NARVIK UNIVERSITY COLLEGE

HIN – Project report
Master of Science

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Abstract:
The technical solution to the power supply and management system onboard the nCube satellite contains of three major parts; the micro controller, the solar cells and the battery. In this report we will discuss different solutions for the power supply system. We have also looked into testing and backup solutions.

Keywords:
CubeSat, Power supply, Power management, Embedded system, Solar cells, Battery, Micro controller

Norske stikkord:
CubeSat, Strømforsyning, Strømfordelning, Innebygde system, solceller, batteri, Mikrokontroller

Preface

This report is a proposal to a technical solution of the power supply and management system to a CubeSat. We are three students who have worked on the project which has resulted in this report. The Norwegian Space centre has decided that Norway should build its first student satellite (in fact Norway's first) and it is why our work is done.

It would not be any problem to build a power system to a CubeSat, many have already been built and much information is availably at the Internet. The thing about these systems is that they are relatively simple and doesn't use the solar cells and batteries at an efficient way. Since we didn't new anything about the pay load of the satellite we concluded that our task were to try to get as much power as possibly available. That could only be done by constructing an effective charging and management system controlled by a microcontroller.

There are many people that have helped us in our work; here are some we specially want to mention.

Waldemar Sulkowski	-recourse at HiN
Per Johan Nicklasson	-room and equipment at HiN
Sverre Mortensen	-computer system administrator at HiN

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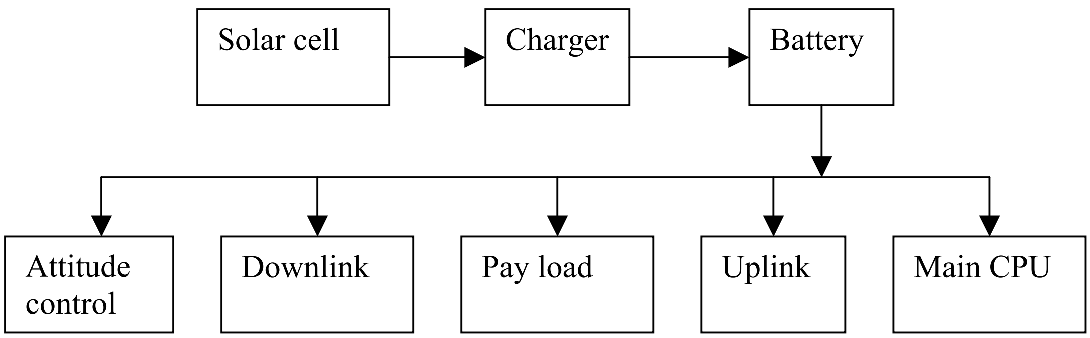
Abstract

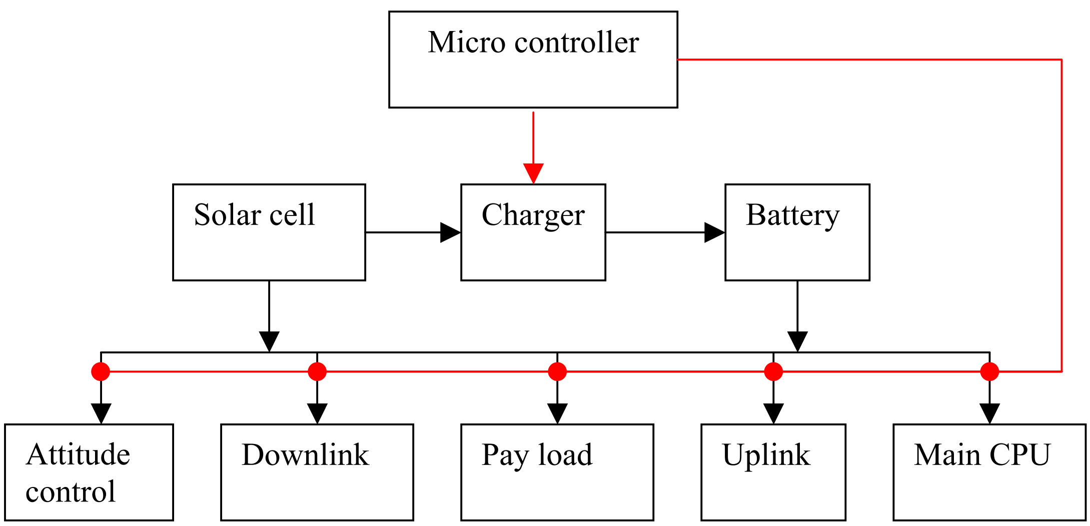
Power supply and management systems of satellites consists of three major parts; solar cells, battery and microcontroller. Other CubeSat projects, already been made, are generally made simpler without the microcontroller. The small calculations which are needed in these systems are made by the satellites main CPU. The problem with these systems is that they aren't so effective.

These systems are basically constructed like this:



The point is that all power is drawn directly from the battery. This isn't an effective way of handling the power since both the charging circuit and the battery doesn't have 100% efficiency. The booth efficiencies are multiplied with each other resulting in a lot of power is spilled. A much better way would be to use power directly from the solar cells when it is possibly. Another thing about simpler system is that all power system control must be handled by the main CPU.

The conclusion is that it is better to use a more advanced system which includes a microcontroller that handles the power system. By doing that, much can be solved. If an active charging control controlled by the micro controller is used, its possible chose how much power that can be drawn directly from the solar cells. The microcontroll can also control the other parts of the satellite and turn off the parts not in use. If different parts need different voltage levels the microcontroll handles the dc/dc converters to make sure that the power always is handled in the right way (most energy efficient). The more components the power is handled by, the more is lost due to lack of 100% efficiency. At the picture there is a simplified schematic picture of how such a system could look like.



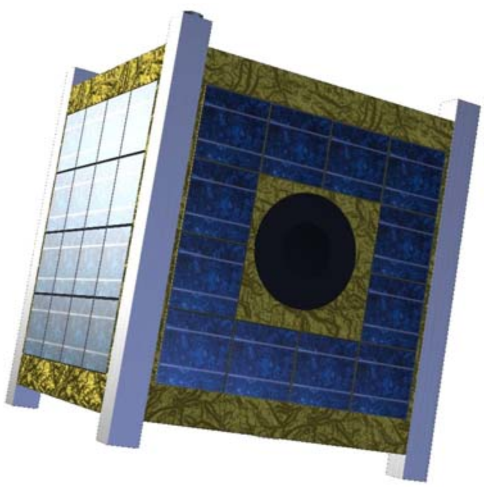
Introduction

Concept

The CubeSat concept is developed by Stanford University (USA). The concept is developed to be able to launce several satellites at nearly the same time from a launcher. The launcher, or the P-POD (Poly Picosatellite Orbital Deployer), is developed by California Polytechnic State University. Each P-POD contains three CubeSats which will be deployed in a sequence. The rocket (launch vehicle) could contain several P-PODS. This is developed to keep a low cost launch.

Specifications nCube

Size:	10x10x10 cm
Mass:	1 kg
Orbit:	Low polar orbit (600 km)
Launch site:	Kazakhstan
Launch date:	Summer 2003



Picture 1: CubeSat

Solar cells

The solar arrays are the only source of gathering energy. Therefore this is the most essential part of the satellite, but also the most expensive one. There are several different types of solar cells, and therefore also different qualities. The first solar arrays were made of silicon (Si) in the 1950's with the efficiency around 7-8%. In the 1960's these cells had reached an efficiency of 12%. Through the 1970's Gallium Arsenide (GaAs) and Indium Phosphor (InP) were the most efficient cells among others. The efficiency had reached 16-18%.

During the 80's and the 90's GaAs cells is the kind that is most used. This is because it's the most inexpensive to construct, due to price and efficiency. The solar cells are built in multilayer, and the efficiency has reached 25-27%. These numbers are at best conditions; they will drop as they're getting warmer.

While studding the nCube project we have been in contact with several companies regarding choice of solar cells. Dutch Space, in the Netherlands, where not able to deliver GaAs solar cells in small sizes. There main goal is to deliver solar arrays to bigger satellites, therefore they were measuring in square meter, kilo watt and weren't able to help us. EMCORE is another company in USA, and they have offered us 100 pieces 2x2 centimeters GaAs single junction solar arrays with the efficiency of at lease 18% for a price of 3500$. With these cells there would be possible to connect 20 cells on each side, and meet the voltage demand. They also produce triple junction GaAs cells, with an efficiency of 26.5 %. But the size of these arrays is measuring 6.89 x 3.95 cm2, which leads to only cover 50-60% of the total surface. Since these cells only have a string voltage of 2.2 V there might be a problem gaining enough high output voltage, (2*2.2V=4.4V). Most of the charging regulators usually need a higher voltage. This could be solved by a step up converter (dc/dc converter), but since they don't have a 100% efficiency it might be better to try to have a higher string voltage at the solar cells.

Since the sun isn't shining at all sides of the satellite at the same time, there will be different voltage levels at the different sides of the satellite. The solar cell strings needs to be shielded from each other to prevent short circuit. That is made by connecting a diode parallel by the cell string. That will cause a voltage fall by ~0.6V. If the string voltage is high the diode doesn't affect the output effect as much as if it were low.

On the other hand, if the voltage difference between the solar cells and system voltage is big then it is necessary to use a step down converter. As step down, step up converters doesn't have 100% efficiency but they are generally better. See *Dc/Dc chapter*.

Table of solar cells

Solar cell	Width (m)	Length (m)	Area (m2)	Cell area (m2)	Eff
SpectroLab triple junction	0,0689	0,0395	0,00272155	0,002692	~27
Emcore triple junction	0,0761	0,03716	0,002827876	0,00275	~27
Emcore single junction	0,02	0,02	0,0004		~18

Table 1: Table of solar cells

To find out how much energy the solar cells can deliver we have made some simple calculations were the two different types (single junction and triple junction) have been compared. Some simplifications have been made; these should not make any difference since they are the same in the two calculations. Eclipse is said to be 33% and the area towards the sun is always 1.41*cell area on one side.

Energy from sun	1352	W/m2
Solar cell area/side	0,00538	m2
Eclipse	33	%
Area towards the sun	0,00761	
Solar cell efficiency	26,5	%
Power after the solar cell on average	1,82775	W
Power after the solar cell	2,72799	W

Table 2: Table of triple junction solar cells

Energy from sun	1352	W/m2
Solar cell area/side	0,008	m2
Eclipse	33	%
Area towards the sun	0,01131	
Solar cell efficiency	18	%
Power after the solar cell on average	1,84471	W
Power after the solar cell	2,7533	W

Table 3: Table of single junction solar cells

As you can see, the power available after the solar cells is about the same. If you have in mind that single junction cells suitable for nCube costs about 3500$ and triple junction costs according to Aalborg University of Denmark about 1.2 million DKr/square meter (~140000$), the choice shouldn't bee too difficult.

However if some company produced triple junction solar cells that were better suited for the cube sat, they would be outstanding. F ex if 90% of each the side of the satellite were cowered with triple junction solar cells there would be an average power of about 3 W.

There is certainly some company that could produce arrays in the exact size, but it's going to be very expensive.

Another problem that has been discovered during the project, are that it will be necessary to have a special clearance to import solar cells from the USA to China or Russia. The nCube should be launched in Kazakhstan and therefore this clearance would be necessary. (We confronted EMCORE with this problem, and they told us that such a clearance would take approximately 6 weeks to get.)

It is important to point out that the *Power after the solar cell on average* and *Power after the solar cell* is the power directly after the solar cells (we have regarded the diodes on the cells). Some power is going to be lost in the power management circuit (charging, batteries, DC/DC converters etc).

Batteries

The batteries is the power storage onboard the satellite. They will be charged by the solar cells through some kind of charger/ regulator. Batteries are produced by almost every known electrical company, so this is of non concern. It's of concern to find the best battery due to shape, weight and efficiency.

Since the consumption of power to the other parts (payload etc.) in the satellite is unknown, it is very hard to calculate the size of the needed energy storage. It depends on eclipse time, big currents needed for a short period of time and the type of power management system used.

On all the other CubeSat projects they have concluded that Li-Ion batteries are best suited for this purpose. Below there is a list of advantages/ disadvantages for Li-Ion batteries. There is a list of several other batteries concerning advantages/ disadvantages in the report from NTNU (Power unit group).

Li-Ion

Advantages
+Sealed cells; no maintenance required.
+ Long cycle life.
+ Broad temperature range of operation.
+ Long shelf life.
+ Low self-discharge rate.
+ High columbic and energy efficiency.
+ High energy density and specific energy.
+ No memory effect.

Disadvantages
- Moderate initial cost.
- Degrades at high temperatures.
- Need for protective circuitry.
- Capacity loss or thermal runaway when overcharged.
- Venting or possible runaway when crushed.

(Since this is a technical solution we shall not discuss this anymore in this report, we have only concluded that Li-Ion is the batteries we want to use.)

The Li-Ion batteries shouldn't be charged below 10 °C and this can cause a problem as the solar cells charging the batteries have its best efficiency at low temperatures. The solution of this problem could be to place the batteries right beneath the solar cells. The batteries should get heated relatively fast and be able to pick up energy. This solution depends on if the satellite rotates. If one side of the satellite is in the shadow all the time and the batteries are placed there, the heating process takes much longer time and the solution fails. In that case some kind of heating device might be needed.

The size of the battery is depending on if some part of the satellite needs battery power at the time when charging not yet taken place. Another aspect which worth thinking of is the time it takes from when the satellite leaves the launch pod to when it can pick up charging.

These are some critical problems regarding the choice of battery size. Most of them will be easy to solve when there is more information available about the other parts in the satellite.

How to handle the battery charging will be discussed in the *charging circuit chapter*. Another problem regarding the battery is how it will behave in vacuum. There might have to be some kind of solution to keep the battery in earth pressure.

Microprocessor / Micro controller

The micro controller is the part on the power management system that handles all the important choices, in example when the battery should be charged and how much power that is allowed to be used by the subsystems. The microcontroller needs to collect some information to be able to make the right decisions. This information is gathered from temperature and voltage sensors on the solar arrays and the batteries. For measuring the voltage the system needs an A/D converter, and for measuring the temperature it would be necessary with a digital communication between the temperature sensor and the micro controller. Another solution is to use an analogue temperature sensor and an A/D converter between the sensor and the processor. When the microcontroller shall regulate the charging current it will also need a digital communication to the charger.

For minimizing the number of components the use of a microcontroller with built in A/D converter is to prefer. The use of a built in A/D converter also reduce the need of both positive and negative voltage that often is required by stand alone A/D converters.

Company	ATMEL	MicroChip	MicroChip	Texas	
Type:	AT90S8535	PIC18F1220	18F4320	MSP430	
Required voltage:	2,7 - 6	2 - 5,5	2 - 5,5	1,8 - 3,6	Volt
Current at 32 kHz	2000*	?	28**	14*	µA
Numbers of I/O	32	16	34	48	Pieces
Numbers of AD	8	7	13	8	Pieces
Accuracy (AD)	10	10	10	12	Bit
Temperature range	-40 - +85	-55 - +125	-55 - +125	-40 - +85	°C
RAM	512	256	512	256	Byte
ROM	8	8	8	8	Kbyte
EEPROM	512	256	256	256	Byte
Communication	UART SPI	USART	SPI, I^2C UART, PSP	USART UART, SPI	Type

* Approximated values

** Is not available before July 2002, the value is from the older circuit and therefore should be lower in the new circuit.

Table 4: Comparison of microcontrollers

For the choice of micro controller we have been in contact with several companies. The companies that has shown interest in our work is Microchip, Atmel and Texas instrument. They all have micro controller with a built in A/D converter and industry temperature range, the only company that have space specifications are Atmel, but that’s a microprocessor without program memory and it’s not a low power processor. All the companies have several micro controllers with different specifications, one of the most important specification are the power consumption. But it’s often a connection between low power consumption and the radiation tolerance.

The micro controller is the brain of the power management system, and will handle the distribution of power to the subsystems. It will be able to measure the amount of power that the solar cells are able to deliver, and with that information it could control which parts in the subsystem that it has enough power to run.

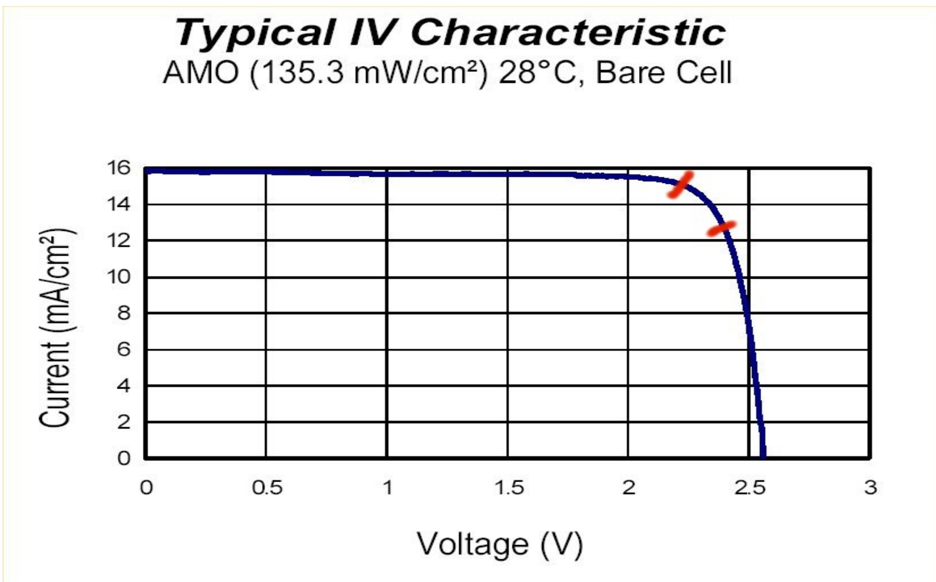
Power management

The way the power management system will work: The micro controller uses voltage and temperature sensors to monitor the solar cells and batteries. With this information the power management will allow the system to use as much power as possible directly from the solar cells.

The solar cells will change characteristics depending on the temperature, when the solar cells are cold the voltage will rises. By selecting a voltage range on the solar cells depending on the temperature in which the solar cells is most effectively.

For example its possible to use the figure below, the temperature is constant. Then there can be chosen a working range between 2.2 and 2.4 Volt. If the voltage is falling down below 2.2 Volt the power management is reducing the charging current to the battery. If the voltage is rises above 2.4 Volt the charging current will increase if the charger allows it. By measuring the voltage from the solar cells the management system can allow different sub system to be used.
Another example is if the voltage is lower than 2.2 Volt and the charging current is off, the power management system will only feed the most important parts of the system. When the voltage from the solar cells is over 2.4 volt and the battery is fully charged then the management system will allow all sub systems to run.
Another way to make the management is to have a constant maximum charging current and only allow as much current that is over to the subsystems. If it is necessary power can be taken from the battery when it's charging to. For example, if the medium current available from the solar cells when the satellite is in the sun side is 500mA. Then the charging current is set to 300mA and the other 200mA's will be available to the subsystems. When the battery is charged the charging current is reduced and more power will be able to the subsystems. The variations of power from the cells due to temperature won't affect the charging current only the current available to the subsystems. The advantage of this is a simpler charging circuit.

The temperature in the figure is for 28°C. If the temperature will change to from +28 to -40°C then the new voltage range will be (-40 * -0.0067 ≈ 0.3) * old range = 2.5 – 2.7 Volt



Picture 2: Typical battery characteristic

Software

Even the best hardware system can't do one thing if the software isn't made in a proper way. To have a micro control that handles the power management system makes it necessary to construct very stable and safe program code. There is no room for errors. There are many different tasks that the micro control shall take care of. F ex have contact with the main CPU, calculating and handling the charging, watching the solar cells and the battery, taking care of all sensors (temp, voltage, current), switching of/on the different sub systems (payload, downlink etc) and so on. There would be ideal to use some kind of RTOS to take care of all tasks and ensures the response time for them is being kept low. An RTOS is an operating system that takes care of all tasks and keeps the response time for them at a minimum. The RTOS also has a complete system for sending messages between the tasks, not causing problems like shared data. The problem whit using such a system is the limitation of memory, an RTOS take up more program memory than it is intended to have on the micro control. That's why a simpler system is necessary. Since there isn't any hard demands on response time a system like Round Robin could be used. But the contact with the main CPU requires fast response that is why interrupts are necessary.

Round Robin means that all tasks is done in a loop, every calculation is made every time the program runs the loop. A task that doesn't need to be done that often can be handled by interrupts. The main CPU can interrupt the micro control when it wants to give it some information. When the micro control receives the interrupt, it stops doing the loop and starts the interrupt routine. Some tasks can be done in interrupt routines where the interrupt are caused by a timer, f ex if some calculation only needs to be done every five seconds a timer gives an interrupt every five second and the routine halts the loop and starts the interrupt routine. Interrupt routines can be given different priority. That gives the micro control the ability to stall one interrupt while taking care of a higher priority interrupt.

If the programming of this kind of system is made in a structural way, there wouldn't be any problem to develop working software.

Other Components

The power management will require some other components as well. For switching off and on the subsystems and to be able to deliver constant voltage here there are some different circuit solutions. But there are some things they all have in common, they all uses a battery charging circuit and some DC/DC step up/down converters.

Charging circuit

There are many different solutions for charging the battery. The problem is that a Li-Ion battery is very sensitive for voltage, current and temperature. The battery must have a current limit and this limit is depending on the size and type of the battery. The maximum charging voltage is 4.2 volt and it should not be charged below 10 °C. In all the charging solutions the micro controller controls that the system doesn’t charges battery below its temperature limits. When the battery is fully charged the current will drop.

Charging a Li-Ion battery

The charging of a Li-Ion battery is done by setting an appropriate voltage level below 4.2 volt. The charging current is controlled by the voltage level; if the current is getting to high the voltage will be reduced. While the battery is being charged the current will sink so the charger has to raise the voltage several times until it has reached 4.2 volt. The more the battery is charged after this point, the more the current will drop until it is fully charged. Then only a low maintenance current will go to the battery.

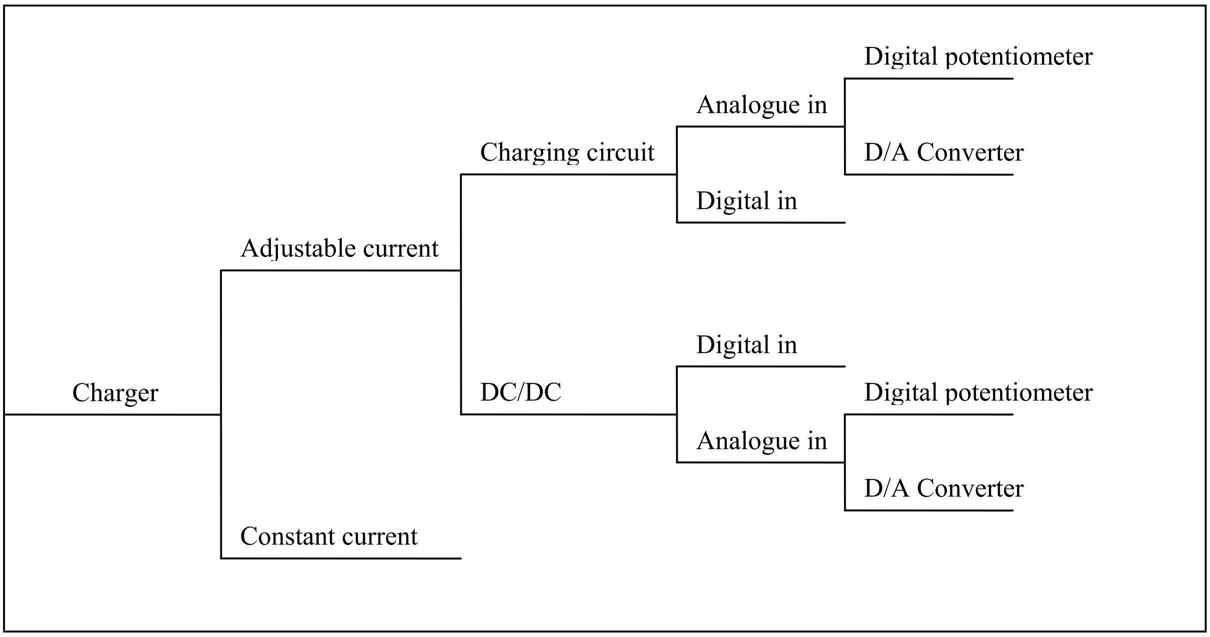
Solutions

One solution is that the micro controller should adjust the voltage within its limits to control the charging current. The rest of the system should always be prioritised, but if none of the subsystems consumes power, the charging can use everything. In other words, the subsystems control the charging current.

Another way of charging the batteries is to set a constant maximum charging current. With this solution the subsystem must not use more power from the solar cells than that they also can feed the charger. In other words, the charger takes what it needs, and the subsystems get the rest.

There are good and bad sides with both methods, the first one is better if we want to be able to run the subsystems for long times and also charge the battery at the same time, but if the subsystems takes too much power then it is possible that the battery will never bee fully charged. But this problem can be solved by software in the management system. The second method is better for the battery because the battery will be in highest priority, this solution is also easiest to implement on the satellite. The problem is that it can affect the function of the subsystems, perhaps the charging current is only 1% to high for the payload to work then the payload must wait for the battery to bee charged. But of course also here the problem can be solved in the management system by shouting down the charging for a short period time if some subsystem should run.

There are different ways to build both these charging system. For the first one there can be used a charging circuit that can be digitally controlled by the microcontroller. The problem here is that we haven't found any circuit that won't need much power itself or that they need to high supply voltage. Another way to build this system is to use a charging circuit with an analogue current set input and attach a digitally controlled potentiometer or a D/A-Converter to that input. A third way is to use a DC/DC converter that has an adjustable output voltage. The best DC/DC would be one with a digital input for setting the output voltage, but we haven't found anyone that can deliver enough current for this purpose. Another way of constructing this is to use a DC/DC with an analogue input and use it together with a D/A-Converter or a digital potentiometer. If a DC/DC converter is used the management system must measure the charging current and adjusting the output voltage after that, this means that one more component is added to the system.



Picture 3: A graphic display on the different ways to build the charger

To constructing the second type of charging system there can be used a simple charging circuit that is only limiting the charging current and voltage to a fixed level. This circuit will only need an on/off input and then it will run on its own. For this purpose there are several circuits in the marked.

Company	Dallas	Fairchild	National Semi	Maxim	Maxim	Maxim	
Type:	DS2770	FAN7563	LM3420	1640	1647	1645	
Required voltage:	2,7 - 5,5	2,5 - 16	13 - 20	5,5 - 26	7,5 - 28	8 - 28	Volt
Current active	80-120	3000	85	2000 - 4000	4000 - 6000	1700 - 6000	μA
Current Sleep mode	0,5	No	No	500	No	700 - 2000	μA
Max Charging current	2,5	?	1	?	1 - 4	3	A
Numbers of Pins	16	14	5	16	20	28	
Resistace	20-30	?	NPN	NPN	75	50	mΩ
Temperature range	-40 - +85	-25 - +85	-40 - +85	-40 - +85	-40 - +85	-40 - +85	°C
Current measurment	15	Analogue	No	No	?	16	Bit
Voltage measurement	15	No	No	No	?	16	Bit
Adjustible current	Analogue	Analogue	Analogue	Analogue	SMBus	SMBus	Type
Regulating type	Linear	Linear	Switched	PWM Switch	PWM Switch	PWM Switch	Byte
Other futures	Built in temperature sensor						

Table 5: Comparison of charging circuits

Temperature measuring circuit

The power management system would require a temperature measuring circuit to measure the temperature on battery and the solar cells. There are two different ways of doing this. One way is to use an analogue temperature sensor that delivers different voltage depending on the temperature; this signal is then converted by the A/D converter. The disadvantage with this solution is that it would always draw power from the satellite. Another way is to use a digital temperature measuring circuit that sends the information directly to the micro controller. The advantage of using an analogue temperature sensor is that it only requires 1 pin to be connected to the microcontroller. All the micro controllers that have been evaluated have at least 8 A/D inputs and there will only be a need of 2-5 depending on which circuit solution that is chosen. The advantage of a digital measuring circuit is that it can be turned off when it's not in use. The disadvantages is that they will require 3-4 pins connected to the microcontroller, but if we use more than 1 digital measuring circuit they can share some of the pins like clock and data.

DC/DC converters

DC/DC converters will be used for stabilizing the output voltage to the sub systems. The number of DC/DC converters is depending on how many different voltage levels the satellite requires. The DC/DC converters efficiency is about 90%. A number of different DC/DC converters from different companies have considered. Which one to be used is depending on the current and voltage from the solar arrays and to the subsystems.

Company	Microchip	Microchip	Maxim	Maxim	Maxim	Maxim	Maxim	Maxim	
Type:	**TC110**	**TC115**	**MAX 608**	**MAX 170**	**MAX 170**	**MAX 710**	**MAX1672**	**MAX 770**	
Quiescent Current	50 - 280	80 -135	85 - 120	35 - 110	65 - 120	100 -140	85 - 125	85 - 110	µA
Shutdown Current	0,5	0,5	2	3	1	0,2	0,1	5	µA
Max. Output current	300	140	1500	800	1500	500	300	1000	mA**
Efficiency	84	85	85	<96	<95	85	85	90	%
Temp. Range	-40 - +85	-40 - +85	-40 - +85	-40 - +85	-40 - +85	-40 - +85	-40 - +85	-55 - +125	°C
Output Voltage	3 / 3,3 / 5	3 / 3,3 / 5	5*	2,5 - 5,5	2,5 - 5,5	2,7 - 5,5	1,25 - 5,5	2 - 16,5	Volt
Input Voltage	2 - 10	0,9 - 10	1,8 - 16,5	0,7 - 5,5	0,7 - 5,5	1,8 - 11	1,8 - 11	2 - 16,5	Volt
Numer of Pins	5	5	8	16	16	16	16	8	Pins
Number of comp.	7	4	7	7	7	6	9	7	Pcs
Step up / Step down	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / Yes	Yes / Yes	Yes / Yes	

*Adjustible with extra components

** Depending on the input voltage

Table 6: Comparison of DC/DC converters

Circuit Solutions

There are several ways to solve this power supply system. Here there are three different solutions. They are all very similar but there is some difference regarding number of voltage level and the way they are controlled by the micro controller. There will also be varied ways for the sub systems to choose power source.

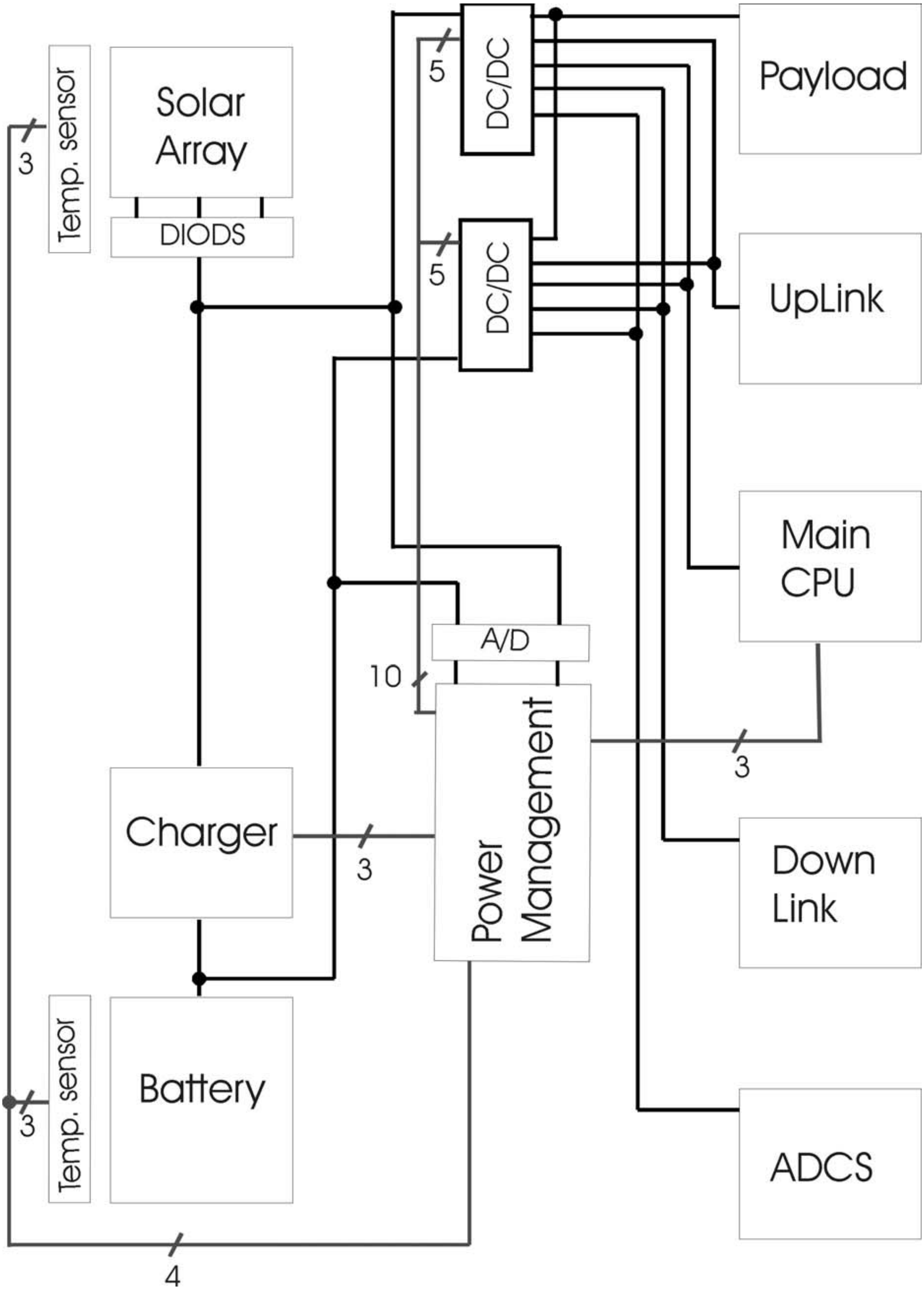
When the solar cells deliver power is it important that it’s used as efficiently as possibly. Normally the solar cells are connected directly to the battery and all power is drawn from them. This solution will lead the power through a charging circuit and about 10% of the energy will be lost. After the charging circuit there will be a DC/DC converter which also consumes about 10%. If it’s possible to draw the power directly from the solar cells, these losses would be reduced. Another benefit with this solution is that the battery won’t have to be used in low temperatures.

One way to choose were the power should be drawn from (solar cells or the battery) is to connect two DC/DC converters to every subsystem (circuit 1). The micro controller can control the DC/DC converters using the power management system. In this case it would be 10 DC/DC converters, but maximum 5 of them (one for each subsystem) will consume power at the same time. The DC/DC converter it self is a very small chip but it’ll require some external components to function, and total solution could be too big to fit.

One way to reduce the number of DC/DC converters is to use a reset or an enable input pin on the sub systems, a pin which almost every components has. But if there are different voltage levels, the DC/DC converters must be used anyway (circuit 2). Another way do reduce the number of DC/DC converters is to get some kind of switching device to choose between the two power sources (circuit 3).

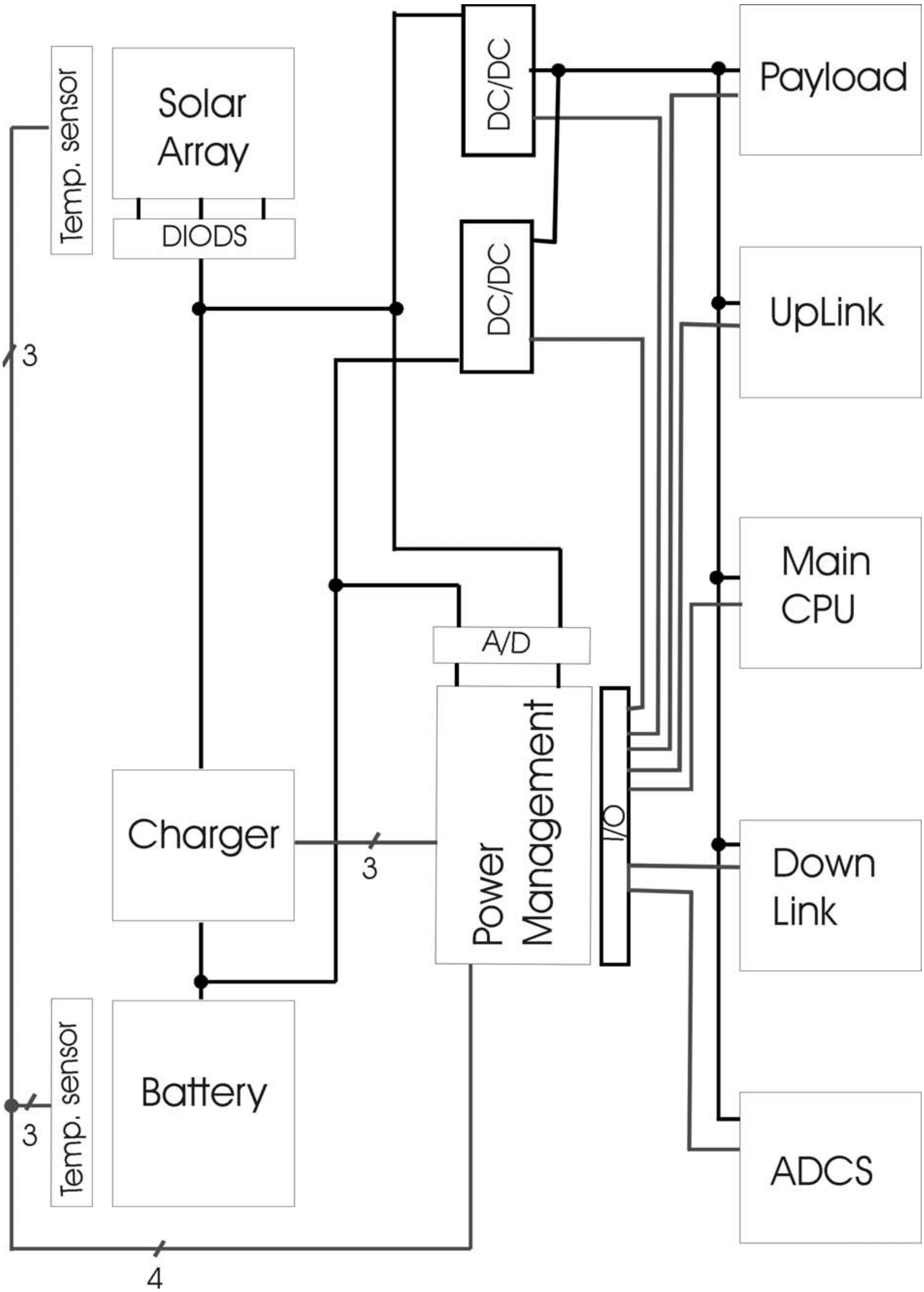
A possible best solution of this circuit could be a combination of all of the three circuits.

Circuit 1



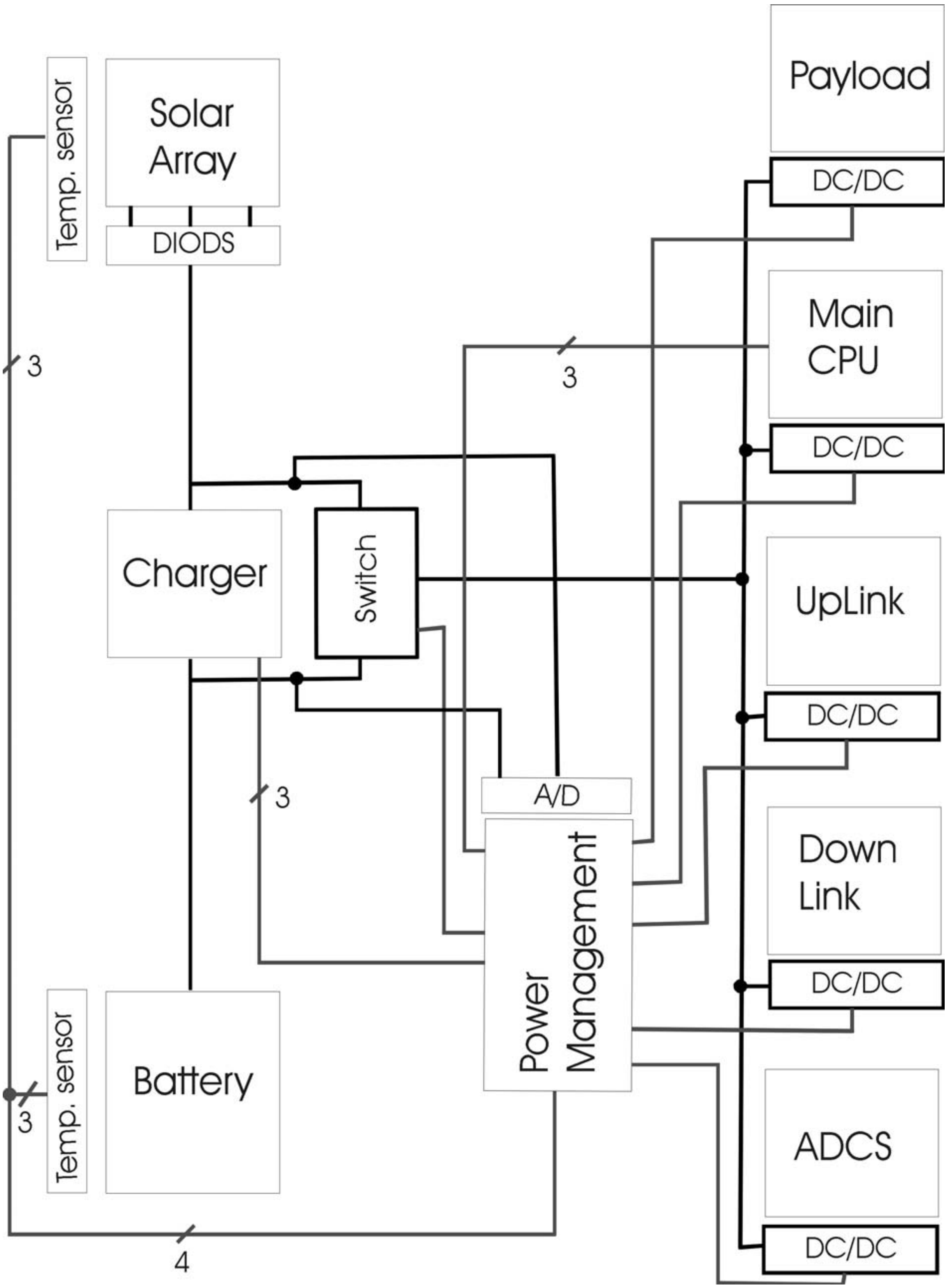
Picture 4: Using ten DC/DC converters. Five DC/DC converters to each power source, witch will be controlled by the micro controller. There will be a possibility within each subsystem explicitly to choose power source and voltage level.

Circuit 2



Picture 5: Using two DC/DC converters. All the subsystems will be fed by the solar cells or the battery. The micro controller controls the subsystems with the reset or chip enable pin. If there is a need of more than one voltage level the circuit will need further DC/DC converters.

Circuit 3



Picture 6: With five DC/DC converters. Some kind of switching device to choose between the two power sources for each subsystem. The five DC/DC converters are controlled by the micro controller, and provide a possibility of one voltage level for each subsystem.

Testing

Battery

It is important to lock at how efficient the batteries are, which means that measure how much of the charging power is wasted when using the battery.

Batteries are very sensitive to temperatures, a cold battery are much less effective than a warm one. It is important to test how the batteries behave in a space like environment. For example how well it can receive charging when it is cold. Another thing that is very important is to check that the battery can handle vacuum.

Much of these parameters can be received from the producer, but some testing to verify that it is correct is important to do.

Solar cells

The most important issue about solar cells is there efficiency. If it is calculated that the cells can deliver some power, and they don’t, the satellite could be in big trouble. All calculations about how much power there is to deliver to the rest of the satellites systems are based on the specifications of the cells. Many questions about how to construct the rest of the power system will be easier to solve when it is known which cells will be bought.

The solar cells must be tested and verified that they can deliver the amount of power they are said to do, and at an appropriate voltage level. This must be tested.

It is also important to test how well the solar cells can handle extreme temperatures. It is vital to know how well the solar cells works at different temperatures, the amount of power that they can deliver changes with the temperature.

Another thing that is very important to look at is the size of the cells. Since the satellite only has a 10 by 10 cm size, and some of that will be covered with other things (antennas etc), it is vital to cover as much as possible with cells. Because all cells are delivered in standard sizes, this must be taken under consideration. Testing that the cells can be attached at a proper way and that connection can be made to the battery charger.

Micro controller

The micro control must be tested against radiation and magnetic fields. It is important to choose a micro controller that doesn’t use much power. There is a problem whit those micro controllers; they tend to be more sensitive to radiation. Only one company that we know about, Atmel, delivers components that are tested and shielded. It is most likely needed some kind of shield to protect the micro control. That must be constructed and tested.

Another ting that needs a lot of testing is the software. The program code needs to be written in a way that bugs newer appear.

Charger and Dc/Dc converter

Both charger and dc/dc converters must be as efficient as possibly, at all temperatures, that is the main target for the testing of these components. It's also important to test these components together whit there external components (resistances etc).

If it is chosen a charging system where the charger always has control of charging voltage and charging current it is very important to build this system and test it. This could be done in an early stadium to determine if it is possibly to implement the system into the satellite. A big question is if such a system is 100% stable at all times. This system must be connected to the micro control to test these systems together. Some kind of shield to protect the system from radiation might be necessary.

Circuit testing

The whole circuit needs to be tested first in the simulated environment where most inputs from space-sensors are replaced by simulated one. The testing procedure with partly simulated sensors is called *hardware in the loop* that will be perfect for those first operational tests without vacuum chamber and radiation sources.

It makes it possible to connect the power system to a software simulator like mathlab/simulink via hardware device to simulate a space environment (general orbit environment cycle, temperature swing, solar cell power variation etc.). This way it is possible to test how the power management system handles all different states the satellite could end up in. The system could be used to check that the battery size and backup system works and is correct constructed. The ting is to discover errors in the construction before the satellite is in space.

Hardware in the loop is a modern and powerful method of validating and controlling hardware, it is often used in aircraft and car industry. Equipment for doing these tests is available at HiN.

Backup solutions, redundancy

Some kind of backup system is needed since the power supply system is a vital part of the satellite. The major issue of this is if two complete systems should be used, one main and one for backup. Another solution would be to use a simpler circuit that is less effective as backup. How simple that circuit could be made depends much of how many voltage levels the different systems needs. There must be a system that detects failures in the main power system and that can switch to the backup. That system must be isolated from the main system.

There would also be possible to only use backup systems on the parts that are most critical. This solution is not to prefer since a lot of switch and detection systems would be required.

The conclusion is that a simple system that is less effective would be the best solution. This system would anyway result in a working satellite. It would be robust, small and simple to construct. The only thing that requires some further work is the detection and switch circuit.

Solar cells

Solar cells are the power source to the satellite, if they brake down it will soon die. If one solar cell brakes down it doesn't matter that much, the satellite will still work. The problem is if one cell short circuits, which will make all solar cells useless. This could be solved by dividing the cells into two systems, which are isolated from each other. If one brakes down, there are still some cells working.

A solution with two systems to protect the cells isn't necessary if the cells never short circuits. This must be controlled with the manufacturer.

Battery

Should only one cell be used or should several be used for redundancy? This question isn't so easy to solve, if you lock just at redundancy several is the answer but there is more to it. If two batteries are used there will be problems connecting them. There must be some kind of switch between them, but both must be used at all times. If one battery short circuits, it must be disconnected immediately to save the other. To have two batteries connected parallel introduces a problem, they discharge each other. To isolate the batteries diodes will probably be used which has a voltage fall of about 0.5 V.

Using several batteries also get heavier and take up more space then only one, then you have to add the additional circuits needed. There must also be some kind circuit to detect if one cell is broken.

Maybe using two or more batteries introduce more problems then it solve? With the power systems described in this report the solar cells can act as a backup for the batteries, but then there are big limitations of what the satellite can do.

Sources

Solar cells:
www.dutchspace.nl
www.emcore.com
www.spectrolab.com/

Microcontrollers:
www.ti.com
www.eu.atmel.com
www.microchip.com
www.motorlola.com

Semiconductors:
www.microchip.com
www.maxim-ic.com
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www.philips.com
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Batteries:
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www.panasonic.com/industrial/battery/oem/chem/lithion/index.html
www.acte.no/produkt/beskrive/Varta.htm

Other CubeSat projects:
www.cubesat.org/
www.space.t.u-tokyo.ac.jp/cubesat/index-e.html
http://horse.mes.titech.ac.jp/srtlssp/cubesat/
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http://motor.maskin.ntnu.no/eit/

Explanation of words

ADCS:	Attitude Determination and Control System
A/D converter:	Analog to Digital converter, converts analog signals to digital.
Charger:	A circuit that handles the current and voltage to the battery at the charging process.
D/A converter:	Digital to Analog converter, converts digital signals to analog.
DC/DC converter:	Direct Current to Direct Current converter, it can change voltage level from input to output. It can be used to turn of the output.
Downlink:	Sender; sends signals to ground segment on earth.
Li Ion battery:	Battery which consists of lithium and ion.
Main CPU:	The satellite main computer.
Microcontroller:	Small computer with some memory and some additional hardware (AC/DC converter).
Triple junction solar cells:	Solar sells which is made by three layers of material.
Uplink:	Receiver; receives signals from the ground segment on earth.
RTOS:	Real Time Operating System.