high side
- What do you think would happen with the same drive waveform at the gate?

High-side Driver
A High-Side Motor Driver

- Consider a MOSFET driving the high side
- What do you think would happen with the same drive waveform at the gate?
  - Nothing! Insufficient gate voltage!
- Remember: MOSFET on/off depends on voltage between its gate and source
  - NOT referenced to the circuit ground
  - But when on, source is at supply voltage
- Must boost gate voltage above the supply
  - Enter the gate predriver chip, MC33883
MC33883 Gate Predriver

- Has four gate drivers:
  - GATE_HS\(_n\) pins, controlled by IN_HS\(_n\)
    - Boosts gate above Vcc when on, discharge to SRC\(_n\) when off
  - GATE_LS\(_n\) output controlled by IN_LS\(_n\)
    - Translates to Vcc when on, discharge to GND when off
  - Generate Vcc-level signals from 3.3v

- Designed to drive H-bridge
  - No shoot-through logic protection
  - Can be used as 4 independent drivers
  - Can use the GATE_HS\(_n\) to apply higher gate voltage to low-side FETs

**MC33883 Functional Block**

source: MC33883 datasheet, by Freescale
MC33883 Misc Tips (for your reference)

Important specs from the datasheet

- Minimum Vcc, Vcc2 of 5.5v and a maximum Vcc of 55v, Vcc2 of 28v
- G_EN pin as gate enable, set low to disable, set >4.5v to enable
  - 3.3v logic-level drive will NOT work!
- At Vcc=7.2v (maximum for Freescale Cup), charge pump output Vcp≈12v
  - Which is ~4.5v over Vcc, sufficient to drive a high-side MOSFET
- 3.3v logic compatible input ports
  - Anything above 2.0v treated as high
  - Anything below 0.8v treated as low
- Maximum PWM frequency of 100kHz

Figure 3. 33883 20-SOICW Pin Connections

source: MC33883 datasheet, by Freescale
You can skip the Zener diodes and use independent MOSFETs, but make sure to tie SRC_x to the MOSFET source of GATE_HS_x.

Figure 14. Application Schematic with External Protection Circuit

MC33883 Application Circuit

source: MC33883 datasheet, by Freescale
So, how does the MC33883 generate gate voltages above Vcc?

▶ Uses a switched-capacitor charge pump

Let’s start with a simple switched-capacitor voltage doubler circuit...

▶ Start by charging capacitor to Vcc
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- Start by charging capacitor to Vcc
- Disconnect capacitor from supplies
  - Capacitor retains its charge

Capacitor floating
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  - Capacitor high-side now at 2Vcc
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- Start by charging capacitor to Vcc
- Disconnect capacitor from supplies
  - Capacitor retains its charge
- Connect capacitor low-side to Vcc
  - Capacitor high-side now at 2Vcc
- Connect capacitor to output filter
  - Charge output filter to 2Vcc
MC33883 Charge Pump (for your reference)

MC33883’s charge pump uses an oscillator and diodes instead of switches

- When oscillator is low, capacitor is charged through diode

Capacitor charging
MC33883 Charge Pump (for your reference)

MC33883’s charge pump uses an oscillator and diodes instead of switches

- When oscillator is low, capacitor is charged through diode
- When oscillator goes high, low-side of capacitor goes to Vcc
  - High side of capacitor rises as well and charges CP through the diode
- (this illustrates the concept but skips details like different voltages and diodes)
got it?
ready to pwn checkpoint 3?
Wiring
American Wire Gauge (AWG) standardized sizing

Copper's resistance is $1.72 \times 10^{-8} \, \Omega \cdot m$

How do you compute resistance?

### AWG Table

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Source: moddiy.com
Wire Gauge

- American Wire Gauge (AWG) standardized sizing
- Copper’s resistance is $1.72 \times 10^{-8} \, \Omega \, m$
- How do you compute resistance?
  - Look up AWG diameter
  - $R = \frac{1.72 \times 10^{-8}}{\pi r^2} l$

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source: moddiy.com
Wire Types

- **Solid**
  - A single solid chunk of copper conductor
  - Rigid but inflexible: helpful in some cases

- **Stranded**
  - Several thin strands bundled together
  - More flexible, especially when there are more (that is thinner) strands

- **Wire gauge (size)** is by cross-section area
  - Equivalent stranded wire is “thicker” because of space between strands

- **Which resists breaking from flexing? Why?**
Wire Types

- **Solid**
  - A single solid chunk of copper conductor
  - Rigid but inflexible: helpful in some cases

- **Stranded**
  - Several thin strands bundled together
  - More flexible, especially when there are more (that is thinner) strands

- Wire gauge (size) is by cross-section area
  - Equivalent stranded wire is “thicker” because of space between strands

- Which resists breaking from flexing? Why?
  - Stranded wire: thinner strands experience lower bending stress

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Stranded Wire

source: Wikipedia, Scott Ehardt
Wiring Topology

Power supply wiring- Star is better!

Do not create ground loops!
Bad Wiring: “Why is my MC3383 Dead?”

What would be better?
Anderson Powerpole

- Physically and electrically hermaphroditic
  - Physically can’t insert it the wrong way
  - Both sides of the connector are identical
- We’re standardizing on the PP15/30/45
  - 15-amp contacts suitable for 16-20 AWG wire
  - 30-amp contacts for larger (12-14 AWG) wire
- Complete set of tools available
  - Crimper and insertion tool
- Use this for all your high-power connectors
  - Battery to board, driver to motor, ...
- Quick demo
Questions?

makes sense?

tl;dr: use stranded wire
Servomotors
Servomechanism: device using feedback loop to provide control
- RC cars use servomotor-actuated steering
  - Motor senses output shaft position and adjusts to hit commanded angle
  - Freescale Cup allows the Futaba S3010
- 3-wire standard servo cable:
  - white / yellow / orange: signal
  - red: positive supply voltage
  - black / brown: ground
PWM Control

- NOT the same PWM as motor control
- Servo setpoint by width of high pulse
  - Allowable width between 1ms - 2ms
  - 1.5ms to set setpoint to center
- Servo expects regular pulses
  - Cheap/old servos expect 50 Hz, fancy ones can run up to 400 Hz
  - Servo will timeout (and turn off) if it doesn’t get regular data
DO NOT USE BBBL SERVO PINS

▶ The Beaglebone Blue has enticingly convenient servo pins ...
▶ DO NOT BEfooLED. DO NOT PLUG THE SERVO INTO THEM.
▶ The 6V rail cannot source enough current for our beefy steering servos.
▶ Use only the signal line, not the power or ground rails.

PWM Waveform
I have a function generator PWM set at $V_{pp}=5\text{v}$, $V_{dc}=2.5\text{v}$, $f=200\text{ Hz}$, 30% duty

What is the period and pulse width?

What will the setpoint be?

What do I do to move it towards one side?
I have a function generator PWM set at $V_{pp}=5\,\text{v}$, $V_{dc}=2.5\,\text{v}$, $f=200\,\text{Hz}$, 30% duty

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  - period=5ms, pulse width=1.5ms

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- period=5ms, pulse width=1.5ms

What will the setpoint be?
- Dead center

What do I do to move it towards one side?

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- period $= 5\text{ms}$, pulse width $= 1.5\text{ms}$

What will the setpoint be?
- Dead center

What do I do to move it towards one side?
- Adjust the duty cycle, say, downwards

Beware of mechanical blockage stalling!
I have a function generator PWM set at $V_{pp}=5v$, $V_{dc}=2.5v$, $f=200$ Hz, 30% duty

- What is the period and pulse width?
  - period=5ms, pulse width=1.5ms

- What will the setpoint be?
  - Dead center

- What do I do to move it towards one side?
  - Adjust the duty cycle, say, downwards
  - Beware of mechanical blockage stalling!
got this down?

we all know how to steer now, right?
Summary

- Apply PWM waveform to motor driver circuits to control speed
- Use a gate predriver to drive MOSFETs from wimpy 3.3v logic
- Steering servos controlled with a different kind of PWM
- Use stranded wire

Parts Handout

- 4 IRFB3006PBF MOSFETs
- Perfboard
- SOIC carriers and MC33883 chips
- Need help soldering SOIC? Come to office hours!