Acta Scientific COMPUTER SCIENCES

Volume 4 Issue 3 March 2022

Research Article

Design Considerations of a Power Conditioning Module for Microsatellites

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Received: November 16, 2021

Published: February 25, 2022

Abstract

One of the most critical subsystems of a small satellite is the Electrical Power System EPS. Power generated on board is necessary for the satellite to operate correctly during its lifetime.

The EPS consists mainly of solar cells, batteries, voltage converters and protection circuits. The EPS is responsible of providing stable power to the rest of the satellite subsystems and payloads.

This paper discusses the design and implementation of the power conditioning module PDM for the coming generation of small satellites for the Algerian Space Agency ASAL. The design must provide a reliable protection for the subsystems from the over-current associated with a device failure.

Keywords: Power System; Small Satellites; Power Conditioning Module; Subsystems; Reliable Protection

Introduction

A spacecraft needs power to carry out its various functions. Satellites in low earth sun synchronous orbits SSO experience about 35 minutes eclipse period out of the 98 minutes average orbital period.

For spacecrafts, the primary source of energy comes from the solar cells. These latter provide power to recharge the onboard battery through a battery charge regulator BCR circuitry. In our design, each solar panel has its own battery charge regulator circuit, figure 1. The power conditioning modules PCM1 and 2, in figure 1, are redundant circuits totally identical. We can switch from PCM1 to PCM2 when PCM1 becomes faulty. In our design, the power conditioning module (PCM) regulates the battery voltage 14V to provide regulated voltages (±10V, +5V) for the spacecraft subsystems and the payloads. The PCM distributes the regulated power from the battery via the PDM to the spacecraft subsystems and the payload.

When designing a power conditioning module for a space mission, one needs to consider the operational environment (i.e. radiation effects and temperature variations) in orbit because it is much different from that on the ground. Besides reliability and efficiency of the electrical power system, over-current and under-voltage protection for subsystems and the payload should be considered. In this work, the design and implementation of a power conditioning module will be investigated.

The baseline 14Volts unregulated bus

Primary power to the satellite is supplied via four (04) body mounted solar panels. The power generated from the solar panels feed into dual battery charge regulators BCRs. The BCRs are selected by means of a relay on the input. The BCR logic monitors the BCR operation and switches to the other BCR should a failure occur. The BCR selection can be overridden by a command from the TTC. The BCRs estimate the maximum power point MPP of the solar arrays using a temperature compensation method, and tracks the end of charge (EoC) of the single battery also by using a temperature compensation method that reduces the charge current when the EoC is reached. This temperature compensation, both for the battery and solar arrays, is based on thermistors potted with adhesive in the battery pack and the solar panel substrates. Both the EoC and the MPP tracking can be overridden using the on-board computer (OBC) control [1-11].

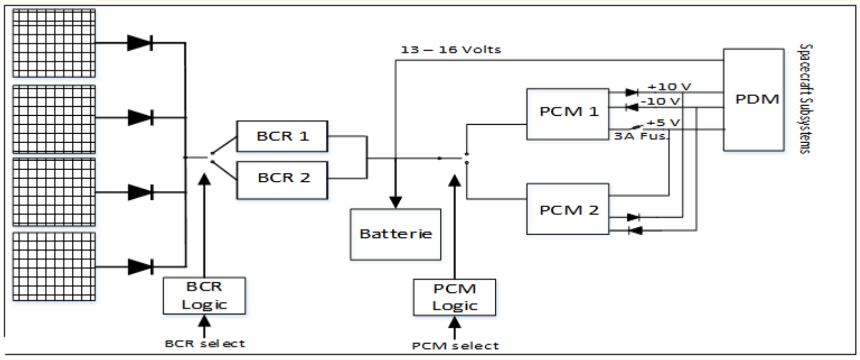

Figure 1: Microsatellite power system bloc diagram.

The circuit, figure 1, shows a power system configuration based on a 14V unregulated bus. The figure depicts that a failure of a BCR results in the automatic switch over to the redundant system. Each BCR design can sustain a continuous power of 80W with sufficient de-rating. In general, for a 60cm*60cm solar panel using single junction GaAs solar cells, assuming a fill factor of 80% and an effective area of 80%, the power from a single panel can reach 60W. This would result in an instantaneous array power of over 80W when 2 panels are illuminated at an angle of 45° to the sun direction. Therefore, the BCR would need to be redesigned to support this increase of power.

The design of the power system reflects the need for autonomous operation, independent of all other systems, and therefore should require no intervention from the ground station in the event of an anomaly arising on the spacecraft [1-11].

Autonomy is obtained by having dual redundant systems that automatically switch between each other in the event that a fault is detected. There are identical Battery Charge Regulators (BCRs), each of which is capable of transferring power from the solar panels to the battery and the rest of the spacecraft. There are also two identical PCMs to ensure that regulated power is always available to the satellite subsystems. The BCRs and PCMs are each equipped with control logic capable of detecting faults and dictating the switching to the redundant (or unused) PCM [1-11].

The hardware is also designed to adapt to environmental changes. The most obvious example of this is the BCR's ability to monitor the temperature of the solar panels and the battery. The BCR is able to predict the Maximum Power Point of the solar panels using the array temperature as a parameter. The battery charge rate is also controlled by the BCR, which predicts when the battery has reached its End of Charge (EoC) voltage. This is due to the BCR's ability to track the battery temperature which is indirectly proportional to the EoC voltage.

The power conditioning module

The function of the PCM is to convert the raw battery voltage into a regulated 5V line and a ±10V line. The ±10V lines are unregulated and low power. PCMA and PCMB are virtually identical, figure 2.

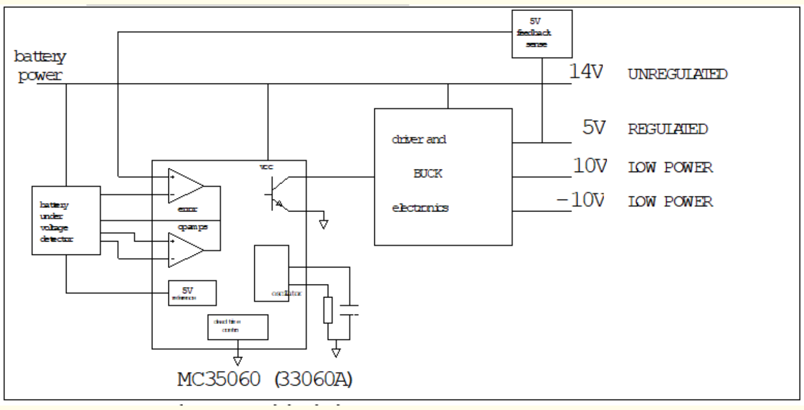

Figure 2: Power Cconditioning Module Block Diagram.

The PCM electronics

The design of the PCM is basically the same as the BCRs. The PCM is a DC/DC switch mode converter of the Forward-Buck type. The design is currently based around the Motorola MC35060 (MC33060A) Pulse Width Modulation control IC, figure 3. PCM A and B are almost identical having only a few minor differences. The main difference is that two different FET types are used in each of the PCMs. PCM A, the main PCM, uses an IRF9Z30 (9Z34) P channel device. PCM B uses the same FET as the BCR, the IRF9540. The IRF9Z30 has a lower R_{DS} on resistance than the IRF9540 and is therefore more efficient. (0.14Ω against 0.2Ω). The IRF9540 however, has a maximum working voltage of 100V and a maximum current handling of 19A against 50V and 18A for the IRF9Z30.

The 5V reference voltage is connected to the negative input of error opamp-1, and the feedback to the positive input. In normal operation these two points are kept at equal voltage by adjusting the PWM. The feedback is obtained from the output via a voltage divider. In this way the output can be set to a value between the reference voltage and 90% of the input voltage. The output of PCMA is set to approximately 5.15 volt. This to allow for 0.15V voltage drop in the power switches and wiring. PCM B is set to 5.25 volt. This voltage is higher so that PCMB will take over when switched in parallel with PCMA [12-19].

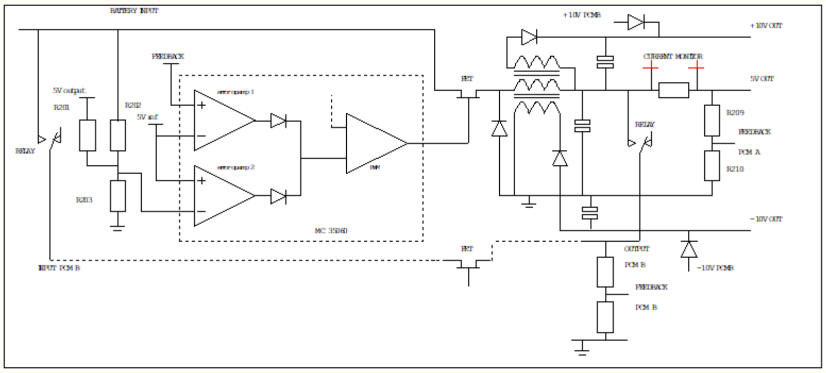

Figure 3: Power Cconditioning Module Electronics.

The feedback of PCMA is obtained after the current monitor resistor(s), so a voltage drop across these resistors has no influence on the output voltage. Because the redundant PCM had to be completely isolated this was not possible, and the feedback is obtained at the output of the PCMB just before the relay switch.

The other feedback path on PCMA is used to provide further protection to the power system. When the input (battery) voltage goes below 9V, the PCM switches off completely to conserve power (also the switched 14V lines will switch off as the telecommand system is switched off.) and will only start up again when the battery has recovered to about 10.3V. This is achieved as follows: [12-19].

The ±10V lines are generated by two extra windings in the inductor. When the PCM is in operation, the inductor acts as a transformer generating waveforms in the two overwindings. These waveforms are half-wave rectified and smoothed, producing 10V DC lines. The ±10V lines are low power and are rated at 50mA each (It is possible to draw more current but at the expense of increased ripple on the 5V line) [12-23].

The +10V winding has the same number of turns as the 5V line. The start of the winding is connected to the 5V output. This 5V, plus the 5V generated in the winding, results in a +10V line. The -10V winding has twice as many turns as the 5V line and is, by definition, a 1:2 transformer, producing 10V on its output from a 5V input. One end of the winding is connected to ground and the other end is connected to the PDM and the loads via a rectification diode, allowing current to flow only in the negative direction relative to the 5V line.

Tests and Results

The power unit testing started first with both PCMs. This is due to the fact that it is necessary to have the 5V line and ±10V lines operational for use, for example, the PCMs and BCRs logic.

PCM A

The 5V output of the PCM was set to a value of about 5.15V. A 14V power supply was connected between ground and the 14V separation switch providing 14V to the input of the PCM. Using a decade resistance box, an appropriate value of select-on-test resistor R209 was chosen. The value chosen was 4.1 kΩ, giving a line voltage of 5.15V at 28°C room temperature. A load of 20Ω was connected to the 5V line and both the +10V and -10V lines were checked as well:

Voltage Line Name	Measured Current (mA)	Measured Voltage (V)
+5V Line	~ 250 mA	5.19V
+10V Line	~ 50 mA	10.58V
-10V Line	~ 50 mA	- 8.69V

Table 1: Line Voltage Measurements for PCM A.

The PCM reset function was then checked by reducing the input voltage until the PCM switches off automatically. This function will ensure that the battery voltage will not fall to a value that is difficult to recover from, putting unnecessary strain on the batteries. It was found that the PCM switched off at 8.963V. The input voltage was then increased in order to see when the PCM would come back on line. This voltage is set to approximately 1V higher than the switch off voltage in order to avoid the PCM toggling between on and off states and also to give the batteries room to recover. The switch on voltage was found to be 10.25V.

PCMA winding inductors have the following measured values: [12-19].

- + 5V winding 119.9 μH
- +10V winding 119.6 μH
- -10V winding 459.0 μH

Figure 4 shows the efficiency of PCM A vs. the output power. It should be noted that only the 5V output power of the PCM was recorded (not the ±10V lines), so the actual efficiency is higher than that shown. The experiment was carried out for both input voltages 10 and 14 volts.

PCM B

On PCM B, the 5V line voltage is set higher than that of PCM A, to about 5.25V. The required value of select-on-test resistor R208 was found to be 17kΩ, giving a line voltage of 5.25V on the output capacitor. A load of 20Ω was connect to the 5V line output of PCM B and both the +10V and -10V lines were checked as well.

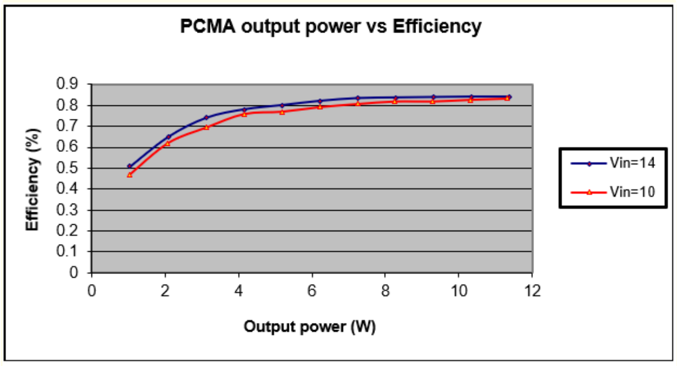

Figure 4: PCM A Output Power vs. Efficiency.

Voltage Line Name	Measured Current (mA)	Measured Voltage (V)
+5V Line	~ 250 mA	5.25V
+10V Line	~ 50 mA	+10.41V
-10V Line	~ 50 mA	-10.50V

Table 2: Line Voltage Measurements for PCM B.

PCM B has no reset function although on testing the converter by reducing the input voltage, it was discovered that PCM B turned off at 6.1V. The safety voltage below which PCM B may not be switched on was 10.7V.

PCM B winding inductors have the following measured values: [12-19].

- + 5V winding 133 μH
- +10V winding 133 μH
- -10V winding 493 μH

Figure 5 shows the efficiency of PCM B vs. the output power. It should, again, be noted that only the 5V output power of the PCM was recorded, so the actual efficiency is higher than that shown. The experiment was carried out for both input voltages 10 and 14 volts.

Figure 6 shows the Power Conditioning Module winding inductors used during testing of PCM A and B. Details and the dimensions of the magnetic ferrites are also shown.

Conclusions

The author explains design steps for a power conditioning module. Tests results are also shown with explanations when necessary

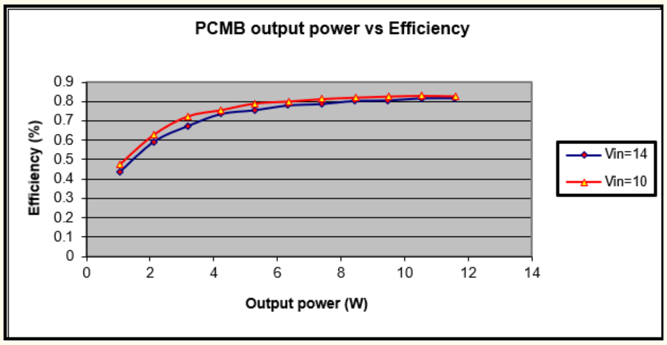

Figure 5: PCM B Output Power vs. Efficiency.

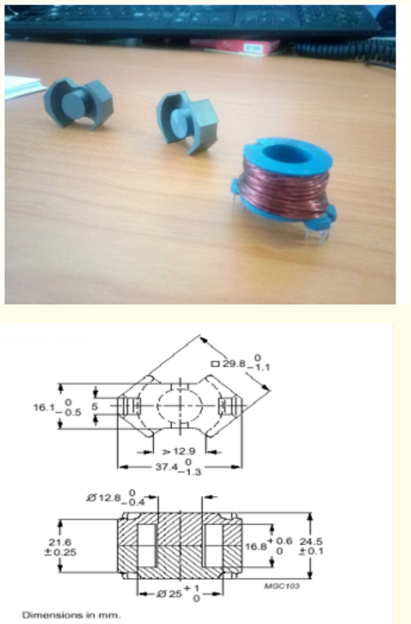

Figure 6: Inductors bobins built on RM 12 cores for PCM A and B.

about the components choice. Figure 6 shows inductors hand built in the frame of this project. The inductors values were measured based on digital equipements PROMAX MZ 505C.

The results obtained as shown on figures 4 and 5 show satisfactory behaviour of boths power conditioning modules PCM A/B with efficiencies above 85%.

To improve these values of efficiencies for PCM A/B, it must be said that the losses are mainly due to the inductors in both PCMs. Research projects are carried out to solve these problems of losses within the inductors and therefore increase the efficiency to 90% or more.

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