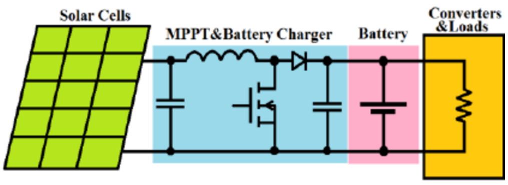
1. Introduction

This report describes the main characteristics of the Electrical Power Subsystem of ValiSat and the design process of its main components.This tutorial is linked to the ValiSat spacecraft model, which will allow you to better understand the design process and create your own similar satellite model in Valispace.



2. Solar arrays sizing

2.1. Design sequence

2.1.1. Estimation of power required from solar arrays

The satellite's solar arrays must be able to provide enough power to support the spacecraft's operations when in sunlight, but also recharge the batteries during eclipses. The power required from the solar arrays P_{sa} will then depend on the power required during daylight, the time of daylight, the power required during the eclipse, the time of eclipse, and the efficiencies of power transfer (from arrays to loads \chi_d and from arrays to batteries and then to loads \chi_e):

$$P_{sa} = \frac{\frac{P_d t_d}{\chi_d} + \frac{P_e t_e}{\chi_e}}{t_d}$$

With a daylight power request of *810.0 W* a time of daylight of *5481.50255205 s*, an eclipse power request of *688.5 W*, a time of eclipse of *982.523770149 s* and efficiencies \chi_d and \chi_e respectively *0.8* and *0.6* , the total power that the solar arrays must provide is *1.21818193037 kW*.

2.1.2. Ideal power flux density evaluation

Considering that the solar flux density (in W/m2) at Earth orbit has an average value of *1368.0 W/m**2*, the different solar cell technologies have a different value for efficiency \eta_{cell}. Considering Ga-As cells with efficiency *0.36* , allows to calculate the ideal power flux density collected by the panels:

$$\Phi_{id} = C_s \cdot \eta_{cell}$$

The resulting ideal solar flux is *492.48 W/m**2*.

2.1.3. Begin of Life power flux density

Now, to evaluate the power flux density at the Begin of Life (BOL), the ideal flux density must be decreased by taking into account an inherent degradation I_d due to the cell assembly, and a the worst solar rays incidence \theta_{max}, to take into account cases where sunlight is not perpendicular to the panels:

$$\Phi_{BOL} = \Phi_{id} \cdot I_d \cdot \cos(\theta_{max})$$

With an inherent degradation factor of *0.954838648874* and a maximum angle of *1.0 h*, the solar flux density at BOL is *347.757983984 W/m**2*.

2.1.4. End of Life power flux density

The power that the solar array shall be able to produce at the End of Life (EOL) depends on a lifetime degradation factor L_d that is calculated as follows:

$$L_d = (1 - F_d)^{N_{years}}$$

With a yearly degradation factor F_d of *0.0092* , the lifetime degradation of the solar arrays after *5.0 years* is *0.954838648874* . Hence the power flux density at EOL will be:

$$\Phi_{EOL} = \Phi_{BOL} \cdot L_d$$

Considering the previous data, the value of \Phi_{EOL} is *332.052763562 W/m**2*.

2.1.5. Sizing of solar arrays area and mass

To evaluate the required area of solar arrays, it is necessary to confront the required power with the actual capacity of the solar array technology with the following formula:

$$A_{sa} = \frac{P_{sa}}{\Phi_{EOL}}$$

The resulting area will be *3.66863963818 m^2*

To compute the solar arrays mass, an area density \rho_{area} in kg/m^2 is used:

$$M_{sa} = A_{sa} \cdot \rho_{area}$$

Choosing an area density of *10.0 kg/m**2*, the resulting mass is *36.6863963818 kg*.

3. Battery sizing

3.1. Introduction

3.1.1. Technology values

The technology chosen for the battery is Lithium-Ion; the main technological parameters are reported in the following table.

	Value	**Symbol**
Depth of Discharge	*35 percent*	DOD
Battery efficiency	*1.045*	\eta_bat
Battery efficiency	*7.36e-3 1/years*	\F_factor

Technological parameters for the battery

3.2. Design sequence

3.2.1. Capacity required during the eclipse

This first step consists in evaluating the power needed by the system during the eclipse. In the case of ValiSat, it was determined that this power corresponds to the maximum of the four modes (nominal, peak, standby, off). This results in a power request of *810.0 W*.

The eclipse time depends on the orbit. For ValiSat, this value results of *982.523770149 s*.

Finally the required capacity of the battery can be calculated with the following formula:

$$C_{req} = P_{req} \cdot t_e$$

The resulting value is *187.907671041 W*h*.

3.2.2. Capacity at End of Life (EOL)

To evaluate the capacity that the battery must have at the End of Life, it is necessary to take into account its inherent efficiency (not related to time) and the chosen Depth of Discharge. The capacity will then be:

$$C_{EOL} = \frac{C_{req}}{\eta_{bat} \cdot DOD}$$

With a battery efficiency of *1.045* and a DOD of *35.0 percent*, the resulting capacity at End of Life is *513.759866141 W*h*.

3.2.3. Capacity at Begin of Life (BOL)

The capacity of the battery at BOL is evaluated taken into account the battery life time and the degradation rate that it will accumulate with time:

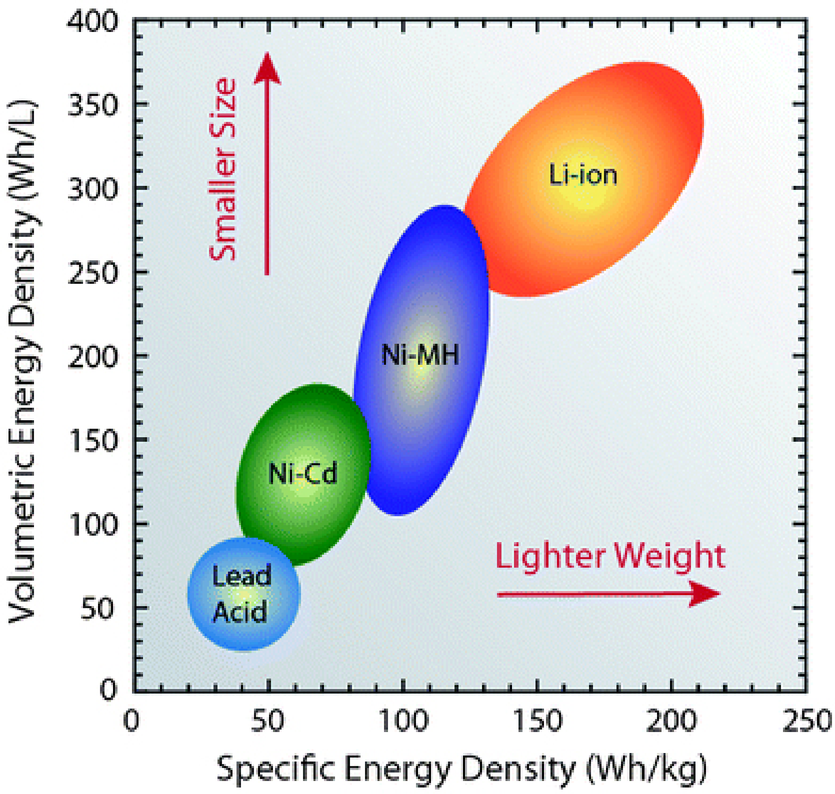
$$C_{BOL} = \frac{C_{EOL}}{1 - F_{fading} \cdot N_{years}}$$

For a *5.0 years3.35 A*h* mission and with a degradation of *0.00736 1/years0.2 deg*, the capacity at BOL is *533.388565346 W*h13.74 kg*, which corresponds to *19049.5916195 mA*h* if a voltage of *28.0 V* is considered.

3.2.4. Estimation of mass and volume

Specific mass and energy density depend on the battery technology chosen. In the following table, various technologies are reported with the relative values. For this exercise, a Lithium-Ion battery is chosen.

Technology	Specific mass [Wh/kg]	Specific mass [Wh/kg]
Nickel Cadmium (Ni-Cd)	60	130
Nickel Metal Hydride (Ni-MH)	110	200
Li-Ion	170	300



Now, once capacity is assessed, empirical values for specific mass \(m_{spec}\) (measured in *Wh/kg*) are used to estimate the mass with the following formula:

$$M_{bat} = \frac{C_{BOL}}{m_{spec}}$$

Choosing a specific mass of *300.0 W*h/liter*, the resulting battery mass is *3.04793465912 kg*.
The volume of the battery depends on the energy density (in *Wh/liter*), which is another parameter depending on the chosen technology. Considering the formula:

$$V_{bat} = \frac{C_{BOL}}{e_{density}}$$

With an energy density of *300.0 W*h/liter*, the total volume is *1.77796188449 l*.

4. References

- Space Mission Analysis and Design (SMAD), 3rd Ed., James R. Wertz and Wiley J. Larson (1999)