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U.S. DEPARTMENT OF ENERGY
Office of Science

DC/DC Conversion (bPOL, 11V → 1.5V)

Samantha Kelly
(under direction of Timon Heim, Karol Krizka, and Zhicai Zhang)

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The Goal

- bPOL is a single-phase synchronous buck converter designed for HEP experiments (variable voltage → constant lower voltage and variable current) that is controlled by AMAC chip
  - Replacement for FEAST2 line
  - Max input voltage recommended is 11V (can technically handle 12V)
  - Max output current recommended is 4A
  - Converts variable DC voltage into constant lower DC voltage with variable current
    - Operates by applying pulse width modulated (PWM) waveform of duty cycle to low pass LC filter
      - Switch is connected to input voltage and inductor
  - Downside of buck converter: noisy
    - Nature of switching regulators

The Goal (cont.)

- Want to describe efficiency of DC/DC conversion performed by bPOL from 11V to 1.5V in terms of temperature (from **P**roportional **T**o **A**bsolute **T**emperature sensor) and output current
  - Want efficiency fit to be true for detector temperature range (-40°C to 40°C)

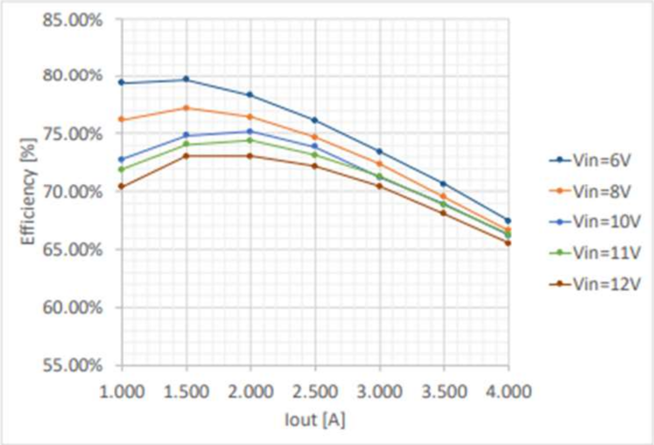
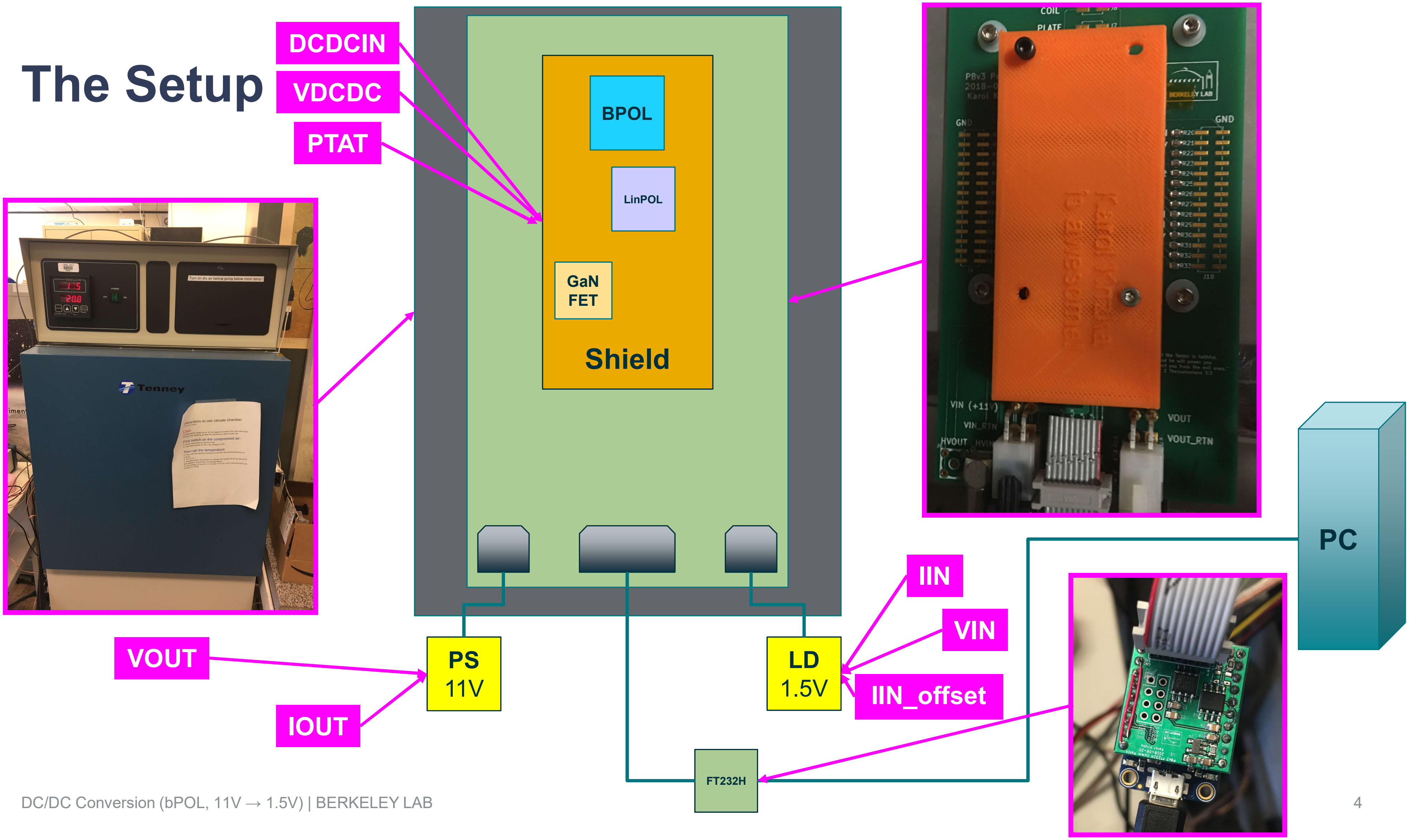


Figure 27: ASIC Efficiency for the Vout=1.5V version (without input+output π filters) and different Vin and Iout with the module in good thermal contact with a cooling plate at about 20°C.

The Setup


DCDCIN
VDCDC
PTAT
BPOL
LinPOL
GaN FET
Shield
Tenney
COIL
PLATE
GND
VIN (+11V)
VIN_RTN
HVOUT
VOUT
VOUT_RTN
PC
IIN
VIN
IIN_offset
LD 1.5V
PS 11V
VOUT
IOUT
FT232H

Wrangling the chiller

Takes much longer than one would think

- Settings on chiller in strips lab are the same as chiller in pixel lab, but are not capable of sustaining the same temperature range
  - -30°C to -40°C impossible, 30°C to 40°C difficult
    - This means the range of temperature tests is truncated to -15°C to 35°C
- Two primary differences: cable hole stopper, and chiller maintenance
  - Cable hole stopper in pixel lab is rubber stopper, cable hole stopper in strips lab are pieces of foam
    - Sometimes foam pieces are pushed out by compressed air
    - Makes a difference, but doesn't fully account for malfunction
  - Chiller maintenance is done on individual chillers, not both uniformly, and tests generally only use one of the two chillers
    - Service being planned to ensure circulation is where it should be, etc.

Taking data well

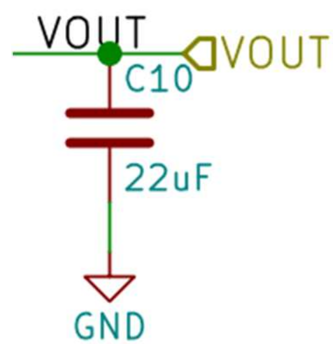
Limited temperature ranges, different efficiencies, calibration, wait times, and temperature ramp

- Take temperature data based on PTAT reading rather than set temperature on chamber
  - For bin X, all data points corresponding to PTAT readings of X – 2.5°C to X + 2.5°C
  - This requires a lot of repetition due to temperature ramp from internal heating
- Use and correct the eff1 measurement calculated in pbv3_eff_temp_scan.cpp (powertools)
  - Two efficiency values calculated
    - eff1 is dependent on VOUT, IOUT, VIIN, IIN, and IIN_offset (ld, ld, ps, ps, ps)
    - eff2 is dependent on VDCDC, IOUT, DCDCIN, IIN, and IIN_offset (amac, ld, amac, ps, ps)
      - ld measurements are from the DC variable load BK85xxx
      - ps measurements are from the power supply
      - amac measurements are from the ADCs on the AMAC chip

Taking data well (cont.)

Limited temperature ranges, different efficiencies, calibration, wait times, and temperature ramp

- When probing output voltage on the board at C10 with multimeter when DCDC set to 0A, voltage matches VOUT
  - C10 = 1.57V, VOUT = 1.57V, VDCDC = 1.35V
  - Conclusion: use eff1
- Modified eff1 to account for voltage drop across the long copper trace
  - At IOUT = 3.5A, C10 = 1.54V, VOUT = 1.26V
  - Graphed |VOUT – C10| vs. IOUT to find trace resistance (slope) was 0.0775Ω
    - » Accounted for the 0.0775Ω offset by using (VOUT + 0.0775*IOUT) instead of VOUT



Taking data well (cont.)

Limited temperature ranges, different efficiencies, calibration, wait times, and temperature ramp

- Run calibrations in pbv3_tune.cpp a singular time before data collection commences
  - calibrateSlope, calibrateOffset, tuneVDDBG, tune AMBG, tuneRampGain, calibrateNTC, calibrateTemperature
- Run calibrateAMACslope at the beginning of each data collection set (multiple collection sets in while loop)
  - Should saturate at 1023 counts around 0.9V input voltage
    - Prior to running tunings, AMAC slope wasn't saturating, reaching 850 counts at 1V
  - Usually takes three minutes to stabilise
  - Modified data collection approach to accommodate this
- Each measurement (multiple measurements per collection set) must stabilise at a given output current before the data is taken

Taking data well (cont.)

Limited temperature ranges, different efficiencies, calibration, wait times, and temperature ramp

- Temperature increases non-uniformly with output current due to internal heating
  - Due to non-uniform heating, scanning current is hard for data collection
  - Scanning temperature for a fixed current value is possible, but takes a while
    - Chiller temperature must stabilise before data collection
  - Solution: Scan currents that satisfy specific temperature bins, and then grossly scan temperature

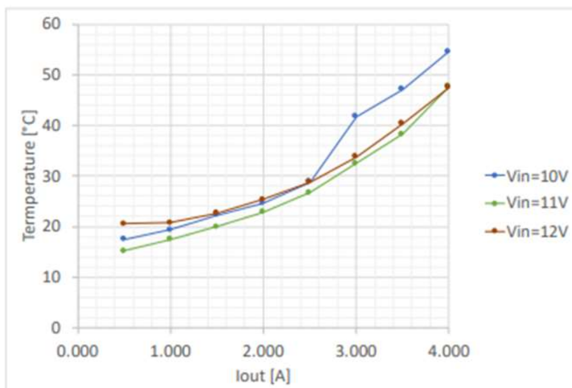
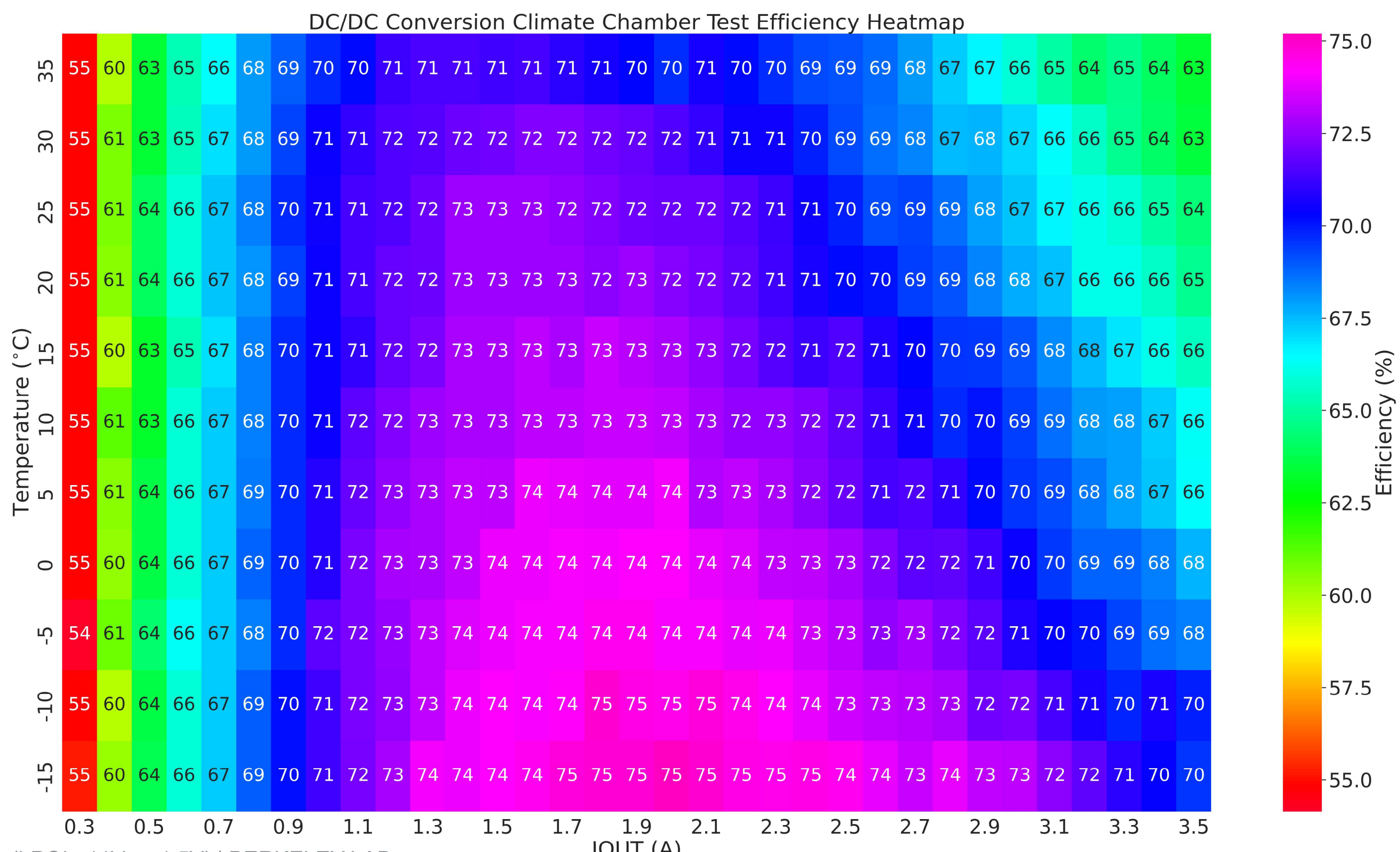


Figure 26: Increase of temperature for the Vout=1.5V version with Vin and Iout, with the module in good thermal contact with a cooling plate at about 20°C.

Efficiency Heatmap

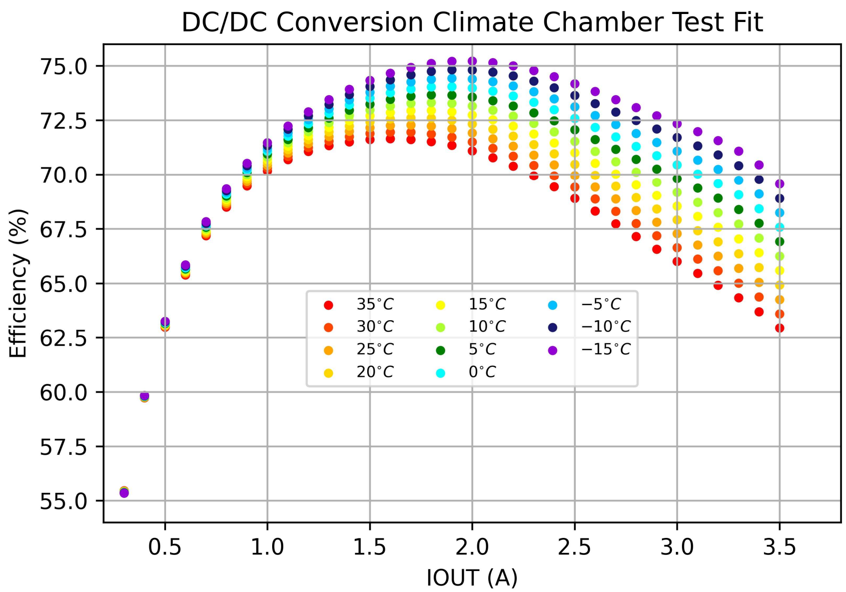


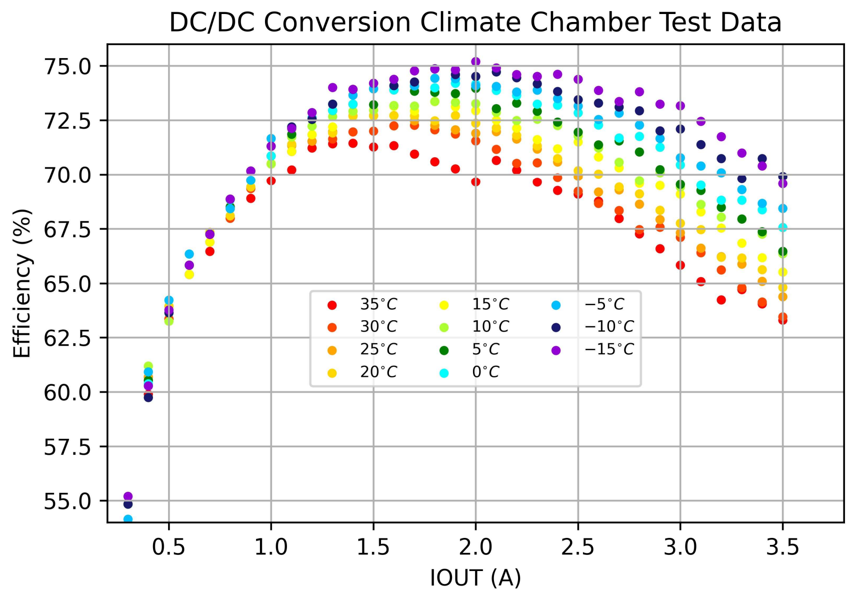
Fit equation

P is PTAT (°C), *I* is IOUT (A)

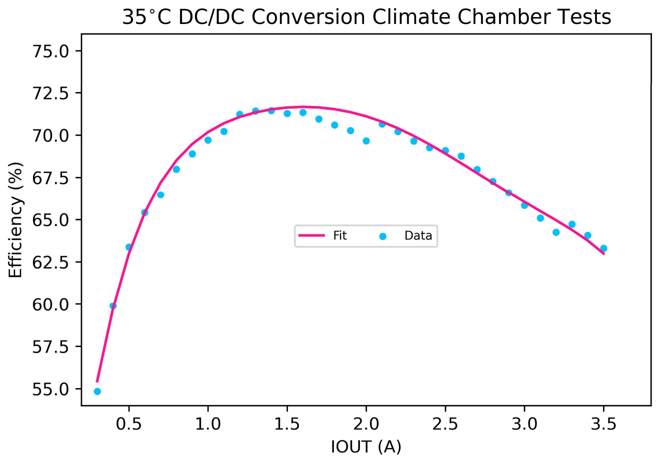
$$\boldsymbol{E(P,I)} = (0.00245273 \cdot P - 0.56929)I^6 + (-0.0268157 \cdot P + 7.1382)I^5 + (0.112837 \cdot P - 35.8580)I^4 + (-0.224422 \cdot P + 92.854)I^3 + (0.206925 \cdot P - 134.97)I^2 + (-0.122281 \cdot P + 110.298)I + (0.0254751 \cdot P + 32.1888)$$

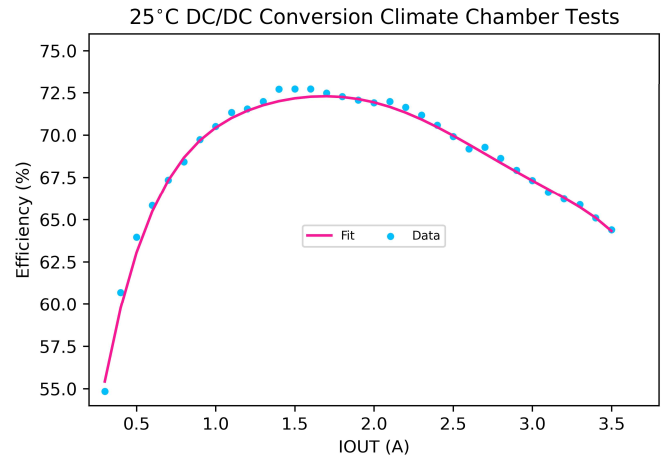
Fit vs. Data

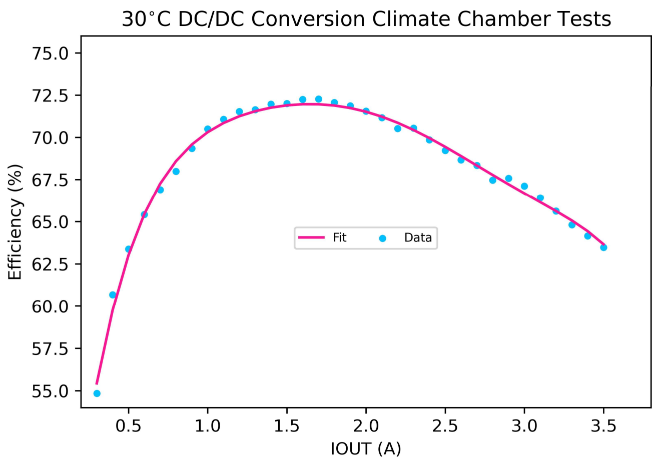

DC/DC Conversion Climate Chamber Test Fit
Efficiency (%)
IOUT (A)
75.0
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
35°C
30°C
25°C
20°C
15°C
10°C
5°C
0°C
−5°C
−10°C
−15°C

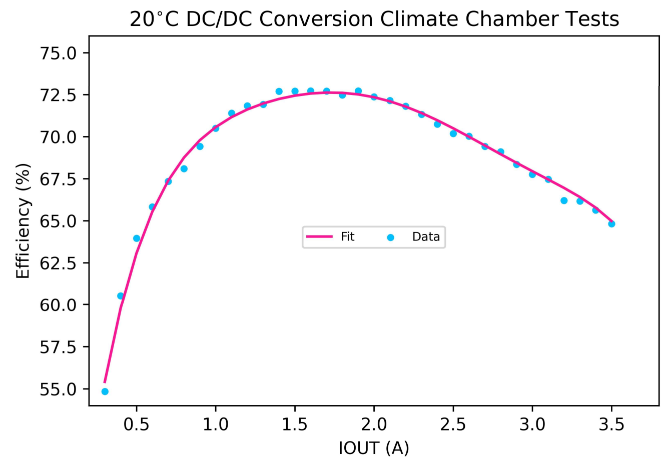

DC/DC Conversion Climate Chamber Test Data
Efficiency (%)
IOUT (A)
75.0
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
35°C
30°C
25°C
20°C
15°C
10°C
5°C
0°C
−5°C
−10°C
−15°C

Fit vs. Data (above room temp)

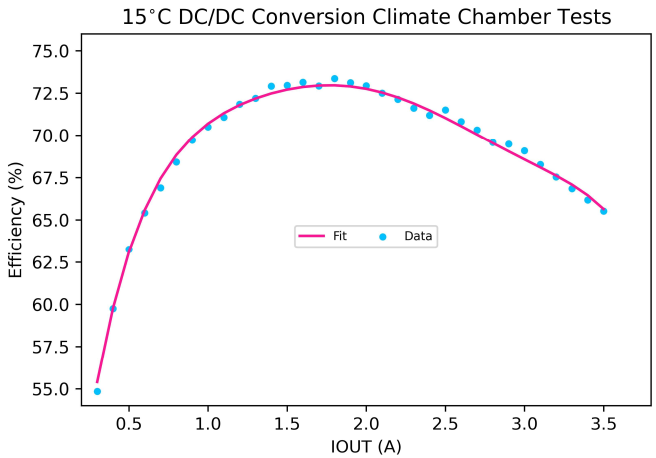


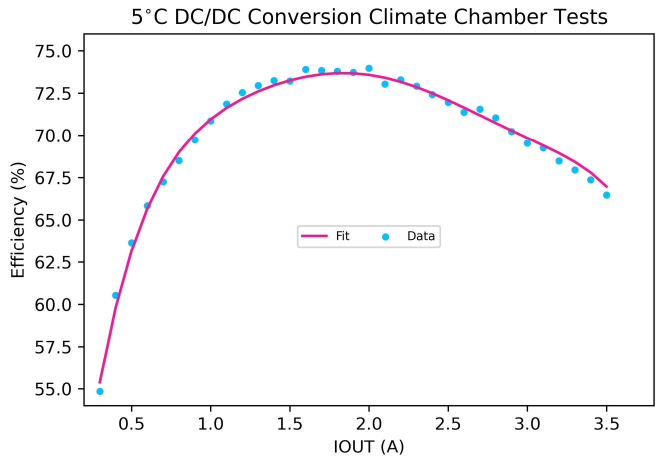


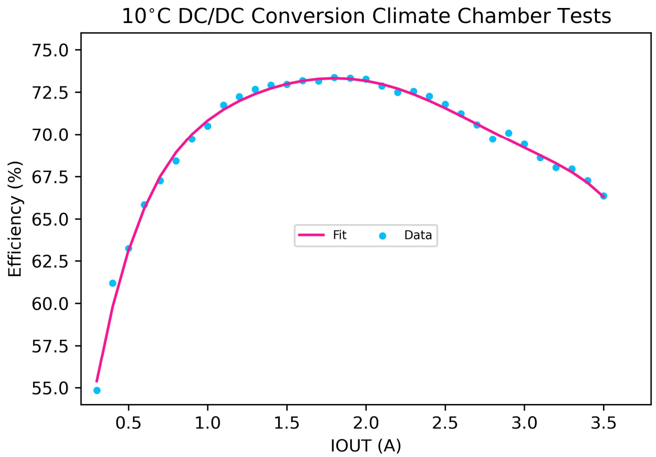


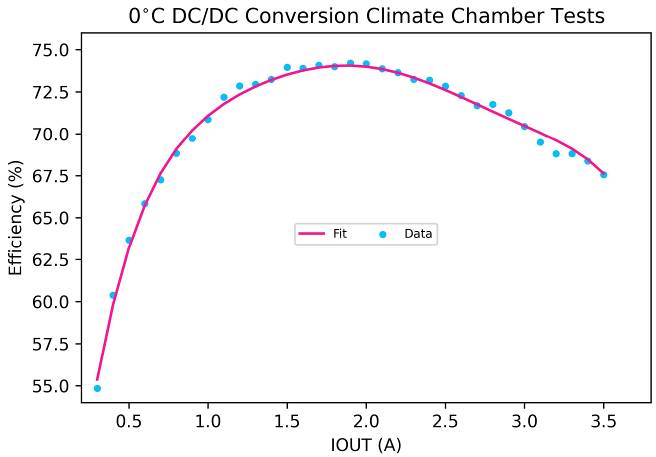


Fit vs. Data (freezing to room temp)

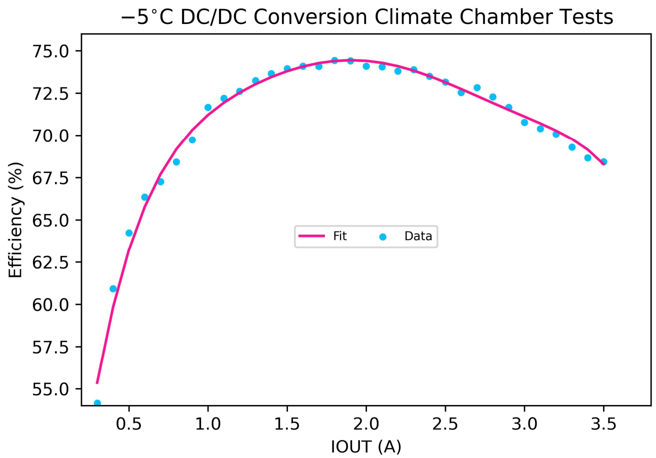


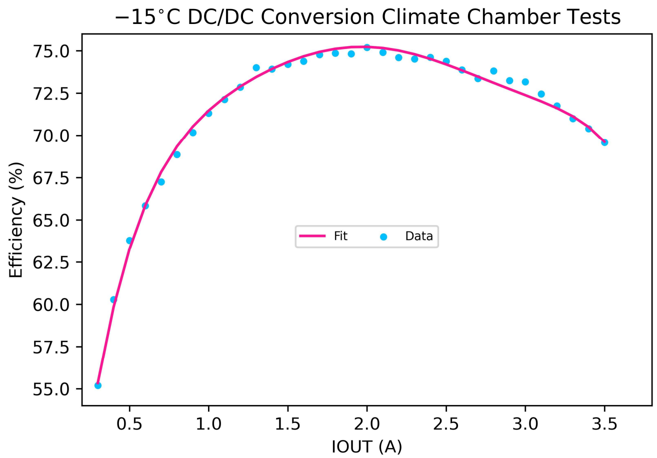


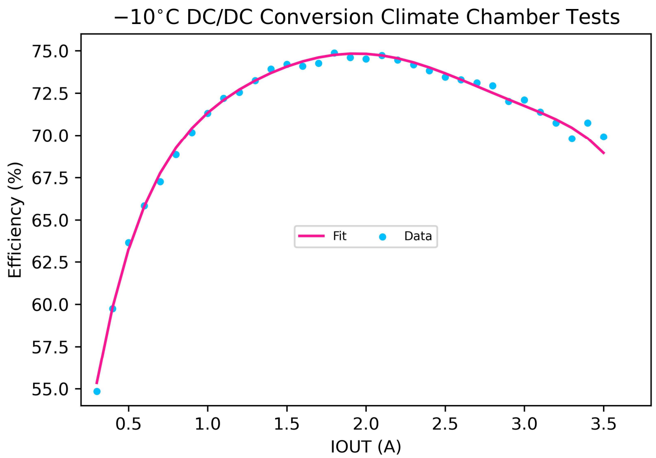




Fit vs. Data (below freezing)







Thank You!