Unmanned Solar Powered Airship Concept Evaluation

Critical Design Report

Electrical Power System

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Normative References

Table 1 – *Normative References for this document*

Document title	**Doc. Ref. No.**	**Doc. status**
Preliminary Design Report - Electrical Power System	USPACE-PDR-EPS-A1	Review
Preliminary Design Report	USPACE-PDR-A1	Review

Acronyms

APR Array Power Regulator

BCR Battery Charge Regulator

BJT Bipolar Junction Transistor

CDR Critical Design Review

COTS Commercial Of-The-Shelf

DM Development Model

ECSS European Cooperation for Space Standardization

EMI Electromagnetic Interference

EPS Electrical Power System

FM Flight Model

GaAs Gallium Arsenide

IC Integrated Circuit

IGBT Insulated Gate Bipolar Transistor

MEA Main Error Amplifier

MPP Maximum Power Point

MPPT Maximum Power Point Tracking

MPPTU Maximum Power Point Tracking Unit

NTC Negative Temperature Coefficient

OpAmp Operational Amplifier

PCB Printed Circuit Board

PDR Preliminary Design Review

PSA Pressure Sensitive Adhesive

PWM Pulse Width Modulated

SAR Solar Array Regulator

SA Solar Array

TBD To Be Decided

TV Thermal Vacuum

UVP Under Voltage Protection

List of Figures

List of Tables

Contents

1 Introduction

The Electrical Power System (EPS) will provide sufficient power to the motors, communication system and payloads. Power is generated from solar cells and stored in batteries. DC-DC regulators are used to control the operating voltage of the solar cell and to provide regulated voltages to payloads and onboard computers.

1.1 Changes from PDR to CDR

The U-SPACE Preliminary Design Review (PDR) for the EPS is documented in [1]. Table 2 lists the major EPS design changes between the PDR and the Critical Design Review (CDR) and the argumentations behind these design changes.

Table 2 – *U-SPACE EPS design changes from PDR to CDR*

Area of change	**Changed parameter**	**Argumentation for change**
Total power budget	increased to $> 40\,W$	Increased airship total mass and size
Solar cells	New part	Old solar cell was much heavier than listed in manufacturer datasheet due to a glass cover
Total system cost	increased to $> 12000\,SEK$	Increased power requirements and new light-weight solar cells are more expensive
Solar cell mounting	New part	New solar cell is flexible instead of rigid and can be mounted with Pressure Sensitive Adhesive (PSA)

2 Functional and Technical Requirements

2.1 Functional Requirements

Below are listed the primary functional requirements for the EPS:

- Provide adequate power to motors and payload
- Proof that flying on solar energy is possible i.e more power produced than consumed

Additional desired requirements are:

- Scalability to higher power levels
- Flexible and robust design, allowing flight in more extreme conditions (altitude, weather etc.)
- Provide adequate protection circuits for battery and loads
- Optimal design and high performance to increase power capability and minimize system mass

2.2 Technical Requirements

The EPS technical requirements are listed in table 3.

Table 3 – *Technical requirements for the EPS*

Minimum power output	$40\,W$
Maximum mass	$1000\,g$(including solar arrays)
Maximum cost	$5000\,SEK^a$
Output voltages	$6.0 - 9.2\,V$(un-regulated), $5\,V$(regulated)
Maximum output current (worst case)	$10.5\,A$
Regulator phase margin	$60\,deg$
Regulator gain margin	$10\,dB$
Control loop bandwidth	$> 10\,kHz$
Operational temperature	$-20°C\,to + 25°C$
Battery capacity	$> 5\,Wh$

[a] Initial budget for 2 students.

2.3 Expected Performance

Table 4 – *Expected performance of the EPS*

Power conversion efficiency(overall)	$80 - 90\%$
Power output(overall)	$\sim 57 - 65\,W$
Battery capacity	$7.3\,Wh$
Mass	$\sim 910\,g$
Total cost	$\sim 12000\,SEK$[a]

[a] Solar cells are significantly more expensive than anticipated. A request for more funds is under preparation.

3 Critical Design

This section describes in more detail the EPS design. A simple block diagram of the EPS design is shown in Figure 1.

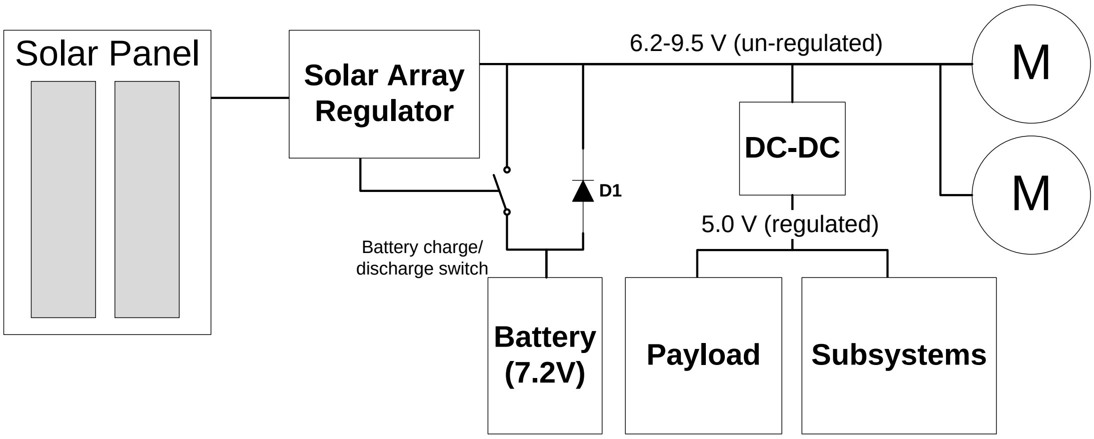

Figure 1 – *EPS simple blockdiagram*

3.1 Solar Array Design

As was mentioned in section 1.1, a new solar cell has been selected. This solar cell is shown in Figure 2 and Table 5 lists the important specifications for this cell.

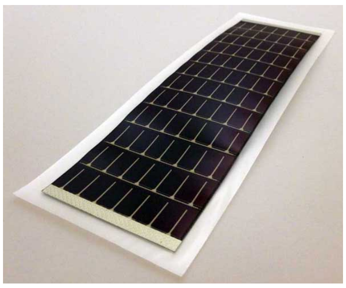

Figure 2 – *Chosen solar cell*

Table 5 – *Specifications of chosen solar cell*

Nominal output current	$100\,mA$
Nominal output voltage	$7.2V$
Nominal output power	$0.72\,W$
Dimensions	$270\,mm \times 90\,mm \times 0.2\,mm$
Weight	$7.6\,g$
No. of required cells	100[a]
Total solar panel area	$2.43\,m^2$ (assuming 100 % fill factor)

[a] [2] offers good discount for +100 units order

The solar panels will be configured with two series-connected solar cells thus having an output voltage of:

$$V_{panel,out} = 14.4\,V \tag{1}$$

3.2 Battery Design

Two Panasonic PA-L60.K02 [3] Li-ion batteries are used. The battery has the following important specifications:

Table 6 – *Specification of chosen battery*

Chemistry	Li-ion
Nominal voltage	$3.6\,V$
Capacity	$1.03\,Ah$ / $3.61\,Wh$
Weight	$25\,g$
Dimensions	$56\,mm \times 34.2\,mm \times 5.8\,mm$
Maximum charge current	$970\,mA$
Maximum discharge current (continuous)	$1.455\,A$

Future Recommendations The chosen type of Li-ion battery supports only a relative low charge- and discharge rate of about $1\,C$. For bigger battery capacity and higher loads, it is recommended to use a battery like [4] which provides much higher discharge rates ($> 20\,C$) and also cheaper price per Wh. Only disadvantage is a mass increase of around $15 - 25\%$.

3.2.1 Battery Charge Regulator

From the battery datasheet, maximum charge current is $I_{REG} = 970\,mA$. From the Battery Charge Regulator (BCR) datasheet, the minimum current sense resistor value is calculated as

$$\begin{aligned} R_{sense} &= \frac{V_{FCS}}{I_{REG}} \\ R_{sense} &= \frac{120\,mV}{970\,mA} = 123\,m\Omega \end{aligned} \tag{2}$$

The required thermal rating of the pass transistor is calculated as

$$P_{max} = (V_{in,max} - V_{bat,min}) \cdot I_{charge} = (9.5\,V - 5.5\,V) \cdot 970\,mA = 3.88\,W \tag{3}$$

3.2.2 Battery Temperature Monitoring

The BCR chip includes a temperature monitoring feature. The battery is rated, in charge-mode, to temperature in the interval $10 - 45°C$. The maximum allowed temperature is set slightly lower to $40°C$. The Li-ion battery has a build-in Negative Temperature Coefficient (NTC) thermistor with $B = 3980\,K$ and $R_{25} = 10k\,\Omega$. The required restance values of the temperature control resistors are determined from the BCR chip datasheet as

$$\begin{aligned} R_{cold} &= R_{25} e^{B(\frac{1}{T} - \frac{1}{T_0})} = 10\,k\Omega e^{3980\,K(\frac{1}{283\,K} - \frac{1}{298\,K})} = 20.3\,k\Omega \\ R_{hot} &= 10\,k\Omega e^{3980\,K(\frac{1}{313\,K} - \frac{1}{298\,K})} = 5.3\,k\Omega \\ R_{T1} &= 2\frac{R_{cold}R_{hot}}{R_{cold} - R_{hot}} = 14.2\,k\Omega \\ R_{T2} &= 2\frac{R_{cold}R_{hot}}{R_{cold} - 3R_{hot}} = 47.8\,k\Omega \end{aligned} \tag{4}$$

3.2.3 Battery Discharge Current Limiter

The selected MOSFET has a typical gate threshold voltage of $V_{Gth} = 550\,mV$. The chosen Bipolar Junction Transistor (BJT) has a typical collector-emitter voltage drop of $V_{CE} = 120\,mV$. The battery is rated for a maximum discharge current of $I_{discharge} = 1.455\,A$. The required current sense resistor is then calculated as

$$\begin{aligned} V_{sense} &= V_{Gth} - V_{CE} = 550\,mV - 120\,mV = 430\,mV \Rightarrow \\ R_{sense} &= \frac{V_{sense}}{I_{discharge}} = \frac{430\,mV}{1.455\,A} = 295\,m\Omega \end{aligned} \tag{5}$$

The exact required resistance must be determined by testing the precise parameters of the discrete components.

3.3 Maximum Power Point Tracking Regulator

In [1] it was decided to use a Maximum Power Point Tracking Unit (MPPTU) for the Array Power Regulator (APR) due to its high efficiency and robustness to changing environmental constraints.

In first step, only the DC-DC converter will be implemented. When time and resources allows the Maximum Power Point Tracking (MPPT) part will be added. A simple buck DC-DC converter topology is used, comprising a transistor, free-wheel diode, inductor and output capacitor. When the full MPPTU is implemented, it will operate in three different operation regions:

- Battery discharge MPPT - when the solar array input power is insufficient to cover the load power demand, the battery is slowly discharged in order to maintain the output voltage.
- Battery charge MPPT - when the solar array input is greater than the load power, the excessive power is used to recharge the battery.
- Input power limitation - when the battery is fully charged, the regulator will operate the solar array at a non-optimal voltage, thus limiting the input power to keep the output voltage constant. The extra potential input power is dissipated as heat externally on the solar arrays.

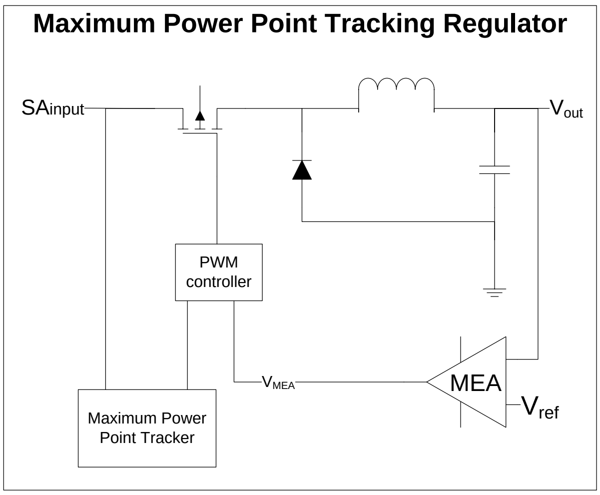

Figure 3 – *MPPT regulator diagram*

3.3.1 Mainbus Under Voltage Protection

The power from battery and solar cells is limited. It is thus possible that the motors will try to draw more current than what can be delivered. If this happens, the output capacitor of the APR will quickly discharge and the main output voltage drops out. To prevent this situation, an Under Voltage Protection (UVP) circuit is added. This is implemented using an $STN888$ PNP BJT along with two resistors, $R3$ and $R4$ as shown in Figure 4. When the main output voltage is around $6.2\,V$ the Base-Emitter voltage drop is close to $1.2\,V$ and the BJT is fully conducting and effectively works as a short circuit. If the output voltage drops significantly below $6.2\,V$ the BJT will begin to decrease the output current until the output voltage stabilizes. The current gain of $STN888$ is about 100, hence to allow an maximum output current of $10\,A$, the resistors $R3$ and $R4$ must be designed to pass $100\,mA$ at $6.2\,V$ output voltage. To minimize efficiency it is important that the forward voltage drop of the BJT is kept as low as possible.

Further Recommendations It is hard to find suitable BJTs rated for much more than $5\,A$. If the power output is increased in future designs, it is suggested to either parallel connect several BJTs however this might cause issues with thermal runaway. Alternatively high current Insulated Gate Bipolar Transistors (IGBTs) can be used, however they have higher forward voltage drops and thus they are more suitable for a design with a higher output voltage.

3.4 Complete EPS Diagram

The complete EPS diagram is shown in Figure 4. For providing the $5\,V$ regulated voltage to the payloads, Commercial Of-The-Shelf (COTS) DC-DC regulator(s) are used. The battery charging/discharging is controlled by the Solar Array Regulator (SAR).

3.5 External Interfaces

The interfaces of the EPS external are listed in table 7.

Table 7 – *External interfaces*

External interface	Implementation
Solar cells mounting	PSA
DC-DC regulators	Mounted on PCB which sits in system housing. Thermal contact points should be included, to remove internal heat dissipation.
Battery telemetry	Analog signals to Microcontroller
Mounting of batteries	To Be Decided (TBD)
Supply voltages	$6.0 - 9.2\,V$ (unregulated) and $5.0\,V$(regulated)

3.6 Telemetry and Telecommands

The required/recommended telemetry and telecommands, EPS , are listed in table 8.

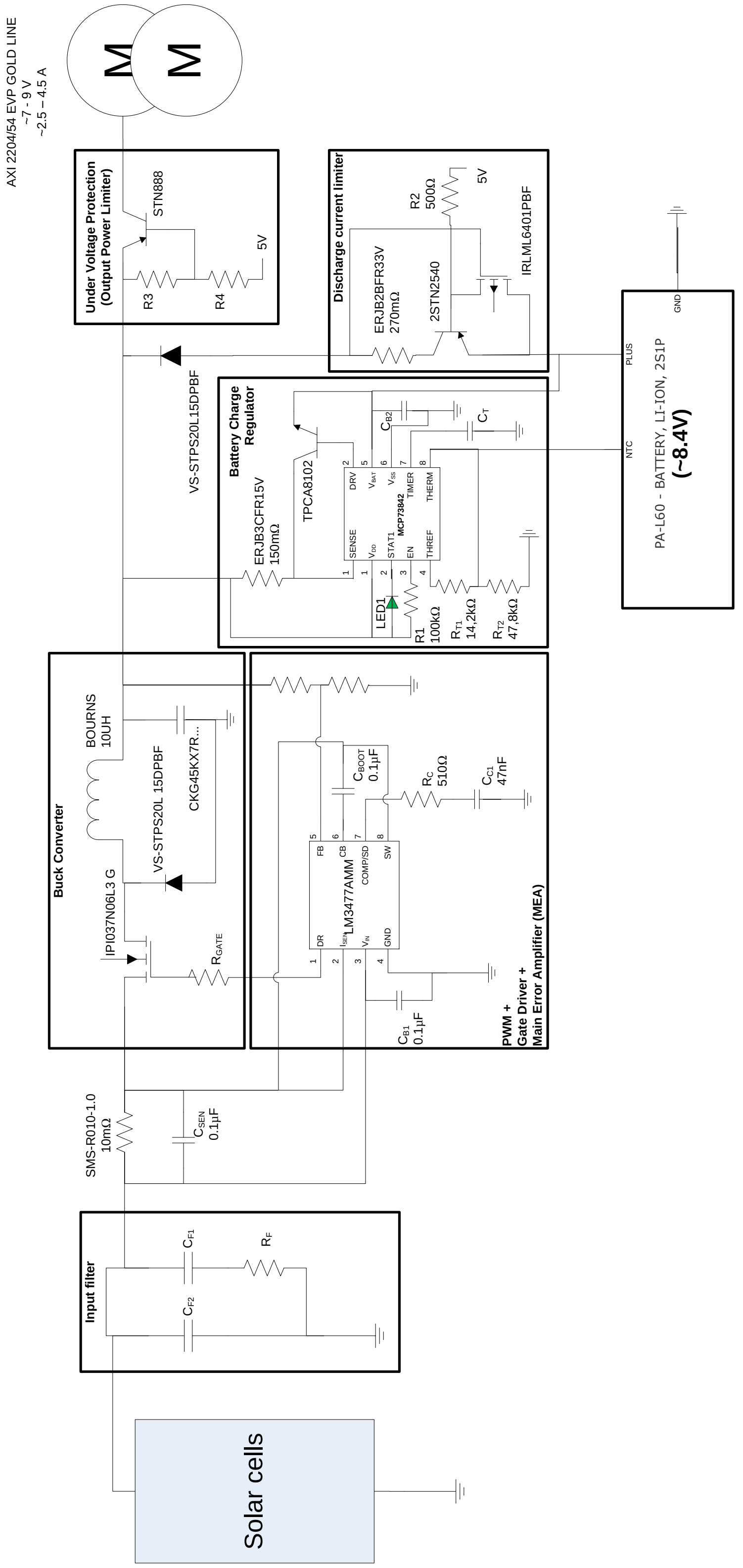

Figure 4 – *EPS detailed block diagram diagram*

Table 8 – *Telemetry and telecommands*

Telemetry	Data rate/frequency	Data size
Battery voltage	Every 30 sec	2 bytes
Battery temperature	Every 5 sec	2 bytes

4 Test and Verification of Design

4.1 Preliminary Verification of Design

TBD...

4.2 Design Models and Verification Methods

PSpice Simulations

PSpice transient and average simulation models of the SAR will be created. These will help in the design and testing of the regulator performance and system stability during transient loading.

Development Model

A Development Model (DM) will be build using self-made "mini-mount" pads and mainly surface-mount components, to minimize parasitic effects. System stability will be tested using a Network Analyzer and MPPT performance will be tested in a Thermal Vacuum (TV) chamber cycling the solar array temperature.

Flight Model

If time allows, a dedicated Flight Model (FM) will be build, using a custom designed Printed Circuit Board (PCB) schematic layout. An optimized PCB layout will minimize the system mass and size while maximizing the efficiency and system robustness.

5 Resources and Scheduling

5.1 Main Tasks

TBD...

5.2 Parts List and Costs

TBD...

5.3 Electronics Ground Support Equipment (EGSE)

TBD...

References

[1] M. Olsen, D. Agten, and Z. Hao. *Preliminary Design Report - Electrical Power System*. Tech. rep. USPACE-PDR-EPS-A1. Luleå University of Technology, 2012.

[2] Avnet Express. *RC7.2-75 PSA*. http://avnetexpress.avnet.com. 2012.

[3] *PA-L60.K02*. http://se.farnell.com/panasonic/pa-l60/battery-li-ion-1s1p-3-7v-1-03ah/dp/1900166. 2012.

[4] RC Flight. *LM Fast Charge 2300 2S 20C LiPo*. http://rcflight.se/visaprodukt.aspx?id=1495.