NATCAR – Background Information

Speed Control and Track Sensing

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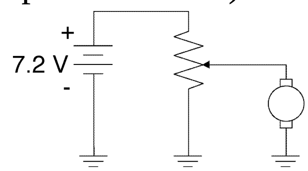
Outline

- DC motor speed control
  - variable DC voltage
  - PWM speed control
- Track sensing
  - Magnetic sensing
  - Optical sensing

Motor Speed Control

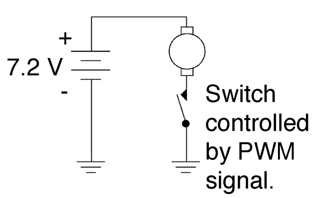
- The speed of a DC permanent-magnet motor varies with the applied voltage. Therefore, one way to drive the motor would be through a variable resistor (this method is used in inexpensive RC cars with a servo moving the wiper on the potentiometer).



- This method of speed control wastes a lot of power in the resistor, can't change speeds quickly, can't reverse direction and requires an additional servo.

PWM Motor Speed Control

If a motor is driven using PWM, then the speed can be changed rapidly, the direction reversed (for braking) and, at least ideally, no power is wasted. The motor speed will be set by the average time it is being driven. Although the drive is not constant, mechanical inertia will prevent the speed from varying so long as the PWM frequency is high enough.



Ideally:

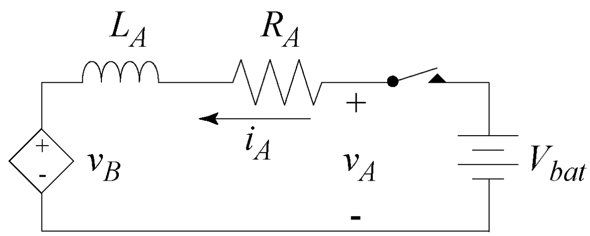
If the switch is on, $V_{SW} = 0$;

If the switch is off, $I_{SW} = 0$;

either way, $P_{SW} = 0$.

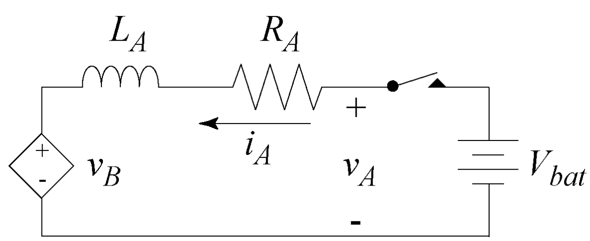
PWM Motor-Drive Switch Transients

- When the switch closes, i_A starts at zero and exponentially builds up toward $i_A = \left(V_{bat} - v_B\right)/R_A$ with a time constant of $\tau = L_A/R_A$.
- When the switch opens, the inductor supplies energy to try and keep the current flowing, which reverses the polarity of v_A and can increase its magnitude dramatically. Without protection, the switch can be ruined.



PWM Motor-Drive Switch Transients

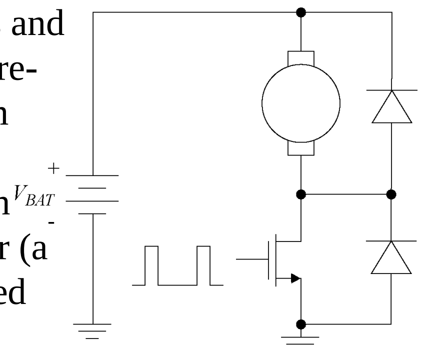
- The DMOS transistors we use have catch diodes built in. These diodes can dissipate significant power and get hot!
- You can also use an external diode if you want to, but it isn't necessary if the DMOS transistor has a good heat sink



PWM Motor Speed Control Revisited

We use a DMOS transistor for the switch and drive the gate with a PWM waveform. The diode in parallel with the MOSFET is included internally in the DMOS power transistors we use and is called either the catch diode or the freewheeling diode.

It is used in DC-DC converters and can function in this circuit to prevent the motor inductance from destroying the FET, but it may be better to use a separate catch diode in parallel with the motor (a series resistor could also be used to limit RFI)



Practical Motor Speed Control

- You must use closed-loop speed control for your motor or you will not be able to set a predictable and stable speed.
  - the battery voltage changes a lot as it discharges
  - not all batteries are exactly the same
  - not all the motors are exactly the same
  - Everything is temperature dependent
- Closed-loop control systems will be covered later.
- You will need some way of measuring the motor speed (really, it is the car speed you want)
  - A DC motor working as a generator works well
  - counting pulses from optical or magnetic sensors can work too, but may not respond to changes fast enough

Sensing the Track

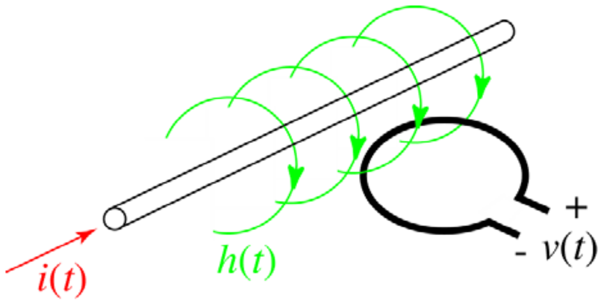
- You can sense the magnetic field created by the 75 kHz current, or you can optically sense the tape, or you can build an artificial vision system, or ??
- Magnetic sensing is sensitive to nearby metal objects (e.g., rebar in the floor), but can be quite robust.
- Optical sensing is sensitive to ambient lighting, the exact contrast between the tape and floor and the height of the sensors, but can also be robust.
- An artificial vision system would be the most sophisticated, but is the most complicated.

Choosing Your Sensing Scheme

- Spend a LOT of time and energy choosing and optimizing your sensing scheme (allow time to come back to it after you have a car moving).
- No one scheme is "best," but the exact implementation matters a lot – you need to think through how you will detect crossings, how sensitive you will be to the unavoidable parameter changes and so on.
- You also need to think through how mechanically robust your design is – a broken sensor can be a major problem if you can't replace it quickly, or the replacement doesn't "match" well enough.

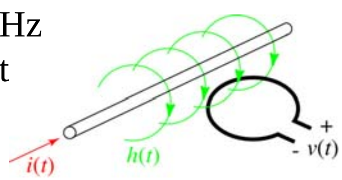
Magnetic Sensing

A changing electric current produces a changing magnetic field, which can induce an *emf* in a loop. The voltage is proportional to the area of the loop, the permeability and the rate of change of the current. It is inversely proportional to the distance from the wire (for an infinite wire).



More Magnetic Sensing

- The 75 kHz current in the wire will induce a voltage in any loop of wire placed in the field. The voltage will be at 75 kHz too. You will want to reject other frequencies with a parallel resonant circuit.



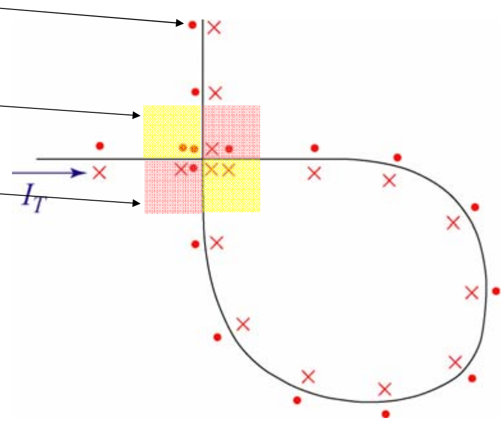
- The coil itself is parallel resonant due to the presence of parasitic capacitance. You will need to use a coil resonant *above* 75 kHz and then add some capacitance to adjust the resonant frequency down to 75 kHz. Be sure to allow for the input capacitance of your circuit (and the scope probe).

Even More Magnetic Sensing

- You should give thought to how you can orient the coils relative to the track if you sense the wire magnetically. There are many different ways to do this and some are better (see example on next slide).
- Also, the number of turns, physical dimensions and core material all make significant differences.
- Finally, if you wind the coils yourselves, be sure to carefully relieve the strain on the soldered connections to the coil so you don't break them every time the car crashes.

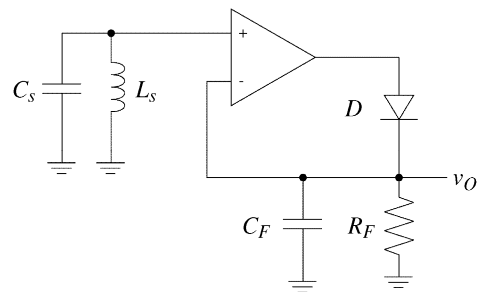
Magnetic Sensing: Example Problem

- Consider what happens when you reach a crossing:
  - The track current is I_T
  - The magnetic field lines perpendicular to the plane are shown
  - Note the fields add here
  - And they cancel here



Magnetic Sensing Continued

- If you use magnetic sensing, you almost certainly want to rectify the AC output and use a capacitor to tune the coil to be resonant at 75 kHz.
- One simple rectifier is the super-diode circuit.

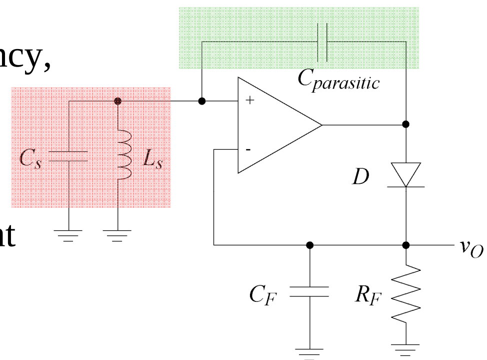


Super Diode Warning !!

- The super-diode circuit shown can easily oscillate!
  - The input node has a *very* high impedance to ground at the resonant frequency, so even a small parasitic capacitance from the op amp output to that node yields significant positive feedback. (shown on the next slide)
  - You can fix the problem through careful layout, or by buffering the output of your coil with another op amp stage.
  - Any op amp gain stage will do – it is the low output impedance of that stage that solves the problem.

Super Diode Oscillation

- The parasitic capacitance forms a voltage divider with the inductive sensor and the input impedance of the op amp.
- The input impedance of the op amp is very large, so ignore it.
- At the resonant frequency, the inductive sensor impedance is also very large, so the feedback factor can be significant even with a very small parasitic capacitance.

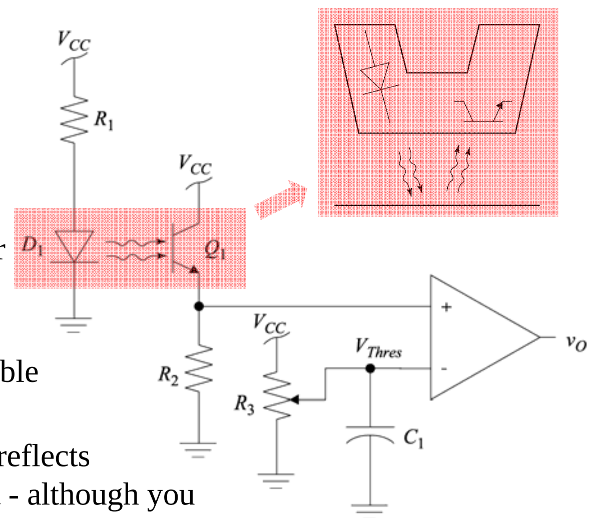


Optical Sensing

- You can use various frequencies of light.
  - Visible light (the reflected light from the tape is greater than from the carpet – but think about shadows & flashes)
  - IR (you will need to provide IR emitters and detectors – they can be affected by camera flashes too)
- Photodiodes and phototransistors use light to generate EHP’s in the semiconductor. For phototransistors, the induced current acts like a base current and turns the device on in proportion to the light intensity.
- Small cameras are not too expensive (< $50) and you can build a vision system.

Typical Optical Sensing Scheme

- The LED is aimed at a surface so that the reflected light hits the phototransistor
- The collector current of the phototransistor is proportional to the reflected light
- This is just one possible circuit
- In our case, the tape reflects better than the carpet - although you need to be able to adjust for different conditions



One Good Optical Sensor