May15-30:
Fast, Compact, High Strength Magnetic Pulse Generator

Team Members

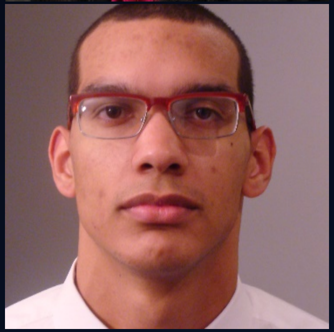
Adam Kaas
Leader

Greg Fontana
Simulator

Meiyong Himmtann
Webmaster

Brittany Duffy
Communication Leader

Alain Ndoutoume
Systems Leader & Commissioner



Brandon Dixon
Layout Designer

Megan Sharp
Coil Designer

Advisors
Dr. Mani Mina, Senior Lecturer
John Pritchard, Graduate Student
Robert Bouda, Graduate Student

Client
Iowa State University High Speed Systems Engineering Lab

Presentation Outline

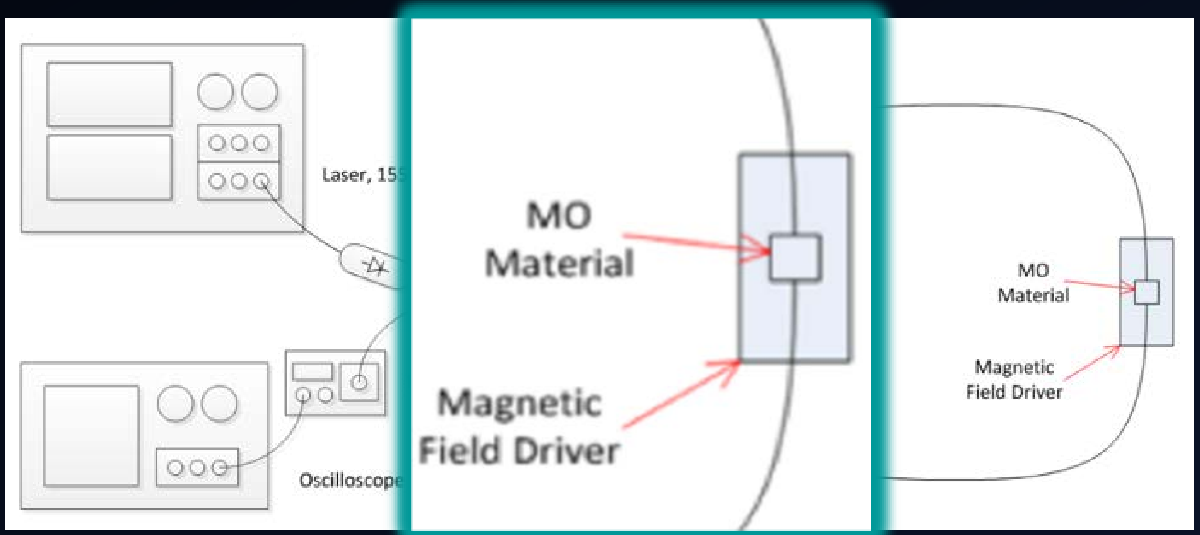
- Problem Statement
- Applications/Needs
- Functional/Non-Functional Requirements
- Basic Circuit Idea
- Design Cycle
- Detailed Design and Analysis
- Testing Approach
- Risk Assessment
- Current Project Status
- Future Project Plans

Problem Statement

- Design a magnetic pulse generator that is:
  - Fast (1μs)
  - Compact (3.5” x2”)
  - High Strength (500 G)

Applications/Needs

- Fast-switching needs
- Magneto-optics
  - Magneto-Optic Interferometer



Sagnac Configuration Interferometer
Photo Courtesy of John W. Pritchard

Functional Requirements

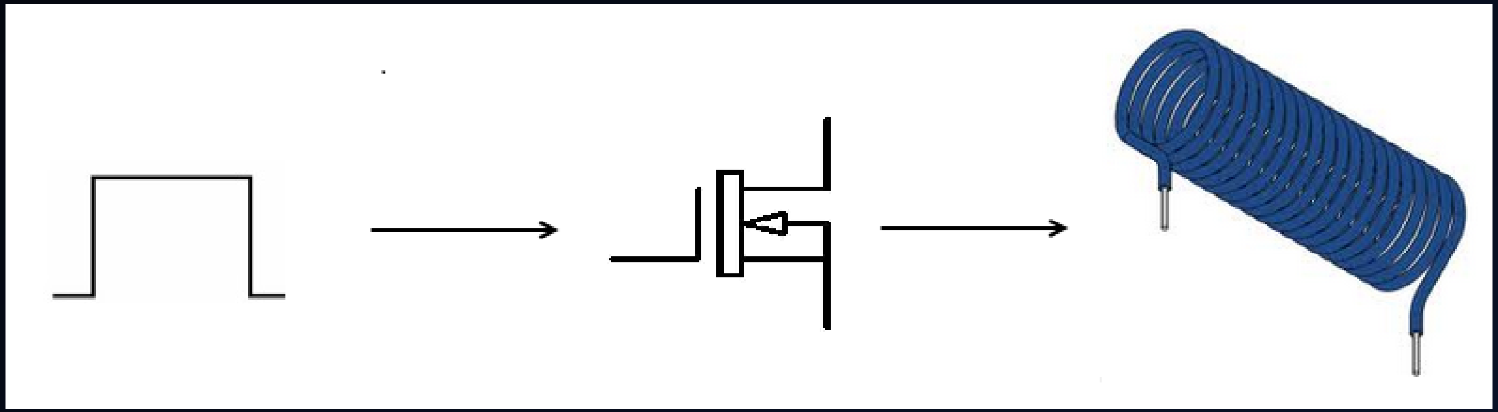
- Magnetic field with strength ≥ 500 gauss
- Magnetic Field 1μs pulse
- Consistent Results

Non-functional Requirements

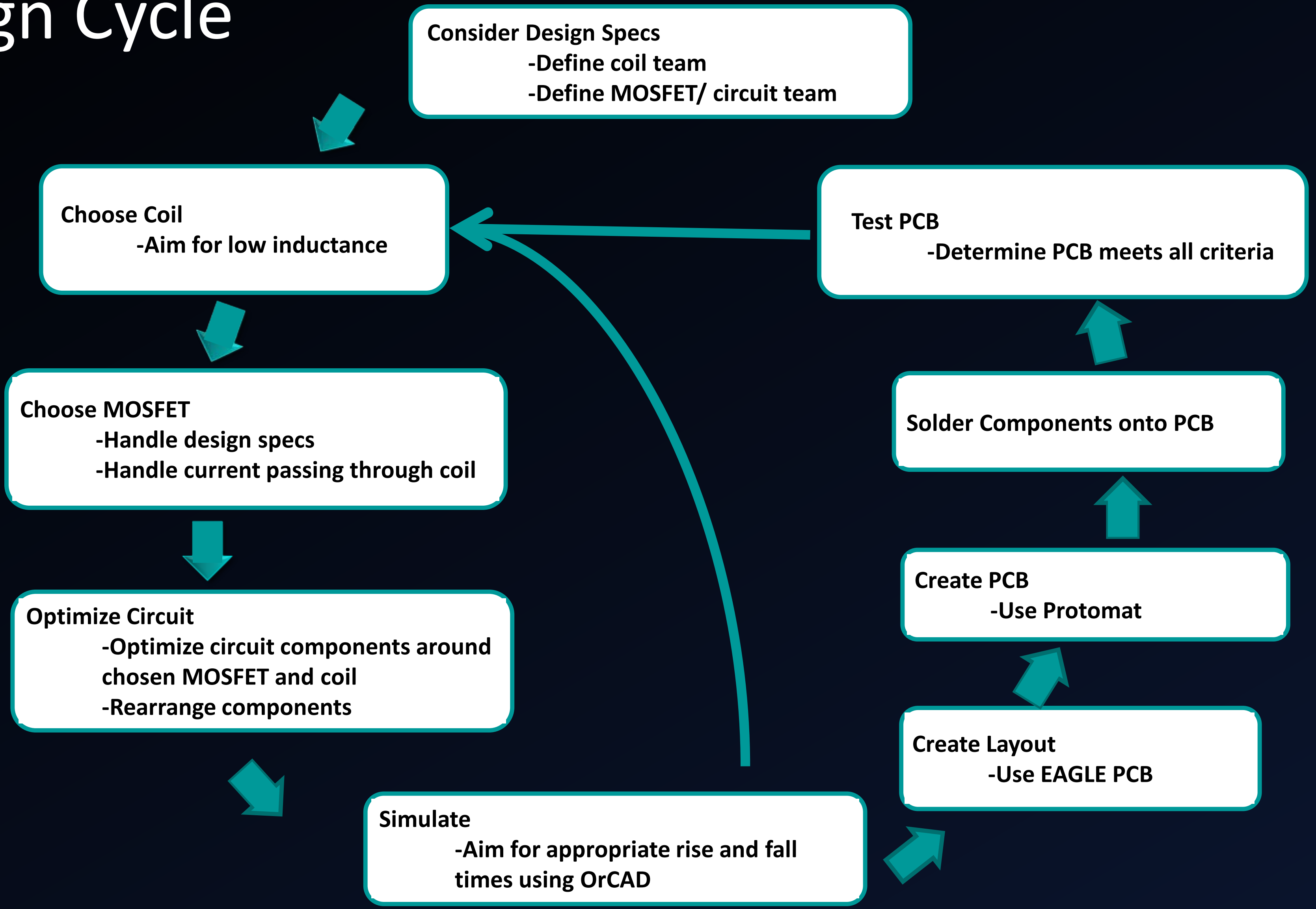
- Dimensions ≤ 3.5" x 2"
- Enclosed Device
- DC voltage source ≤ 15 volts

Basic Circuit Idea

- Pulse to turn MOSFET on and off
- Coil to generate magnetic field

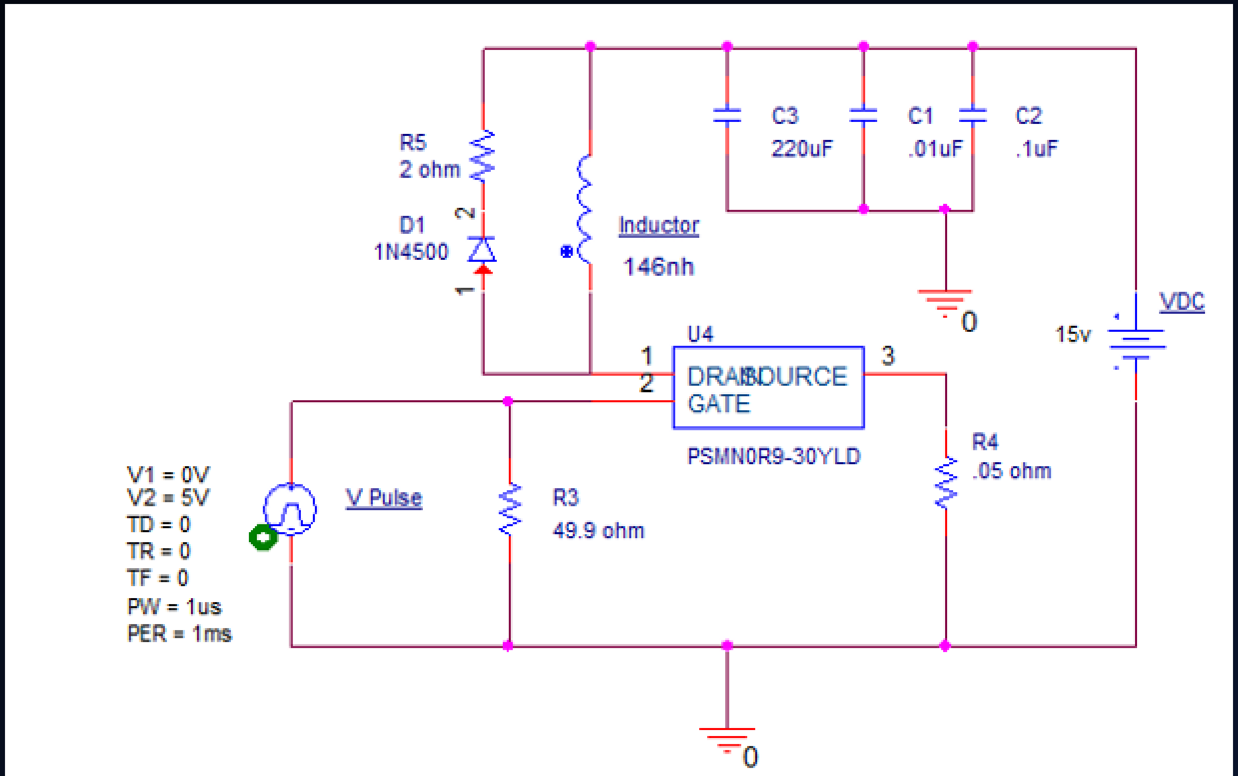


Design Cycle



Detailed Design

- Coil
- MOSFET
- Resistors
- Capacitors
- Diode

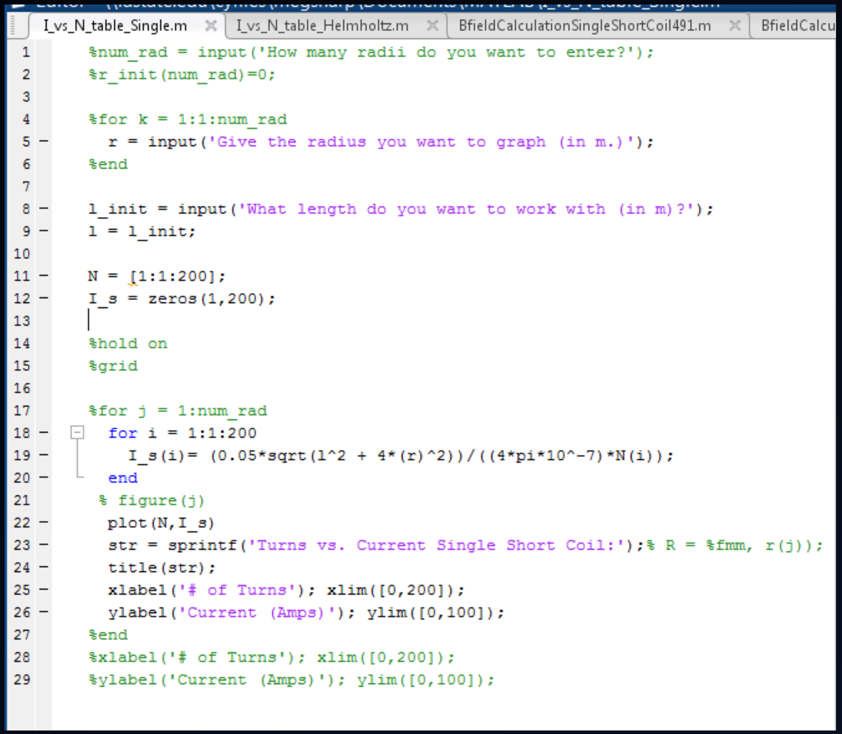


Coil

- 500 gauss
- Inductance
- Resistance

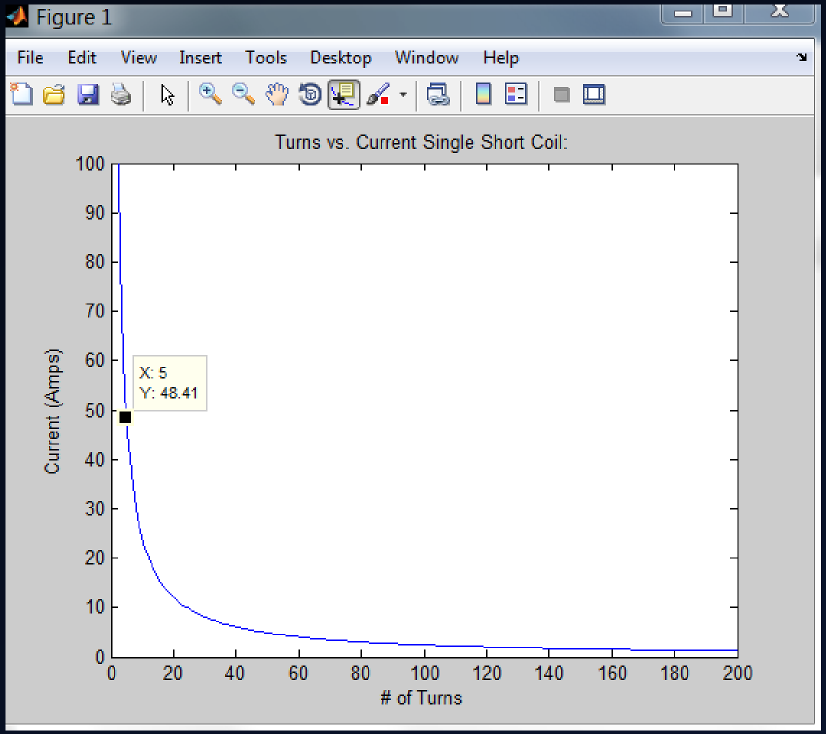
Preliminary Analysis

CALCULATE MAGNETIC FIELD AND INDUCTANCE



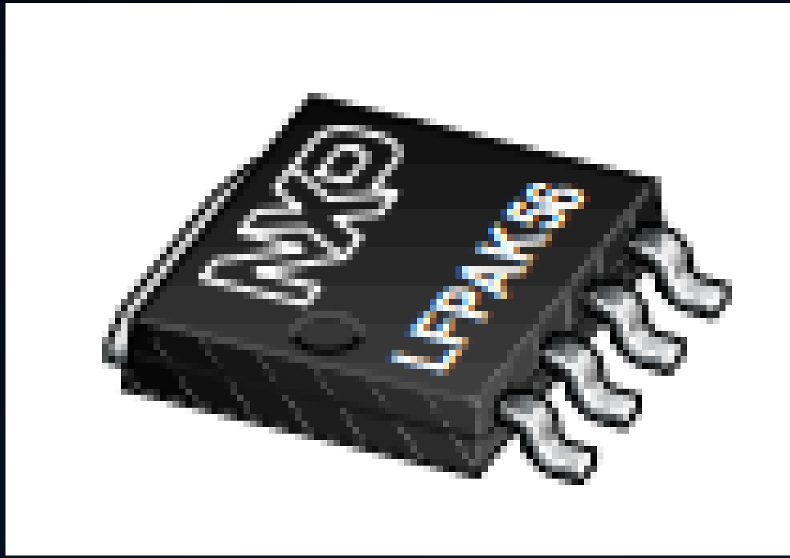
```
%num_rad = input('How many radii do you want to enter?');
%r_init(num_rad)=0;

%for k = 1:1:num_rad
  r = input('Give the radius you want to graph (in m.)');
%end

l_init = input('What length do you want to work with (in m)?');
l = l_init;

N = [1:1:200];
I_s = zeros(1,200);

%hold on
%grid

%for j = 1:num_rad
  for i = 1:1:200
    I_s(i)= (0.05*sqrt(l^2 + 4*(r)^2))/((4*pi*10^-7)*N(i));
  end
 % figure(j)
  plot(N,I_s)
  str = sprintf('Turns vs. Current Single Short Coil:');% R = %fmm, r(j));
  title(str);
  xlabel('# of Turns'); xlim([0,200]);
  ylabel('Current (Amps)'); ylim([0,100]);
%end
%xlabel('# of Turns'); xlim([0,200]);
%ylabel('Current (Amps)'); ylim([0,100]);
```

TURNS VS CURRENT FOR 500 GAUSS



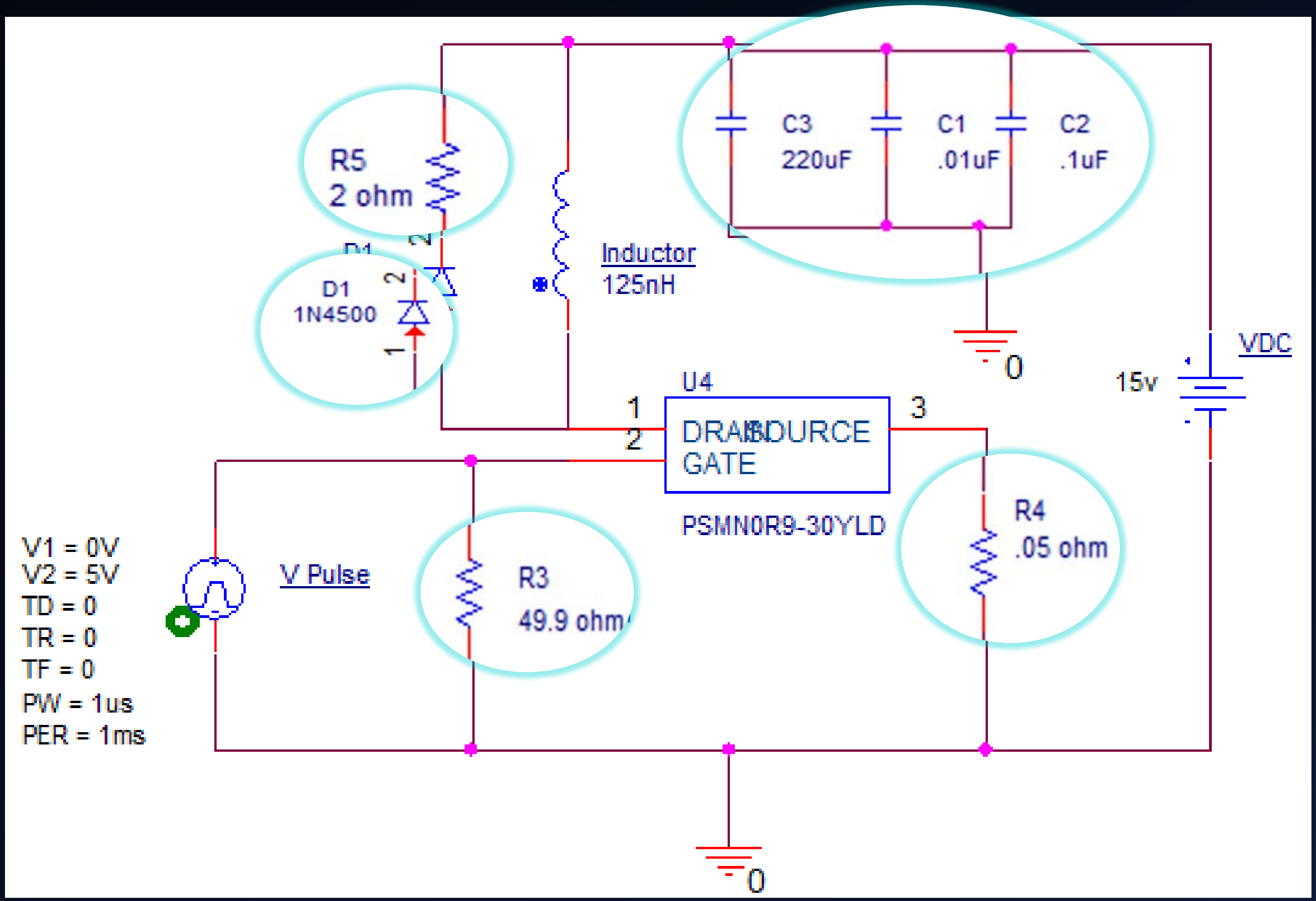
MOSFET

- “High Speed”
- Continuous Drain Current (100A)
- Large Max Drain-Source Voltage (50V)
- Low Parasitic Inductance and Resistance



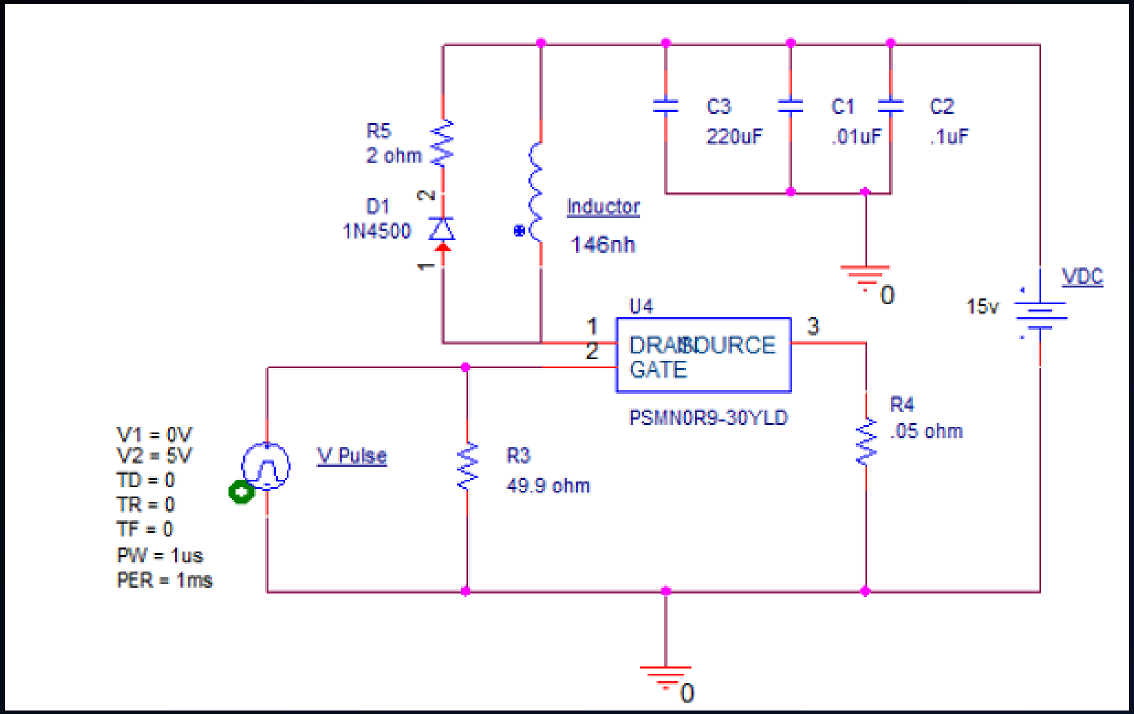
Resistors, Capacitors, and Diode

- Three Resistors
  - 49.9Ω, 2Ω, 0.05Ω
- Three Capacitors
  - 0.01uF, 0.1uF, 220uF
- One Diode
  - 200 V reverse breakdown

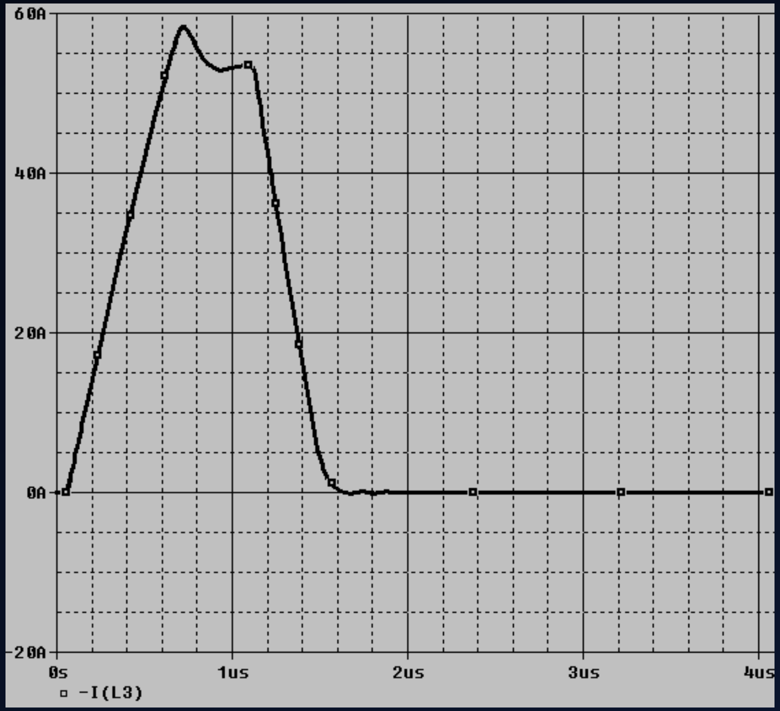


Simulations

SCHEMATIC

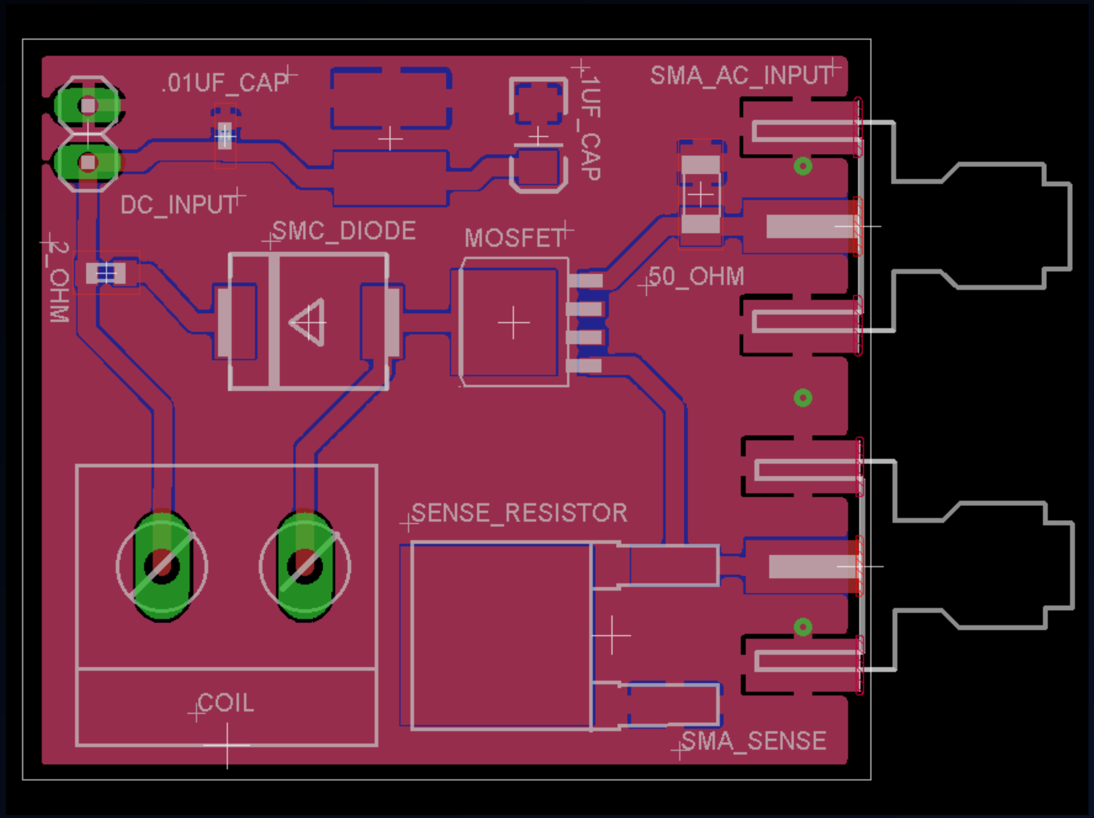


SIMULATIONS



Eagle PCB/Protomat S62

LAYOUT



1.49 x 1.30 inches

FABRICATE BOARD

Testing Approach

- 0.05Ω Current Sense Resistor
- Magnetic Field Calculations
  - Current
  - Number of Turns
  - Radius of Coil
  - Length of Coil

Risk Assessment

- Ordering enough parts early enough to compensate for additional prototyping
- Physical Dangers:
  - Risk of shock
  - Risk of burning
- Mitigation of risk:
  - Following lab safety instructions

Current Project Status

- Major Milestones:
  - Working Proof of Concept due 12/19/14
    - Parts received 12/3/14
  - Website developed and up-to-date
- Second Semester Short-Term Goals:
  - New parts selected by February 3rd

Plan for Next Semester

- Circuit testing
- Helmholtz coil
- Professionally fabricated PCB
- Device enclosure

Questions?

Project Milestones & Schedule

- Assessment of proposed solution: Big progress and better comprehension of what we are doing: (adding capacitors, sensing resistor, SMA connectors to our circuit and etc...)
- Project Plan and Design Document due by end of first semester
- Proof of Concept by 12/19/14
- 4/17/15, final paper complete and deliver final product

Resource/Cost Estimate- Prototype Hardware and Software

Item	Where to Obtain	Quantity	Cost Per	Total Cost
OrCAD Software	http://www.orcad.com	1	$-	$-
EAGLE PCB Software	http://www.cadsoftusa.com	1	$-	$-
MATLAB	http://www.mathworks.com	1	$-	$-
MOSFET	digikey.com	10	$1.79	$17.86
0.1uF Capacitor (Tantalum)	digikey.com	10	$0.33	$3.29
220uF Capacitor (Tantalum)	digikey.com	4	$10.88	$43.52
0.01uF Capacitor (Ceramic)	digikey.com	10	$0.01	$0.12
Diode	digikey.com	10	$0.72	$7.22
49.9 Ohm Surface Mount Resistor	digikey.com	10	$0.10	$1.00
0.05 Current Sense Resistor	digikey.com	2	$9.13	$18.26
Wire-to-Board Connector (30A/300V Rating)	digikey.com	2	$1.04	$2.08
Coaxial Connector	digikey.com	4	$4.84	$19.36
Coil wire (3m)	Iowa State High Speed Systems Lab	1	$-	$-
Coil glue	Iowa State High Speed Systems Lab	1	$-	$-
Insta-set (fast dry glue)	Iowa State High Speed Systems Lab	1	$-	$-
Tweezers	Megan Sharp	1	$-	$-
Exacto knife	Megan Sharp	1	$-	$-
Ruler	Iowa State High Speed Systems Lab	1	$-	$-
Balsa Wood	Iowa State High Speed Systems Lab	1	$-	$-
Charcoal (used for winding)	Iowa State High Speed Systems Lab	1	$-	$-
Sandpaper (for coil)	Iowa State High Speed Systems Lab	1	$-	$-
Soldering Station	Iowa State Parts Shop	1	$-	$-
Solder	Iowa State Parts Shop	1	$-	$-
PCB Fabrication	Iowa State Parts Shop	3	$-	$-
Total				**$112.71**

Resource/Cost Estimate– Final Product

Table 3: Final Product Costs

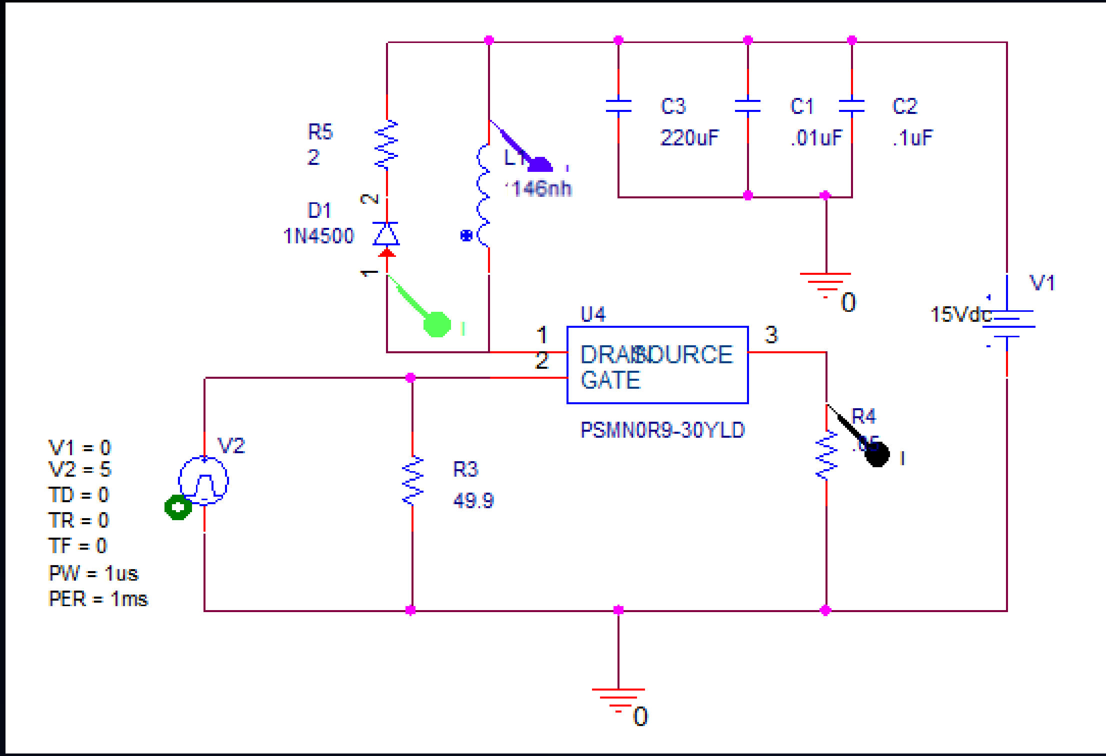
Item	Description	Quantity	Cost Per	Total Cost
N-channel MOSFET	digikey.com	1	$1.79	$1.79
Single Coil (Resistance Wire)	Iowa State High Speed Systems Lab	1	$-	$-
0.1uF Capacitor (Tantalum)	digikey.com	1	$0.33	$0.33
220uF Capacitor (Tantalum)	digikey.com	1	$10.88	$10.88
0.01uF Capacitor (Ceramic)	digikey.com	1	$0.01	$0.01
Diode	digikey.com	1	$0.72	$0.72
49.9Ω Surface Mount Resistor	digikey.com	1	$0.10	$0.10
0.05 Current Sense Resistor	digikey.com	1	$9.13	$9.13
Wire-to-Board Connector (30A/300V Rating)	digikey.com	1	$1.04	$1.04
Coaxial Connector	digikey.com	2	$4.84	$9.68
PCB Fabrication	oshpark.com	1	$10.00	$10.00
Total				**$43.68**

Equations

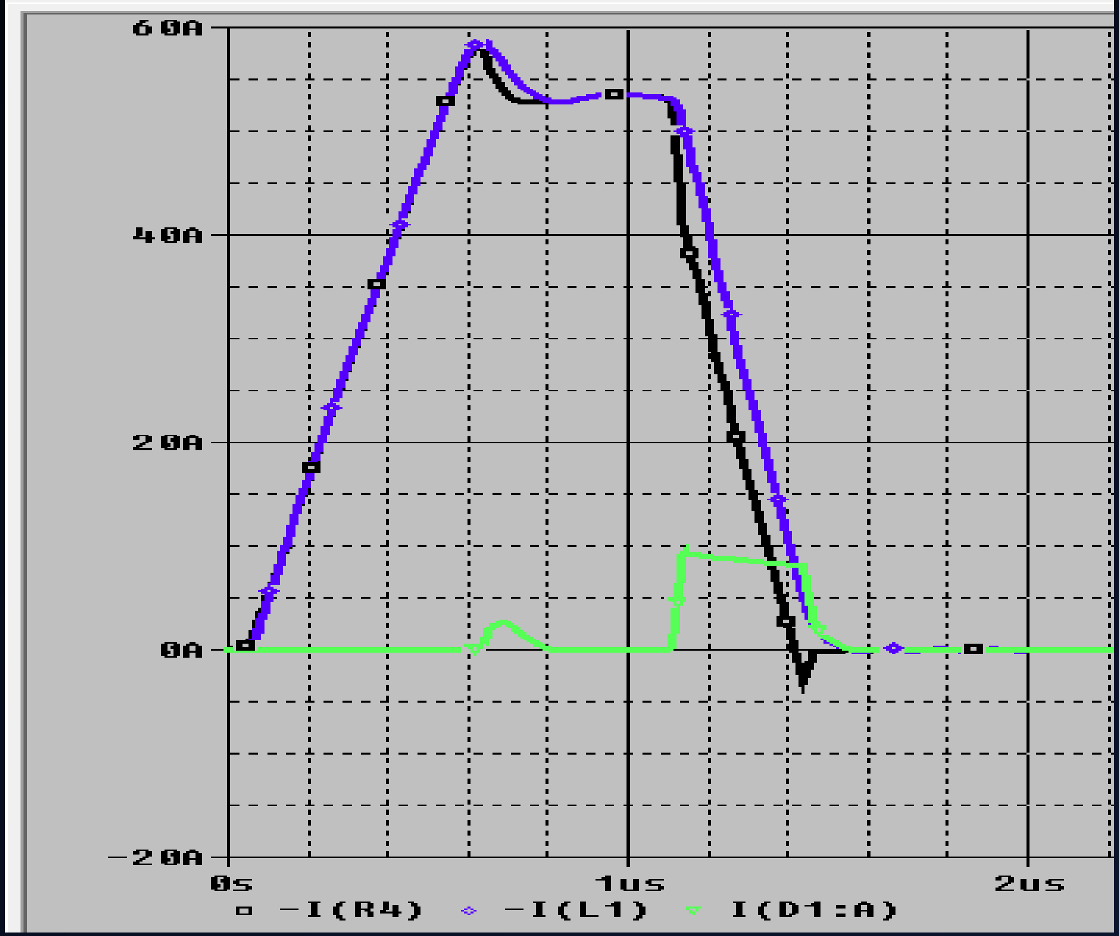
- $$\frac{Current * Pulse\ Width}{Voltage} = Capacitance$$
- $$\frac{48.41\frac{Coulomb}{second} * 1 * 10^{-6} seconds}{15\ Volts} = 3.227\ \ uF$$
- $$L = \frac{\mu N^2(\pi R^2)}{\sqrt{l^2+4R^2}} = \frac{(4\pi\ x\ 10^{-7})5^2(\pi * (3\ x\ 10^{-3})^2)}{\sqrt{(1\ x\ 10^{-3})^2+4(3\ x\ 10^{-3})^2}} = 146nH$$
- $$B = \frac{\mu NI}{\sqrt{l^2+4R^2}} = 0.057865\ Teslas = 578.65\ gauss$$

```
% To verify the equation used above we did a dimensional analysis:
%      u*N*I
% B =  -----
%        R
% UNITS:
% B -> Tesla(T) -> V-s/A*m
% u -> H/m -> Wb/A*m -> V-s/A*m
% N -> dimensionless
% I -> Amperes(A)
% R -> radius(m)
% V-s   V-s/A*m * A   V-s/m   V-s
% --- = ----------- = ----- = ---
% m^2       m           m     m^2

% Then we found that 1 Gauss = 0.0001 Tesla

```

Currents

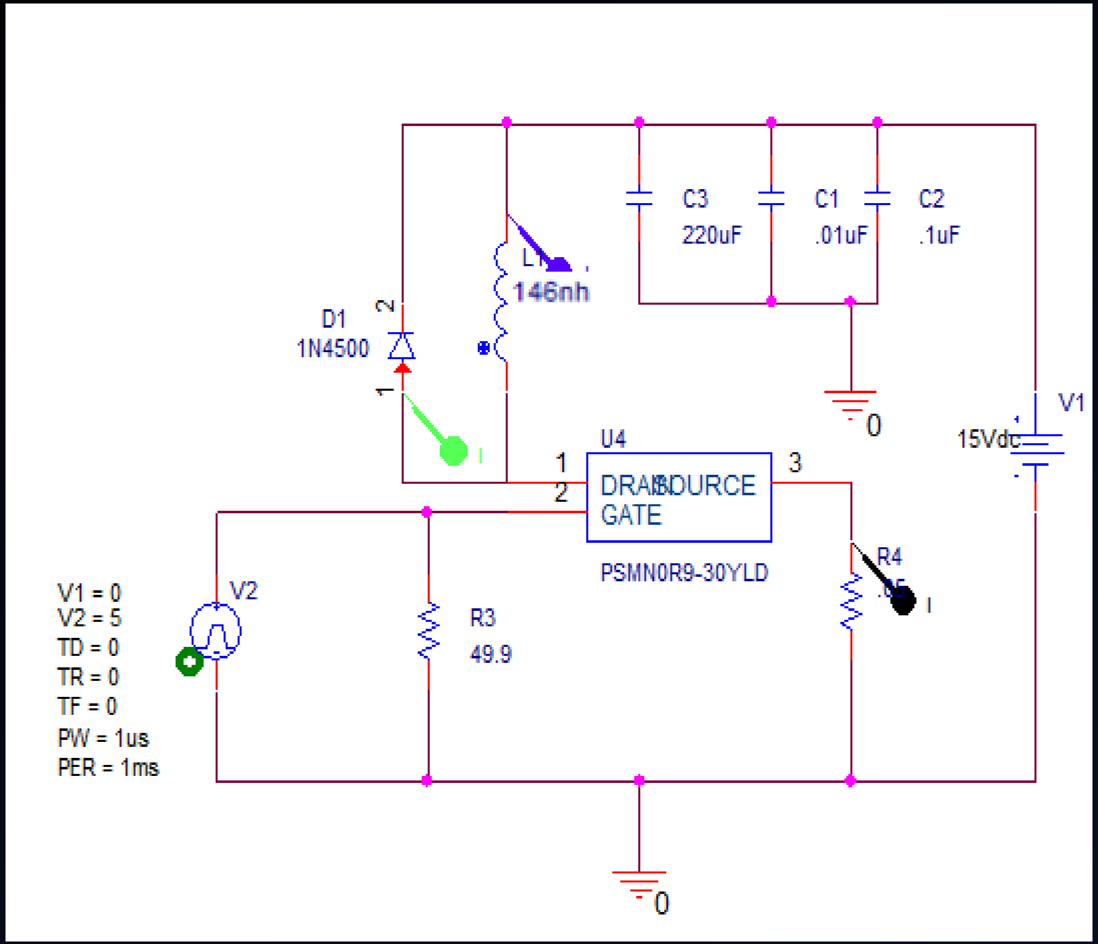


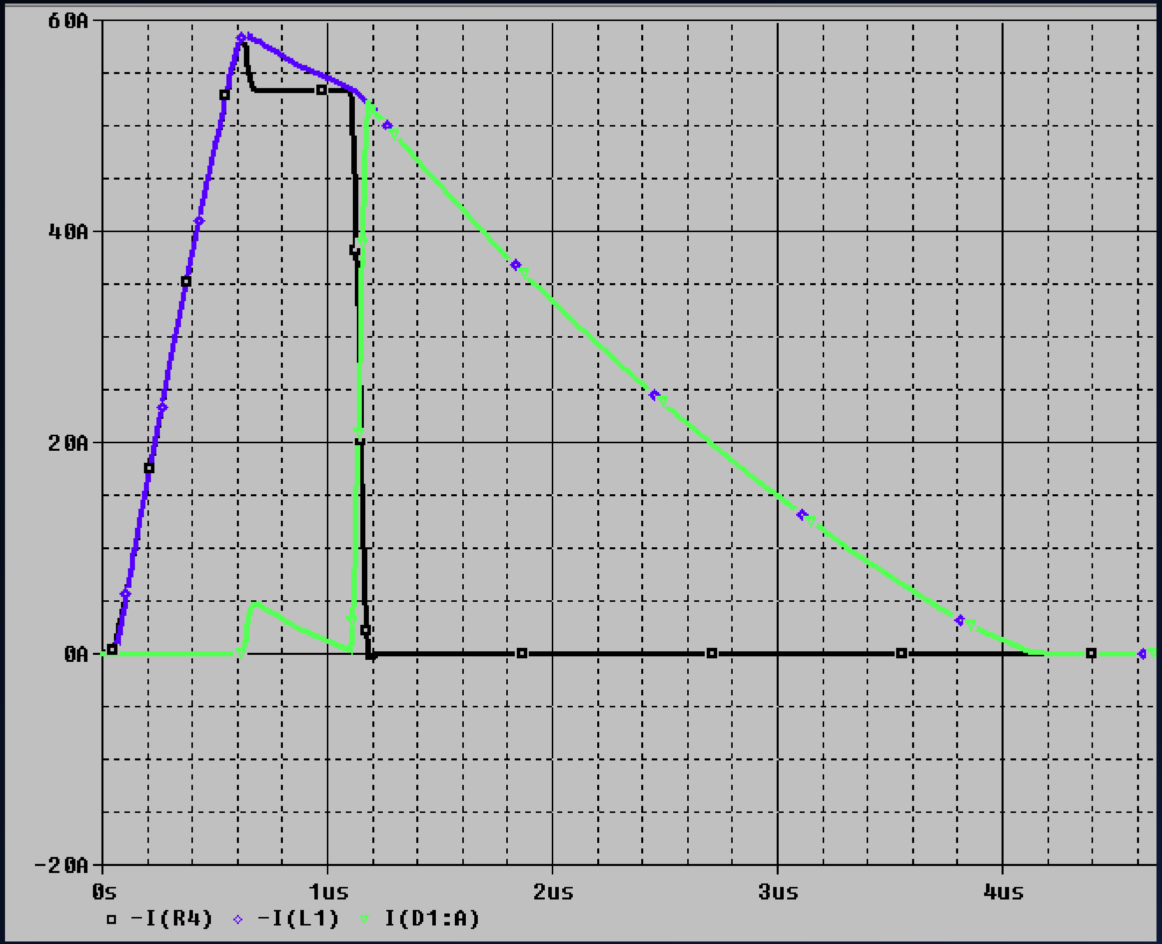
R5
2
D1
1N4500
L1
146nh
C3
220uF
C1
.01uF
C2
.1uF
0
V1
15Vdc
U4
DRAIN
SOURCE
GATE
PSMN0R9-30YLD
R4
V1 = 0
V2 = 5
TD = 0
TR = 0
TF = 0
PW = 1us
PER = 1ms
V2
R3
49.9
0



60A
40A
20A
0A
-20A
0s
1us
2us
-I(R4)
-I(L1)
I(D1:A)

Without 2Ω Resistor





MOSFET Datasheet

Table 1. Quick reference data

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
V_{DS}	drain-source voltage	25 °C ≤ T_j ≤ 175 °C		-	-	30	V
I_D	drain current	T_{mb} = 25 °C; V_{GS} = 10 V; Fig. 2	[1]	-	-	100	A
P_{tot}	total power dissipation	T_{mb} = 25 °C; Fig. 1		-	-	349	W
T_j	junction temperature			-55	-	150	°C
Static characteristics							
R_{DSon}	drain-source on-state resistance	V_{GS} = 4.5 V; I_D = 25 A; T_j = 25 °C; Fig. 10		-	0.79	1.09	mΩ
		V_{GS} = 10 V; I_D = 25 A; T_j = 25 °C; Fig. 10		-	0.65	0.87	mΩ
Dynamic characteristics							
Q_{GD}	gate-drain charge	V_{GS} = 4.5 V; I_D = 25 A; V_{DS} = 15 V; Fig. 12; Fig. 13		-	13.5	-	nC
$Q_{G(tot)}$	total gate charge	V_{GS} = 4.5 V; I_D = 25 A; V_{DS} = 15 V; Fig. 12; Fig. 13		-	51	-	nC
Source-drain diode							
S	softness factor	I_S = 25 A; V_{GS} = 0 V; dI_S/dt = -100 A/µs; V_{DS} = 15 V; Fig. 16		-	0.9	-	

[1] Continuous current is limited by package.