Mechatronics Systems Design Laboratory
ECE 491

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Upcoming Checkout

- This week:
  - Motor controller – Using MAX620 (Lab 5)
- Next week:
  - DC – DC Converter – Lab 6

Quiz 2 (2/28/2017)

- 30 min at start of class
- Topics:
  - DC-DC converter
  - OP-Amps
  - Encoders (incl. today)

PCB Board 1

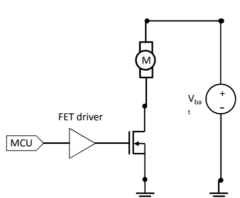
- Designs to John by Wednesday 3/8/2017
  - Noon
- Use template provided for you
- Shall contain:
  - power supply (DC-DC)
    - Remember disconnect switch
  - Motor controllers

Midterm (3/14/2017)

- Open Book/Open Notes
- Topics:
  - Motors
  - Motor controllers
  - FET review
  - DC-DC converter
  - OP-Amps review
  - Encoders (incl. today)

Motor Controllers Topologies

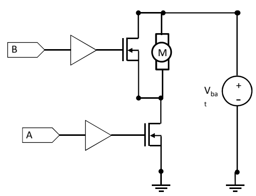
- Single FET motor controllers have the simplest topology
  - Can only accelerate, and coast to stop
- Other topologies allow for:
  - Breaking
  - Backwards motion
- Most common, full H-bridge
- Possible to use a half-bridge to simplify the controller design



single transistor controller

Motor Controllers Topology: Half-Bridge

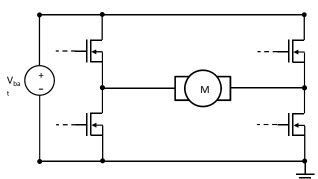
- It is possible to accelerate breaking by use the concept of **dynamic breaking**
- The V_{emf} generated by the motor is used to drive current through armature to cause breaking of the motor
- Required additional FET



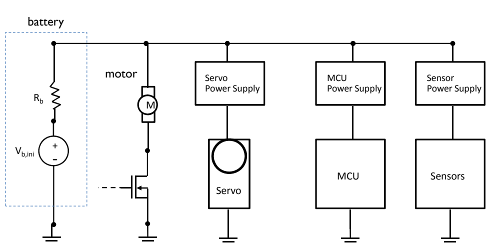
Half-bridge

Motor Controllers Topology – H-Bridge

- The most versatile motor controller topology is an H-bridge
- Requires four (4) FETs per motor

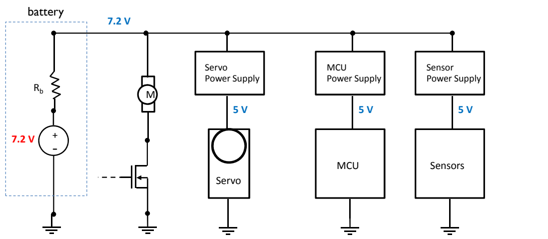


Review: Power Supply for Autonomous Car



Schematic of the required power supply for the sub-systems

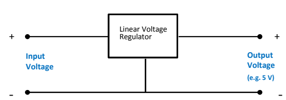
Review: Power Supply for Autonomous Car



Schematic of the required power supply for the sub-systems

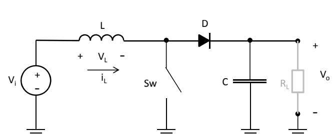
Power Supply 1: Linear Voltage Regulator

- Reduces the supply voltage to a stable value set value
  - Output voltage less than input voltage
  - A variable (controlled) resistor
- Key parameters
  - Output voltage (e.g. 5 V)
  - Input voltage range
    - Output current
    - Dropout
- E.g.: LM2940CT-5.0/NOPB
  - 5 Vout
  - 0V to 26V input
  - 1 A max output
  - 500mV Dropout

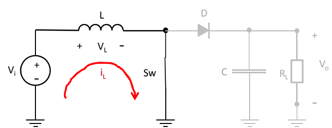


Power Supply II: Boost Converter

- Used to boost the input voltage
- Uses a storage inductor as the storage element for the boost stage



Power Supply II: Boost Converter – 1 Charge Stage

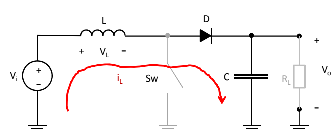


- The switch is closed
- The inductor starts storing magnetic energy by conserving current passing through

Voltage across an inductor: $V_i = L\frac{di_L}{dt}$

$$\frac{V_i}{L} = \frac{di_L}{dt}$$

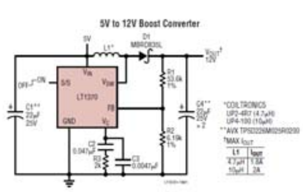
Power Supply II: Boost Converter – 2 Step-up Stage



- The switch opens
- Inductor "attempts" to maintain current and thus throws large inversed voltage to maintain current i_L.
- The current i_L passes through diode D and charges up capacitor C

Power Supply II: Boost Converter – LT1370

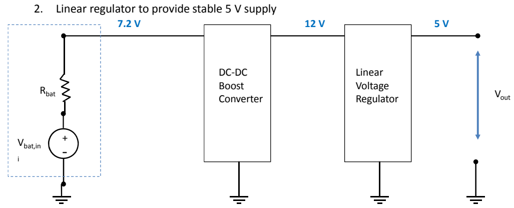
- Solid state solution switching regula
- Low (minimum) supply voltage 2.7 \
- Maximum 6A output current
- Typical application:
  - 12 V boost converter
- Use low ESR capacitors



Datasheet, LT1370, Linear Technology

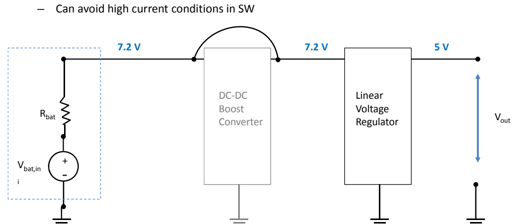
Power Supply for Autonomous Car – Entire System

- Two-component stable power-supply:
  1. Boost converter to make sure input voltage to linear regulator is always > 5 V + $V_{dropout}$
     - E.g. 12 V
  2. Linear regulator to provide stable 5 V supply



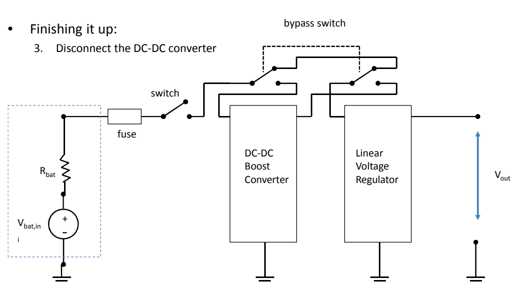
Power Supply for Autonomous Car – Entire System

- Redundancy:
  - Reliability through redundancy – can disconnect the DC-DC converter and still most likely be ok.
  - Can avoid high current conditions in SW



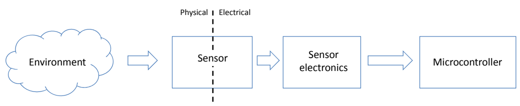
Power Supply for Autonomous Car – Entire System

- Finishing it up:
  3. Disconnect the DC-DC converter



Sensors - An Introduction

- Obtains the information about the environment
- Provides transduction between the physical (mechanical) and electrical domains
  - Transduction: Conversion of energy between energy domains



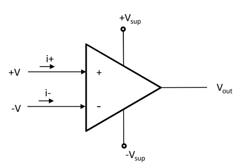
Review – Operational Amplifiers

- Operational Amplifiers (OpAmps) are commonly used to amplify (precondition) sensing signal for input to a microcontrollers

- OpAmps are analyzed as ***ideal***

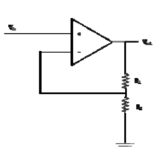
Ideal OP-Amp: $\boxed{V_{out} = A(V^+ - V^-)}$

- High input impedance (i+ ≈ 0, i- ≈ 0)
- Low output impedance
- Infinite gain (A is very large)

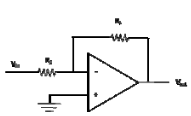


Review – Operational Amplifiers

- Two main configurations:



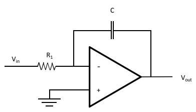
Non-inverting Amplifier



Inverting Amplifier

Review – Operational Amplifiers

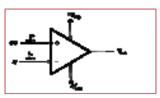
- Inverting OpAmp as charge integrator

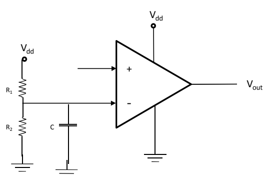


$$V_{out}(t') = -\int_0^{t'} \frac{V_{in}(t)}{RC} dt + V_{out}(0)$$

Review – Operational Amplifiers

- Single supply inverting OpAmp
  - Need to create a virtual ground at ½ Vdd



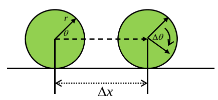


Summary: Sensors and Operational Amplifiers

- Sensors provide information about the state of the Environment to the microcontroler
- Operational Amplifiers (OpAmps) are often used to amplify the sensing signal
- OpAmps come in two flavors
  - Non-inverting
  - Inverting
- Gain of a non-inverting amplifier is always > 1
- A virtual ground can be used if an amplifier is used as single supply

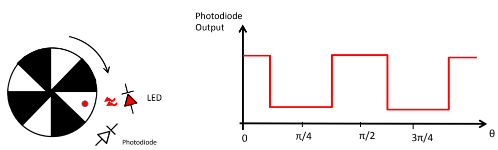
Optical Rotary Encoders and Velocity Sensing

- Velocity sensing is necessary for a car to reach a set velocity
  - Recall $\tau \propto i_m$
  - To reach the desired velocity, the car has to accelerate, i.e. increase i_m
  - Once desired velocity is reach the car has to coast, reducing i_m to counteract friction and drag
  - I_m must be larger to maintain same velocity if traversing an incline
- Velocity = distance / time
- Assuming a no-slip condition:
  $$\Delta x = \Delta\theta \cdot r$$
- Resulting velocity:
  $$v = \frac{\Delta x}{\Delta t} = \frac{\Delta\theta}{\Delta t} \cdot r = \omega \cdot r$$

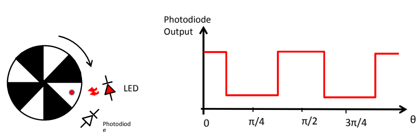


Optical Rotary Encoders and Velocity Sensing

- Optical Rotary Encoders:
  - Non-contact way to measure rotation/angular velocity
  - Can be purchased enclosed, or can be build onto the car wheel base
- Basics of operations:



Optical Rotary Encoders and Velocity Sensing



- Two ways to measure velocity:
  1. Count number of transitions (edges) within a fixed amount of time.
  2. Measure time between two transitions, i.e. the width of pulse or valley.
- Depends on the number of transitions v.s. sampling rate

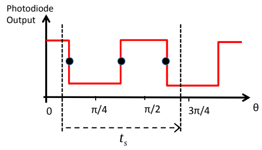
Optical Rotary Encoders and Velocity Sensing

- Count number of edges in a fixed amount of time:

$$\boxed{v = \frac{n\Delta\theta_{e-e}}{t_s} \cdot r}$$

where t_s is sampling time, n is the number of transitions, and θ_{e-e} is the angle between transitions, in this case π/4.

Error: $\pm \frac{\Delta\theta_{e-e}}{t_s} \cdot r$



Optical Rotary Encoders and Velocity Sensing

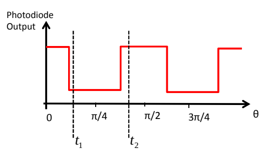
- Measure time between transitions:

$$\boxed{v = \frac{\Delta\theta_{e-e}}{t_2 - t_1} \cdot r}$$

where t_1 is the time of first transition, t_2 is the time of second transition θ_{e-e} is the angle between transitions, in this case π/4.

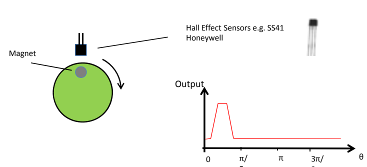
Error: $\pm \frac{\Delta\theta_{e-e}}{t_e} \cdot r$

where t_e is the sampling interval.



Velocity Sensing – Alternative Approaches

- Optical encoder is just one way to measure velocity
- Other approaches include:
  - Back EMF from the motors
  - Other types of proximity sensors to mark a revolution of the wheel
    - Good example is Hall-effect sensors



Summary: Optical Rotary Encoders and Velocity Sensing

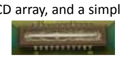
- Non-contact way of measuring rotation, can be integrated on the wheel
- Assuming no-slip conditions, wheel rotation corresponds to distance traveled
- An optical rotary encoder wheel can be used to measure rotation
- Two approaches:
  - Measure time between transitions
  - Count number of transitions within a time interval
  - Which approach to chose depends on: velocity, sampling time, allowable error
- Other approaches, such as sensing back EMF or hall effect (magnetic) sensing can be used to estimate the velocity

Optical Line Camera and Line Following

- A vision system is a key component in any autonomously driving car
- Optical camera projects an image onto a surface composed of light sensitive pixels
- Charge Coupled Device (CCD) image sensor:
  - An array of light sensitive pixels fabricated on a silicon chip, used to detect projected images
  - 2D array an essential component in many digital cameras

wikipedia

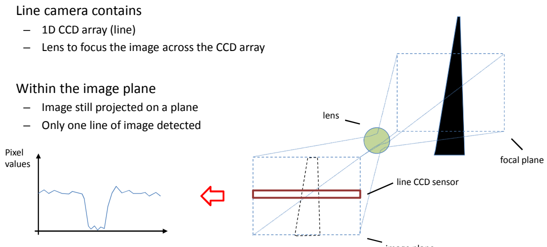
- Sophisticated image reconstruction algorithms usually need
- Line or edge following can be constructed using a 1D CCD array, and a simplified algorithm.



wikipedia

Optical Line Camera and Line Following

- Line camera contains
  - 1D CCD array (line)
  - Lens to focus the image across the CCD array
- Within the image plane
  - Image still projected on a plane
  - Only one line of image detected



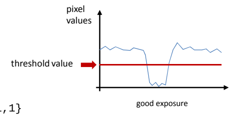
Optical Line Camera and Line Following

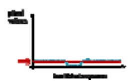
- Detecting line center
  - Thresholding an effective method
  - NOTE: need to adjust the level of thresholding as well as the exposure level
- Pixels (image elements) as array of 1's and 0's
- Simple algorithms to detect line locations
  - Pixel counting

{1,1,1,1,1,1,0,0,0,0,0,1,1,1,1,1,1}

line width

distance to center





Optical Line Camera and Line Following

- Recommended line camera: TAOS TSL1401CL
  - 128 x 1 linear optical sensor array
  - 3 – 5 V V_{dd} power supply