Mechatronics Systems Design Laboratory

ECE 491

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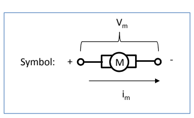
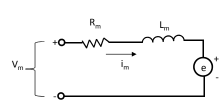
Upcoming Checkout

- This week:
  - Altium Tutorial (Lab 4)
- Next week:
  - Motor controller – Using MAX620

Motor: Electrical Equivalent Circuit





$V_{emf} = k_e \omega$

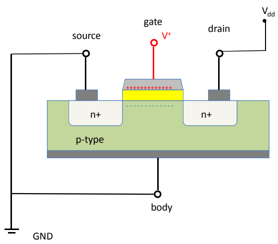
$\tau = k_t i_m$ $\quad V_m = k_e \omega + i_m R_m$ ← Assumes $\frac{di_m}{dt} \approx 0$

An equivalent circuit can be constructed to model the operation of the motor from an electrical perspective.

Field Effect Transistor: A Review

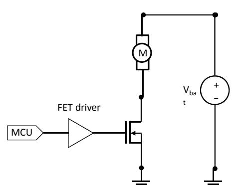
FET Operation (n-channel)

- To switch transistor on, gate is connected to positive voltage
- Accumulation of **positive** charges on the gate electrode attracts **negative** charges just underneath the gate, in the channel region



Motor Controllers Topologies

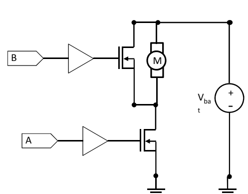
- Single FET motor controllers have the simplest topology
  - Can only accelerate, and coast to stop
- Other topologies allow for:
  - Breaking
  - Backwards motion
- Most common, full H-bridge
- Possible to use a half-bridge to simplify the controller design



single transistor controller

Motor Controllers Topology: Half-Bridge

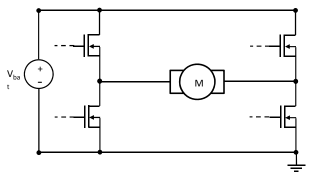
- It is possible to accelerate breaking by use the concept of **dynamic breaking**
- The V_{emf} generated by the motor is used to drive current through armature to cause breaking of the motor
- Required additional FET



Half-bridge

Motor Controllers Topology – H-Bridge

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



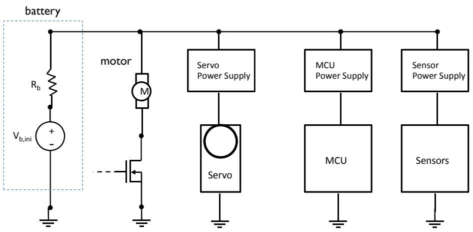
- Review of power supply for autonomous car
- Power Supply I: Linear Voltage Regulators
- Power Supply II: DC/DC converter
- Complete power supply solution

Review: Power Supply for Autonomous Car

- Different power needs for various sub-systems
- On-board power supply needed to:
  - Drive the motors (large currents)
  - Drive the servo (moderate currents)
  - Power the MCU (low currents, voltage stability)
  - Power the sensors (low currents, voltage stability
- Battery is the main reservoir of on-board power
- Many battery types
  - Most common types for electric vehicles are Lithium ion batteries (high energy density, moderate cost, large discharge/charge cycle life)

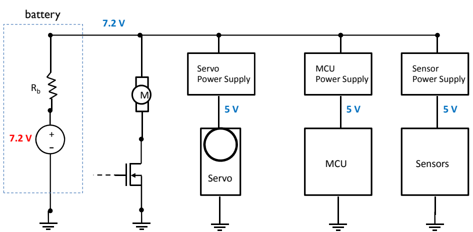
http://www.wirelessmadness.com/

Review: Power Supply for Autonomous Car



Schematic of the required power supply for the sub-systems

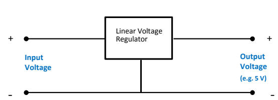
Review: Power Supply for Autonomous Car



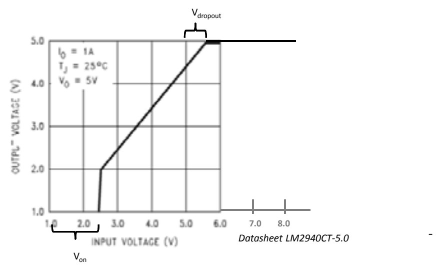
Schematic of the required power supply for the sub-systems

Power Supply 1: Linear Voltage Regulator

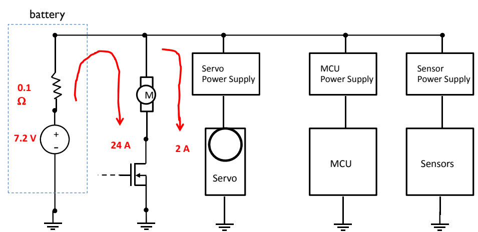
- Reduces the supply voltage to a stable value set value
  - Output voltage less than input voltage
  - A variable (controlled) resistor
- Key parameters
  - Output voltage (e.g. 5 V)
  - Input voltage range
    - Output current
    - Dropout
- E.g.: LM2940CT-5.0/NOPB
  - 5 Vout
  - 0V to 26V input
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



Power Supply 1: Linear Voltage Regulator

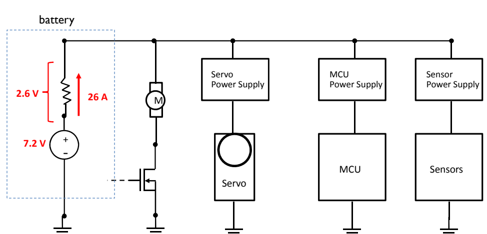


Review: Power Supply for Autonomous Car



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 II: DC/DC Converter

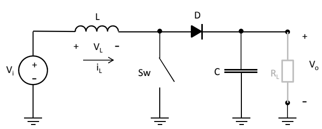
- Must elevate the voltage to provide a stable power supply (say 5 V)
- This can be down using switching power supplies

- Switching power supply:
  - Uses capacitors or inductors to store energy
  - Switches between a charge and discharge cycle
  - During the discharge cycle the energy is added or subtracted from the input voltage
  - Boost converter adds the stored voltage to boost supply voltage
  - Buck converters subtract the stored voltage to decrease the supply voltage

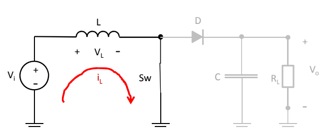
- This class will design a boost converter

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

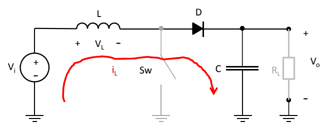


- The switch is closed
- The inductor starts storing magnetic energy by conserving current passing through

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

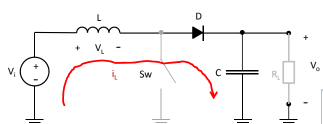
$$\frac{V_i}{L} = \frac{di_L}{dt}$$

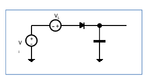
Power Supply II: Boost Converter – 2 Step-up Stage



- 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 – 2 Step-up Stage





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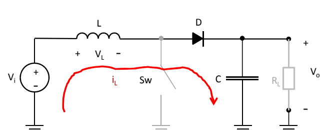
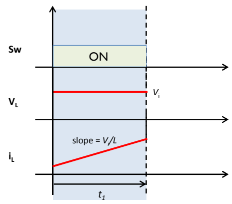


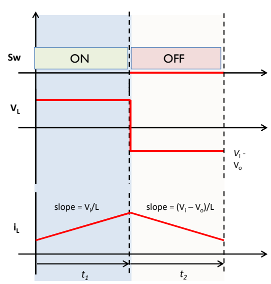
- The step-up current (slope) through the inductor is now: $\frac{V_I - V_O}{L} = \frac{di_L}{dt}$
- Inductor is discharging

Power Supply II: Boost Converter – Charge Step Revisited



The inductor is charging up. After t_1 we open the switch (Sw → OFF).

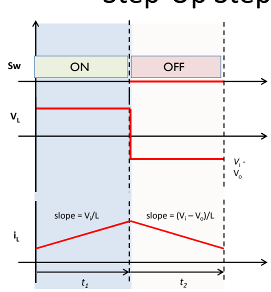
Power Supply II: Boost Converter – Step-Up Step Revisited



The inductor is charging up. After t_1 we open the switch (Sw → OFF).

The inductor is now dis-charging and transf. Afting charge to capacitor C for the duration of t_2.

Power Supply II: Boost Converter – Step-Up Step Revisited



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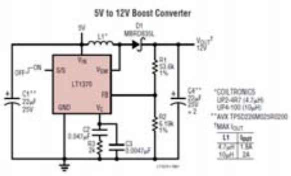
At steady state: $V_o = \dfrac{V_i}{\left(t_2 / (t_2 + t_1) \right)}$

Power Supply II: Boost Converter – LT1370

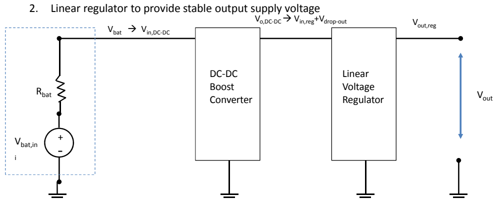
- Solid state solution switching regula
- Low (minimum) supply voltage 2.7
- Maximum 6A output current
- Typical application:
  - 12 V boost converter
- Use low ESR capacitors



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 output supply voltage



Power Supply for Autonomous Car – Entire System

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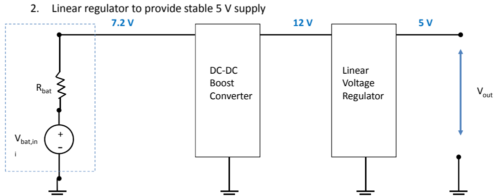
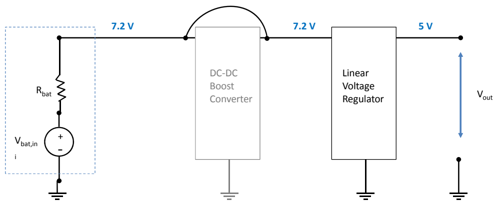
  2. Linear regulator to provide stable 5 V supply



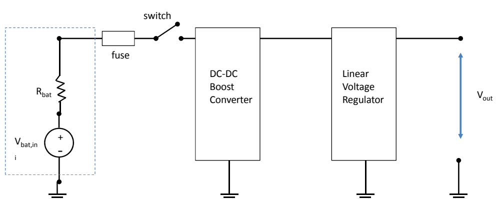
Power Supply for Autonomous Car – Entire System

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



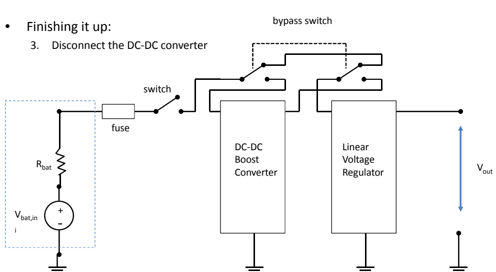
Power Supply for Autonomous Car – Entire System

- Finishing it up:
  1. Fuse (battery protection)
  2. Emergency stop switch



Power Supply for Autonomous Car – Entire System

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



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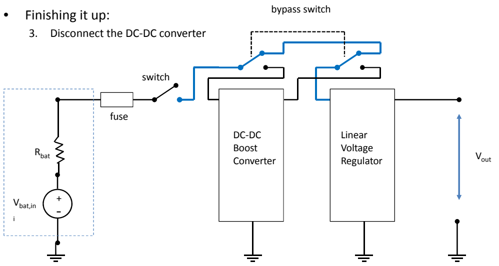

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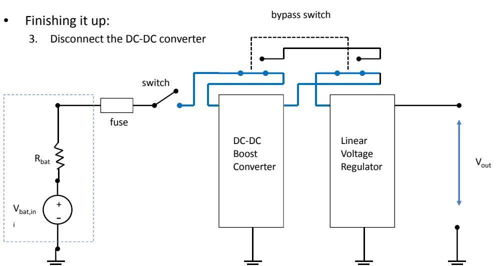


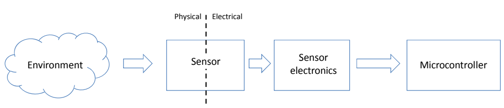
Summary: Power Supply for Autonomous Car

- Reliable supply necessary to provide different voltage or current to car sub-systems
- Output battery voltage can vary as a function of current
  – Can cause problems at stall, turning
- Linear Voltage Regulator can provide a stable output voltage
  – As long and $V_{out} > V_{in}+V_{dropout}$
- A switching (DC-DC) converter can both reduce or increase the voltage a desired level
- A DC-DC boost converter, together with one or more linear voltage regulator, can provide a stable supply voltage

Sensing

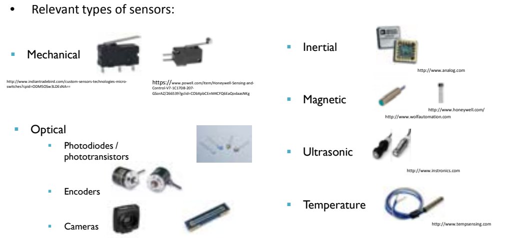
Sensors - An Introduction

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



Sensors - An Introduction

- Relevant types of sensors:

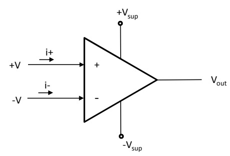


Review – Operational Amplifiers

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

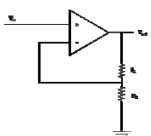
Ideal OP-Amp: $\boxed{V_{out} = A(V^+ - V^-)}$

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

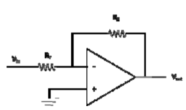


Review – Operational Amplifiers

- Two main configurations:



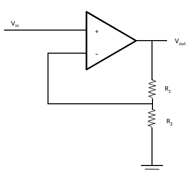
Non-inverting Amplifier



Inverting Amplifier

Review – Operational Amplifiers

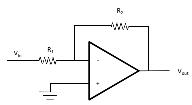
- Non-Inverting OpAmp



$$\boxed{V_{out} = \frac{R_1 + R_2}{R_2} V_{in}}$$

Review – Operational Amplifiers

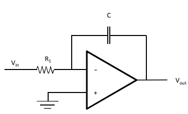
- Inverting OpAmp



$$\boxed{V_{out} = -\frac{R_2}{R_1} V_{in}}$$

Review – Operational Amplifiers

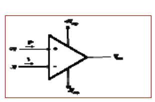
- Inverting OpAmp as charge integrator

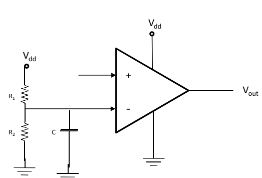


$$\boxed{V_{out}(t') = -\int_0^{t'} \frac{V_{in}(t)}{RC} dt + V_{out}(0)}$$

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