Experiment 3

**DC-DC converter**

**Battery charge controller**

**Peak power tracker**

Buck converter

Gate driver with isolation transformer

Pulse-width modulator

Microcontroller

Sensors

Peak power tracking and battery charge control

Battery current and voltage
Due dates

This week in lab:
  Experiment 1 report (one from every group)

Next week in lecture:
  Exp. 3 prelab assignment (one from every student)

Next week in lab:
  Exp. 2 scoresheet (you should be able to submit in lab this week, but beginning of lab next week at the latest) (one from every group)

Late assignments will not be accepted. Assignments are due within five minutes of beginning of period.
Lab reports

• One report per group. Include names of every group member on first page of report.
• Report all data from every step of procedure and calculations. Adequately document each step.
• Discuss every step of procedure and calculations
  – Interpret the data
  – It is your job to convince the grader that you understand what is going on with every step
  – Regurgitating the data, with no discussion or interpretation, will not yield very many points
  – Concise is good
Experiment 2: this week
Orientation to MSP430F2616 and Code Composer Suite tools

- No prelab or report
- Instead: get TA to initial sheet at end of experiment procedure
- See Lecture 2 slides and Exp. 2 procedure

Materials needed for this lab:
- MSP430F2616 board
  In power lab kit
  You will need to solder JTAG header and power supply leads
- MOSFET, gate driver, etc.
  In power lab kit
- Oscilloscope probe
  In undergraduate circuits kit, or available at E store
Goals in upcoming weeks
Exp. 3: A three-part experiment

Exp. 3 Part 1:
Demonstrate dc-dc converter power stage operating open loop, driven by MSP430 PWM output
Inside, with input power supply and resistive load
Outside, between PV panel and battery
DC system simulation

Exp. 3 Parts 2 and 3:
Demonstrate working sensor circuitry, interfaced to microprocessor
Demonstrate peak power tracker and battery charge controller algorithms, outside with converter connected between PV panel and battery
Exp. 3, Part 1
Demonstrate dc-dc power stage inside
Converter Power Stage
Some choices

**Buck converter**
- Steps down voltage
- Industry workhorse
- High efficiency

**SEPIC**
- Can step voltage up or down, to peak power track over wider voltage range
- More complex
- Good efficiency
Gate drive circuit with transformer isolation

- Gate driver output $v_d(t)$ has a dc component when $d \neq 0.5$
- Transformer will saturate if we apply dc
- Primary blocking capacitor removes dc component
- Secondary capacitor and diodes form a diode clamp circuit that restores the dc component
Gate driver transformer

- Use ferrite toroid in your kit
- Leakage inductance is minimized if bifilar winding is used
- Need enough turns so that applied volt-seconds do not saturate core:
  \[ \Delta B = \frac{V_1 DT_s}{n_1 A_c} \]
Alternate smaller version of gate driver

- Uses only one gate driver instead of two, to produce half the voltage swing on primary
- Transformer turns ratio is 1:1
- Produces half as much gate current
- Suitable for smaller MOSFETs
Exp. 3, Part 1
Test open-loop converter, outside

Basic control characteristics:
How does the duty cycle control the PV and battery voltages and currents?
Prelab assignment
Exp. 3, Part 1

Design your buck converter power stage

1. Work out the current waveforms of each component: MOSFET, diode, inductor, capacitors

2. Design your inductor
   • Use $K_g$ method explained in ECEN 4797/5797
   • You decide how much ripple to allow, how much power loss to allow, etc.
   • Use one of the ferrite cores in your kit

3. Check the voltage and current stresses on each power component and make sure the components operate within their datasheet ratings

Contents of parts kit, with links to datasheets, is on web at

http://ecee.colorado.edu/~ecen4517/components/kit.html
Core Material 7070
TSC Ferrite International

See parts kit web page for complete datasheets

Kit includes ferrite cores made of this material, in three geometries:
- PQ 32/20
- PQ 26/25
- 13-07-06 toroid
Converter modeling and simulation

Conduction modes
- Continuous conduction mode (CCM)
- Discontinuous conduction mode (DCM)

Equivalent circuit modeling
- The dc transformer model: CCM
- DCM model

Simulation
- Averaged switch model in CCM
- Averaged switch model in DCM
- A combined automatic model for PSPICE (or Simulink, optional)
Averaged switch modeling
Basic approach (CCM)

Given a switching converter operating in CCM

Buck converter example

Separate the switching elements from the remainder of the converter

Define the terminal voltages and currents of the two-port switch network
Terminal waveforms of the switch network

Relationship between average terminal waveforms:

\[ \langle v_1(t) \rangle_{T_s} = \frac{d'(t)}{d(t)} \langle v_2(t) \rangle_{T_s} \]

\[ \langle i_2(t) \rangle_{T_s} = \frac{d'(t)}{d(t)} \langle i_1(t) \rangle_{T_s} \]
Averaged model of switch network

\[ \frac{\langle v_1 \rangle}{d'} = \frac{\langle v_2 \rangle}{d} = \langle v_g \rangle \]

\[ \frac{\langle i_2 \rangle}{d'} = \frac{\langle i_1 \rangle}{d} = \langle i_L \rangle \]

So

\[ \langle v_1 \rangle = \frac{d'}{d} \langle v_2 \rangle \]

\[ \langle i_2 \rangle = \frac{d'}{d} \langle i_1 \rangle \]

Modeling the switch network via averaged dependent sources
PSPICE simulation
Exp. 3 Part 1: open loop

- Use your PV model from Exp. 1
- Replace buck converter switches with averaged switch model
- CCM-DCM1 and other PSPICE model library elements are linked on course web page
- You may optionally develop a Simulink model instead
Sensing the battery current and voltage
Exp. 3 Part 2
Exp. 3 Part 3

- Implement maximum power point tracking algorithm
- Demonstrate on PV cart outside