Reconfigurable Payload Power Management System for Rockets

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Abstract. In modern aerospace systems, the integration of payload electronics with the rocket's primary power infrastructure introduces constraints related to power compatibility, isolation, activation timing, and inertia distribution. This paper presents a reconfigurable payload power management system designed to provide galvanic isolation and touch-less activation for payloads with independent power supplies. The proposed system enables activation of payloads post-integration via a contact-less transformer interface, eliminating the need for umbilical connections, thus mitigating issues such as battery discharge during launch delays and minimizing disassembly requirements. A thyristor-based power-on circuit ensures reliable one-way activation of the controller, while custom-designed optical isolated switching modules provide safe, low-resistance connections between payloads and their power sources. The design minimise the event of possible ground loops, allows for modularity, and provides robustness in plasma environments. A modular and symmetrical hardware layout enables seamless integration into spin-stabilized rockets. Preliminary testing confirms the system's robustness and suitability for deployment in dynamic aerospace environments.

1 Introduction

The power system for an aerospace vehicle is organically designed according to the needs and characteristics of the service systems and payloads. If a payload needs to be activated or powered by the rocket energy source, the payload designers are constrained to follow the specification dictated by the rocket's power system requirements. The standard described is advisable and safe, but in the proposed design, we are considering a power management system that can be relatively flexible, for customers who want to use a battery within its payload. If a payload has its own battery, it can be activated before being enclosed in the rocket. However, in the event of a possible launch delay, the battery may discharge, necessitating disassembly of the rocket to recharge the power sources. The proposed system permits the integration of the payload into the rocket without being activated. Once the nose cone is closed, just before the launch, the electronics can be activated without any umbilical using the touch-less transformers. The system permits control of a payload, ensuring the galvanic isolation between the payload and the rest of the rocket's electronic systems. The isolation prevents the ground loop and propagation of failures.

2 High level system description

The power management system is designed to switch Off and On the payloads that use their own internal power sources. To better understand how the payloads are connected, it is useful to observe the high level diagrams of Figure 1. In the block diagram, with S_{wn}, is indicated the n switch belonging to payload n, while Sw_g is the general switch that activates the controller board. In a similar system, the physical switching can be a transistor BJT or a MOSFET high or low side connected. In both of these scenarios, the ground is shared between the payload and the controller board. In the device the switches and the controller block are galvanic isolated. The isolation is required to avoid ground loops. The switch Sw_g is used to activate the controller. The SW_g is not a mechanical switch, but represents a thyristor activated by a touch-less transformer positioned externally to the rocket's nose cone. The only flaw in the design is that once the control board is active, it is not possible to shut down the system.

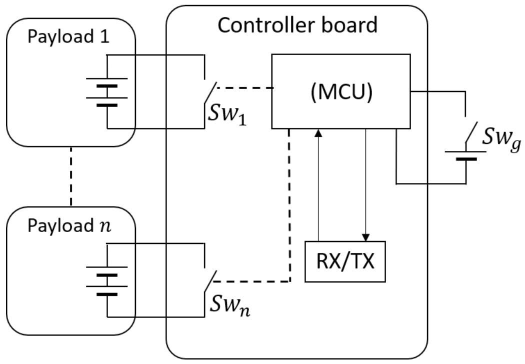
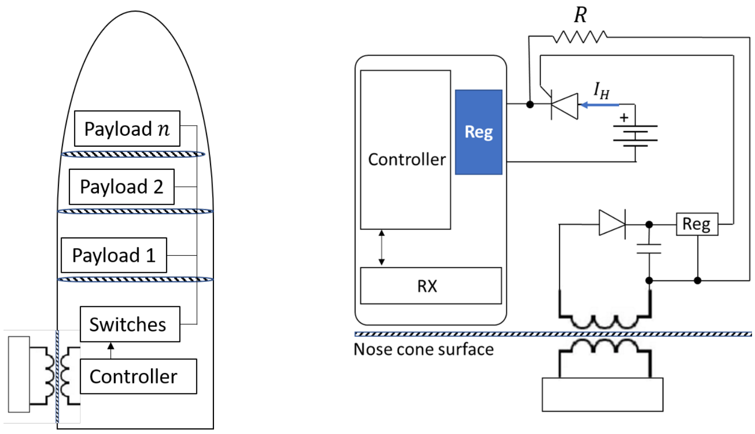


Figure 1: High level block diagram, of the power management system.

3 Boot-up of the controller board

The nose cone's geometric design enables optimal payload integration, achieving a balanced mass distribution around its central axis. A schematic representation of the cone and the position of the touch-less transformer is represented in Figure 2a. In the system, the power controller board is positioned at the bottom, and just above the battery pack[1].



(a) Possible payload distribution. (b) activation system of the controller board.

Figure 2: Representation of the cone, and the position of the touch-less transformer.

Once the rocket is positioned on the gantry, the primary coil of the transformer is close to the secondary coil as depicted in Figure 2b. Just before the launch, from the Mission Control Room the primary is activated and from the secondary, the alternating voltage is rectified by a simple filter.The rectified signal is processed by a linear regulator, generating a controlled output voltage that supplies the necessary gate current to sustain thyristor conduction. In this scenario the thyristor is used, since in direct current, if the load draws a current equal to or greater than the holding current I_H, the thyristor stays in a conduction state. The resistance R is used just for polarization purposes. Unfortunately, once the controller board is activated, it is not possible to deactivate. The circuit proposed was tested with the micro-controller with all the pins at logic level zero, and it was observed that the current drawn is sufficient to keep the thyristor in a conduction state.

4 The switches

Electronically controlled switching systems can be implemented using various methods, including mechanical relays or photo-coupled solid-state relays, which offer galvanic isolation and are resistant to vibration. Given the need for protection circuitry due to the presence of plasma, a custom-designed circuit solution is required.

[1] This is not a constraint, and it depends on the specific needs of the system

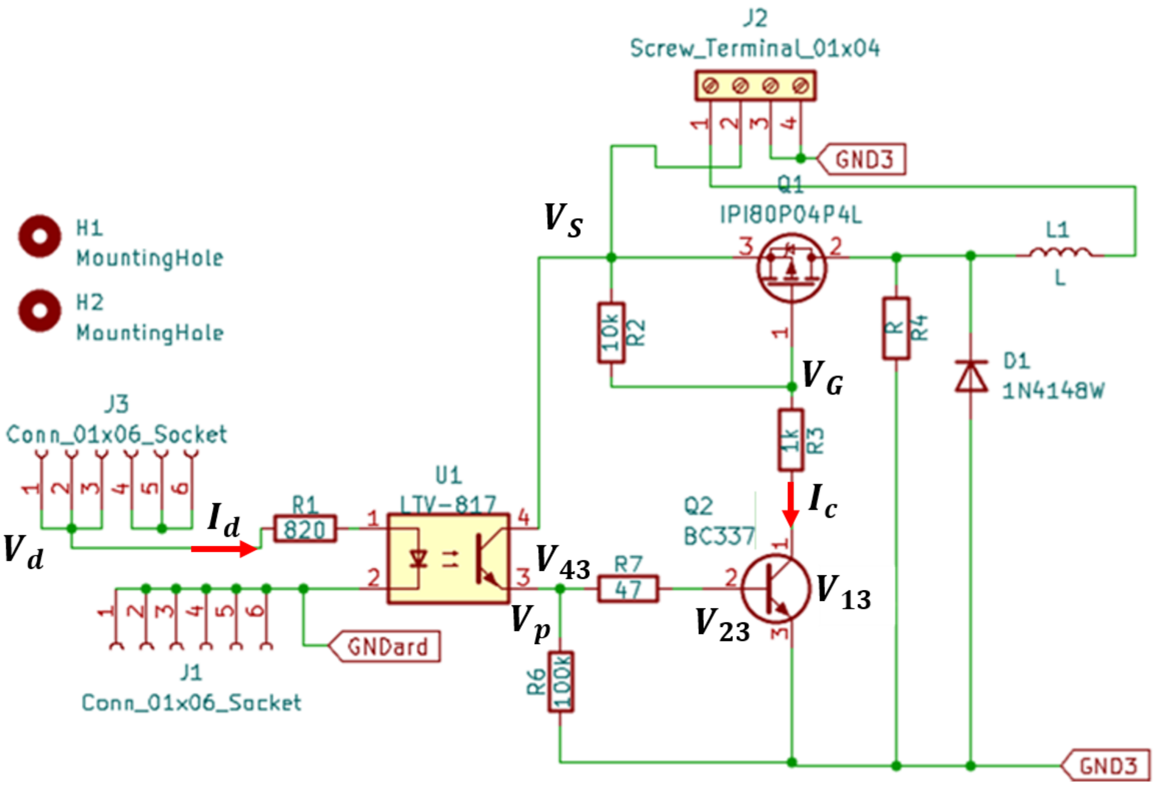


Figure 3: Single switch schematic. The printed circuit board is designed in a way that is possible to stack two switches, to exploit the vertical geometrical distribution.

4.1 Circuit qualitative analysis

The switch is controlled by a Micro-controller Unit (MCU), through the connector J3. The connector J1 share the MCU ground. Considering a high logic level of $5V$, and at the low logic level, the voltage is approximately 0V. The battery of the payload is connected at pin 2 of the connector J2, with a voltage V_S. When the MCU pin is at the low logic level, the current I_d is zero and there is no photon emitted by the LED of the optocoupler. The absence of the light results in the transistor working within the cut-off region, and the voltage V_p is approximatively 0V[1]. For these values of V_p, the transistor Q2 is also cut-off, and the voltage on the gate node is $V_G = V_S$. Since $V_G - V_S = 0\text{V}$, the P-channel MOSFET Q1 results as an open circuit. The power absorbed in this working point is approximately 0V.
If the control pin of the MCU changes to V_p, the current I_d flows into the LED of the optocoupler, and if it is properly designed, the voltage V_{43} decreases to a value between 0.1V to 0.2V. At the node V_p the voltage is now close to V_S, and a base current I_B flows to the transistor Q2. The base current saturates the transistor Q2, and the voltage V_{13} decrease between 0.7V to 0.8V. Since $V_{GS} = V_G - V_S < 0\text{V}$ the resistance between the drain and source is approximately 0V and now the current can flow from the positive of the battery to the payload, with a minimal drops of voltage[2].
Ideally the circuit proposed can work in its current state, but for an aerospace vehicle it is necessary to include some protection against plasma bubbles. If the vehicle encounters plasma, there is a possibility of spikes been present at the drain of the MOSFET, that may destroy the device. By placing an inductor L1 the MOSFET is protected. If the current flows into the inductor, at the same instant the MOSFET becomes an open circuit, the highest voltage will be present at the source. By placing the diode, when the MOSFET is in an off-state, the voltage across the inductor forward bias the diode, and the energy will be discharged into the inductor.

4.2 Design of the switching, and the controller board

The circuit is designed to work with TTL logic, this means that the logic level 1 corresponds to 5V, and the logic level 0 corresponds to 0V. When the logic level 0 is present, the voltage V_d is equal to 0V, and the MOSFET can be simply seen as an open circuit. In the following calculations the values of the tested circuit are left out, since the reader can replicate the design by using other components[2]. In the design it is also necessary to take into account the maximum deliverable current of the digital pin of the MCU. When $V_d = 5\text{V}$, the current that flows into the LED is:

$$I_d = \frac{V_d - 1.2}{R1}. \tag{1}$$

The current I_d needs to be able to saturate the transistor, in order to achieve a voltage V_{43} at least at 0.2V. In this specific case the current I_d is 5mA. After the current I_d is determined, the voltage across the transistor of the optocoupler V_{43} is known, and the voltage V_p is:

$$V_p = V_S - V_{43}. \tag{2}$$

The base current I_{R7} can be determined by the generalized Ohm's Law, as shown in Equation (3).

$$I_{R7} = \frac{V_p - V_{BE}}{R7}. \tag{3}$$

The voltage $V_{BE} = V_{23}$ can be considered constant. In this design, for the BC337, the voltage Base-emitter can be considered at 0.7V. The base current calculated reduces the voltage V_{13} to 0.2V. The current I_C only depends on the resistance $R2$ and $R3$. The collector current is determined by Equation (4).

$$I_c = \frac{V_s - 0.2}{R2 + R3}. \tag{4}$$

The voltage at the gate V_G is:

$$V_G = I_c \times R3 + V_{13}. \tag{5}$$

The voltage between the gate, and the source $V_{GS} = V_G - V_S$, is negative, and the MOSFET results to have a small resistance between the source and the drain. In general this circuit can be used with any P-channel MOSFET, but because the system works at low voltage levels, a digital MOSFET is required to obtain a minimal resistance[3]. As was stated in the previous sections, the switches are controlled via the controller board. The controller board implements the MCU. The MCU is powered by using a DC-DC converter with separate ground[3]. In this way the MCU is also galvanically isolated. The schematic of the main board is represented in Figure 4. The power for the

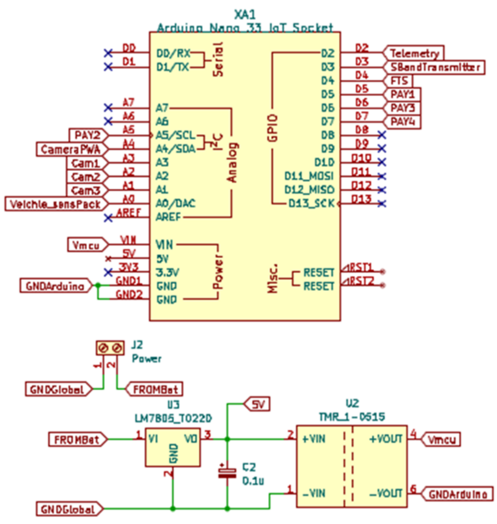


Figure 4: Schematic of the controller board.

controller board is connected to a voltage regulator [4], which its output is connected to a DC-DC converter. The adopted DC-DC converter has the input and output ground separated. The design wants to avoid any sources of noise that can potentially exist in the overall system.

[2] In some specific case for example it is necessary to use a space grade optocoupler, which may have different electrical characteristics. The circuit can also change according to the MCU use, since some MCUs do not run at 5V, but at 3.3V

[3] To use a standard MOSFET will increase the complexity of the circuit in order to generate a negative polarization voltage at the gate.

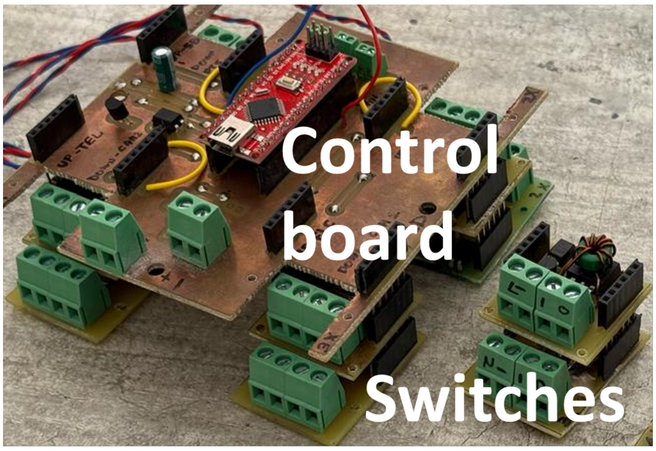


Figure 5: Picture of the tested board.

5 The hardware design

The hardware proposed needs to be implemented into a small rocket that is spin stabilized. The inertia distribution requires particular attention, and the device was designed to be symmetric with respect to the center of rotation. The controller board is designed to allocate the switching boards as a stackable devices. The geometry of the final prototype is represented in Figure 5 The actual design considers an Arduino Nano, and in this project RX of the controller board is represented by the serial communication between the MCU and the computer of in the control room. It is possible to replace the Arduino Nano used in this system with an Arduino Nano ESP32, which has the same pinout configuration of the Arduino Nano, but the WiFi is embedded in the board[5].

6 Conclusion

The proposed power management system offers a practical and adaptable solution for integrating independently powered payloads into launch vehicles. By employing galvanically isolated switching mechanisms, and a touchless transformer-based activation circuit, the system addresses critical challenges such as pre-launch battery depletion, ground loop interference, and electromagnetic susceptibility. The modular architecture, based on stackable boards and compact controller design, facilitates integration in geometrically constrained and dynamically sensitive rocket environments. Future iterations may incorporate bidirectional communication and deactivation capabilities, particularly through the adoption of microcontrollers with wireless interfaces such as the Arduino Nano ESP32[5]. The proposed system contributes meaningfully to the development of robust and adaptable aerospace subsystems, especially in the context of reconfigurable payload deployment and autonomous flight readiness.

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