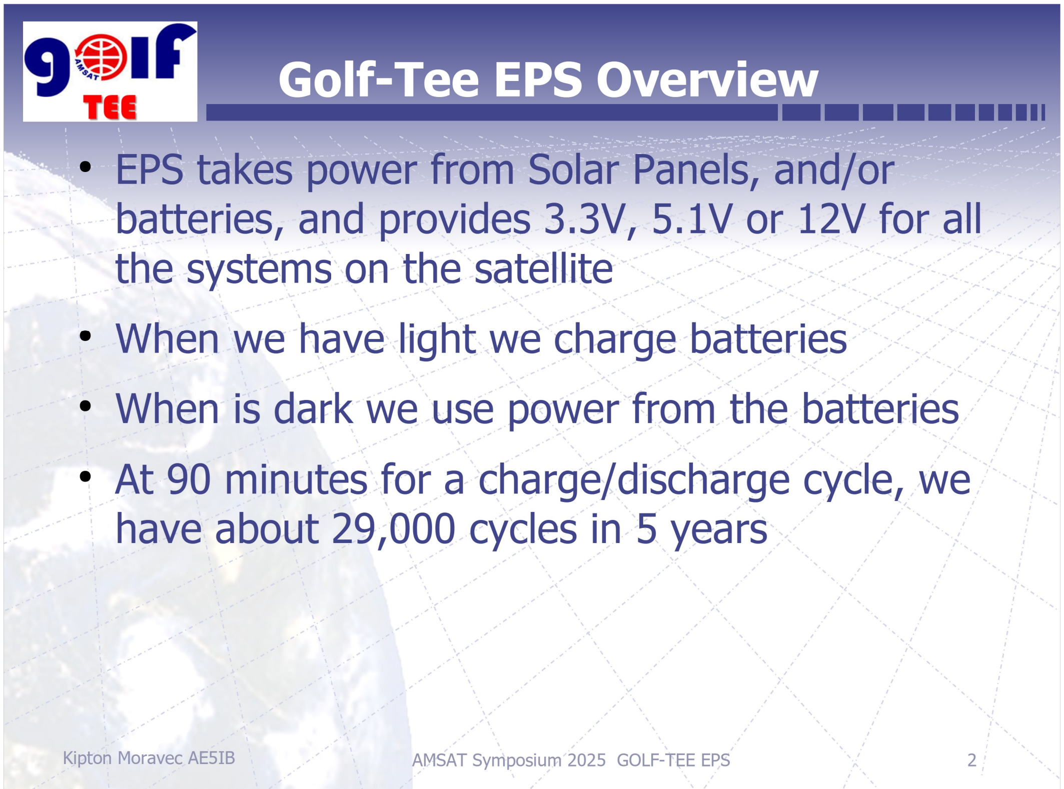
Hello. My name is Kipton Moravec, but I usually go by Kip, unless my wife is mad at me.

I am going to spend the next 30 minutes talking to you about the Electronic Power Subsystem or EPS for the GOLF-TEE satellite.

I find it hard to believe I presented the EPS concept at the 2022 AMSAT symposium in Minneapolis, and now the hardware is almost finished. And now there is still a ways to go with the software.



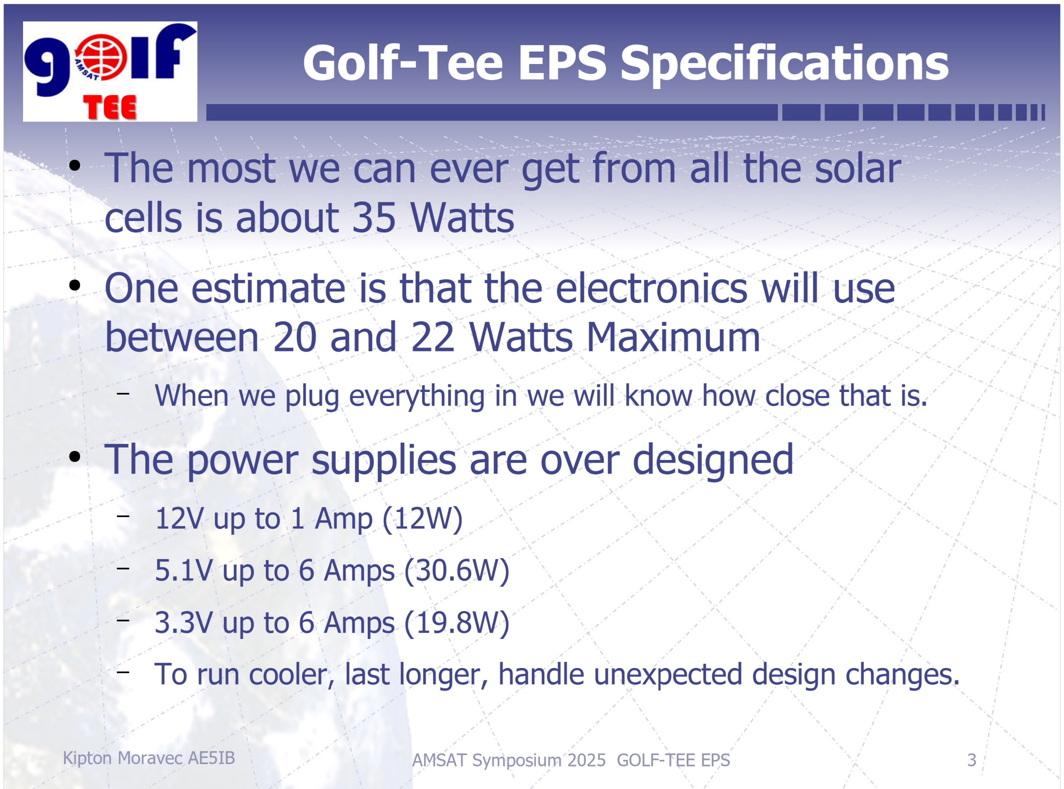
The EPS is pretty simple in concept. We take power from the solar cells, charge the batteries and provide power to the rest of the satellite when we can see the sun.

When we cannot see the sun we will run off of battery power. If we need more power than the sun can provide, we can also use battery power to supplement the shortage for a short time.

For low earth orbit satellites we go around the earth about every 90 minutes. In the 5 year life span of the GOLF-TEE that means about 29,000 charge/discharge cycles. Full charge / discharge of batteries kill batteries after about 700 cycles.

So we have decided not to do that.

I will talk about this issue in the Battery/BMS section.



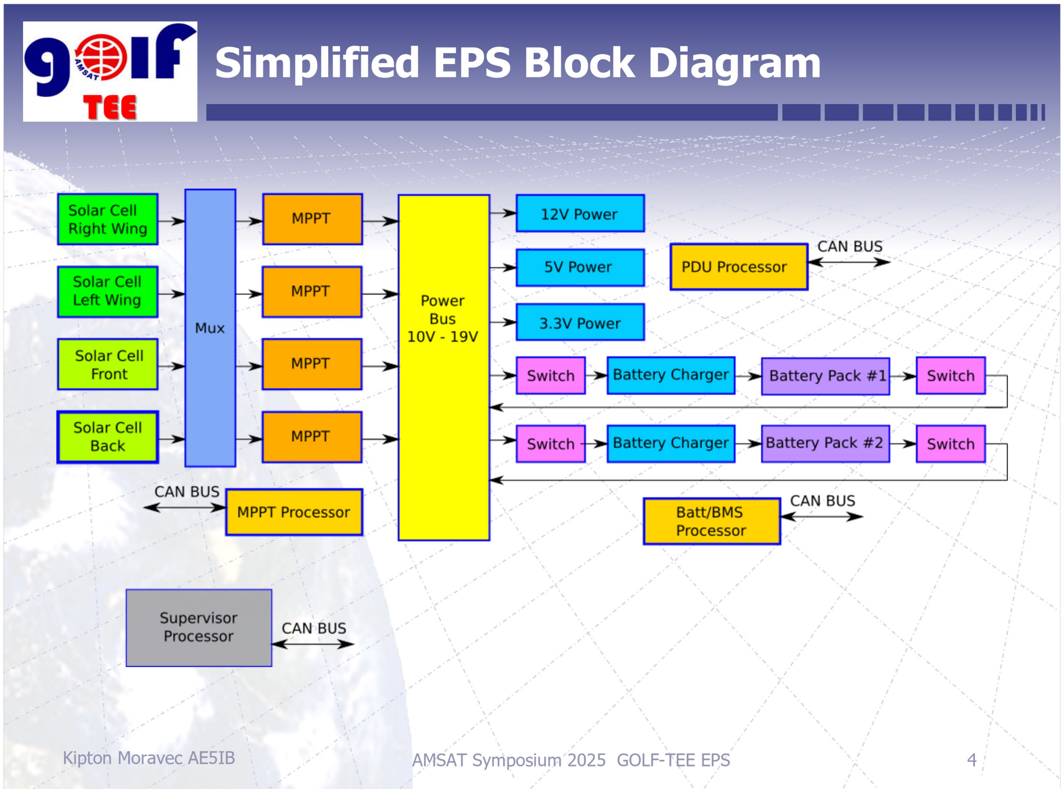
The solar cells can produce a maximum of about 35W. That is with ideal conditions and the solar cells pointing at the sun.

We currently estimate the electronics will use between 20 and 22 watts of power maximum. But I have not seen any good breakdowns of how much power for what voltage. And we do not know how accurate the estimate is. We probably will not know until everything is put together.

I over designed the power supplies.
12V up to 1 Amp (12W)
5.1V up to 6 Amps (30.6W)
3.3V up to 6 Amps (19.8W)

With the larger inductors (lower resistance) and diodes (lower forward voltage) it will run cooler. That will make it more reliable. And we can handle unexpected power differences.

Remember it is hard to get rid of heat in space. You cannot just put a fan on the hot part.



This is a simplified block diagram of the EPS System. It is pretty close to what I presented in 2022 with just a few changes.

Power from the solar calls come from the panels on the exterior of the satellite to a MUX. The MUX allows me to reroute the power in case one of the MPPT channels fails.

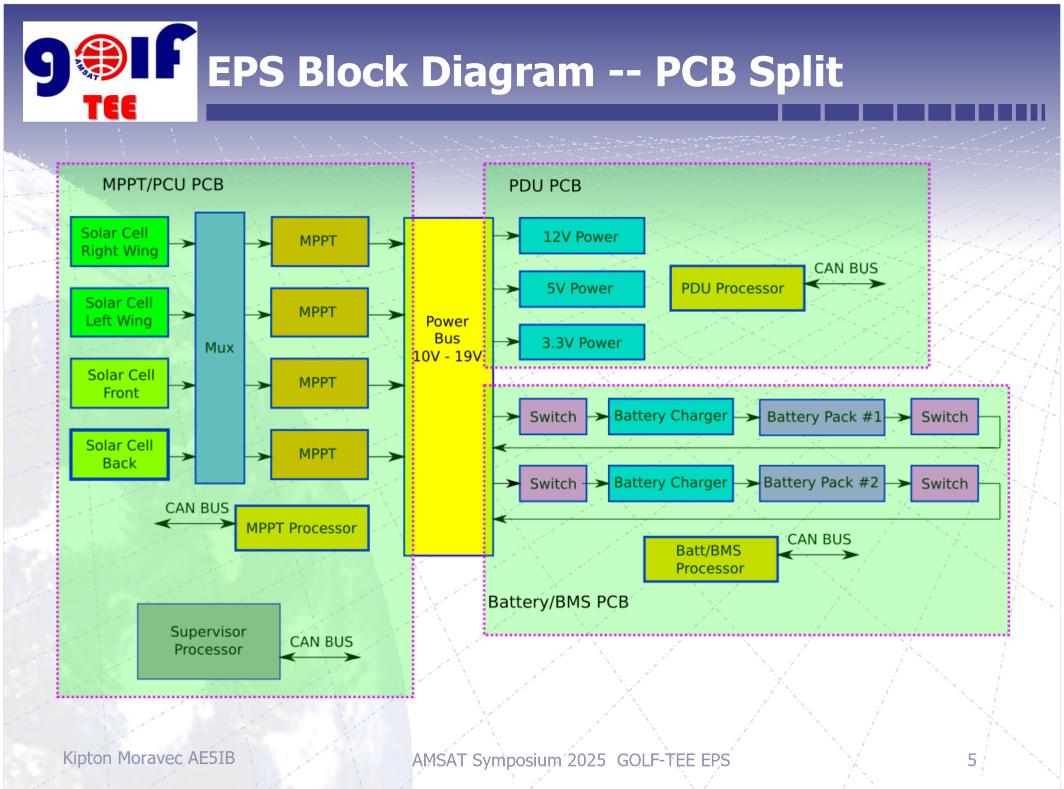
The Maximum Power Point Tracking or MPPT circuit is designed to get the most power from the solar cells and in the ideal case outputs 19V to the Power Bus. There is a processor dedicated to the MPPT chips to help keep them working together. And to provide power information to the system over the CAN Bus.

The redundant 12V, 5.1V and 3.3V power supplies provide power to all of the systems of the satellite.

There are two independent battery packs made of 4 18650 batteries in series. Each has its own charger and fuel gauge to show the state of the batteries.

Most of the chips are not radiation tolerant or hardened. The Supervisor Processor is radiation tolerant, and it will check the rest of the system to reset parts that are not working correctly from a radiation or other events.

All systems report status and telemetry information to the CAN Bus, which attaches to all the satellite subsystems and provides mostly the IHU with status of each subsystem.



This is how I split the blocks into the three PCBs.

The MPPT/PCU PCB takes the power from each solar panel and converts to 19V on the Power Bus.

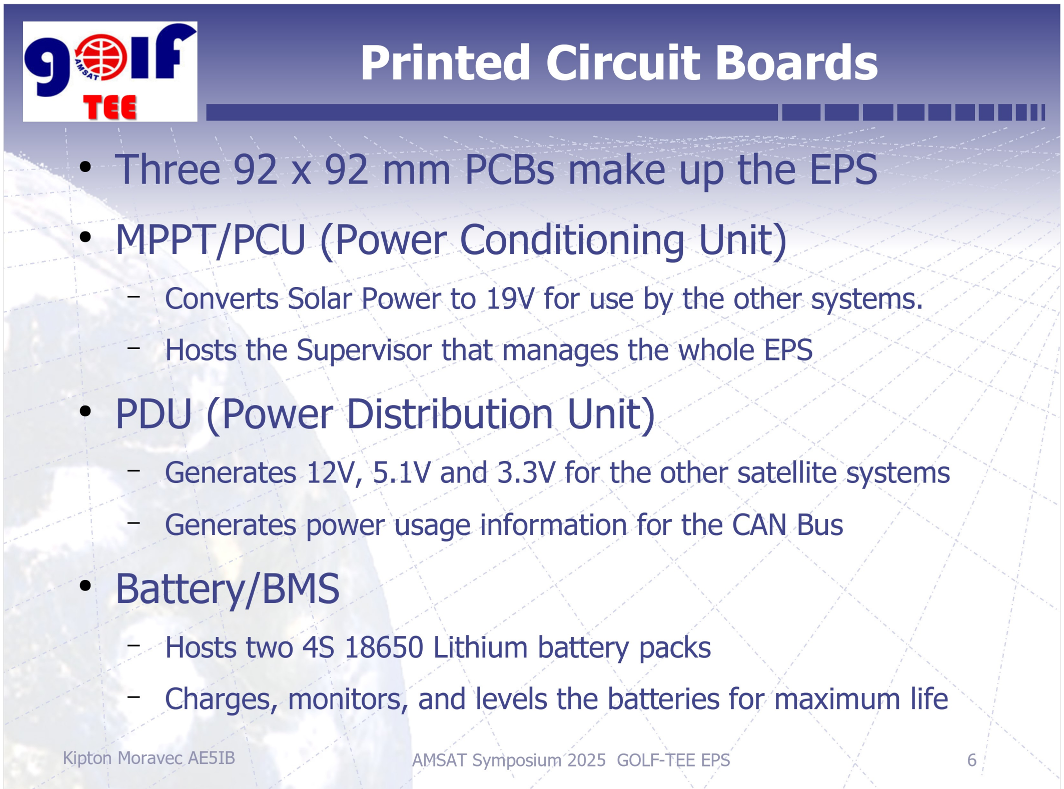
The PDU takes the 19V and converts it to 12V, 5.1V and 3.3V for the rest of te system.

The Battery/BMS uses the 19V to charge the batteries. When the MPPT cannot provide enough power for the system and the power drops, the batteries provide the power for the satellite operations.

The Supervisor processor monitors the operation of the EPS and determines if something has failed, and takes corrective actions. It is the only radiation tolerant processor in the EPS.

One of the changes from 2022 is placing processors on the PDU and Battery/BMS PCBs. This simplifies the inter board connections, and makes each PCB more independent and modular. It will be easier to test each PCB independently from the rest of the boards. And each PCB can report the status on the CAN bus without going through the Supervisor processor as originally envisioned.

All EPS processors will spend most of their time in low power sleep mode and only wake up when there is something to do.



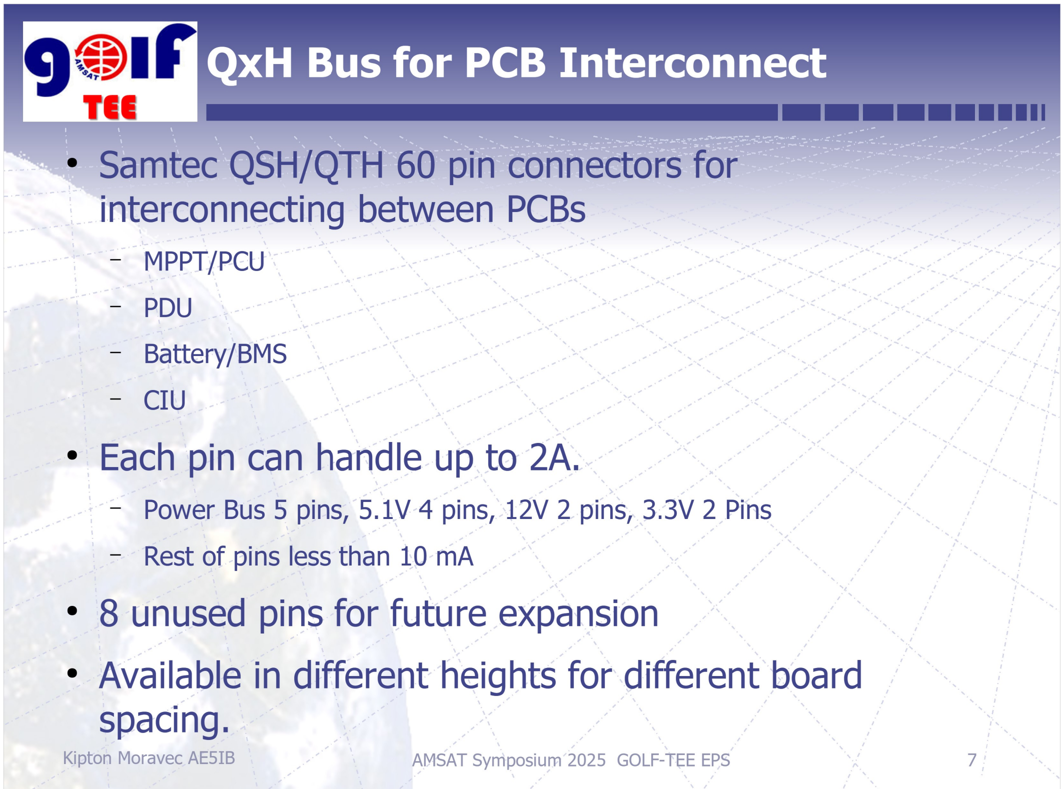
Currently three PCBs make up the EPS

First the MPPT/PCU which is Maximum power point Tracking / Power Conditioning Unit, is the densest PCB. It has 8 PCB layers.

Second, the PDU is the least dense PCB. It has 4 layers.

And third, the Battery/BMS PCB is in between on the density, with 6 layers. It has 4 18650 batteries on each side, and the charger, fuel gauge, and control processor. So the electronics are jammed together where the batteries are not.

One of the reasons we have so many layers is that we have a ground plane next to the outside layer to lower emitted radiation from the high frequency switching power supplies. This should help our RF receivers.



The stack of PCB have to have a connector connecting them with each other. We have chosen the Samtec QSH/QTH 60 pin connectors.

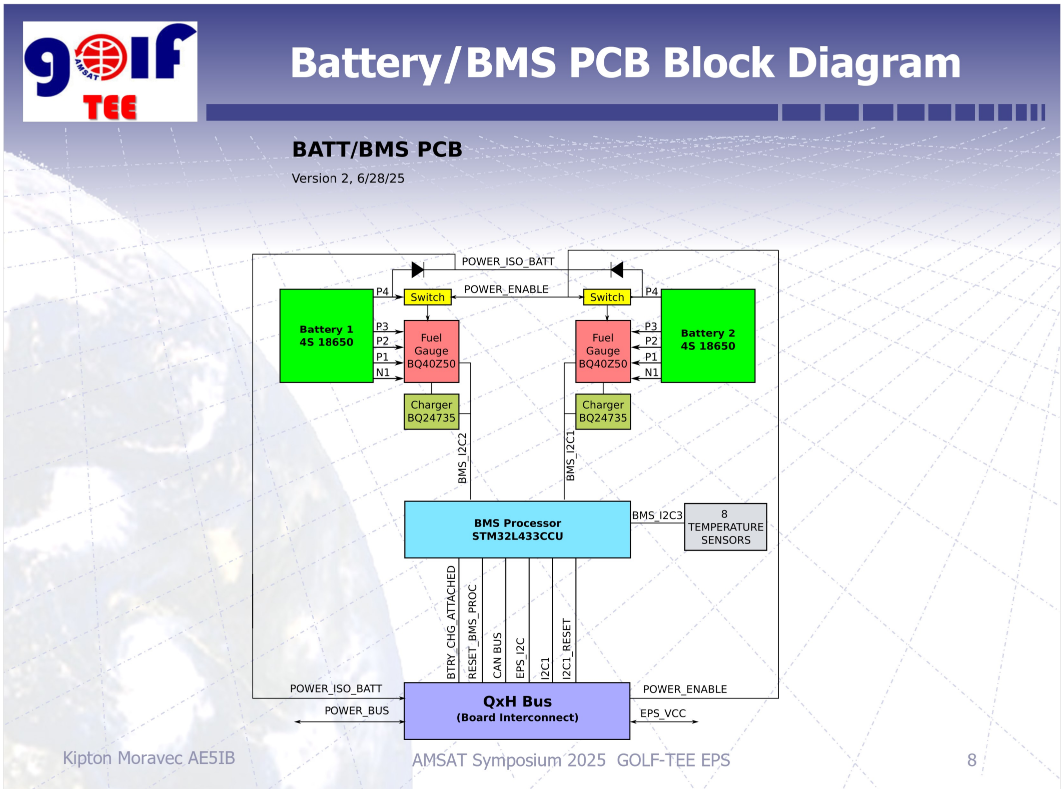
They are small with a pitch of 0.5 mm (19.7 mils) and the QTH part is available in different heights to accommodate different PCB spacing. For example the Battery/BMS PCB has 18650 batteries on each side, which are way taller than any of the components on the other PCBs.

Currently the MPPT/PCU, PDU, Battery/BMS, and CIU each have these connectors and they will stack together.

Each pin can handle up to 2A. While most of our connections are less than 10 mA range for signals, we use multiple pins for the power. The Power Bus uses 5 Pins, the 5.1V power uses 4 pins, the 12V and 3.3V power uses 2 pins each.

The connector has 4 additional separate ground pins that can handle up to 25A total.

Currently we have 8 pins unused for future expansion.



This is a block diagram of the Battery/BMS PCB

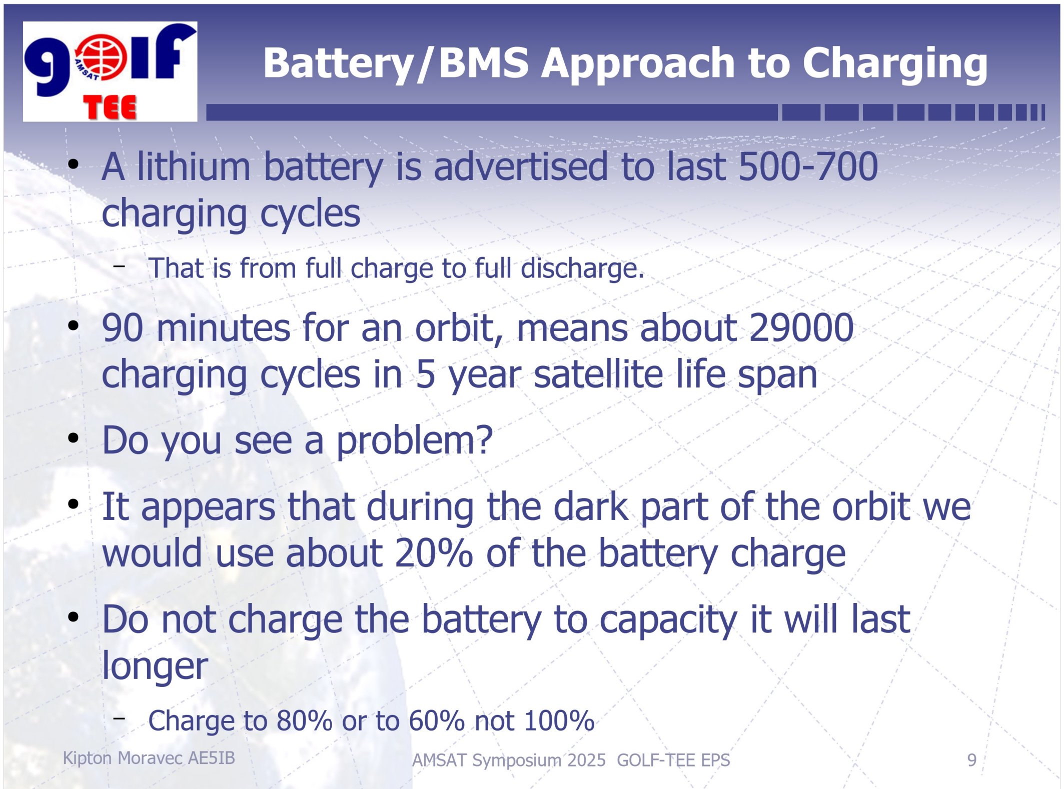
There are 4 18650 batteries in series to make a battery pack. There are two battery packs.

As you can see the batteries, fuel gauge and charger for each group are independent of each other. Because the charger chips have fixed I2C addresses I have two independent I2C busses from the processor for controlling the charge and reading the fuel gauge for the battery array.

Each fuel gauge has its own set of 4 thermistors to help control the charge and for reporting the state of the battery. In addition the processor also has 8 temperature sensors to closely monitor the battery temperature. Heat reduces battery life.

We are using the TI BQ40Z50RSMR-R2 Fuel gauge to track the charge of the batteries and to allow us to level them when needed. The data from this chip will be used to determine how to charge the batteries.

The TI BQ24735 Charger IC is used to charge the string of batteries. The fuel gauge chip could direct the charger without a processor. Its goal is to charge the batteries as quickly as possible safely. We have to take into consideration the rest of the power used in the system to limit the charge to available free power, not the maximum charge rate for the condition of the battery. So the charge will be under the control of the processor for each string.



A lithium battery is advertised to last for 500-700 charging cycles.

Our 5 year mission means 29,000 charging cycles.

That is a problem.

Fortunately for us, the 500-700 comes from full discharge to full charge. If you do not fully charge or fully discharge, you can get a lot more cycles.

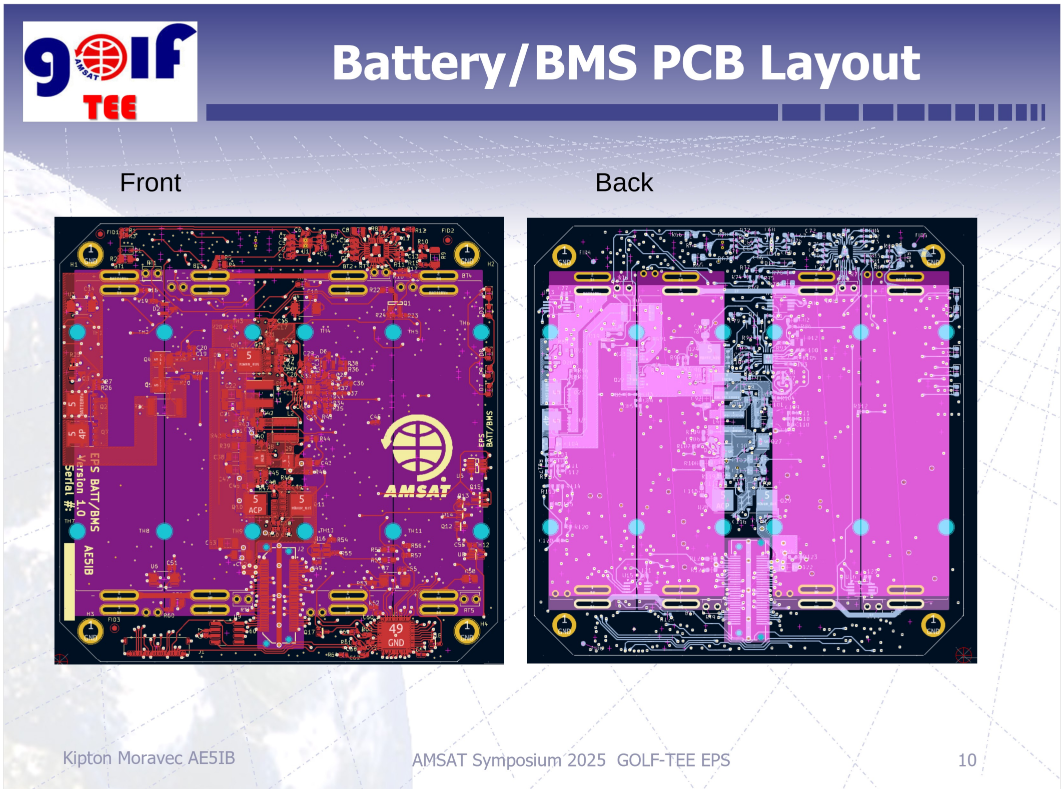
When I did the calculations, it looks like we will use 20% of the battery charge during the dark part of the orbit.

So if we charge the battery to only 80%, we will increase the number of charge cycles dramatically. 80% charge means it will discharge to 60% charge.

I am guessing if we charge to 60%, then it goes down to 40% charge and we can get even more charge cycles. But I have not seen any actual studies about it.

If one pack fails the other pack can still work since they are independent.

If both battery packs fail, the satellite will shut down during the dark times and wake up when there is light.



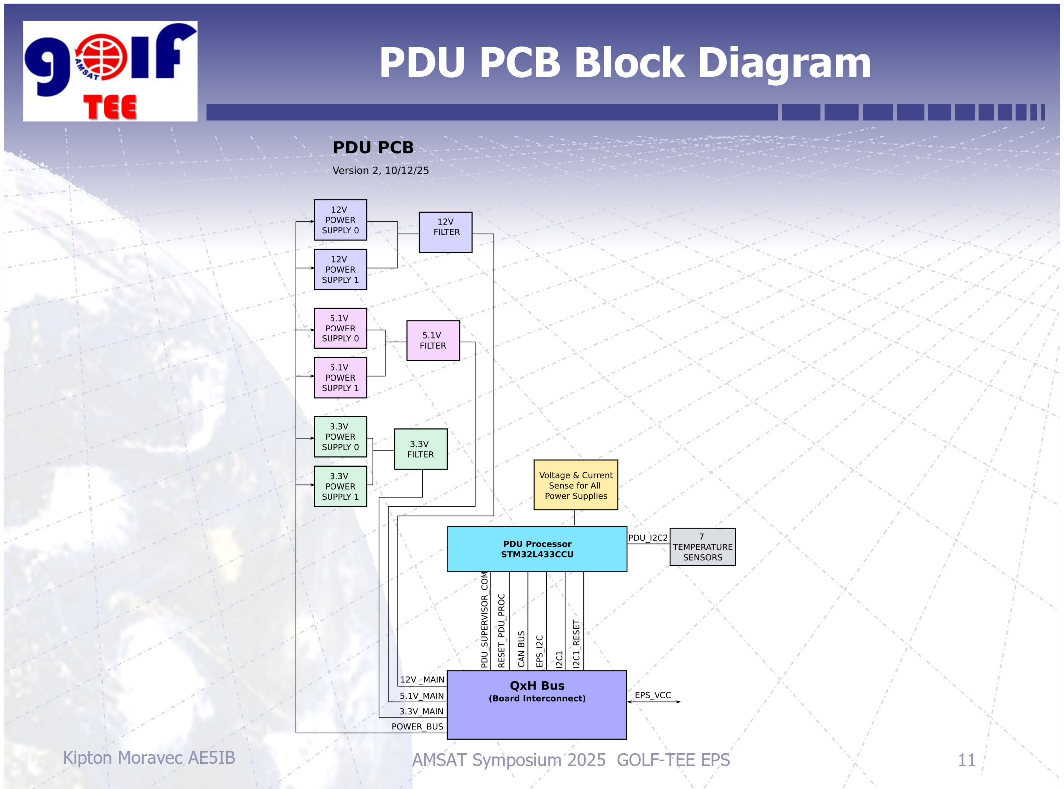
This is the front and back view of the Battery/BMS PCB.

I know it is hard to see, but there are a couple of things I want to point out.

First, there are two independent Battery and BMS systems on the board, and the BMS is in the same side of the board as the corresponding set of 4 batteries in series.

Second, there is one processor to help manage both sets of the battery management systems.

This is a 6 layer PCB.



This is a pretty simple board. As mentioned earlier it is a 4 layer PCB

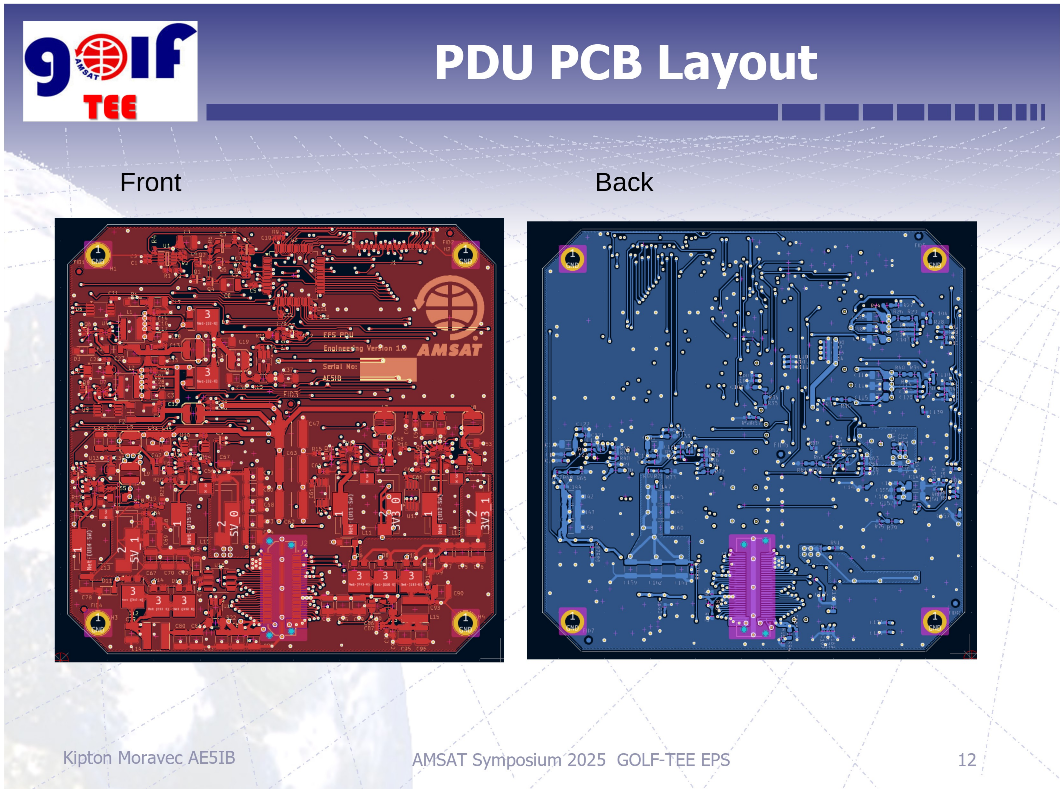
The Power Bus will provide 10-19V and this board converts the power to 3.3V, 5.1V and 12V for the rest of the satellite.

Each power supply is redundant. That means there are two 3.3V power supplies, two 5.1V power supplies, and two 12V power supplies.

One will be on and the other will be off. The processor will be monitoring and decide which is active.

With high frequency switching there is a concern of RF noise being generated by the switching power supplies. So there is a wide band filter on the outputs of the power supplies to knock down the switching noise that is in the RF frequencies.

Also like in all the boards there is a ground plane under the top layer to help minimize emitted radiation. The high current paths in the power supply have very wide copper traces again to minimize EMI. Finally we control the switching edges to reduce the high frequency parts of the edge.

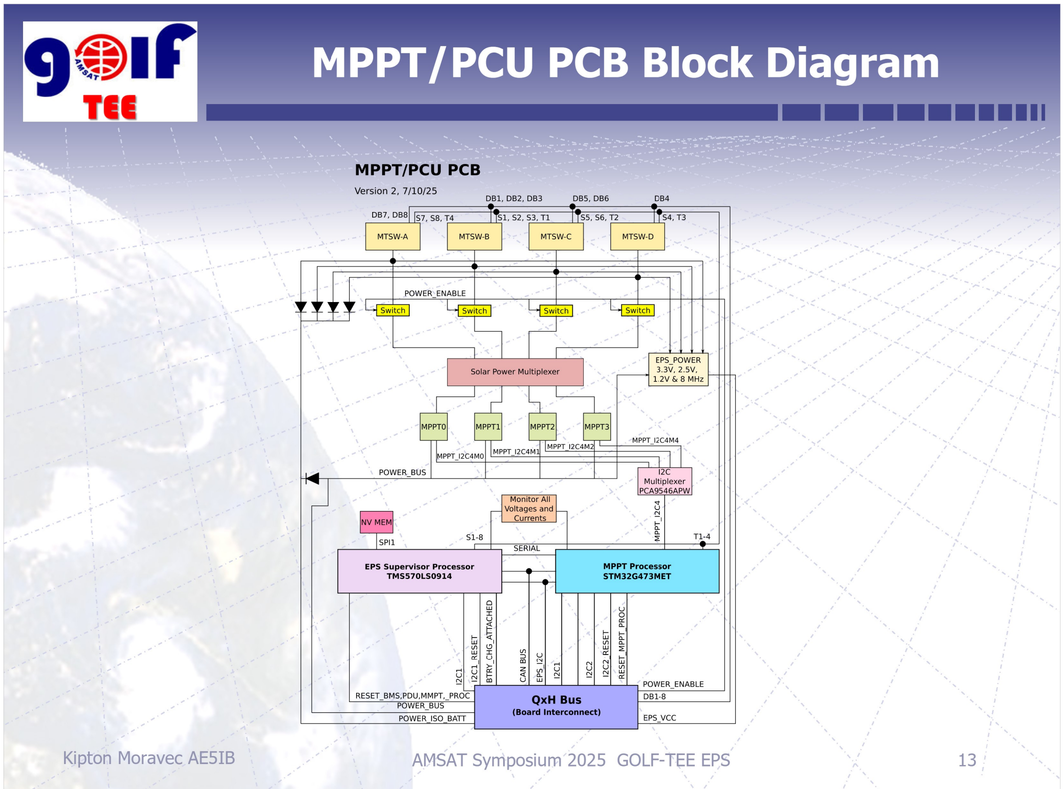


This is the front and back view of the PDU or Power Distribution Unit PCB.

I know it is hard to see, but there are a couple of things I want to point out on this one also.

This board has some extra space on it. The upper right quadrant does not have many parts on it. We have room for more functions.

This is a 4 layer PCB.



There is a lot going on in this block diagram.

First there are 4 independent MPPT chips. One for each set of solar cells. TI intended each system to have one MPPT charger so they gave it a fixed address. To talk to 4 devices with the same address you need either 4 different I2C busses, or an I2C multiplexer (MUX) to put each MPPT Chip on a separate segment. And then activate one segment at a time. On this board, I went with the MUX.

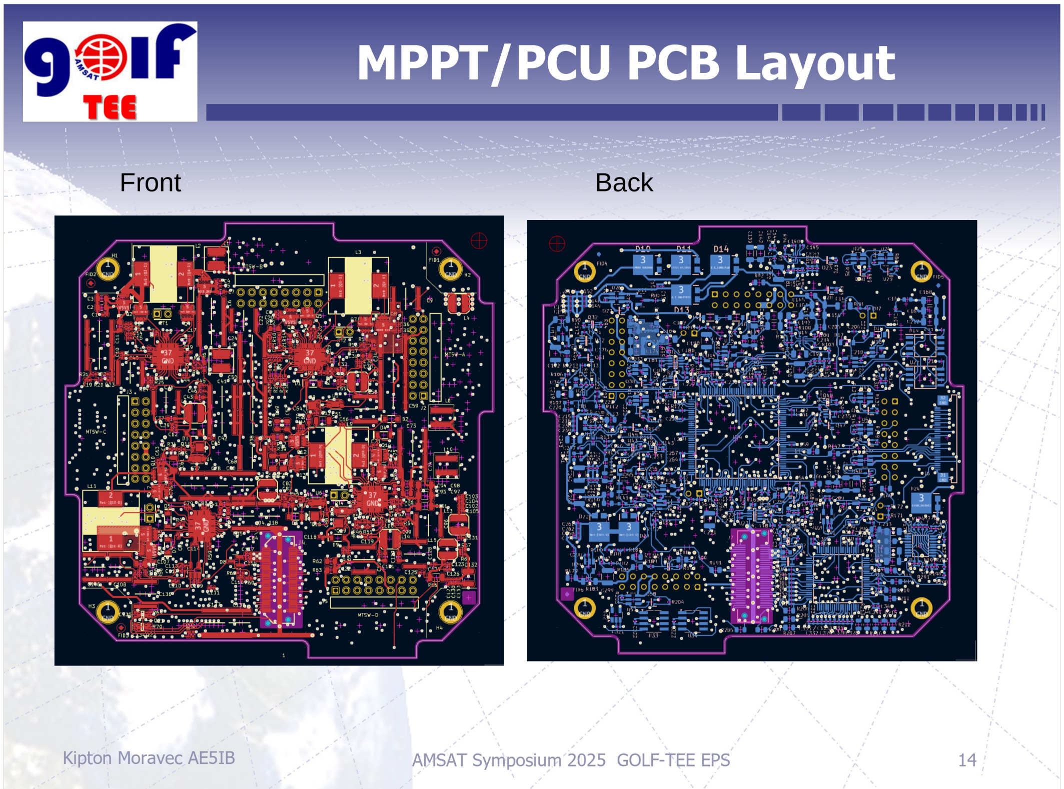
The TI BQ25756R is a MPPT charger chip. It is designed to charge a battery from a solar panel. However it can also be used as a MPPT Power Supply. However when used as a power supply, they recommend a 1000 uF capacitor on the output, so the voltage does not sag too much when they stop switching to check the output. I do not have room for a 1000 uF capacitor that is space qualified. So I am betting that with 4 of these in parallel, I will not need the additional capacitance.

The STM32G474VET3 is the processor to monitor and control the MPPT Chips. It checks each one and provides status information to the CAN Bus.

The MPPT/PCU board also has a 3.3V power supply that is independent from the PDU 3.3V for the rest of the satellite. This lets the EPS start up before the rest of the satellite gets power. It also has a 1.2V power supply required for the Supervisor Processor.

The MPPT also has a 2.5V reference and a 8 MHz clock that is used by all EPS boards. The reference makes sure all of the Analog to Digital conversions have the same result. The 8 MHz makes sure communications are exactly correct between each processor and there is a common time base.

The supervisor processor is a Radiation Tolerant TI TMS370LS0914 144 pin chip. It is also used on the RT IHU board for the satellite. I chose it because it was radiation tolerant, and is used elsewhere on the satellite so there is SW experience using it.



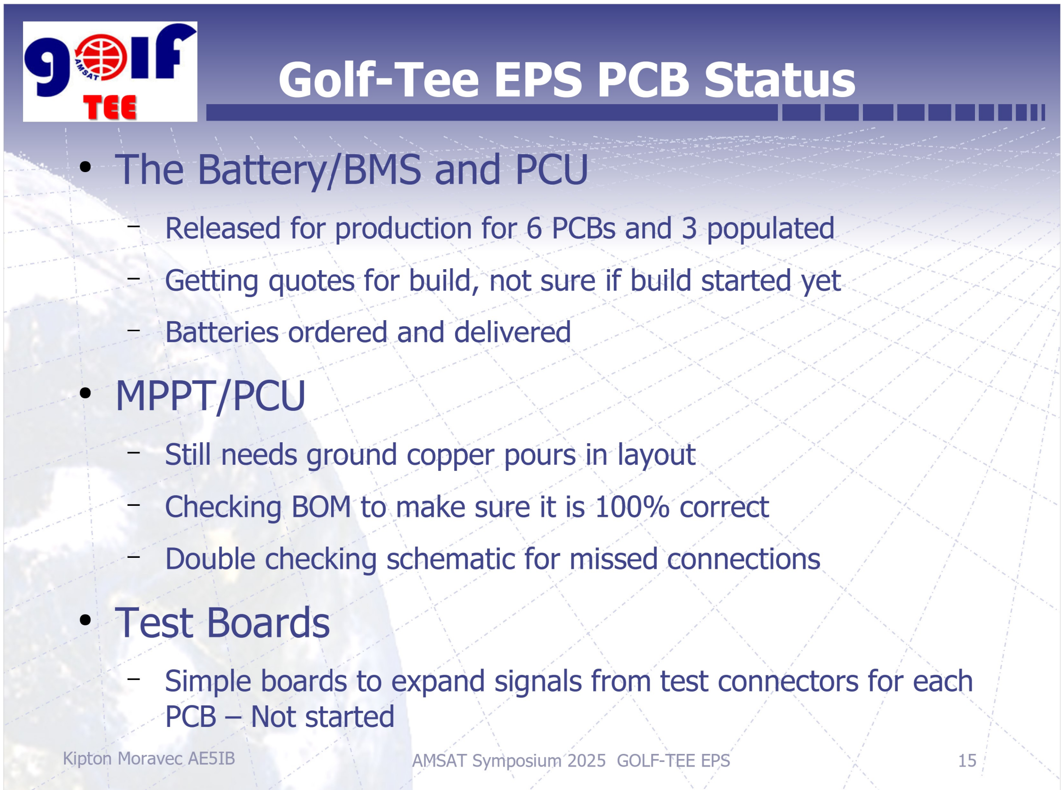
This is the front and back view of the MPPT/PCU PCB.

First, there are 4 connectors to the solar panels you can see on the top side.

Second, mostly the top side has the MPPT circuits, and the bottom side has the Supervisor Processor. Everything else is where it could fit.

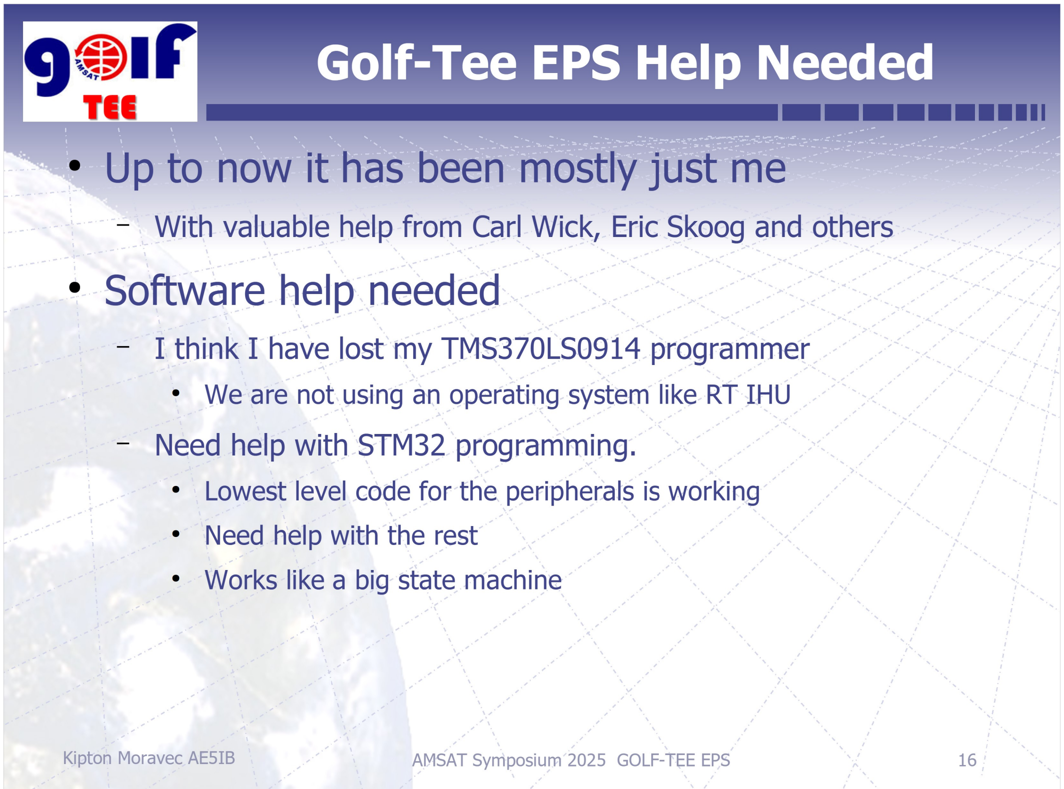
This is a very dense board. I tried to do it with 6 layers and could not make it work, so I had to go to 8 layers. The second and seventh layers are ground planes. And the 4 inner layers are connections.

The PCB images are not the final design. I still have to go in and put ground copper pours in the unused areas. This will help make the PCB lower RF radiation, or EMI.



The Battery/BMS and PCU assemblies have been released for production. We have been getting quotes to have them built, and I do not know if the build has begun.

The MPPT/PCU layout still needs the copper pours as I mentioned before. That is an automatic process in KICAD. I am going through the BOM to verify all the parts are correct. I am double checking all of the connections in the schematic to verify nothing is left hanging. Then it will be released. I am hoping for a release by the end of October 2025.



Now for my requests.

I am going to need help with software.

I have three boards with 4 processors that need programming. I cannot do all of them at the same time. And I really need to be concentrating on the MPPT part of the EPS.

My biggest concern is the TI TMS370LS0914 I have no experience programming it, and would love to have someone pick it up.

The three STM32 processors have working lowest level code for peripherals working, as I have been programming these chips for a while, and have base working code for all the peripherals which gives us a good start.


The End
Thank you for the opportunity to present at the 2025 AMSAT Symposium
Questions?
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