# EXPERIMENT 3-2 LAB REPORT

ECEN 5517 (Spring 2017)
Power electronics and Photovoltaic Power Systems Laboratory

3/10/2017

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# Objectives

The objectives of this experiment are:
- To design and interface a sensor circuitry to measure battery voltage and current
- To design and test an MPPT algorithm that extracts maximum power from solar panel

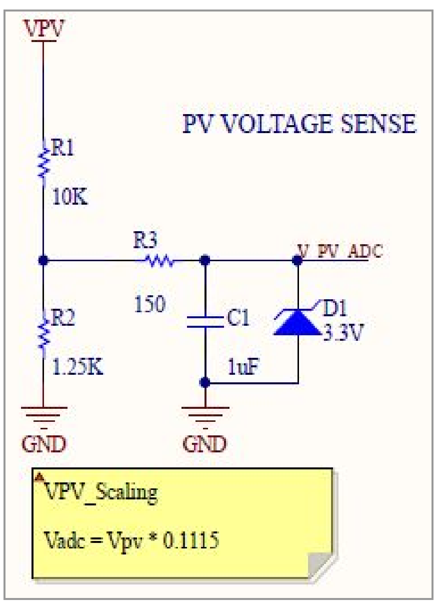
# Experimental data

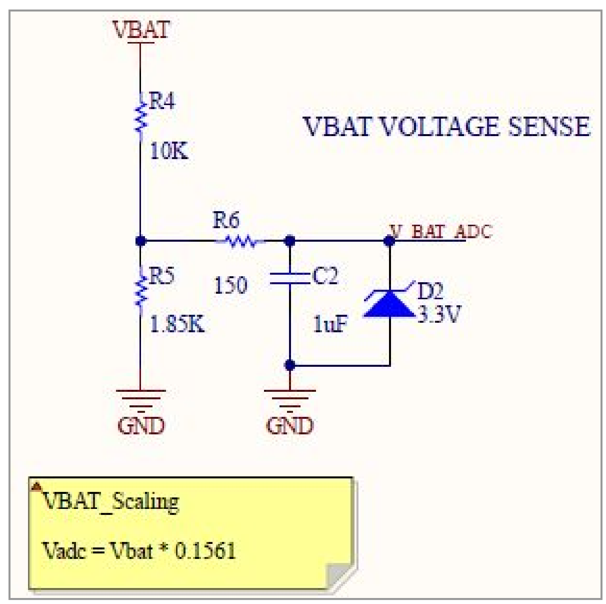
## Equipments used

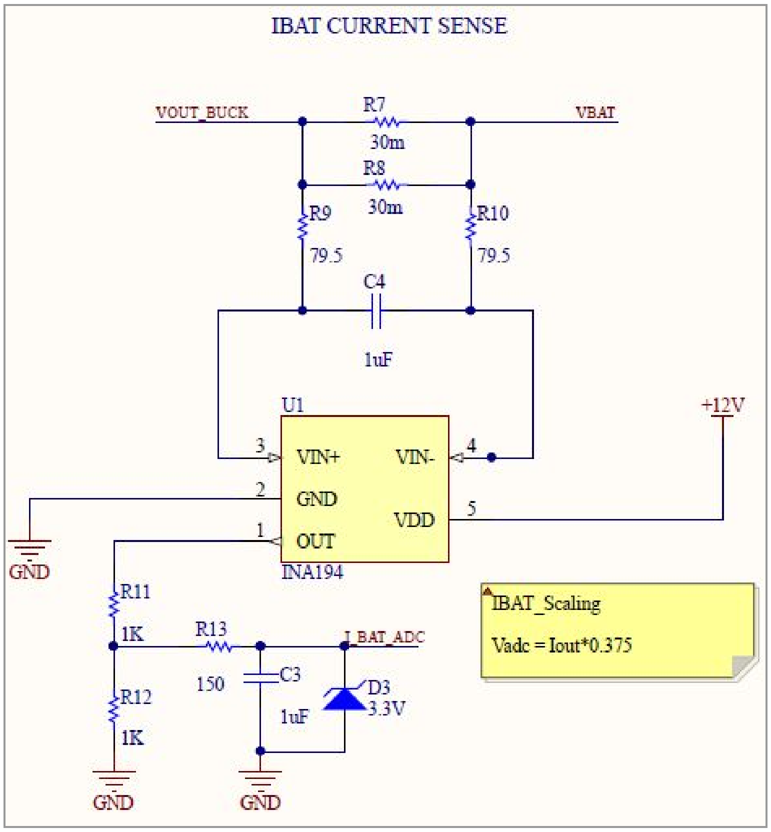
| **Power** | **Measurement** |
|---|---|
| Power Supply: 30V-5A Dual Power Supply<br>Rheostat: 0 -15.5 Ohms<br>SQ85-P Solar panel | Meters: FLUKE 45<br>Oscilloscope |

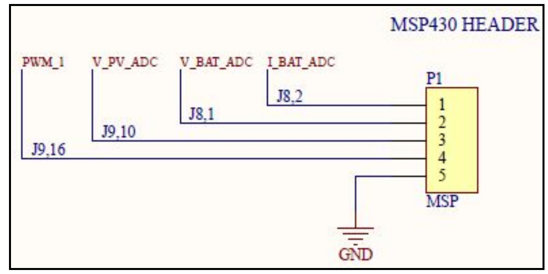
## Sensor circuitry and schematics

3 sensors were designed: **Battery voltage**, **Battery current** and **Panel voltage**
The complete Buck sensing circuitry with expressions for adc voltages is shown below:






# ADC Input voltage Expressions

## PV VOLTAGE

R1 = 10 KOhms, R2  = 1.25 KOhms

Vadc = Vpv * 1.25/11= Vpv * 0.1111

## VBAT VOLTAGE

R1 = 10 KOhms, R2 = 1.85 KOhms

Vadc  = Vpv * 1.85/11.85 = Vbat * 0.1561

## IBAT CURRENT

Sense Resistor = 10 mOhms, R_filt = 79.5 Ohms; C_filt = 1uF, Rdiv = 1K, INA194_gain = 49

Vadc = Ibat*0.245

- The actual gain observed was much less than this, because two 20mOhm shunt resistors were connected in parallel. Since the connection was not made exactly at Kelvin point of the resistors, the actual resistance was somewhat lower than 10 mOhm
- The actual gain observed was **Vadc = Ibat*0.125**

# ADC Measurements

- An internal reference of 12V was used for adc conversions

## Panel voltage sensing

| Meter measurements | | MSP430 ADC measurements | | |
|---|---|---|---|---|
| V_panel (V) | V_adc (V) | ADC Counts | V_adc (V) | Error (%) |
| 8.9 | 0.9537 | 391 | 0.954 | 0.01 |
| 10.22 | 1.0952 | 445 | 1.086 | 0.368 |
| 16.92 | 1.812 | 751 | 1.833 | 0.84 |
| 17.17 | 1.8394 | 755 | 1.843 | 0.144 |
| 17.78 | 1.893 | 770 | 1.879 | 0.56 |

## Battery Voltage (Tested by connecting load resistor at the output of the buck)

| Meter measurements | | MSP430 ADC measurements | | |
|---|---|---|---|---|
| V_battery (V) | V_adc (V) | ADC Counts | V_adc (V) | Error (%) |
| 5.406 | 0.8246 | 339 | 0.8284 | 0.152 |
| 7.44 | 1.1349 | 463 | 1.1314 | 0.14 |
| 9.552 | 1.457 | 581 | 1.4198 | 1.488 |
| 12.722 | 1.9406 | 711 | 1.7375 | 2.153 |
| 13.038 | 1.988 | 719 | 1.757 | 2.327 |

## Battery Current (Tested by connecting load resistor at the output of the buck)

| Meter measurements | | MSP430 ADC measurements | | |
|---|---|---|---|---|
| I_battery (A) | V_adc (V) | ADC Counts | V_adc (V) | Error (%) |
| 1.347 | 0.1683 | 55 | 0.1344 | 1.356 |
| 2.292 | 0.2865 | 97 | 0.2370 | 1.98 |
| 3.152 | 0.394 | 119 | 0.2908 | 4.128 |
| 5.121 | 0.6401 | 217 | 0.5303 | 4.392 |
| 6.337 | 0.7921 | 275 | 0.6720 | 4.804 |

- There are a few points where the adc error is quite high, especially in battery voltage and current. This could have been calibrated to obtain more accurate readings, but accuracy is not required for the MPPT algorithm
- It’s enough if the ADC results are monotonic i.e, adc readings increase as power increases since MPPT requires only the direction of power
- Also, in the version of MPPT that has been implemented, accurate panel measurement is required, which as seen from the readings meets the requirements

# Design and Evaluation of MPPT

## ALGORITHM

- The central part of our MPPT algorithm is the input voltage Proportional_Integral (PI) loop
- Since the panel MPP voltage is almost constant (it changes with temperature but not irradiation), it is enough if the panel voltage (input voltage of the buck) be regulated at this voltage. Panel will then be operating at Maximum Power Point for irradiation changes
- Once every 5 minutes an MPPT sweep is performed, that sweeps the input voltage from 14V to 18V. Power at each point is calculated and stored in a buffer. From this buffer, the max operating point is determined and then the panel is regulated to this input voltage.

## EVALUATION AND TESTING PROCESS

The MPPT algorithm was designed and tested in following steps:

1. Sensing circuitry design and testing
2. Input Voltage Proportional-Integral loop design and testing
3. MPPT development and testing
4. MPPT final performance evaluation with solar panel

Each step is briefly described below

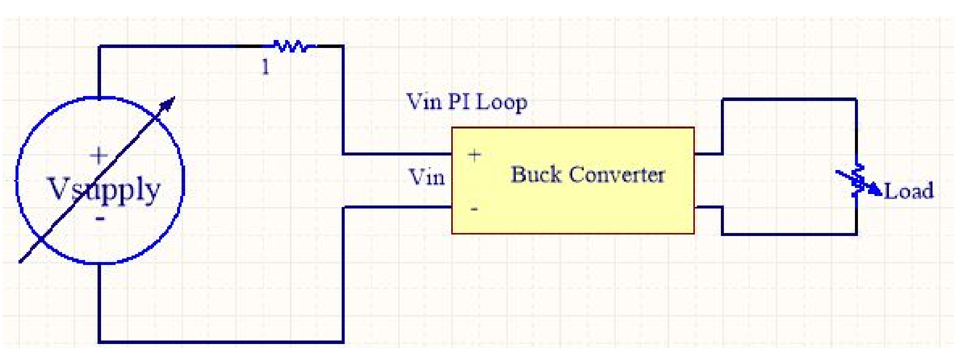
### SENSING CIRCUITRY AND DESIGN

Sensing circuitry was designed and tested as per section 1. Results are shown in section of this report.

### INPUT VOLTAGE PI LOOP TESTING

In this step, a PI loop was designed that regulates the input voltage to a particular set point. Panel operation was emulated by connecting a 1 Ohm resistor in series with input source. The test setup is shown below:

**Setup for PI loop and MPPT initial testing**



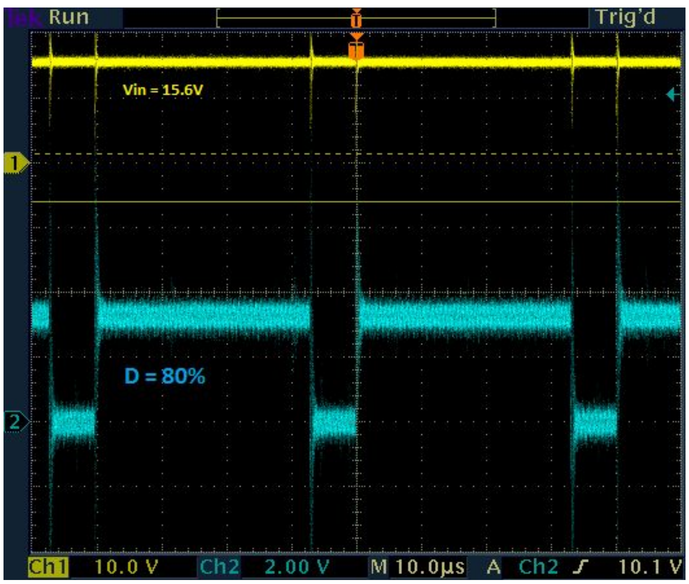
## MPPT DEVELOPMENT AND TESTING

In this stage, the MPPT sweep algorithm was implemented and tested in the same setup shown above. An MPPT sweep is performed every 5 minutes that sweeps Vin from 14V to 18V and settles at the highest power point till the next sweep is performed

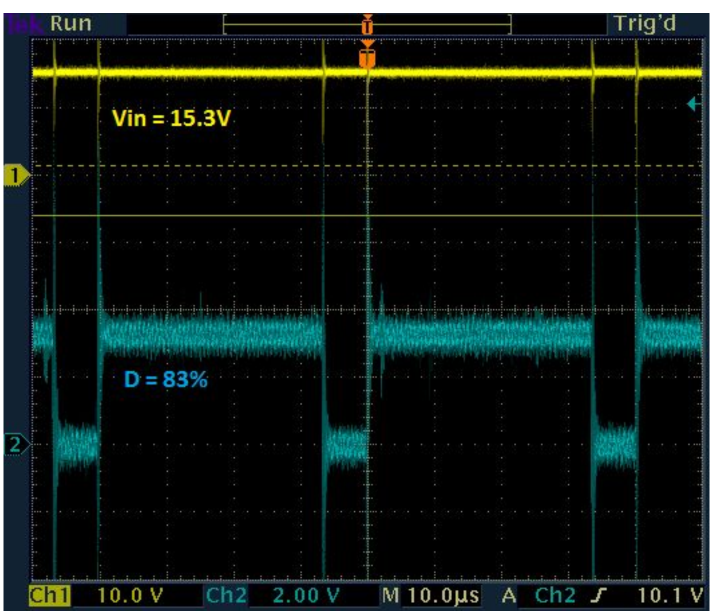
## MPPT FINAL EVALUATION AND TESTING

Finally, the Buck converter was tested with solar panel and battery. The results of this step are presented in the following sections

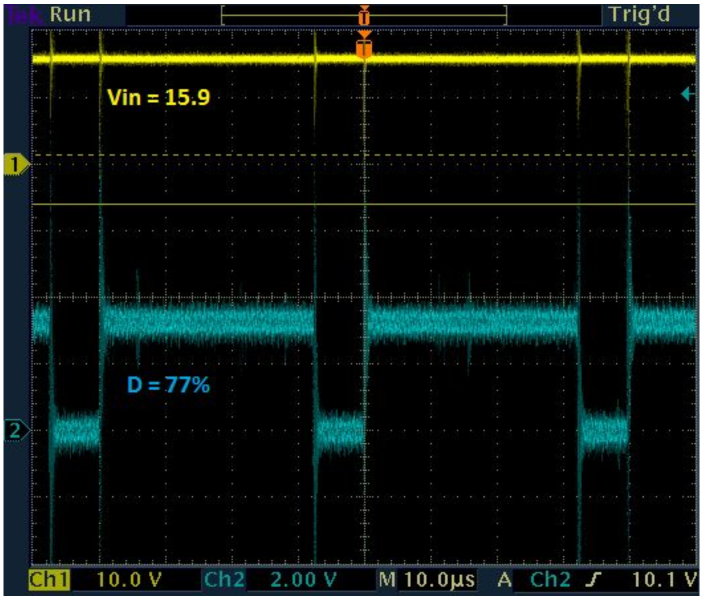
# MPPT WAVEFORMS AROUND OPERATING POINT




**Operation at MPP**
**D = 0.8**
**Vpv = 15.6V**
**Pin = 78.01W**




**Operation below MPP**
**D = 0.83**
**Vpv = 15.3V**
**Pin = 76.43W**




**Operation below MPP**
**D = 0.77**
**Vpv = 15.9V**
**Pin = 77.10W**

# MPPT MEASUREMENTS

The table below gives the result of one MPPT sweep from 14 to 18V in steps of 0.2V

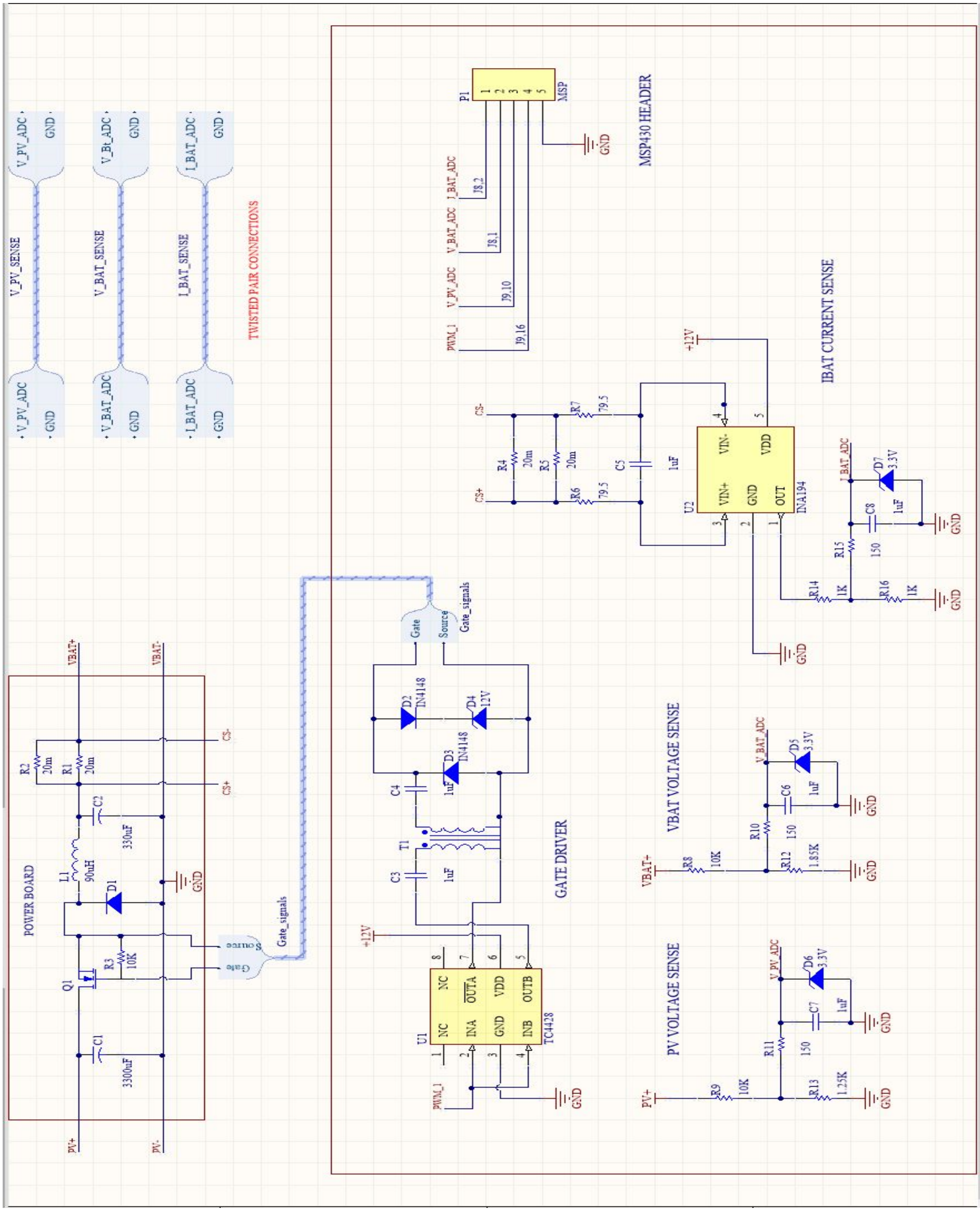
- The entire Vpv sweep was performed once every 5 minutes
- Each step of the sweep was performed every 3 seconds

**MPPT sweep readings**

| Vpv (V) | Ipv (A) | Ppv (W) | Vbat (V) | Ibat (A) | Pbat (W) | Efficiency |
|---|---|---|---|---|---|---|
| 14.0 | 5.210 | 72.940 | 12.891 | 5.381 | 69.366 | 0.951 |
| 14.2 | 5.200 | 73.840 | 12.891 | 5.447 | 70.222 | 0.951 |
| 14.4 | 5.150 | 74.160 | 12.900 | 5.490 | 70.823 | 0.955 |
| 14.6 | 5.136 | 74.986 | 12.901 | 5.551 | 71.611 | 0.955 |
| 14.8 | 5.110 | 75.628 | 12.910 | 5.594 | 72.225 | 0.955 |
| 15.0 | 5.080 | 76.200 | 12.915 | 5.641 | 72.847 | 0.956 |
| 15.2 | 5.050 | 76.760 | 12.921 | 5.709 | 73.766 | 0.961 |
| 15.4 | 5.016 | 77.246 | 12.921 | 5.745 | 74.234 | 0.961 |
| **15.6** | **5.000** | **78.000** | **13.939** | **5.378** | **74.958** | **0.961** |
| 15.8 | 4.900 | 77.420 | 12.930 | 5.742 | 74.246 | 0.959 |
| 16.0 | 4.830 | 77.280 | 12.925 | 5.734 | 74.112 | 0.959 |
| 16.2 | 4.690 | 75.978 | 12.913 | 5.637 | 72.787 | 0.958 |
| 16.4 | 4.572 | 74.981 | 12.910 | 5.564 | 71.832 | 0.958 |
| 16.6 | 4.446 | 73.804 | 12.900 | 5.452 | 70.335 | 0.953 |
| 16.8 | 4.331 | 72.761 | 12.900 | 5.353 | 69.050 | 0.949 |
| 17.0 | 4.210 | 71.570 | 12.891 | 5.291 | 68.206 | 0.953 |
| 17.2 | 4.109 | 70.675 | 12.890 | 5.225 | 67.353 | 0.953 |
| 17.4 | 3.994 | 69.496 | 12.884 | 5.130 | 66.090 | 0.951 |
| 17.6 | 3.809 | 67.038 | 12.873 | 4.932 | 63.485 | 0.947 |
| 17.8 | 3.691 | 65.700 | 12.860 | 4.848 | 62.349 | 0.949 |
| 18.0 | 3.548 | 63.864 | 12.850 | 4.697 | 60.351 | 0.945 |

- From the above sweep, max power (**$P_{mpp}$**) of **78W** was achieved at **$V_{PV}$ = 15.6 V.** The algorithm successfully identified this operating point and settled to this value on completion of a sweep.
- Also efficiency at all operating points was measured and peak efficiency of 96.1% was obtained

# POWER AND CONTROL STAGE SCHEMATICS



# PEAK EFFICIENCY

Converter efficiency at different operating points have been tabulated in the previous section. The peak efficiency reading is reproduced here for reference.

| Vpv (V) | Ipv (A) | Ppv (W) | Vbat (V) | Ibat (A) | Pbat (W) | Efficiency |
|---|---|---|---|---|---|---|
| 15.6 | 5.000 | 78.000 | 13.939 | 5.378 | 74.958 | 0.961 |

# DIRECT ENERGY TRANSFER IN UNSHADED CONDITIONS

| Vpv (V) | Ipv (A) | Ppv (W) |
|---|---|---|
| 13.01 | 5.27 | 68.56 |

Only **68.56 W** of power was extracted when Direct energy transfer was used to charge the battery. Compared to this the buck converter yielded **78 W** of power which is 13.7% increase in extraction

# DIRECT ENERGY TRANSFER IN SHADED CONDITIONS

4 cells were shaded and power was measured in both approaches

| DIRECT ENERGY TRANSFER | | | BUCK CONVERTER | | |
|---|---|---|---|---|---|
| Vpv (V) | Ipv (A) | Ppv (W) | Vpv (V) | Ipv (A) | Ppv (W) |
| 12.535 | 0.522 | 6.543 | 15.59 | 0.525 | 8.18 |

- The Buck converter approach performs better than Direct Energy transfer even when the panels are shaded.
- Even then, both approaches yield suboptimal extraction from panel. When 4 cells are shaded only 18 cells of the panel conduct and Vmpp drops to 8V. Since buck converter cannot operate with input voltage less than output voltage, the converter fails to operate at maximum power.
- One approach to extract maximum power even during shaded conditions would be to replace  the Buck with a **SEPIC**. SEPIC can both boost and buck voltages. This will ensure maximum power point operation in both shaded and unshaded conditions.

# CONCLUSION

- An MPPT algorithm was designed that periodically sweeps the panel voltage to find the operating voltage at which the panel must be regulated to yield maximum power.
- The performance of the above algorithm was evaluated under different irradiations and was found to have satisfactory peak power tracking.