Motor Driver Circuits

Wiring

Servomotors

Summary
Motor Driver Circuits
- This simple driver design gives you on/off control while only needing one transistor.

![Single-transistor driver](image)
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.
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- When the switch is on, current flows through the motor, causing it to spin.

[Diagram of motor driver circuit with Vcc and motor symbols.]
Half-Bridge Recap (for your reference)

- This driver design gives you drive and braking control using two transistors.
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- 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, a condition called shoot-through.
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Motor Driver Topologies

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Shoot-through
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H-bridge driver
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- 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

- So I’ve got a demo circuit set up:
  - All running off benchtop power supplies
  - MOSFET switch on the low side (source to GND, drain to the motor)
  - Function generator drives MOSFET gate
- Basically, allows a logic-level signal (like from your microcontroller) to control a huge current source (to the motor)
  - Note that most MCUs can only source / sink up to 25mA per pin
  - But motors require many amps...
Remember how PWM fades LEDs (checkpoint 1)?
- Same principle applies to motors
- 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-stop”
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?
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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    - Motor chatter (significant accel and decel during each period)
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- What happens if ...
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    - Motor chatter (significant accel and decel during each period)
  - ... I increase the frequency?
    - Smoother operation, but thermal effects (switching puts MOSFET through low-efficiency linear region) and slew

Motor Driver Circuit

Gate Waveform
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

Back-EMF measurement
Sensing speed with back-EMF

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  - 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 diagram]
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\_x pins, controlled by IN_HS\_x
    - Boosts gate above Vcc when on, discharge to SRC\_x when off
  - GATE_LS\_x output controlled by IN_LS\_x
    - Translates to Vcc when on, discharge to GND when off
    - Generate Vcc-level signals from 3.3v

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

Figure 2. 33883 Simplified Internal Block Diagram

source: MC33883 datasheet, by Freescale
Imported 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

source: MC33883 datasheet, by Freescale
MC33883 Application Circuit (for your reference)

Datasheet page 18 has all you need to know

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

![Capacitor charging diagram]
So, how does the MC33883 generate gate voltages above Vcc?

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- Disconnect capacitor from supplies
  - Capacitor retains its charge

![Capacitor floating diagram]
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▶ Connect capacitor low-side to Vcc
  ▶ Capacitor high-side now at 2Vcc

Voltage doubled
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- Disconnect capacitor from supplies
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- Connect capacitor low-side to Vcc
  - Capacitor high-side now at 2Vcc
- Connect capacitor to output filter
  - Charge output filter to 2Vcc
MC33883’s charge pump uses a 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 a 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)
Questions?

got it?

ready to pwn checkpoint 3?
Wiring
Wire Types

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

- **Stranded**
  - Made of individual strands of copper wire
  - More flexible, especially when there are more (and thinner) strands

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

- Which is more resistant to breaking from flexing? Why?

Stranded Wire

source: Wikipedia, Scott Ehardt
Wire Types

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- Wire gauge (size) is by cross-section area
  - So stranded wire has “thicker” conductor, because of space between strands
- Which is more resistant to breaking from flexing? Why?
  - Stranded wire: more flexible

Stranded Wire

source: Wikipedia, Scott Ehardt
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
  - We have many 15-amp contacts, suitable for 16-20 AWG wire
  - 30-amp contacts also available 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: negative supply voltage
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
  - Wikipedia says at least once per 20ms
  - But varies from model to model
  - Servo will timeout (and turn off) if it doesn’t get regular data

![PWM Waveform]
Check your Understanding (Live Demo Edition!)

- So I have a function generator PWM set at Vpp=5v, Vdc=2.5v, f=200 Hz, 30% duty
- What is the period and pulse width?
- What will the setpoint be?
- What do I do to move it to one side?
- Now I want to move it hard to the other side. What do I set the width and duty cycle?
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What is the period and pulse width?
- period = 5ms, pulse width = 1.5ms

What will the setpoint be?

What do I do to move it to one side?

Now I want to move it hard to the other side. What do I set the width and duty cycle?
Check your Understanding (Live Demo Edition!)

So I have a function generator PWM set at 
Vpp=5v, Vdc=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 to one side?

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Servomotors

Check your Understanding (Live Demo Edition!)

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- period=5ms, pulse width=1.5ms

What will the setpoint be?
- Dead center

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

Now I want to move it hard other side. What do I set the width and duty cycle?

Beware of mechanical blockage stalling!
Servomotors Protocol

Check your Understanding (Live Demo Edition!)

- So 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?
  - period=5ms, pulse width=1.5ms
- What will the setpoint be?
  - Dead center
- What do I do to move it to one side?
  - Adjust the duty cycle, say, downwards
- Now I want to move it hard other side. What do I set the width and duty cycle?
  - pulse width=2.0ms, duty cycle=40\%
  - Beware of mechanical blockage stalling!
Questions?

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

Get 3 NDP7060 MOSFETs per team

Re-use your LED perfboards for the motor driver checkpoint

SOIC carriers and MC33883 chips to be handed out Friday

Need help soldering SOIC? Come to office hours!