ECEN 4517/5517

Power Electronics and Photovoltaic Power Systems Laboratory

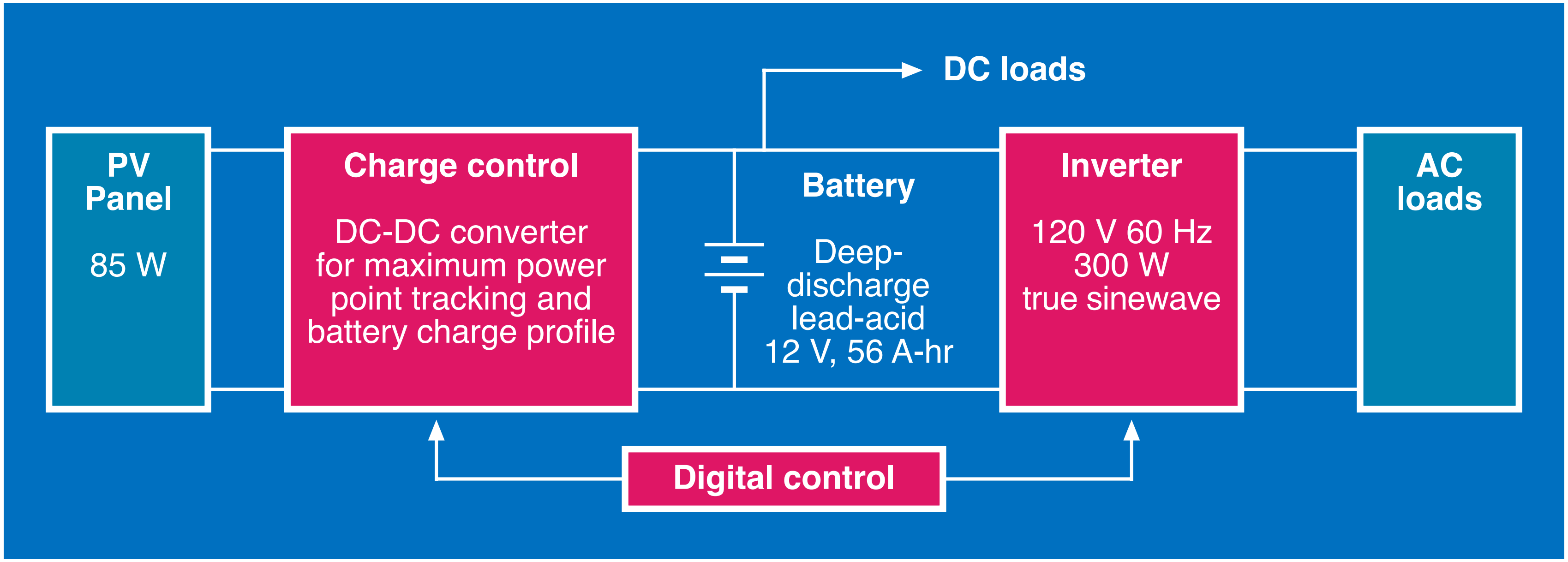
Lecture 5

Maximum Power Point Tracking

Announcements

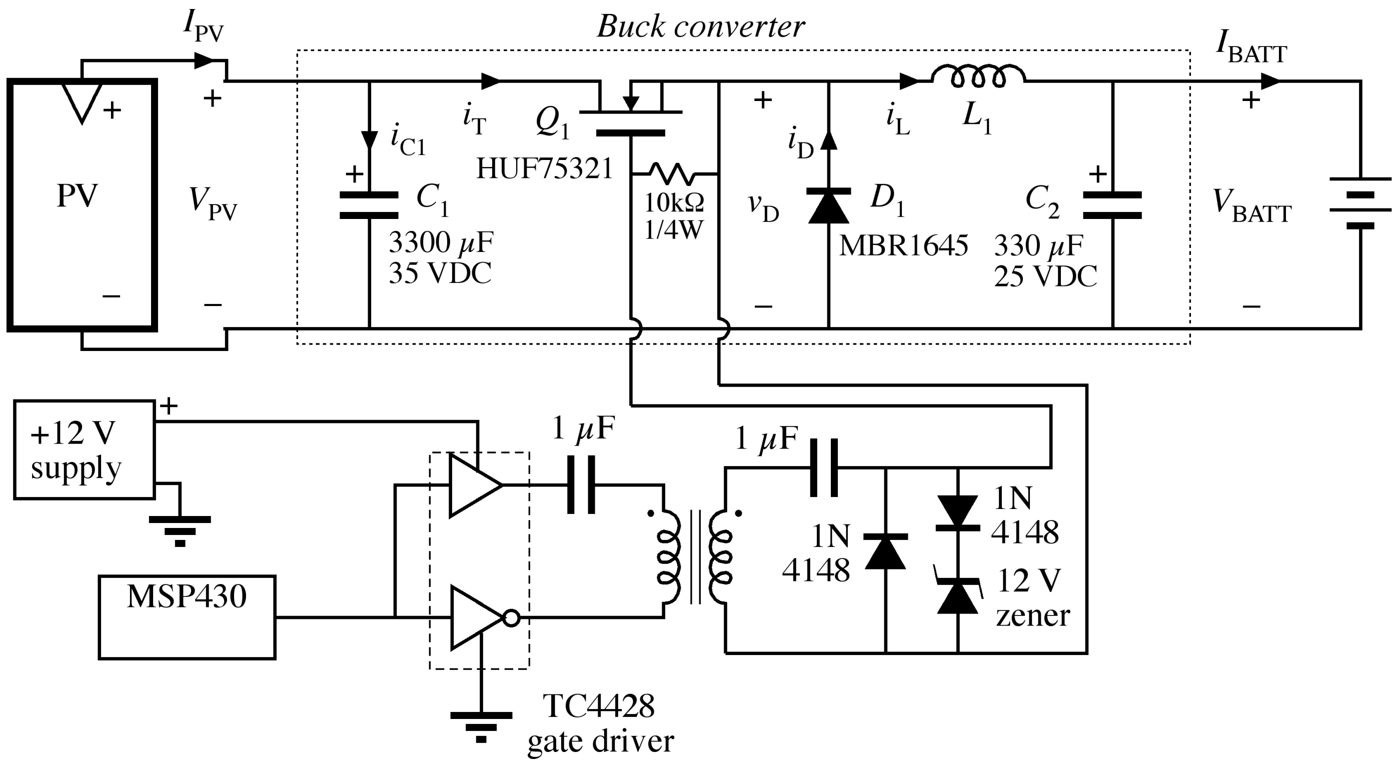
- This week's lab: Finish Experiment 3-1
  - Run converter open-loop, take data outside and do simulations
  - Exp 3-1 Lab Report due by 11:59 pm (MT) on Friday February 24, 2017
- Experiment 3-2 Pre-Lab Assignment is out
  - Due 11:59 pm (Mountain Time) on Friday February 17, 2017
- Next week: Start Experiment 3-2
  - Have 2 weeks to work on Experiment 3-2
  - Exp 3-2 Lab Report due by 11:59 pm (MT) on Friday March 10, 2017
- Following this: Experiment 4
  - Experiment 4 has a pre-lab (due 11:59 pm on Friday March 3, 2017)
  - Have 3 weeks to work on Experiment 4
  - Exp 4 Lab Report due by 11:59 pm (MT) on Friday April 7, 2017
- Quiz 1: Monday, February 27, 2017 (in class)

Experiments



- Exp 1 – PV panel and battery characteristics and direct energy transfer
- Exp 2 – TI MSP430 microcontroller introduction
- Exp 3-1, 3-2 – Buck dc-dc converter for PV MPPT and battery charge control
- Exp 4 – Step-up 12V-200V dc-dc converter
- Exp 5 – Single-phase dc-ac converter (inverter)
- Expo – Complete system demonstration

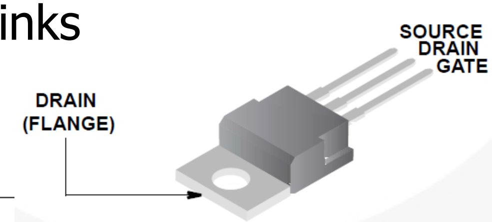
Experiment 3-1



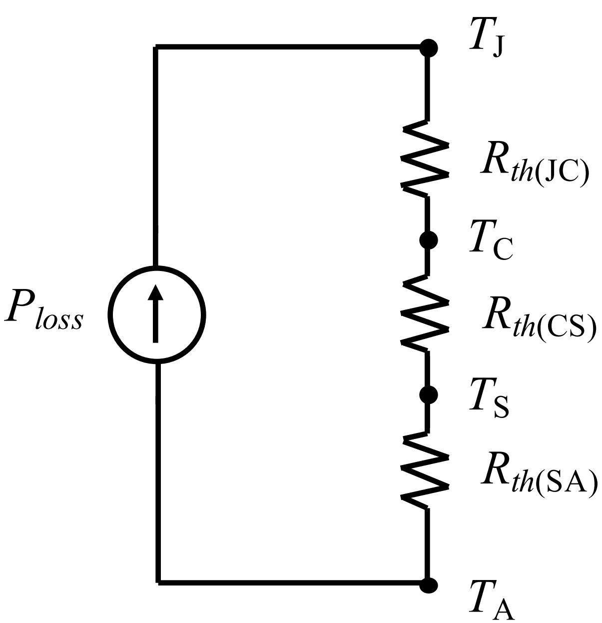
- Demonstrate dc-dc converter power stage operating open loop, driven by MSP430 PWM output:
  - Inside, with input power supply and resistive load
  - Outside, between PV panel and battery
- Compare experimental results with simulation

Thermal Management

- Power semiconductor devices generally require heat sinks
- Example: HUF75321P3 (55V, 35A, 34mΩ MOSFET)

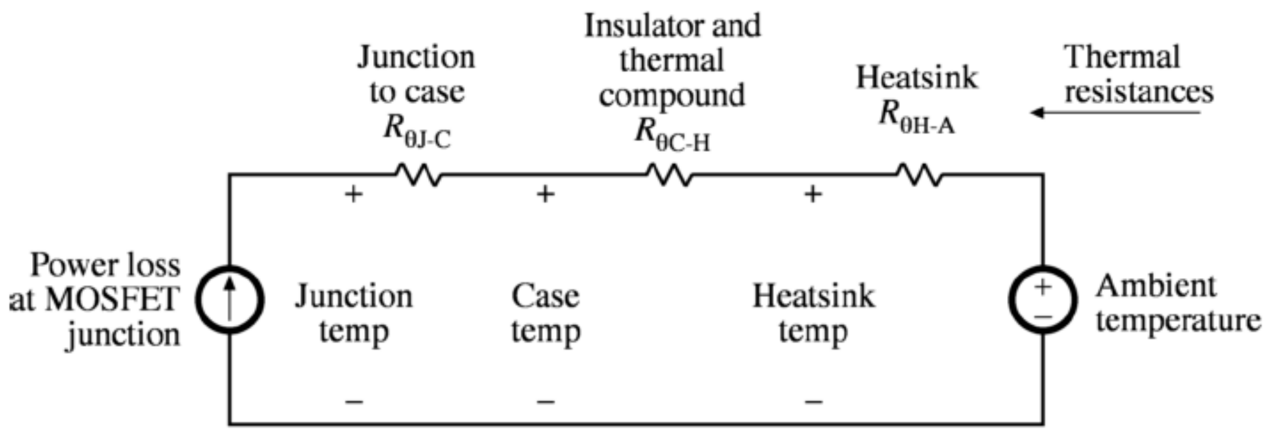


THERMAL SPECIFICATIONS						
Thermal Resistance Junction to Case	$R_{\theta JC}$	(Figure 3)	-	-	1.6	°C/W
Thermal Resistance Junction to Ambient	$R_{\theta JA}$	TO-220	-	-	62	°C/W

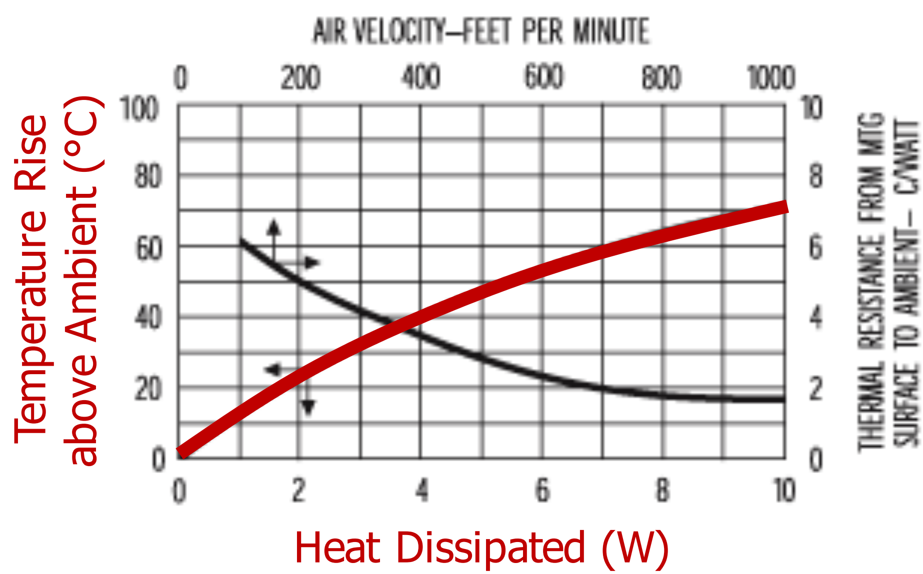


- Without heat sink, the thermal resistance is very high (62°C/W)
- With 25°C ambient temperature, and no heat sink, device will reach rated limit of 175°C if its power dissipation is 2.4 W
- For reliability reasons, we like to limit temperature rises to much lower values
- A heat sink can lower the temperature rise considerably, since the junction to case thermal resistance is only 1.6°C/W

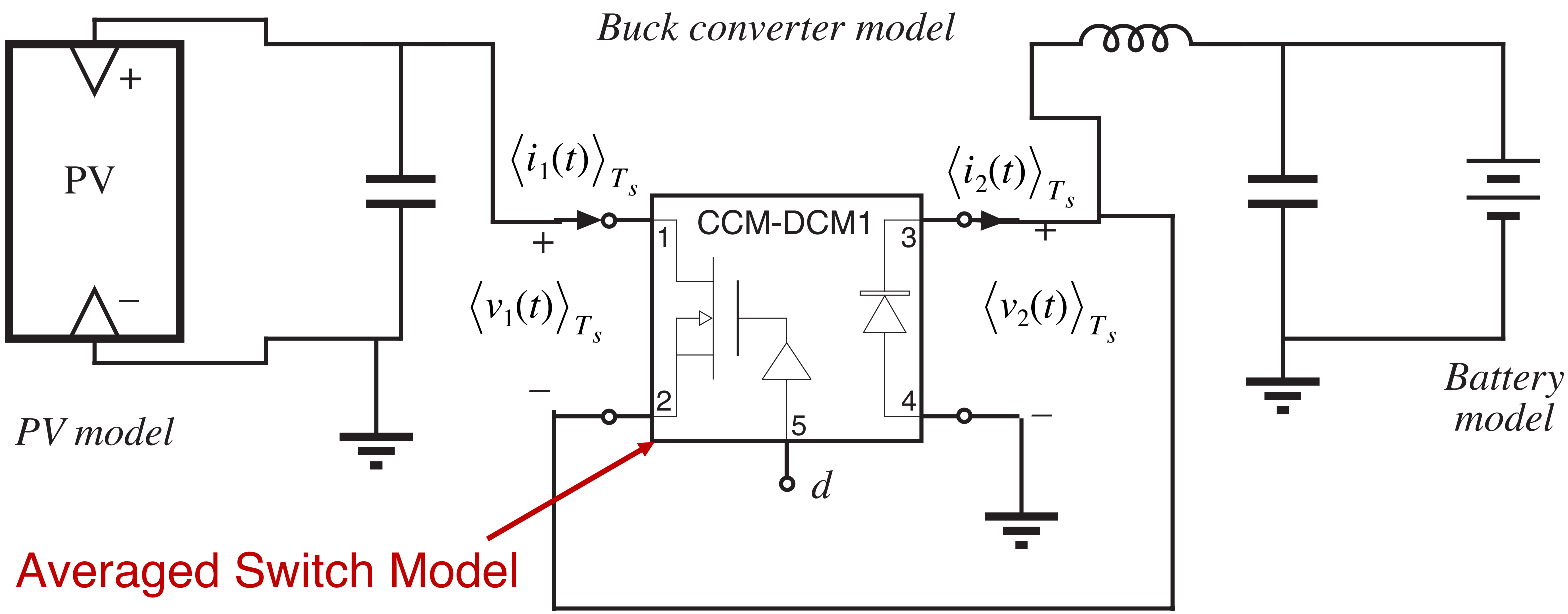
Heat Sinking



- 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
- Junction-to-case temperature rise would be another: (1.6°C/W)(2.4W) = 4°C

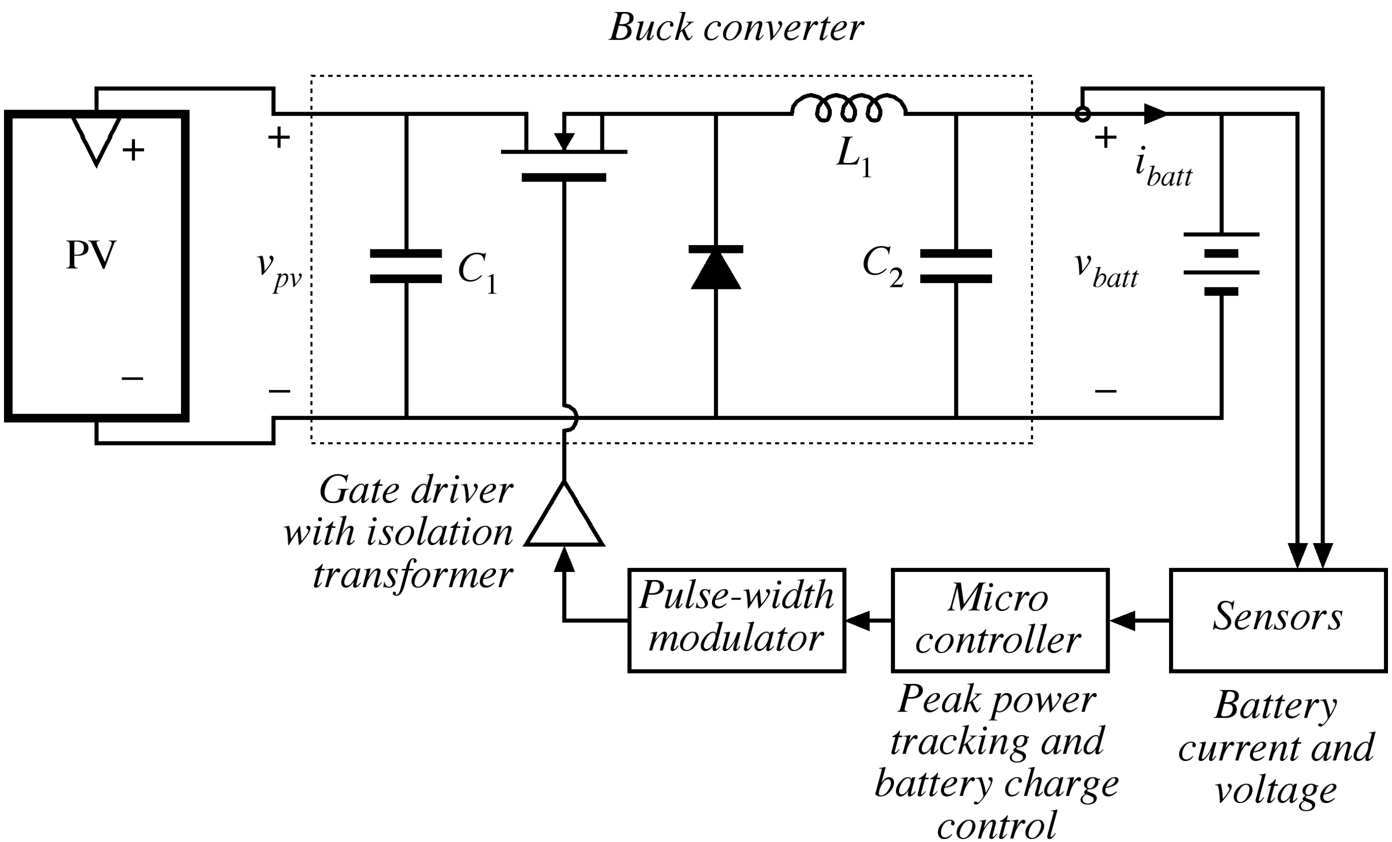


Simulation of Buck Converter in SPICE



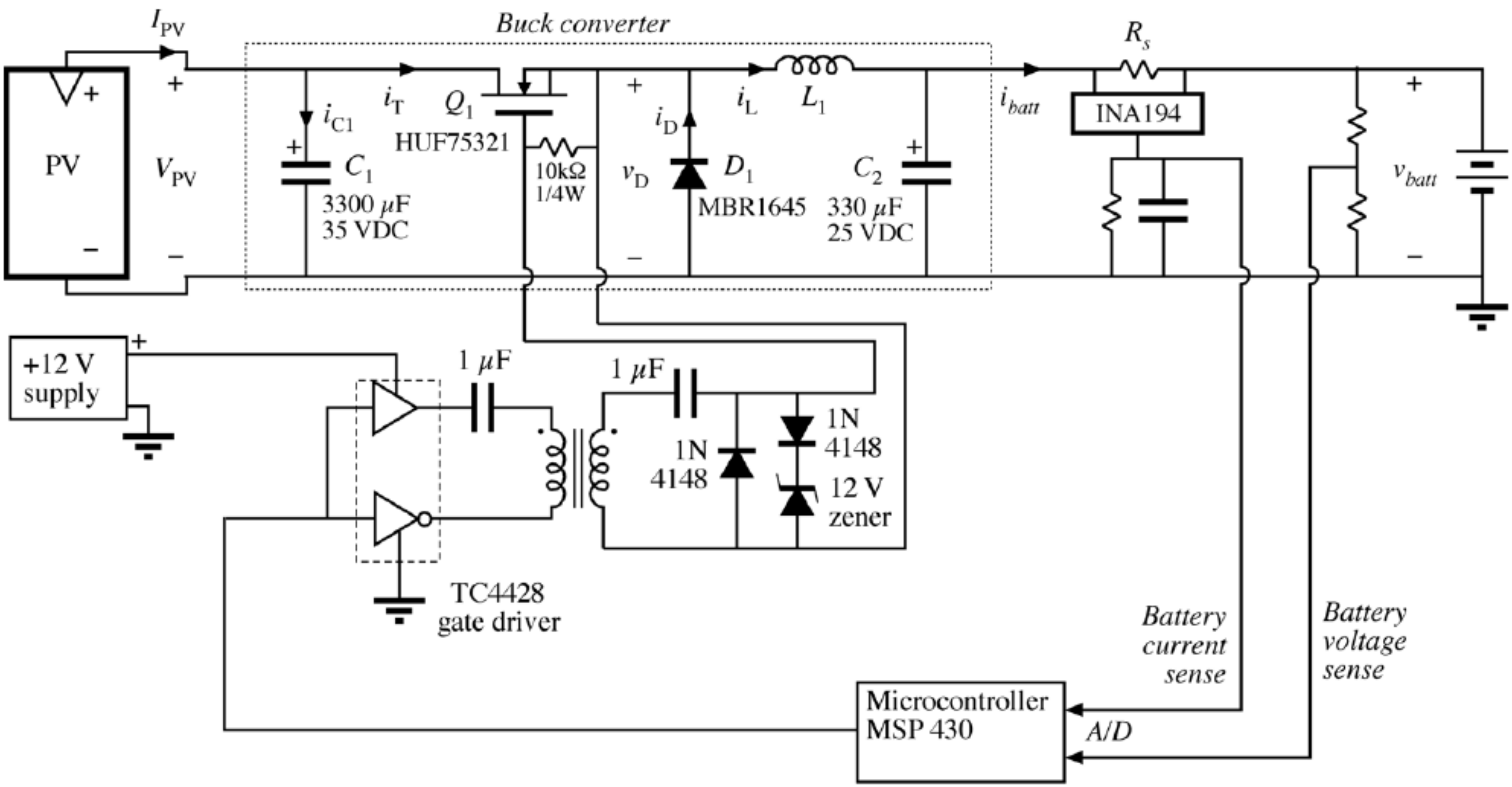
- Replace buck converter switches with averaged switch model CCM-DCM1
- CCM-DCM1 (in switch.lib) and other SPICE model library elements (in LTspice.zip) available from D2L (also available at: http://ecee.colorado.edu/ecen4517/pspicelib/index.html)
- Use your PV model from Experiment 1

Experiment 3-2



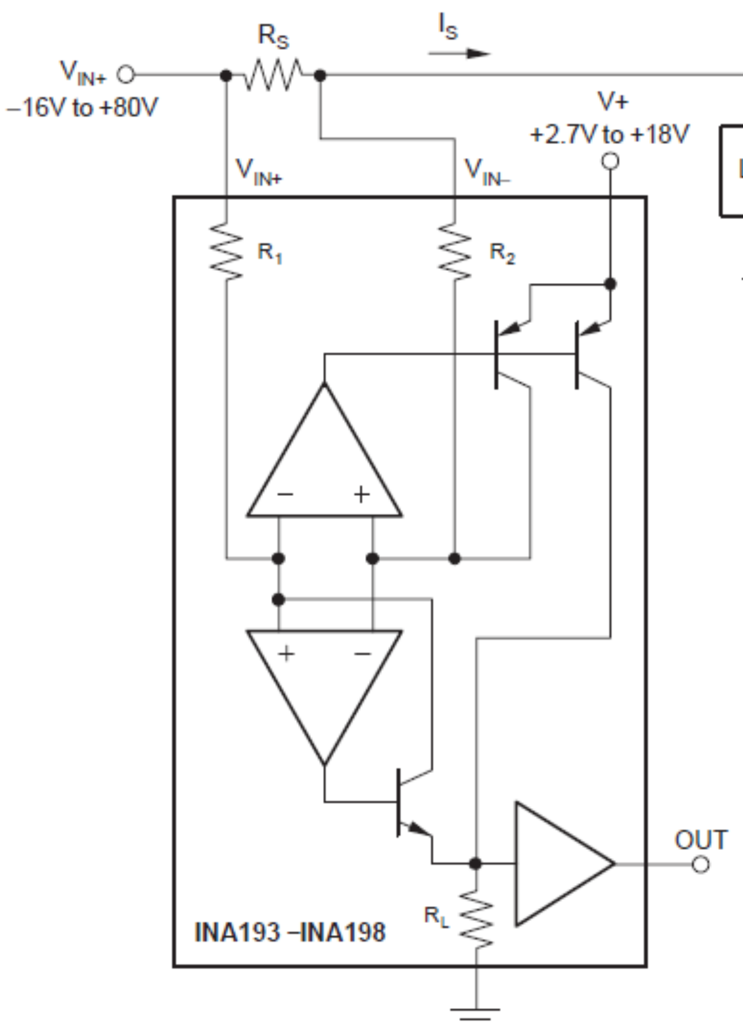
- Demonstrate working sensor circuitry, interfaced to microcontroller
- Demonstrate maximum power point tracking algorithm, outside with converter connected between PV panel and battery

Battery Current and Voltage Sensing Circuit

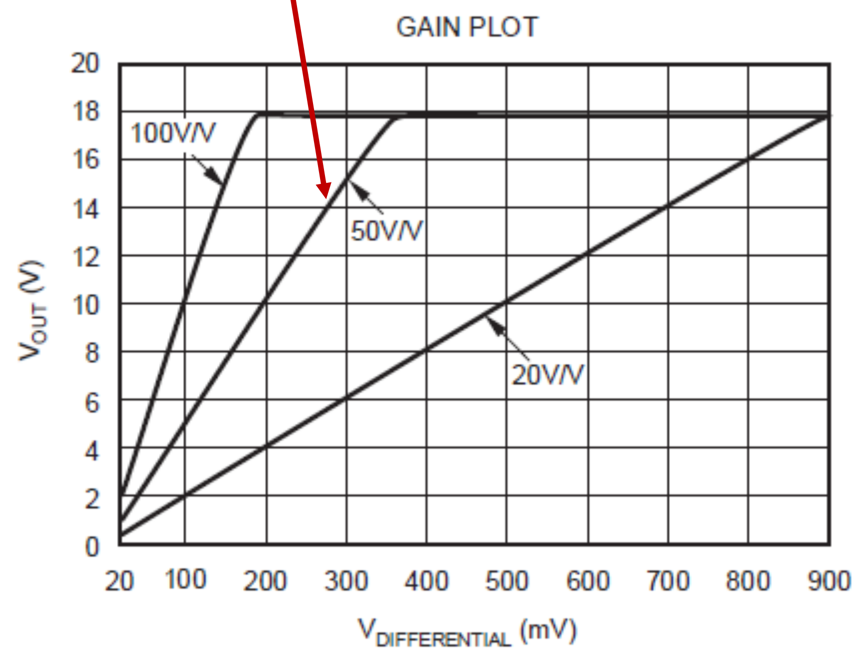


- Use INA194 current sense IC to measure current
- Use voltage divider to measure voltage

INA194 High-Side Current Sense IC



INA194: gain = 50V/V



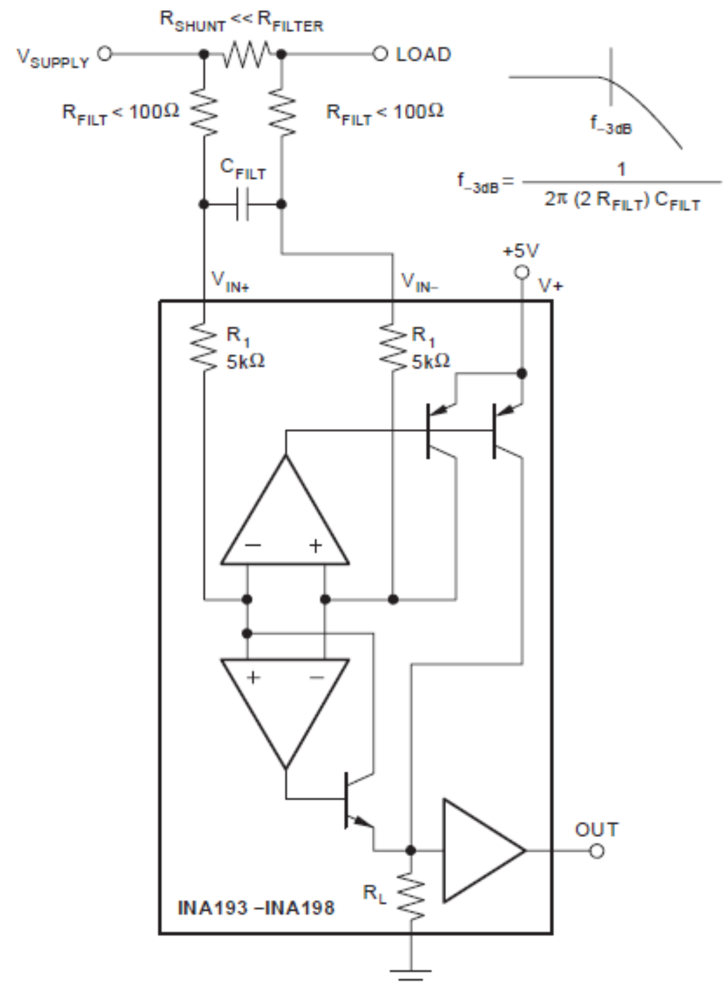
- INA194 datasheet contains useful application notes

INA194 Practical Issues

- For stability, must bypass power supply pins of the IC
- Input filtering will be needed
- However, input filter resistors effect INA194 amplifier gain:

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

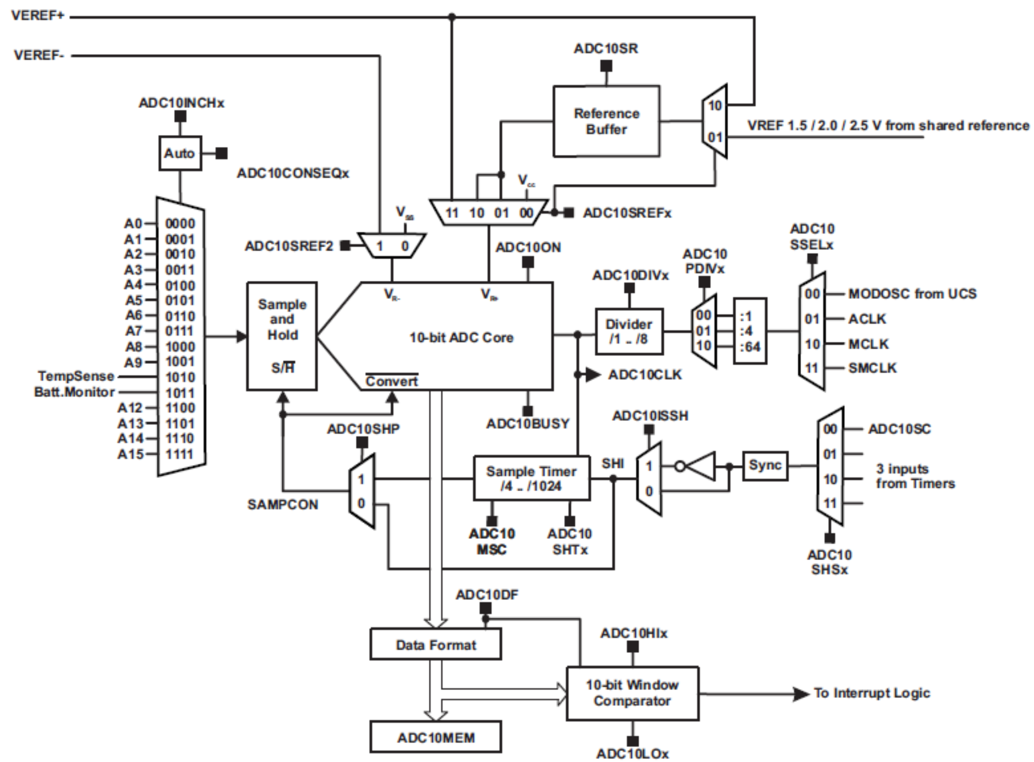
- Use twisted pair to transmit signal from INA194 output to MSP430 board
- An RC filter will likely be necessary at ADC input of MSP430



MSP430 10-Bit A/D Converter (ADC10)

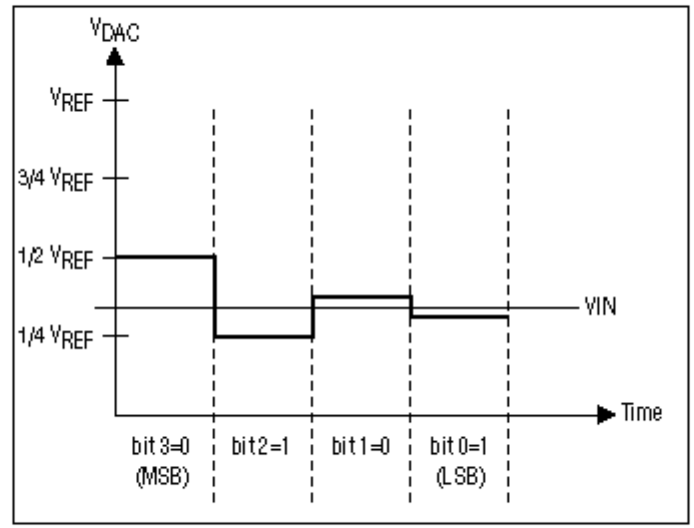
Key features:

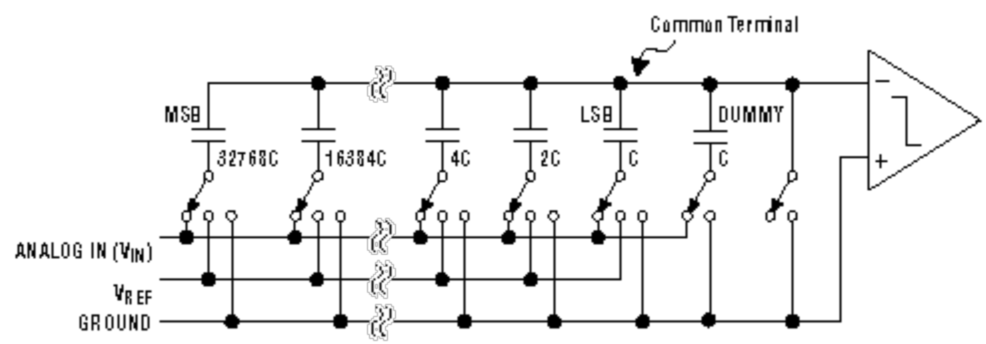
- Multiplexed inputs
- Sample and hold circuit
- Successive approximation register, driven by selectable clock
- Selectable reference sources
- Buffered output memory
- 10 bit or 8 bit conversion



Successive Approximation Register (SAR) ADC

- Compares analog input with different references and successively homes in on the result
- After the input signal has been sampled, the 10-bit SAR requires 11 clock cycles to generate an output
- The MSP430 uses a switched capacitor scheme to perform the comparisons





- References:
  - MSP430x5xx Family User's Guide, Chapter 27
  - John Davies, MSP430 Microcontroller Basics, Elsevier, 2008

Setting up 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 μsec.

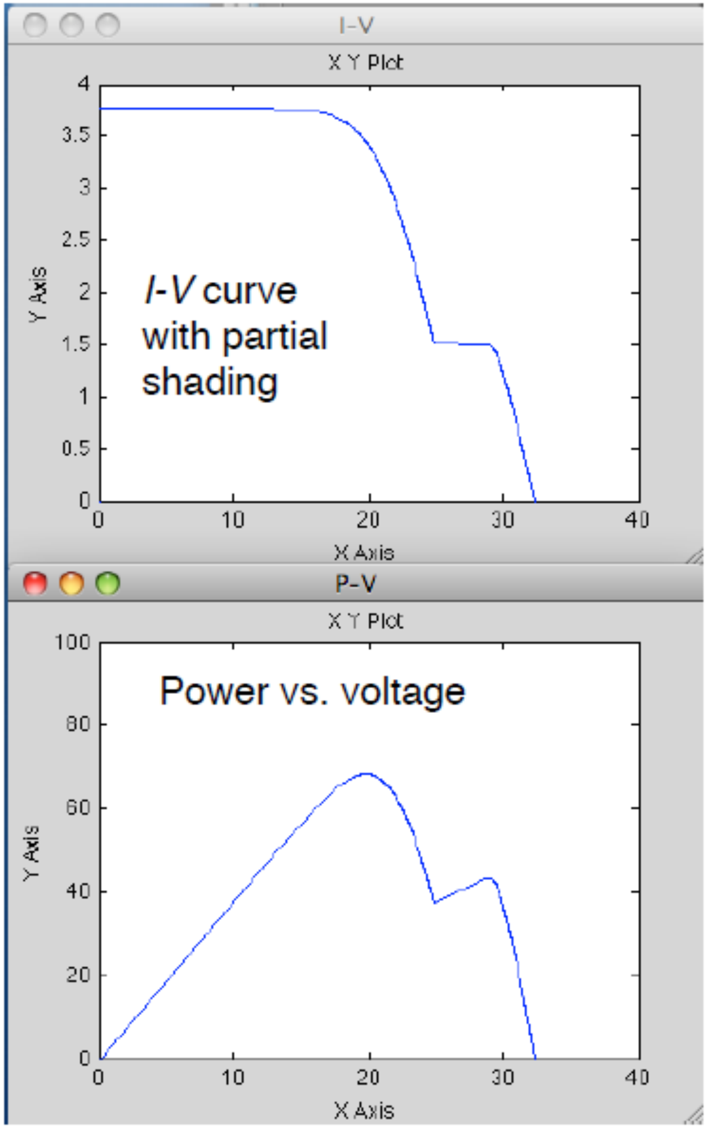
Sampling the ADC10 Input

```
ADC10CTL0 |= ADC10ENC + ADC10SC;        // sampling and conversion start
while(ADC10CTL1 & ADC10BUSY);           // wait for completion
X = ADC10MEM0;                          // ADC10MEM0 contains result
```

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.

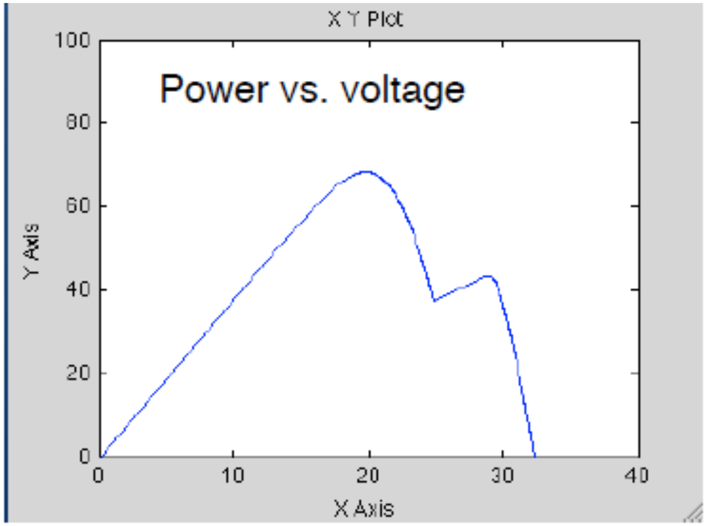
Maximum Power Point Tracking (MPPT)

- MPPT automatically operates the PV panel at its maximum power point
- Some possible MPPT algorithms:
  - Perturb and observe
  - Periodic scan
  - Newton-Raphson method, or other hill-climbing algorithms
- Other differences depend on the choice of control variable and where the power is measured
- In Experiment 3-2 pre-lab assignment you will propose a MPPT algorithm and submit its flowchart and code



MPPT Example: 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



MPPT Example: Periodic Scan

- Set Pmax = 0
- Start at V = minimum PV voltage
- Loop:
  - Wait for system transients to settle
  - Measure power P
  - Is P > Pmax?
    - Yes: set Pmax = P, Vopt = V
  - Increase V by one step
  - Repeat until V = Voc
- Set V = Vopt
- Wait some time, then scan again