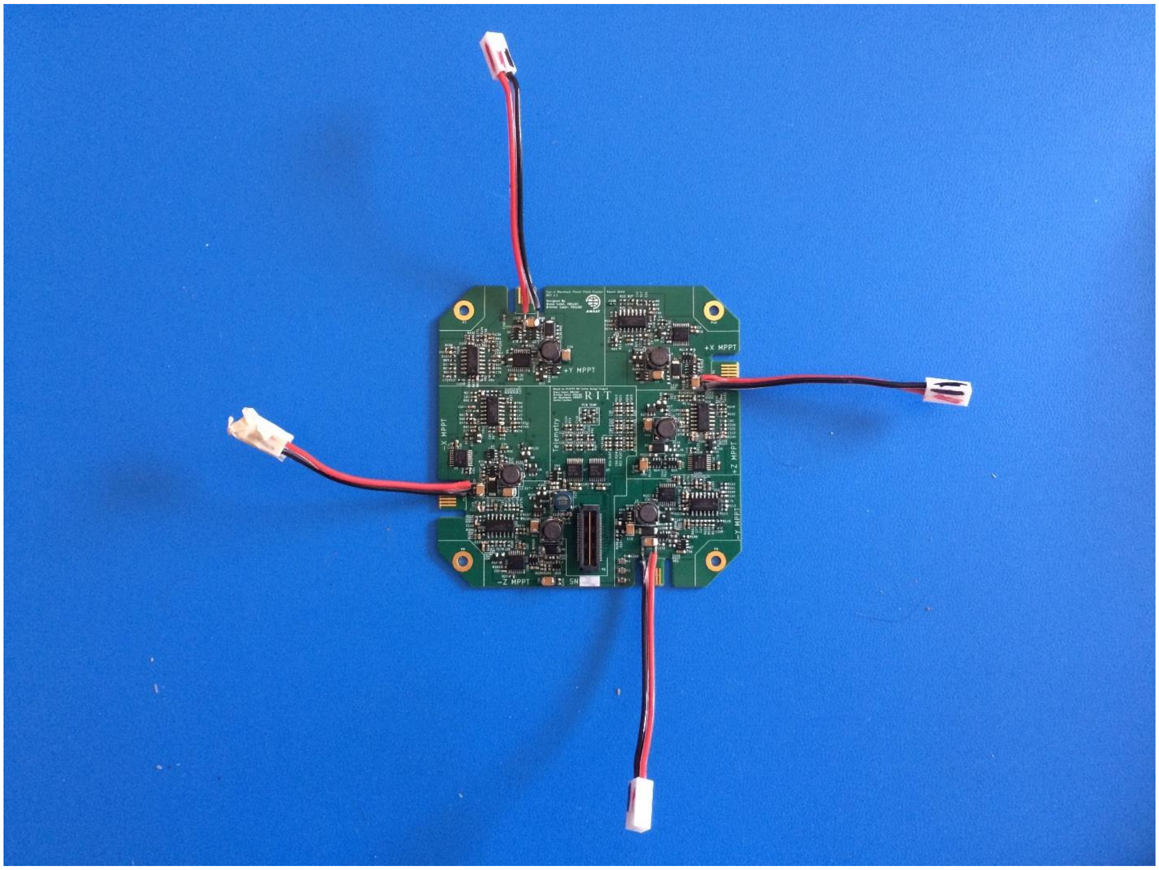
Fox-1 Maximum Power Point Tracker EMI Testing



MPPT Serial Number	2

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Introduction

The Fox-1 Maximum Power Point Tracker, *MPPT*, is an analog solar panel interface which maximizes the power extracted from two series connected Spectrolab UTJ solar cells. It will force the solar panel, or simulator, to operate at a constant voltage predicted to be the maximum power point only if maximum power is being requested by the load. Otherwise, the panel voltage is allowed to rise to the appropriate voltage for the given load and temperature. Each MPPT PCB has six individual channels which can operate in two modes being output voltage regulation and maximum power point tracking.

This document will overview basic hardware setup for use with items sent to Dan Habecker, W9EQ, for RFI sniffing. It also serves as a basic document for using the MPPT in a testing environment with common test gear associated with DC/DC converter and MPPT testing.

MPPT Test Setup

Hardware required for testing the MPPT include

- Fox-1 Maximum Power Point Tracker Rev 1.1 PCBA
- AMSAT Fox-1 Motherboard
    - Semtec connector harness adapter (Optional)
    - Associated motherboard harness
- Solar Panels/Simulation Hardware (At least one)
    - Solar Panels
    - LM723 Solar Simulator
    - Solar Panel Series Resistance Simulator
- Input and output cables./harnesses
- Battery/Supercapacitors
- Load
    - Resistive or active

Equipment Shipped

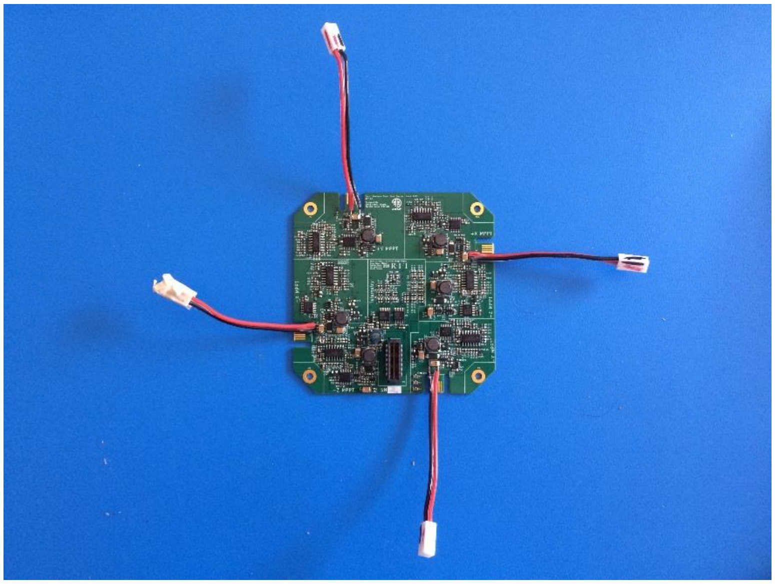

Figure 1 Fox-1 Maximum Power Point Tracker Rev 1.1 with test pigtails soldered onto PCBA (QTY: 1)

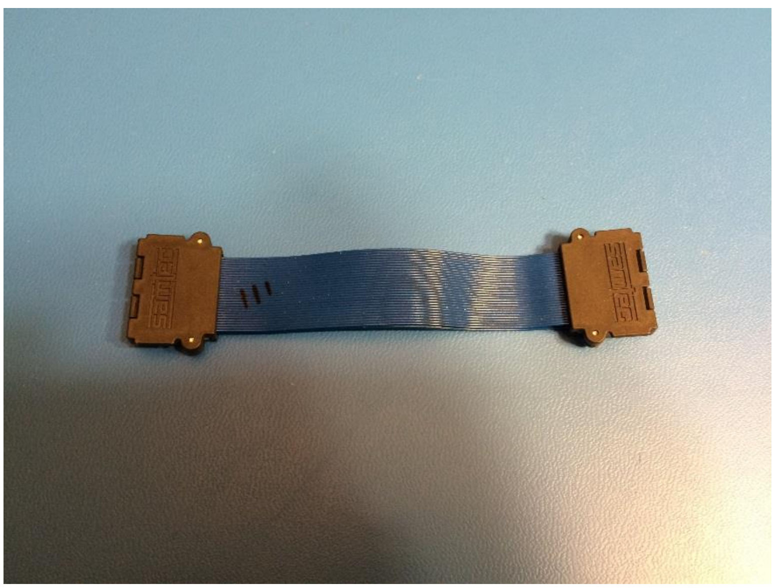

Figure 2 Semtec connector adapter cable (QTY: 1)

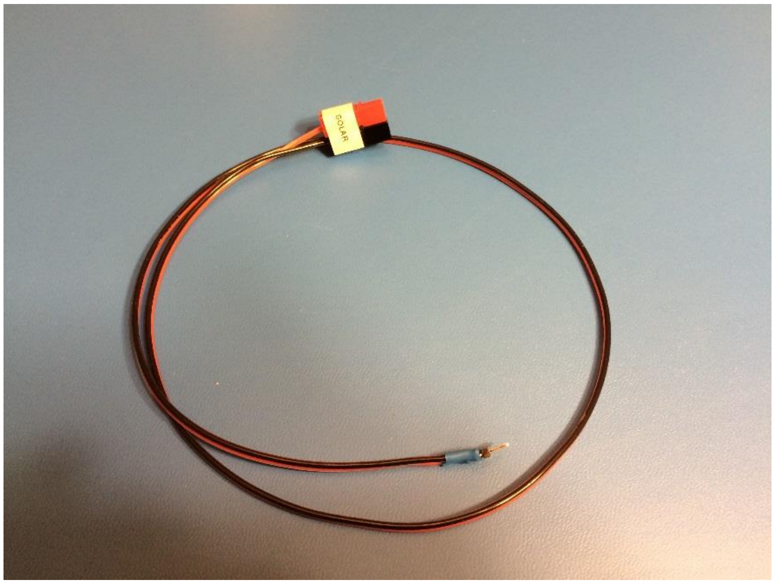

Figure 3 Solar panel pigtail to Anderson power pole cable (QTY: 2)

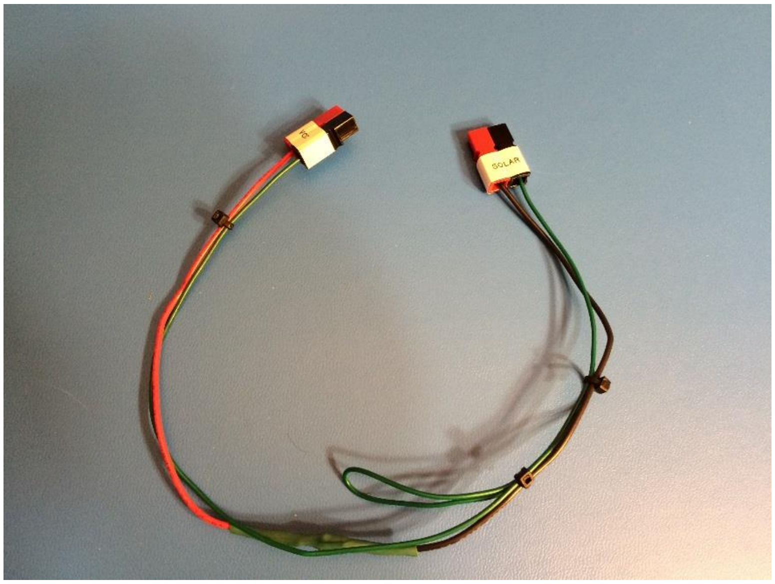

Figure 4 Solar panel series resistance simulator. Resistance = 1.4Ω (QTY: 1)

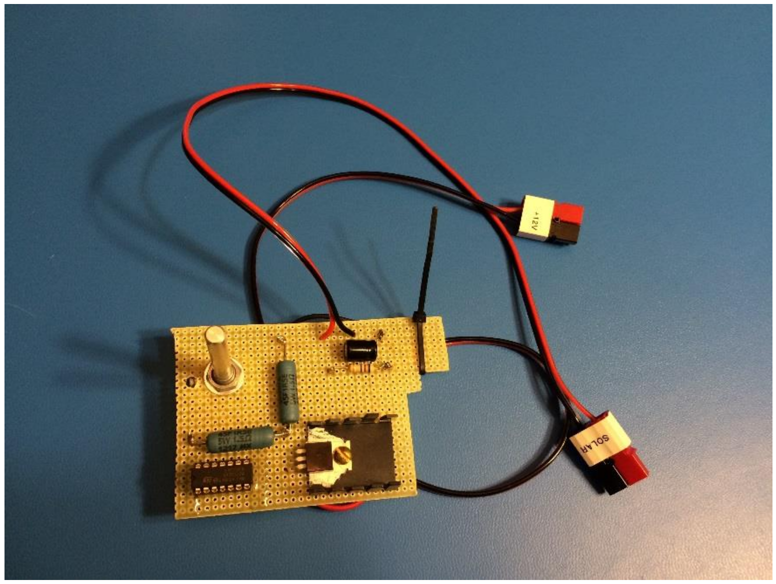

Figure 5 LM723 Solar Simulator (QTY: 1)

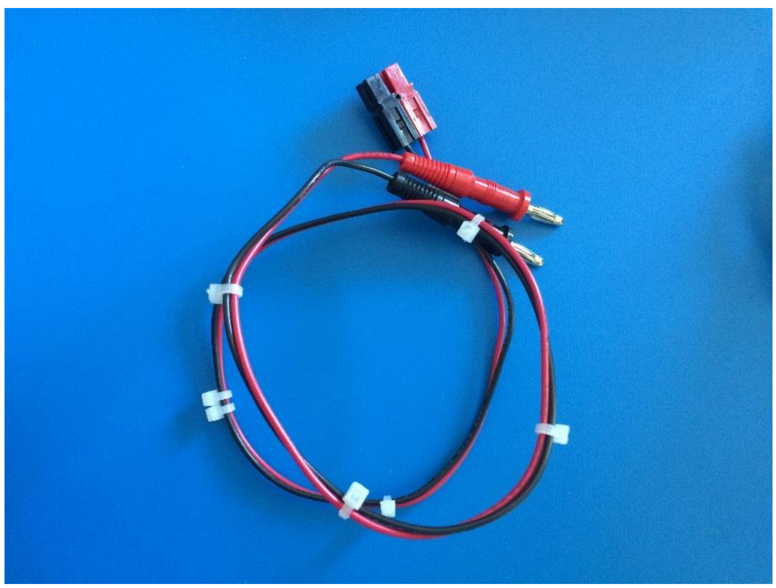

Figure 6 Anderson power pole to banana plug cable (QTY: 2)

Figure 7 2.5 Farad 5.4V Supercapacitor with banana plugs

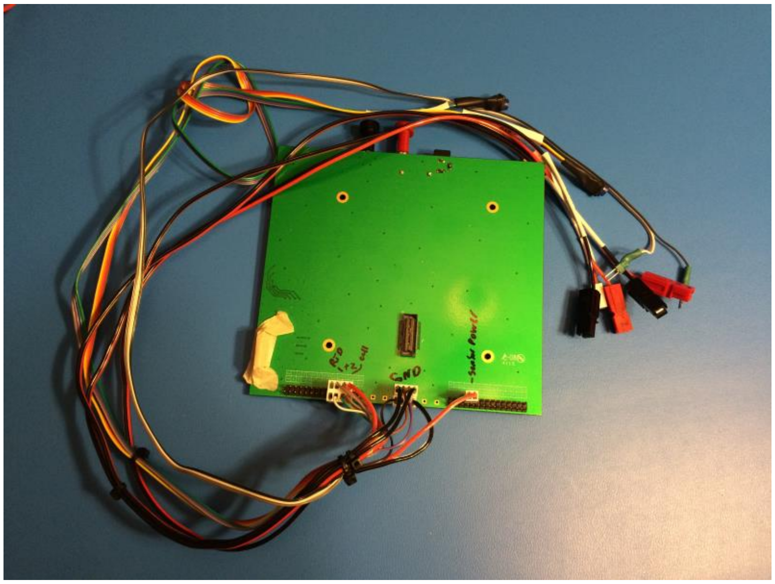

Figure 8 AMSAT Fox-1 motherboard with MPPT harnessing

Items Not Shown

- Anderson power pole to wire terminal cables (QTY: 2)

MPPT Test Setup

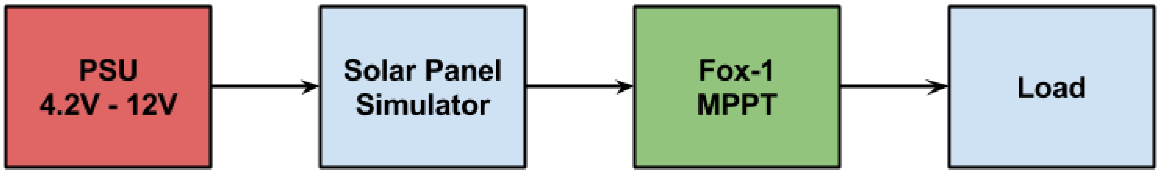

Figure 9 General test setup for using the MPPT

The MPPT only operates correctly with a power source that looks like a solar panel. Now, solar panels have current-voltage (IV) curves but the MPPT simply requires that it is able to change the input voltage with a change of input current.

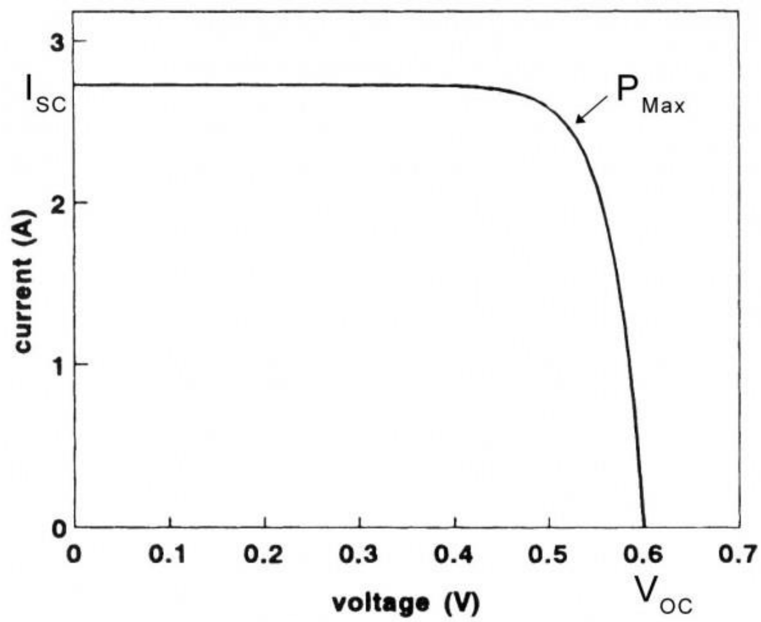

Figure 10 Solar panel IV curve for reference only

Solar panels have a series resistance that is the easiest to mimic. <u>This is essentially the slope of the line in Figure 10 from right to left before the "knee" of the curve around 0.55V in the example IV curve</u>. This can be confusing, please keep in mind that a solar panel sitting in the sun attached to no load is all the way right in Figure 10 at V_{OC} and a solar panel that is shorting its output wires is all the way left sitting at I_{SC}. <u>As load increases on the IV curve above the operating point moves from right to left</u>.

Resistive Solar Simulation

A simple resistor combined with the correct power supply voltage will allow the MPPT to operate along a linear voltage drop across its input. Carefully setting up the voltage and resistance will allow the MPPT to reach the appropriate current input at the exact point it hits the voltage it wants to regulate the input to as shown in Figure 11.

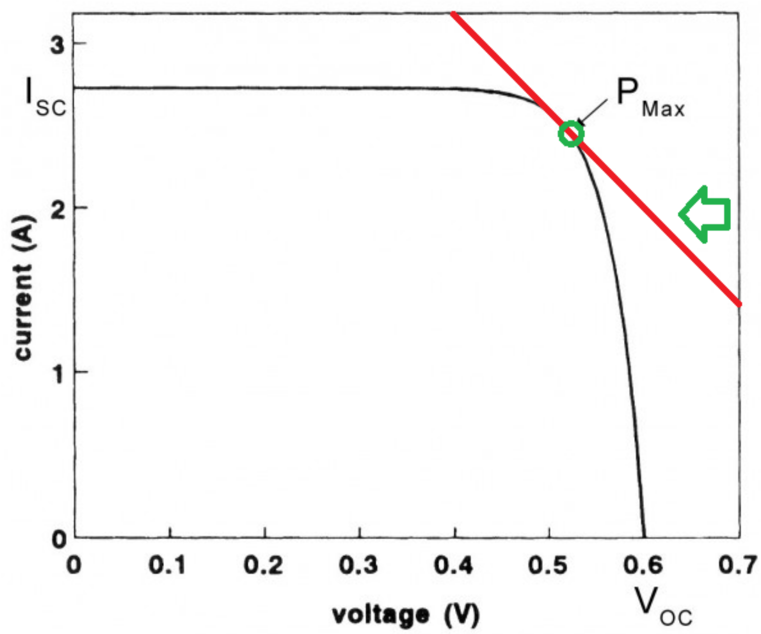

Figure 11 Example IV curve with a red resistive voltage drop line the MPPT will follow right to left as load is increased

An example 0°C operating point for solar simulation is show in Table 1. To properly reach the 5.064V maximum power point voltage (3% tolerance) at the correct 440mA current a 1.4Ω series resistance will require an open circuit voltage of 5.68V. Therefore setting a bench-top power supply to 5.68V and then attaching the resistive solar simulator, Fox-1 MPPT, and an output load will result in the test setup following a linear line all the way to the maximum power point voltage. This will deliver about 2.228W into the input of the MPPT.

Connection to the MPPT is made through Anderson power poles directly to the Fox-1 motherboard harness and/or the Anderson power pole to 0.100" pigtail cables.

0°C Resistive Simulation Values				
V_{OC}	R_{Series}	V_{MPP}	I_{MPP}	P_{MPP}
5.680 V	1.400 Ω	5.064 V	0.440 A	2.228 W

Table 1 Operating values for a 0°C resistive solar simulation

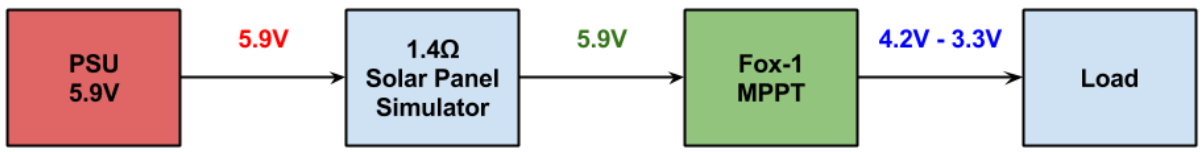

Figure 12 Example block diagram of a MPPT test using the resistive method of solar simulation

$$V_{OC} = V_{MPP} + (I_{MPP} \times R_{Series}) = 5.064V + (0.440A \times 1.4\Omega) = 5.68V$$

More simulation settings for the resistive simulator can be found in MPPT_Expected_Voltages.xlxs.

LM723 Solar Simulation

The LM723 is a voltage regulator and is used as a simple IV curve tracer. A pass transistor allows > 100mA currents to be sourced from it. A basic operational overview is that the regulator is set to regulate to the intended open circuit voltage adjusted for the slope of the IV curve it is tracing (which differs from resistive methods due to different series resistance). As the load is increased the voltage will drop at the input of the MPPT until VMPP is reached or the LM723 current limit is hit. Once the LM723 current limit is reached (about 410mA) the simulator drops almost all the voltage from the power supply and the MPPT input voltage crashes towards 0V. This simulates a very basic IV curve.

V_{OC} is adjusted with the potentiometer on the simulator while the power supply voltage should be sufficiently higher than the V_{OC} to account for dropout. Values for the simulator are shown in Table 2 and a block diagram of the test setup with example voltages are shown in Figure 13. Connection to the MPPT is made through Anderson power poles directly to the Fox-1 motherboard harness and/or the Anderson power pole to 0.100" pigtail cables.

0°C LM723 Simulation Values				
V_{OC}	R_{Series}	V_{MPP}	I_{MPP}	P_{MPP}
5.684 V	0.000 Ω	5.064 V	0.410 A	2.076 W

Table 2 The LM723 solar simulator 0°C operation values

Figure 13 MPPT test setup with the LM723 simulator

More simulation settings for the LM723 simulator can be found in MPPT_Expected_Voltages.xlxs.

MPPT Load

A load, resistive or active, must be placed on the output of the AMSAT Fox-1 Motherboard by attaching to the banana plugs shown in Figure 8. Please note that by the definition of an MPPT output voltage will plummet once maximum input power is achieved. This is conservation of power as power in = power out – inefficiency and if the load current keeps increasing then the voltage must decrease! A supercapacitor or battery in parallel with the output will stabilize the voltage under load causing more flight-like conditions.

Fox-1 Maximum Power Point Tracker Operation

MPPT SN2 Hardware

The serial number 2 PCB sent has 5 MPPTs on it that should be used. One MPPT, X- panel, works but requires a minimum load of 50mA or else the output will climb to the solar panel voltage (6V or so). Technically this is proper operation as DC/DC converters have a hard time regulating output voltage below a minimum current as they move into discontinuous conduction mode (DCM). I designed this MPPT for 50mA minimum load. However, the MPPTs should all operate fine without the minimum load so this is an open issue I'm investigating to make it easy on the integration team. I've taped over the –X Panel pigtail for now, please do not use it unless you provide the minimum load, **especially with the supercaps as they could explode if you let them charge > 5.4V**.

A bottom QSH connector is not present as soldering was not successful. Please use the Semtech cable adapter shown in Figure 2 if you want to access the top of the PCB while operating the MPPT with the PCB connected to the motherboard.

Connecting Solar Power

The +Z and –Z MPPT inputs are achieved through the QSH/QTH connectors and therefore there are two Anderson power poles for these MPPTs in the AMSAT motherboard harness shown in Figure 8. The +X, -Y, and +Y MPPTs are powered through the pigtails near each Semtec PCB edge MEC connector in Figure 1. Please be extremely careful about not reverse polarizing the MPPTs with the 0.100" connector pigtails as this will likely damage the channel. Appropriate adapters for the connections have been provided, including wire terminal to Anderson power pole cables for the power supplies and load.

Multiple MPPT Operation Connection

When operating multiple MPPT channels simultaneously please keep in-mind that the PCB was designed for no more than two full power MPPTs operating at once. In orbit, one panel will be in direct sunlight while several other panels will be in indirect sunlight, three maximum at one time. Therefore, do not operate the MPPT with more than two full powered solar simulators.

The LM723 solar simulator needs a different voltage than the V_{OC} power supply requirements of the resistive simulation method. This means that a separate power supply should be used for the LM723 and resistive simulators that provides a nominal 12V to the LM723 simulator and V_{OC} to the resistor.

MPPT SN2 Solar Panel RTD Setting

The SN2 MPPT channels require a resistance in place of the RTDs used to measure each solar panel temperature. The MPPT was designed for PT100 RTDs which are 100Ω at 0°C. Therefore the –X, +X, -Y, and +Y channels have been hardware set to 100Ω with resistors soldered to the PCB. This cannot easily be changed. However, the –Z and +Z MPPT channels connect to potentiometers in the Fox-1 motherboard harness and can be varied over at least 74Ω to 124 Ω. **When using 0C voltages as described above, please make sure the –Z and +Z potentiometers are set to 100Ω**! These voltages are easily accessible on the Motherboard 0.100" connector pins for the RTDs.

RTDs are driven with 1mA so 100mV across the resistors = 100Ω

Proper Operation of Fox-1 MPPT

The MPPT was designed for certain output conditions as shown in Table 3. The only valid voltage range is 4.2V to 3.3V. If the load is increased enough to bring the output voltage below 3.3V the results are no longer valid and MPPT operation is outside its design range. 1A can be sourced from the MPPT output when operating in combined dual panel operation. The minimum current is indicated as a design limit for guaranteed output voltage regulation. It should be noted that most MPPT channels don't need this minimum current.

Fox-1 MPPT Outputs			
$V_{out\ Max}$	$V_{out\ Min}$	$I_{Out\ Max}$	$I_{Out\ Min}$
4.200 V	3.300 V	1.000 A	0.050 A

Table 3 Output voltage and current values for valid operation

Fox-1 MPPT Operational Modes

Voltage Regulation

When the load is light on the MPPT the output voltage will be regulated to no more than 4.2V. The solar panel voltage is allowed to rise until it reaches the open circuit voltage. Once the current in the solar panel reaches its designed maximum power point (440mA for resistive method or 410mA for LM723) the operational modes will switch from voltage regulation (regulating the output voltage only) and into MPPT (regulate the input voltage only).

Due to I^2R losses the output voltage of the MPPT will linearly droop with increasing load up until the I_{MPP}. Rest-assured the output capacitor of each MPPT is a rock-solid 4.20V. Durin this time the input solar panel voltage will be dropping with increased load.

Maximum Power Point Tracking

Once the load is heavy enough the MPPT switches off operating modes and the output voltage begins to fall out of regulation while the input solar panel voltage remains at the V_{MPP}. The output power will remain the same (minus losses) while the current increases to the load but the voltage decreases. **Do not increase the load such that the output voltage drops below 3.3V.**

Output Supercapacitor/Battery use

The output voltage can be held higher with increasing load by using a battery or supercapacitors. This increases efficiency as the voltage on the output stay high with increasing power. Be careful, supercapacitors will stay charged for a very long time and it's important to discharge then when complete.