Lecture 5
ECEN 4517/5517

Experiment 3

Buck converter
Battery charge controller
Peak power tracker

Gate driver with isolation transformer

Pulse-width modulator
Micro controller
Sensors

Peak power tracking and battery charge control
Battery current and voltage
Upcoming deadlines

This week in lab: finish Exp. 3 Part 1; converter running open-loop, take data outside, do simulations

Online modules and quizzes on simulation due Friday Feb 21

Exp. 3 Part 1 report due Feb 28

Exp. 2 prelab 2 (sensing circuitry + MPPT code) due Feb 24

Exp. 3 Part 2 in the lab: Feb 25/26 and March 4/5

No lecture next week
Exp. 3, Part 1
Demonstrate buck power stage inside
Heatsinks

The power semiconductors generally require heatsinks. Example—from the HUF35371 (our 55 V, 34 mΩ MOSFET) datasheet:

<table>
<thead>
<tr>
<th>THERMAL SPECIFICATIONS</th>
<th>$R_{\theta JC}$</th>
<th>(Figure 3)</th>
<th>-</th>
<th>-</th>
<th>1.6</th>
<th>°C/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Resistance Junction to Case</td>
<td>$R_{\theta JC}$</td>
<td>(Figure 3)</td>
<td>-</td>
<td>-</td>
<td>1.6</td>
<td>°C/W</td>
</tr>
<tr>
<td>Thermal Resistance Junction to Ambient</td>
<td>$R_{\theta JA}$</td>
<td>TO-220, TO-263</td>
<td>-</td>
<td>-</td>
<td>62</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

Multiply thermal resistance by power loss to find temperature rise

With no heatsink, the thermal resistance is quite high (62°C/W)
With a 25°C ambient temperature and no heatsink, this device will reach the rated limit of 175°C if its power dissipation is

$$P_{\text{loss}} = \frac{(175°C - 25°C)}{(62°C/W)} = 2.4 \text{ W}$$

A heatsink can lower this temperature rise considerably. The junction-to-case thermal resistance is only 1.6 °C/W.

For reliability reasons, we like to limit temperature rises to much lower values—perhaps a few tens of °C
Heatsinks: Thermal model

From the graph, 2.4 W of loss causes a 30 °C rise, which would make the heatsink operate at 55°C for a 25°C ambient. Plus junction-to-case temperature rise of (1.6°C/W)(2.4 W) = 4°C
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
Exp. 3 Part 2

- Implement maximum power point tracking algorithm
- Demonstrate on PV cart outside
ADC10: The 10-Bit A/D Converter of the MSP430

Key features:
- Multiplexed inputs
- Sample and hold circuit
- Successive approximation register, driven by selectable clock
- Selectable reference sources
- Buffered output memory
- 10 bit or 8 bit conversion
Successive Approximations

- After the input signal has been sampled, the 10-bit SAR requires 11 clock cycles to generate an output
- Compare analog input with references
- The MSP430 uses a switched capacitor scheme to perform the comparisons
- See MSP430x5xx Family User’s Guide, Ch. 27

Capacitor bypassing is required

What the User’s Guide recommends:

Also need capacitance at analog input pin
Setting up the A/D Converter ADC10

// Configure ADC10
ADC10CTL0 = ADC10SHT_2 + ADC10ON;  // sample time of 16 clocks, turn on
   // use internal ADC 5 MHz clock
ADC10CTL1 = ADC10SHP + ADC10CONSEQ_0;  // software trigger to start a sample
   // single channel conversion
ADC10CTL2 = ADC10RES;  // use full 10 bit resolution
ADC10MCTL0 = ADC10SREF_1+ADC10INCH_5;  // ADC10 ref: use VREF and AVSS
   // input channel A5 (pin 10)

// Configure internal reference VREF
while(REFCTL0 & REFGENBUSY);  // if ref gen is busy, wait
REFCTL0 |= REFVSEL_0 + REFON;  // select VREF = 1.5 V, turn on
_delay_cycles(75);  // delay for VREF to settle

The above code sets up the 10-bit ADC with A5 as its only input, with 1.5 V
giving a reading of $2^{10} - 1$, and 0 V giving a reading of 0. Each reading will
employ a sampling window of 16 ADC clocks = 3.2 $\mu$sec.
Sampling the ADC input

The above code is simple and a good start. See CCS5 code examples for use of interrupts that do not require the processor to wait during the conversion time.
ADC12MCTLx
Conversion control register

<table>
<thead>
<tr>
<th>EOS</th>
<th>SREFx</th>
<th>INCHx</th>
</tr>
</thead>
<tbody>
<tr>
<td>rw–(0)</td>
<td>rw–(0)</td>
<td>rw–(0)</td>
</tr>
</tbody>
</table>

Modifyable only when ENC = 0

**EOS**
Bit 7  End of sequence. Indicates the last conversion in a sequence.
0      Not end of sequence
1      End of sequence

**SREFx**
Bits  Select reference
6-4
000  \(V_{R+} = AV_{CC}\) and \(V_{R-} = AV_{SS}\)
001  \(V_{R+} = V_{REF+}\) and \(V_{R-} = AV_{SS}\)
010  \(V_{R+} = V_{REF+}\) and \(V_{R-} = AV_{SS}\)
011  \(V_{R+} = V_{REF+}\) and \(V_{R-} = V_{REF-}\)
100  \(V_{R+} = AV_{CC}\) and \(V_{R-} = V_{REF-}\)
101  \(V_{R+} = V_{REF+}\) and \(V_{R-} = V_{REF-}\)
110  \(V_{R+} = V_{REF+}\) and \(V_{R-} = V_{REF-}\)
111  \(V_{R+} = V_{REF+}\) and \(V_{R-} = V_{REF-}\)

**INCHx**
Bits  Input channel select
3-0
0000  \(A0\)
0001  \(A1\)
0010  \(A2\)
0011  \(A3\)
0100  \(A4\)
0101  \(A5\)
0110  \(A6\)
0111  \(A7\)
1000  \(V_{REF+}\)
1001  \(V_{REF-}\)
1010  Temperature diode
1011  \((AV_{CC} - AV_{SS}) / 2\)
1100  \(GND\)
1101  \(GND\)
1110  \(GND\)
1111  \(GND\)
Sensing the battery current and voltage
Exp. 3 Part 2

ECEN 4517

14
INA194 High-side current sense IC

INA194: gain = 50V/V

![GAIN PLOT](image)

- $V_{IN+}$: -16V to +80V
- $V_{IN-}$: +2.7V to +18V

IN193 –INA198

OUT
About the INA194

Must bypass power supply pins!

Filtering the waveforms:

\[ \text{Gain Error\%} = 100 - \left( 100 \times \frac{5k\Omega}{5k\Omega + R_{\text{FILT}}} \right) \]

- Use twisted pair to transmit signal from INA194 output to your MSP430 board
- An \( R-C \) filter will likely be necessary at A/D input of MSP430
Maximum Power Point Tracking

Automatically operate the PV panel at its maximum power point

Some possible MPPT algorithms:

- Perturb and observe
- Periodic scan
- Newton’s method, or related hill-climbing algorithms
- What is the control variable? Where is the power measured?

Next week’s prelab assignment: propose a MPPT algorithm, submit flowchart/block diagram
Example MPPT: Perturb and Observe

Measure power
Loop:
  - Perturb the operating point in some direction
  - Wait for transients to settle
  - Measure power again
  - Did the power increase?
    - No: reverse direction for next perturbation
    - Yes: retain direction for next perturbation
Repeat
Example MPPT: Sweep

Start at $V = \text{minimum PV voltage}$. Set $P_{\text{max}} = 0$.

Loop:
- Wait for system transients to settle
- Measure power $P$. Is $P > P_{\text{max}}$?
  - Yes: set $P_{\text{max}} = P$, $V_{\text{opt}} = V$
  - Increase $V$ by one step
- Repeat until $V = V_{\text{oc}}$
- Set $V = V_{\text{opt}}$. Wait some time, then sweep again.