Pre-Production MicroTPCB Manual:

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1. Introduction:

The microTPCB shall serve as the star ground point for the local station. The local grounds from all components of the local station shall be connected at the microTPCB and presented to earth ground at this point. The microTPCB was selected as a cost-saving option to the TPCB board, however it is believed that the majority of the cost savings will not be apparent in the parts cost. The largest component of cost-savings is perceived to be in board development, debugging, and testing.

The microTPCB board attempts to utilize the available resources of the Unified Board to accomplish conversion and control aspects of the solar power control system. The microTPCB enables the Unified Board to handle all necessary control functions as well as ADC conversions. The microTPCB shall be as simple as possible and only provide signal conditioning and fusing where necessary. The microTPCB has been designed to be as easy to fabricate as possible and with parts that are readily available to collaborators in Argentina as well as the US. Finally, the microTPCB has been designed to be robust and fool-proof, yet be the point of failure in the instance of a catastrophic power system failure.

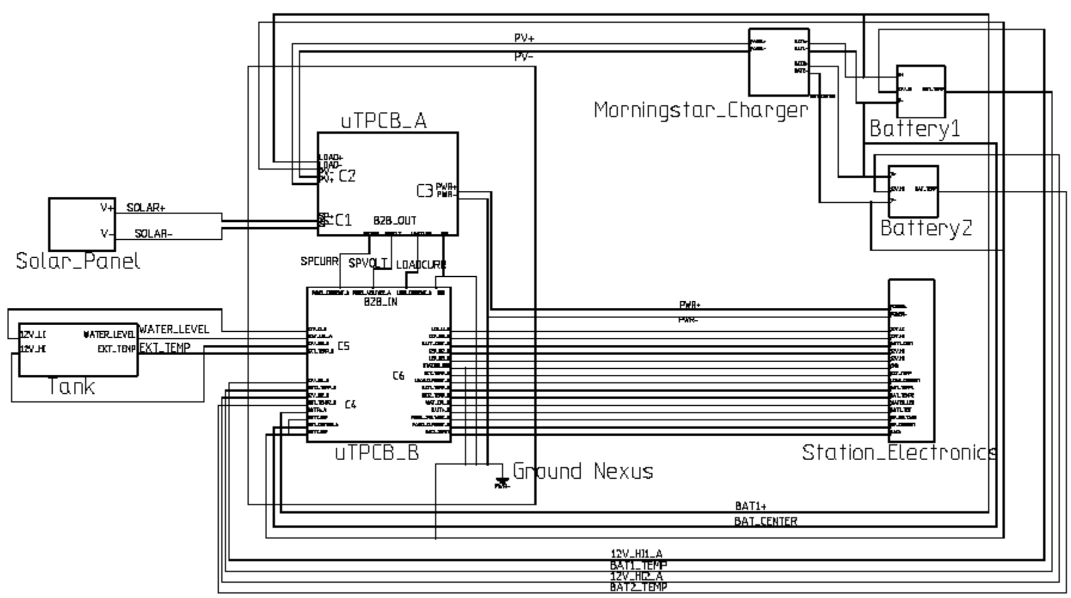


Fig. 1: Surface Detector solar power system with respect to microTPCB

2. Micro TPCB Specifications:

This section will provide a brief summary of the specifications that the microTPCB was designed to satisfy. As this is just a summary, the reference document co-authored by J. Beatty and P. Clark[1] should be consulted if a re-design is deemed necessary. The information provided in the lists below specify the basic requirements of the board functionality but to obtain more detailed specifications, the reference should be consulted.

2.1 Inherited Specifications:

Power Consumption: < 0.4 W max
Absolute Accuracy: ~1-5%
Size: must fit extruded RF box (2.4" x 5.78')
Temp Range: -20 C to +70 C
Time to failure: 20 years
Cost: < $90 w/connectors

2.2 Functionality Specifications:

High Side current measurement.
Fusing: 2A and 10A fusing for load and solar panels respectively
Output voltage range: Vmin = 0V Vmax = 5V

2.3 Construction Specifications:

PCB layer requirements: 2 layers maximum
Component selection: all passives shall be through-hole variety whenever possible.

2.4 Measurement Accuracy:

The measurements should be accurate within these ranges at the given resolutions.

Quantity	Range	Min. Resolution	Percentage Accuracy
Battery Sum:	6 V– 36 V	→ +/- 0.12 V	0.33%
Battery Center Tap:	3 V to 18 V	→ +/- 0.12 V	0.67%
Solar Panel Voltage:	3 V to 50 V	→ +/- 0.12 V	0.2%
Load Current:	0 A – 1 A	→ +/- 0.012 A	1.2%
Solar Panel Current:	0 A- 5 A	→ +/- 0.125 A	2.5%

3. Board Mechanics:

This section will elaborate on the physical and mechanical aspects of the microTPCB design. The connector positions and pin-outs will be discussed as well as the board dimensions, and enclosure dimensions.

3.1 Board Dimensions:

The microTPCB was originally to be designed so that it would fit within the same RF enclosure as the radio box. However, a little analysis of the board mechanics revealed that even with the design separated into two boards, these boards simply could not fit within the radio box enclosure. The large size of the MOLEX Mini-Fit Sr. connectors was the primary source of problems. Unfortunately, the use of the MOLEX Mini-Fit Sr. connectors (or an equally large replacement) is essential to the operation of the solar power system. The connections between the solar panels and the battery boxes needed to be extremely low resistance as the voltage margin between the solar panel voltage and the battery voltage is only a few volts. To provide adequate spacing for the MOLEX connectors, a new enclosure was designed by the University of Minnesota collaborators. The new enclosure has dimensions of 4.92” x 2.78” x 6.00”. The internal measurements of the enclosure constrain the microTPCB board to a size of 4.685” by 6.00”. The diagrams below show the dimensions of the enclosure and the dimensions of the PC boards.

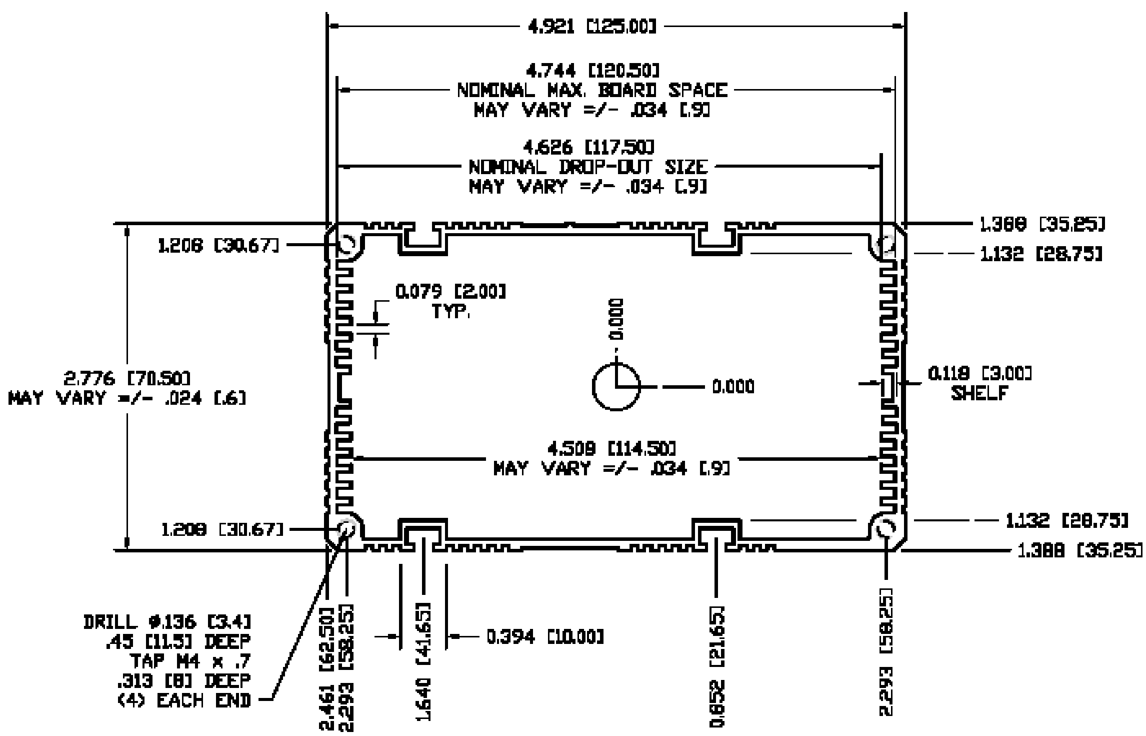


Figure 2: microTPCB enclosure designed by Minnesota

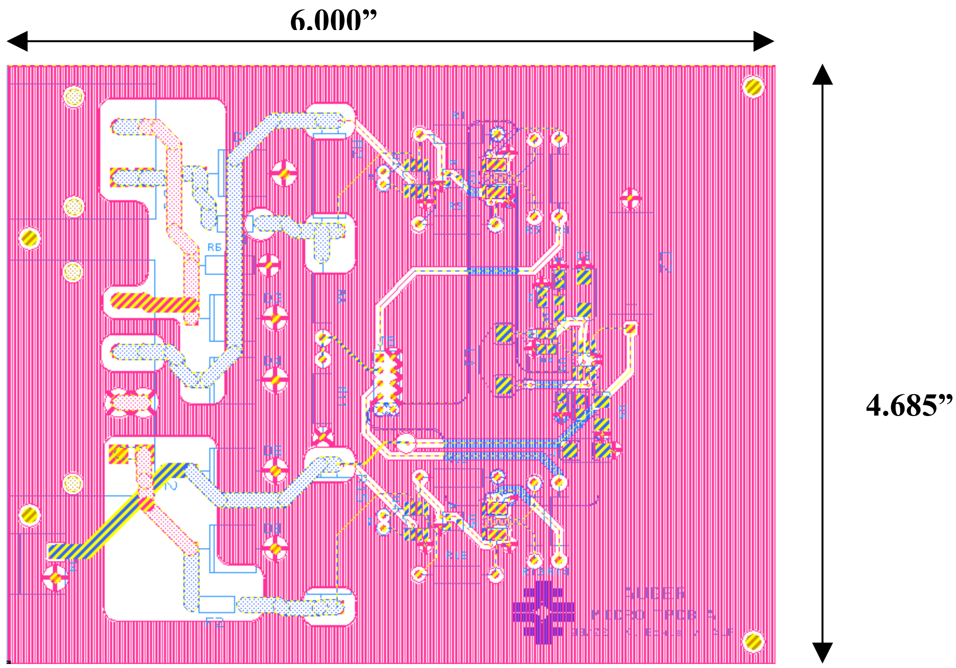
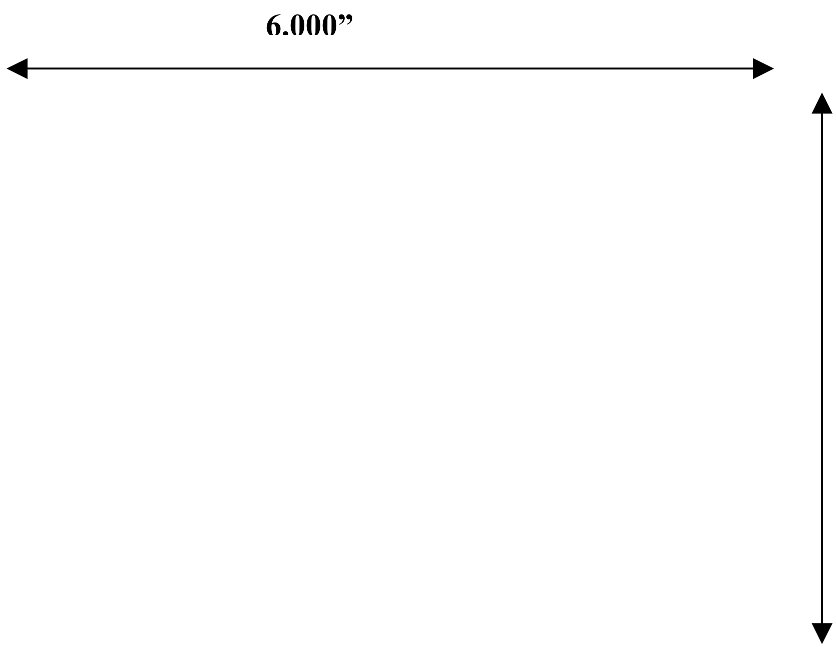
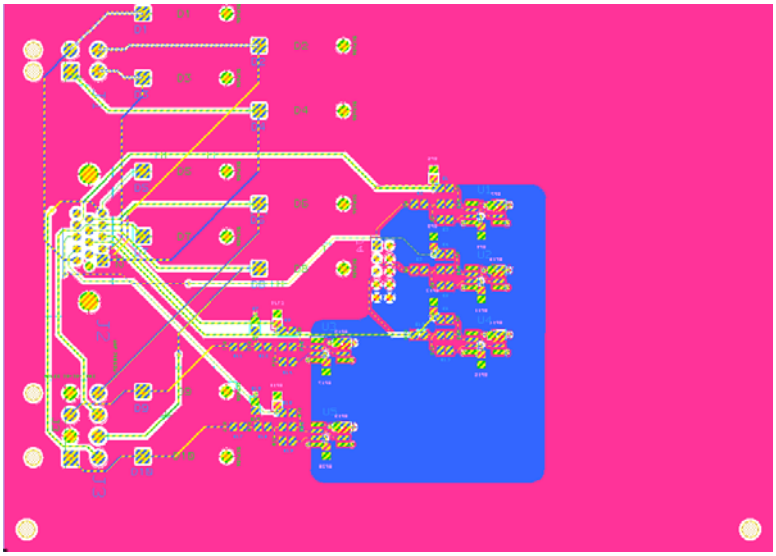


Figure 3: microTPCB Board A





4.685”

Figure 4: microTPCB Board B

3.3 Connector Locations and Pin-outs:

After the PC board size was selected and finalized (not an easy task), the connector placement and pin-outs fell into place. The next diagrams display the rough connector placements and pin-outs. Exact location information for the connector holes in the faceplates may be found on Minnesota’s website.

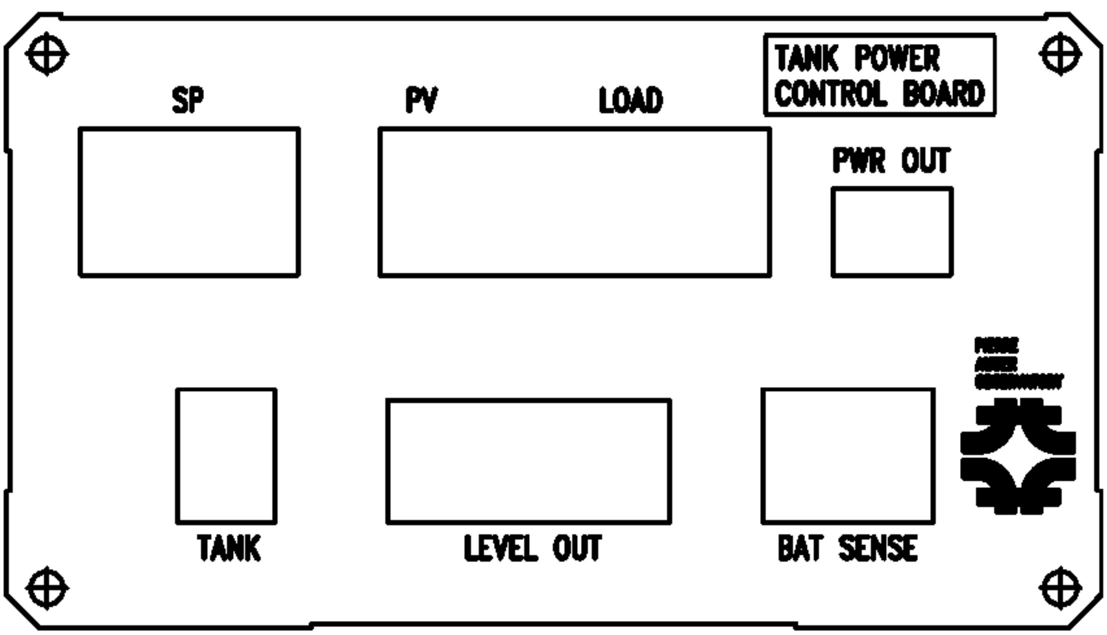


Figure 5: Connector placement relative to front panel

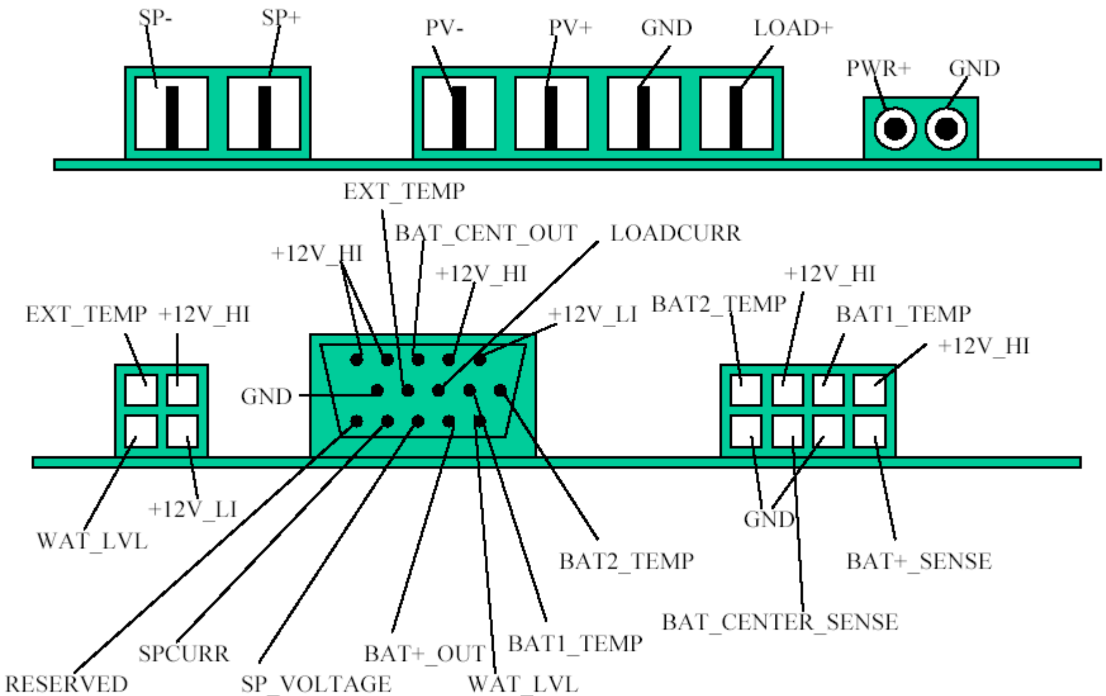


Figure 6: microTPCB pin-outs

4. Design Decisions:

The design of a PC board hopefully proceeds in a logical and organized manner, however, there is no set formula for how to proceed on every design. Also, each design has its own most important or relevant parameters such as cost, precision, power consumption, etc. There is rarely such thing as the ideal design for all situations. As a result, it is often necessary to make tradeoffs to order the weighting of the board parameters. This section will discuss the tradeoffs that have been selected for the microTPCB design.

4.1 Fast Prototype Development:

Several decisions were made simply to ensure that a prototype could be turned around quickly. The compromises made here generally fall into two categories: simplifying procurement, and using tested designs. These two compromises were central to the overall design of the microTPCB boards. These two goals really aid in getting a prototype to layout in a very quick manner. The entire electrical design took about two weeks as a result of placing these two goals highest in the design tradeoff weighting. For example, by using the LT1787HV current shunt monitor, which had been proven to work acceptably in P. Clark's designs, we were able to short-circuit a parts selection process which could take days. Similar shortcuts were made when selecting the AD627 instrumentation amplifiers, shunts, and the transient suppressors.

In addition to understanding the configuration of devices beforehand, selecting proven parts often enables shortcuts when procuring parts for prototypes. Often times when reusing parts, enough are available for prototypes from the previous design's spares. Even when no spares are available, most of the procurement channels and shortcuts are well known, so procurement may proceed more rapidly. This was definitely the case with the microTPCBs. In fact, a good portion of the pre-production microTPCB procurement re-uses spare parts purchased for the last EA versions of the TPCB.

4.2 Noise Immunity and Precision:

The next major concern was that the precision must be as close as possible to the specifications (see section 2.4). The microTPCB boards succeed by design is nearly all of the precision categories if the passive components are suitably precise. The microTPCB design consists solely of amplifiers, filters and power supplies. The precision components of the design may be characterized by the amplifier selection. All amplifiers were chosen such that their noise performance and offsets were small enough to satisfy the precision specifications of the design. The decision was made to place only 1% tolerance passive parts for the prototypes and pre-production boards to limit cost and lead times. However, if it is proven that the precision is needed, the design may utilize 0.1% resistors where needed to achieve the necessary precision. The only portion of the design that does not meet the specifications with the correct passive selections are the current measurements. The LT1787 has an intrinsic gain error of 5% that is unavoidable, however, as this part was selected as an approved part as discussed in section 4.1, this was believed to be an acceptable tradeoff especially as this gain error is a part-to-part gain error and only affects absolute accuracy not accuracy over time or temperature. Calibration may easily remove this error term.

4.3 Output Signal Range

Another important concern was the drive strength of the output filters. The desired signaling levels for the outputs of the microTPCB were not to exceed 5V. Ideally, the output voltage would be exactly 5 volts at full scale for each of the signals of interest. However, as the regulator selected was a 5V regulator, it became obvious that there would be a small decrease in output range to accommodate the physical limitations of single supply amplifiers. To ensure a single-supply amplifier could be found that could operate reliably in its linear range throughout the entire signal range of the inputs, the output signal range was decreased to 4.8V. An alternate solution might have been to increase the output voltage of the regulator. The choice to simply decrease the output range simplified the design and had no adverse affect on the ability to meet the precision specifications.

4.4 Cost/Availability

The final factor in selecting parts for the microTPCB design was selecting parts that were readily available and economically feasible. Often times, several parts meet the specifications derived for the design, but cost or availability was an issue. All parts selected are still in production and in wide distribution with the exception of the shunts, which are custom parts, but are readily available through the manufacturing vendor. It would be truly unfortunate to have a good design but be unable to produce it either because of cost or because of lack of parts availability.

5.0 Architecture:

Before any analysis or parts selection may be accomplished, a fixed architecture must be selected. The architecture describes how the design is broken down into smaller modules and how these modules are interconnected. As the microTPCB is a very simple analog board, the architecture is fairly simple and there are very few possible design choices and tradeoffs. The microTPCB hierarchy tree only has three (3) levels. The top level in the hierarchy describes the partitioning of the board into high-current and low-current boards. The next level of the hierarchy separates the design into the measurement and signal conditioning circuitry and circuitry to power the board or protect the inputs. The final hierarchical level describes the partitioning of the board into amplification/attenuation and filtering circuitry. Once the architecture is completed, the partitioning of the circuitry between the two boards becomes a simple process. The diagram below shows how the circuitry is separated into two separate PC boards.

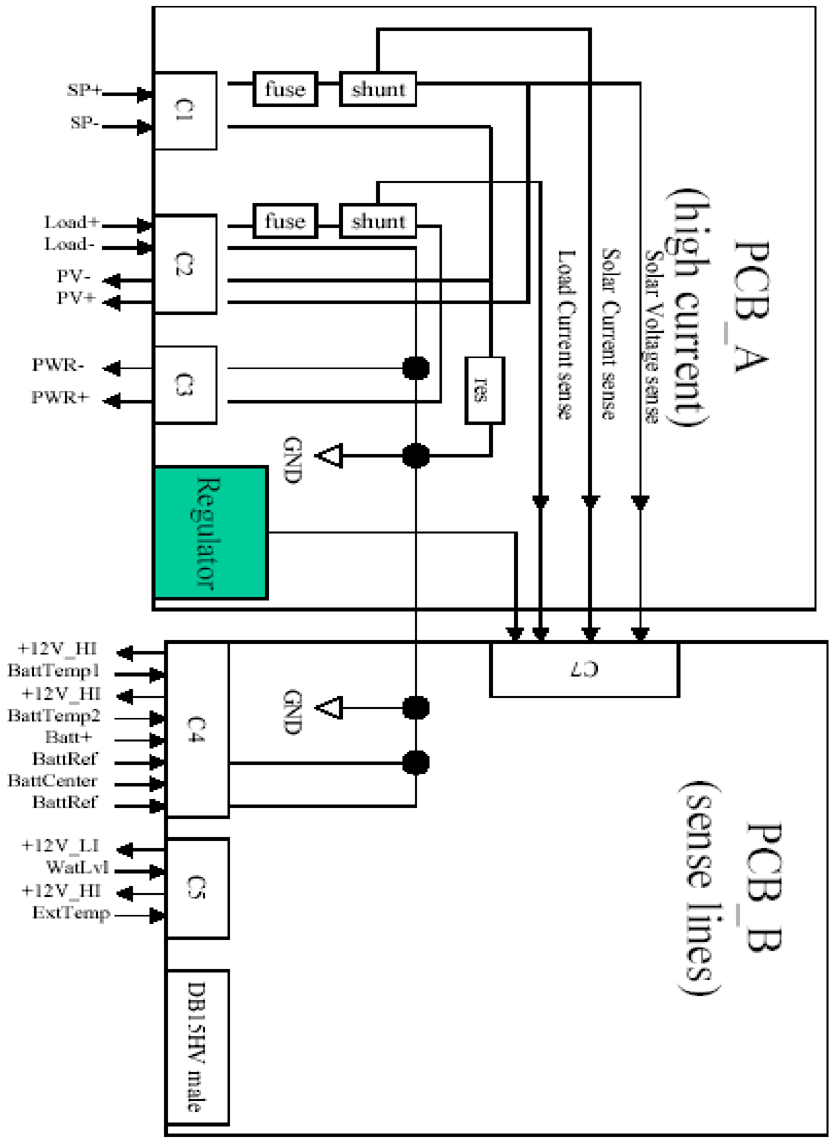


Figure 7: Architecture overview

6.0 Electrical Design/Analysis:

The micro TPCB is a very simple design idea. The micro TPCB board is in essence an analog board operating at frequencies very near DC. However, there is the possibility of moderate speed switching of significant voltage levels in the vicinity of the solar panel current monitors and the switching regulator. As a result, it is expected that there will be unwanted switching spikes on the outputs of the signals of interest. In an attempt to eliminate these spikes, filtering circuitry has been added to the output buffers. In additon to the core functionalities of amplification and filtering, the microTPCB must power all of its electronic circuitry as well as protect its circuitry from surges and spikes. The following section will provide detail on each functional portion of the microTPCB boards.

6.1.1 Shunt Measurement Precision/ Accuracy

Current Measurements:

Table I shows all of the signal ranges and their associated tolerances. The maximum accuracy quoted in the initial requirements was on the order of 0.2%. This was the starting point for the amplifier design. The first step was to create an error budget based upon the pre-selected LT1787HV current monitor chip. This chip is a precision device with small input offsets compared to the input range. The dynamic range accuracy would enable this amplifier to work well with a 12-bit ADC. The quoted maximum input offset for the LT1787 is +/-250uV. The maximum shunt voltage differential of the currents that will be measured are as follows:

Panel current (10 mOhm shunt) → 50mV
Load current (100 mOhm shunt) → 100mV

The maximum relative necessary accuracy in Amps is required for the load current which needs relative accuracy of 0.012A at a maximum current of 1A. This translates to a maximum allowable input error of 1.2% of the full-scale input range. However, one of the tradeoffs of the original EA TPCB was to limit board power consumption by utilizing small current sensing resistances for the solar panel shunts. It will be shown that although this decrease in shunt resistance adversely affects the achievable precision, the design still operates better than even more strict the load current precision spec. The precision figure on the current measurement is a function of the selected shunt resistance. The design decision was to attempt to use the remaining shunt resistors from the TPCB boards. However, it was important to ensure that making this decision does not place the design outside of the specified precision requirements. The precision requirements in Table I refer to the amount of relative error that is acceptable for the design. Analysis shows that with the 50mV input range, the relative input measurement error is 1% due to the offsets of the amplifier. This error term propagates to the output with gain and becomes an output error of 1% on an output signal of 400mV. The selected instrumentation amplifier (AD627A) has an input offset and 445uV. This is much smaller than 1% of the input range (400mV), and also much less than the uncertainty on the output of the LT1787 (4mV). Adding these uncertainties gives an uncertainty at the input of the AD627A of 4.445mV. The AD627 lists the output offset as a parameter as well: 1mV over the entire –40 to +85C temperature range. Taking this value into account, adding it to the other uncertainties and gaining it by 12 at the output give an error before filtering of 54.3mV. Note that this value of 54.3mV corresponds to less than 1.11% of the full-scale output voltage. The accuracy figure just quoted does not take into account amplifier gain errors, which may reach 5%, or uncertainties on the resistors, which are currently set to 1%. As a result, deviation of the actual output voltages from the expected values may be significantly higher. The accuracy calculations discussed above simply states the best achievable performance with the selected ICs and biasing conditions. It is apparent that the derived performance of 1.11% is better than the 2.5% required for the solar panel current.

Voltage Measurements:

The previous calculations detail the precision achievable when measuring the current levels of the batteries and the solar panels. The design of the voltage measurement circuitry also should comply to the accuracy specifications. The design of the amplifiers and filters for the voltage measurement do indeed comply with the specifications. However, a conscious choice was made for cost purposes to use all 1% tolerance for passive components to ensure minimal cost. As a result, the maximum absolute accuracy is roughly 1% regardless of how precise the amplifier sections are.

There is a slight design error in the microTPCB battery voltage measurement circuitry that will induce a 0.12% error, but even this error term is within the accuracy specification. The error comes from the fact that the negative lead of the battery cables is attached to the board ground. By attaching the negative lead to board ground, the battery voltage measurement subtracts out the voltage drop of the low-side cables. As a result, the measurement is not the battery voltage at the battery box, but rather a quantity that is 21 mV or 0.12% (conservative estimates) less than this voltage. The production re-design should fix this error by not making the connection to ground for the battery voltage measurement.

6.1.2 Amplification/Attenuation

This section will detail the amplification and attenuation parameters of each portion of the microTPCB design. The amplification/attenuation is determined by the fullscale range of each of the components and each of the full-scale ranges divided by the maximum output voltage of 4.8 Volts. The resulting gain enables simple linear calculation of the signal levels on the slow control cable using the gains listed below:

Signal Name	Full Scale Voltage	Gain/Attenuation
Battery + Voltage	36 Volts	1 / 7.5 = 0.13333
Battery Center	18 Volts	1 / 3.75 = 0.26667
Solar Panel Voltage	50 Volts	1 / 10.4167 = 0.096
Solas Panel Current	0.40 Volts (after LT1787)	12
Load Current	0.80 Volts (after LT1787)	6

6.1.3 Filter Design

The next step was to determine the requirements for the filtering circuitry. The actual filter design is a very simple design that may be accomplished with many single supply rail-to-rail op-amp in the market today. The filter requirements were much more stringent for passband flatness than they were for bandwidth. The filter architecture that was selected was a simple 2-pole Bessel filter with a cutoff frequency of 10Hz. The rolloff rate is fairly slow as the filter selected is a Bessel filter. The accuracy in the passband measurements may be econmomically accomplished with either a Bessel or Butterworth type low-pass filter. The Bessel filter was chosen rather arbitrarily, however it should be noted that the Bessel filter allows the shape of any passband waveforms to be preserved more accurately. The selection of a Butterworth filter could potentially distort any passband waveforms due to the nonlinear phase characteristic. However, waveform shape should not be an issue as the frequencies of interest are very close to DC. Nonetheless, it would be beneficial to be able to accurately observe any unexpected passband waveforms.

6.1.4 Supply Design

The power supply design for the board consists of finding a supply that can power the board's amplifiers at a fairly constant level of 5V over a wide input voltage range (7V to 36V) and with very high efficiency. The worst case scenario would have the regulator itself consuming more power than the circuitry that it is trying to power. The microTPCB electronics and passives combine to consume less than 50mW of power. The only exceptions are the shunt resistors. The shunt resistors push the power consumption to over 350mW. The table below illustrates the power consumption of each component of the design that consumes appreciable power.

Part	Voltage	Current	Watts
I-Monitor1: LT1787	0-50V	0-5A	
I-Monitor2: LT1787	0-36V	0-1A	
10 mOhm shunt	50 mV	5A	0.25 W
100 mOhms	100 mV	1A	0.10 W
All AD627	5V	80uA	0.4 mW
All AD820	5V	800uA	4 mW
Load Sense resistors	18, 36V	240uA, 480uA	22mW
Panel Sense Resistors	50V	250uA	25 mW

EMI/RFI is not a very crucial issue since the measurement signals will be filtered at such a low frequency compared to the switching frequencies of most switching regulators. Any radiated switching artifacts should be filtered out of the transmitted signals by the output filters. A Buck type DC to DC converter was selected to power the microTPCB boards. The Buck converter is a tuned circuit that uses external passive components for charge storage and filtering. The Buck converter, since it is a switching regulator boasts very high efficiency (ratio of power transmitted to the load to total incident power.) The particular Buck regulator selected for this design (LT1676) generally operates at an efficiency of upwards of 80%. It is important to verify that any conducted switching noise will not adversely affect the precision of the microTPCB measurements. To accomplish this goal, the Power Supply Rejection Ratios must be consulted (PSRR). The worst quoted PSRR of the amplifiers used in this design are the AD820A chips, which have PSRRs of 70dB. After reviewing the specifications, one can see that the most accurate measurement required targets an accuracy of 0.2% error on a 4.8V output signal or 9.6mV. Analysis shows that to affect a signal by 9.6mV, the power supply must vary by much more than 5V which will never happen. As long as the AD820 operates in the linear range, precision will not be affected by modest ripples on the regulator output. The only caution is to ensure that the ripple does not push the 5V supply rail below the 4.8V output voltage limit.