Launch Controller Enhancement

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Introduction

Electric launch control circuits have been around since the beginning of the hobby, ranging from simple doorbell pushbutton-and-battery schemes to modern wireless, processor-based systems. Regardless of their tech and complexity, they all serve the same goal – deliver sufficient energy to successfully fire a model rocket igniter.

In the earlier Part 1 article, I discussed the energy aspects of launch systems and provided our design for PSC's simple, but robust, handheld launch controller. In principle it's basically the same as an Estes Electron Beam, only it contains its own high-capacity power source, and its heavy gauge igniter extension leads minimize losses as firing current flows to the igniter. Used properly it will provide the user many years of reliable service.

As is the case in most engineering projects, keeping things simple usually enhances user functionality and device reliability. However, in the case of the PSC Handheld Launch Controller, while its operation is intuitively obvious, its overly simple design doesn't necessarily offer the best long-term reliability. In this article, I'd like to share with you a design enhancement that will extend the life of the device.

The Problem

Figure 1 illustrates the control circuit used in the PSC Handheld Launch Controller. It's evident that it's a simple device, connecting ignition power directly from the battery through to the igniter by way of a Safety Key Switch and a LAUNCH pushbutton. A PNP-transistor-based low current continuity check circuit (nominally 2.36mA) is included, and this function is available even when the unit is unpowered. The Key Switch is a DPST switch, its back pole being used to isolate the Power indication circuit from a reverse current sneak path through the LAUNCH pushbutton[1]. A 10A thermal circuit breaker is included as a measure of overcurrent protection.

As simple as this circuit is, its life depends on the durability of the switch contacts in the Key Switch and the LAUNCH pushbutton (we consider the battery to be a consumable). Those switches have a max contact rating of 4A and 5A respectively, and while they work just fine, over time their continued exposure to ~10A per firing will eventually stress the contact points through heating and, where switching occurs under load, arcing and pitting, leading to premature failure. It's a price paid because of the super simple design.

It's at this point my Engineering Project Advisor Dr. Aitken would say, "Ok, but what's the So What?" Well, the "So What' here is the accelerated life impact on the switches. As the circuit in Figure 1 shows, the switches could carry a peak current of 10A or so, per firing event (e.g.: an igniter and ~30' of two-conductor 16AWG cable). That's at least two times their maximum contact rating. With a bit of math, we can characterize a derating factor that gives us a view of the impact this overstress condition can have on the switches.

[1] A series diode could have been used to block the sneak path, negating the need for a second pole on the ARM switch, but that would mean the diode would present a large power loss (~10-12W) when forward biased with the firing current. Accordingly, a DPST switch was used to minimize firing current loop losses.

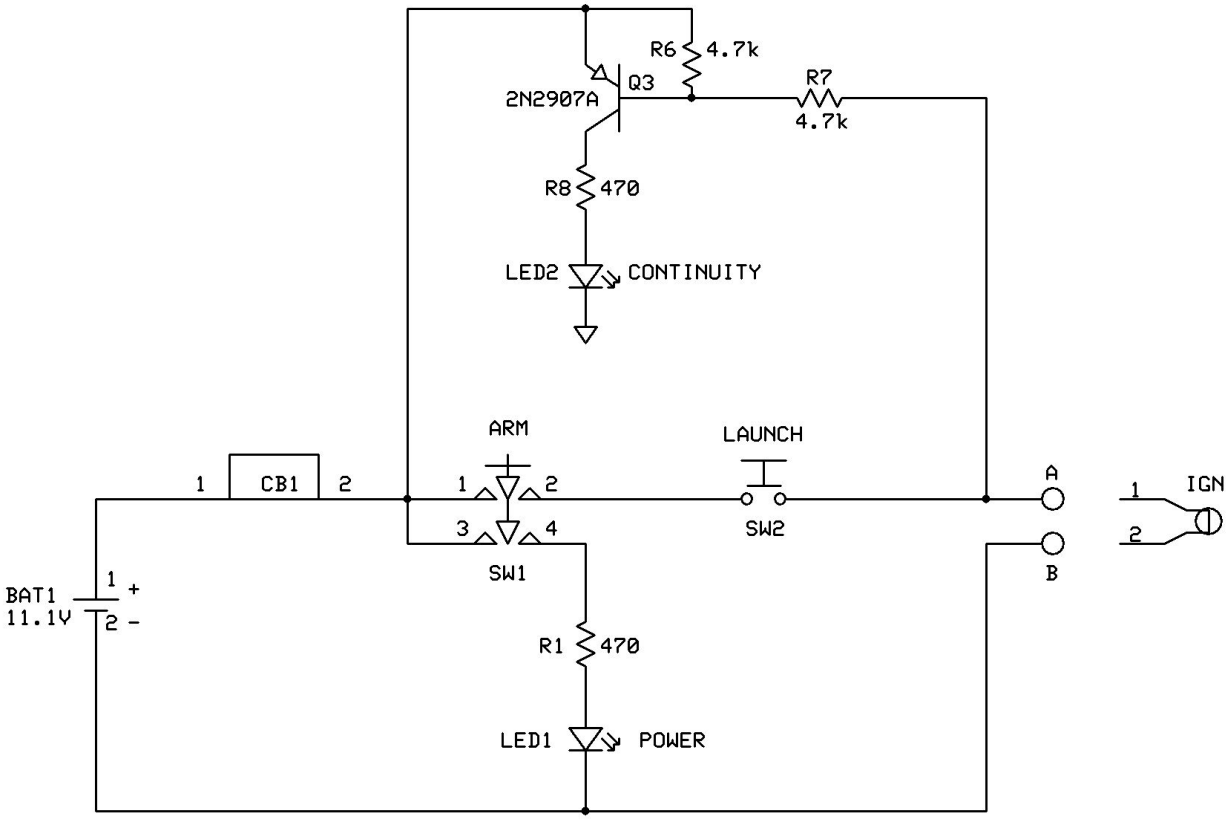


Figure 1: PSC Handheld Launch Controller

Accelerated-life analyses frequently use an Inverse-Power relationship[2] to describe how a component's life declines as a consequence of accelerated applied stress. In our example, if switched current is treated as the accelerating stress, the relationship can be written as:

$$\frac{L_{\text{actual}}}{L_{\text{rated}}} = \left(\frac{I_{\text{rated}}}{I_{\text{actual}}}\right)^{n}$$

Where 'L' is the life of the part. The exponent in an inverse-power life relationship is normally determined empirically and is not known for the switches used here. However, we can make a thumb-suck assumption because degradation processes in electrical contacts are strongly nonlinear with overstressing current. Recall that resistive contact heating alone varies with the square of current, while elevated contact temperature, arcing, material transfer and erosion introduce additional stresses. All these effects conspire to accelerate the electrical degradation of the contacts, brought on by the excessive overcurrent. Accordingly, for purposes of illustrating the potential effect of substantial electrical overstress, we'll assume an exponent of 4.

[2] ReliaSoft, *Inverse Power Law Relationship*, Accelerated Life Testing Data Analysis, ReliaSoft documentation. The inverse-power-law relationship is commonly used to model the effect of non-thermal accelerated stresses on component life.

So, doubling the switched current then produces:

$$\left(\frac{5\ \text{A}}{10\ \text{A}}\right)^4 = \frac{1}{16}$$

Using these assumptions, a switch operated at twice its rated current could have an electrical life on the order of one-sixteenth of its rated-load life. Note this is not a specific life derating prediction for the selected switches, but rather an indication of how rapidly their life *could* decline in their stressed state, based on the assumed inverse-power exponent[3].

If we were to apply this indicative derating factor, forcing 10A through a 5A switch would correspond to a life reduction factor of 16 (again, indicative, not definitive). Returning to the design in Figure 1, the selected ARM and LAUNCH switches have full load electrical contact life ratings of 6,000 and 200,000 cycles, respectively. Of the two, only the pushbutton operates while firing current is passing through it. So, the indicative derating factor, above, would reduce its electrical cycle rating to ~ 12,500 cycles, a dramatic reduction.

We can't apply this derating factor to the Key Switch, as it's never operated while the firing current is passing through it; instead, it just sees the short ~50ms firing current pulse pass through when the LAUNCH pushbutton is pressed. This operating scenario makes the derating factor, above, much too aggressive and inapplicable here. Instead, the relevant overstress mechanisms for the Key Switch include contact heating and the possibility of contact welding, a different derating problem from the switching-life analysis applied to the pushbutton. We'll spare ourselves from a further analytical rabbit hole here and instead observe that our comparative experience with the Key Switch shows that it doesn't suffer a markedly shorter or different service life than that of the pushbutton.

All that said, most hobbyists don't care – and practically speaking, Dr. Aitken has a point. We can imagine that most would be quite fine with a switch that lasts for several thousand firings, as that lifespan will likely outlast the flyer and/or his/her time in the hobby. Everyone banks on the likelihood that the controller's use pattern will fit within the derated life of the parts, and usually that's the case because of the frequency by which the controllers are used. And, just as important, keeping the controllers simple also keeps them cheap - nothing wrong with that. But with the addition of a few parts, we can eliminate the contact stress entirely and allow the switches to operate more comfortably within their rated electrical ranges.

Design Strategy

In making this upgrade we'll preserve the system's high-side switching architecture. This configuration ensures that power never appears on the high side of the igniter until the system is armed and the LAUNCH pushbutton is pressed. Otherwise, there is a risk that any accidental shorting of the igniter's return leg to circuit return could cause an unintended igniter firing, which is a safety hazard.

[3] This exponent should not be regarded as a direct attribute of these switches (that would take a significant amount of product testing to determine) but rather a ballpark prediction of the effect of the accelerating stressor.

In addition, to mitigate the electrical overstress on the control switch contacts, we'll insert a high amperage transistor in series with the firing current loop. A few additional components will be added to support the control of the firing transistor.

Circuit Design

Figure 2 illustrates the updated design. Here, the firing current is now switched by a high amperage P-channel enhancement MOSFET (Q2). The output transistor is controlled by the switch appliances by way of a control transistor Q1, an N-channel enhancement MOSFET. The continuity check circuit remains as is and is electrically connected in the same way as the original circuit in Figure 1.

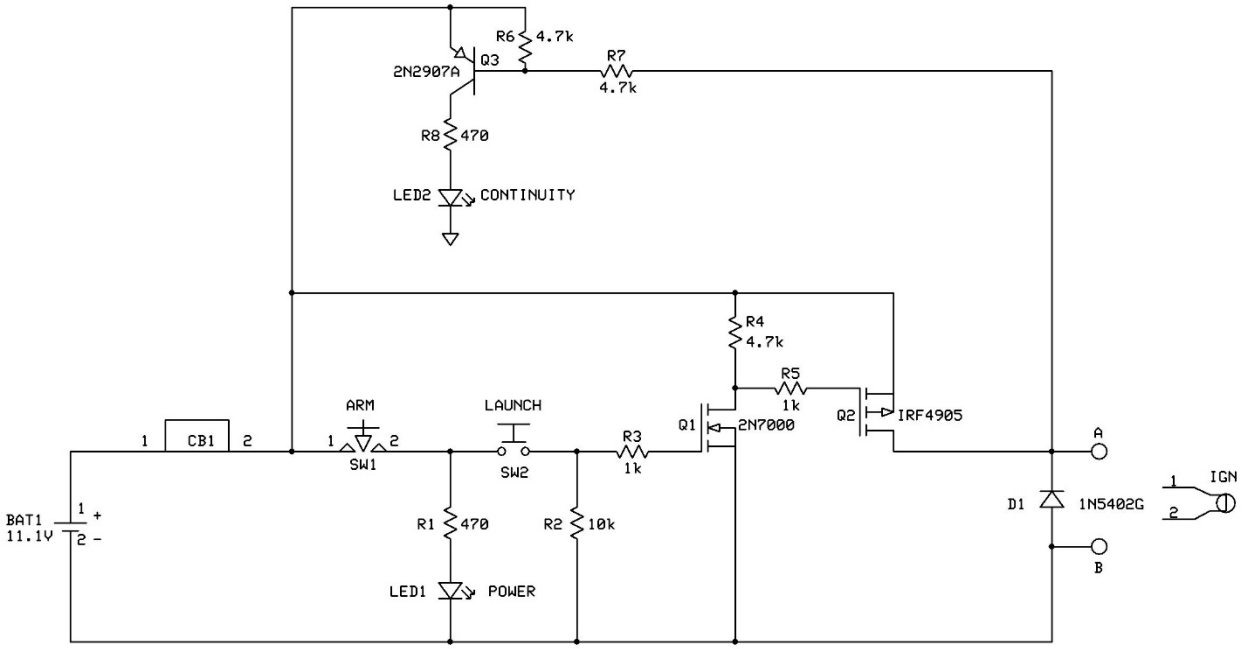


Figure 2: Controller with MOSFET Output Drive

The former DPST ARM switch has been replaced with a SPST version, the former sneak path to the Power indicator now resolved by the presence of the output control transistor Q1. With the intervening transistors, the two serially connected switch appliances are now exposed to negligible current:

- When turned ON, the ARM switch contacts only see the Power indicator current (nominally ~20mA).
- When the LAUNCH pushbutton is pressed, two additional current loads are drawn:
    - The current drawn by Q1 pulldown resistor R2. This is nominally 11.1V/10k = 1.11mA and continues to flow for the duration of the pushbutton press.

- A very brief Q1 gate charging current transient of about 11.1mA (11.1V/1k) which rapidly collapses as the internal gate capacitance charges. This spike has a very short duration of less than 150ns. Following this, there would be a nominal ~10nA quiescent current drawn by the gate while the LAUNCH pushbutton is pressed.

So, as one can see, instead of 8–10A of overstressing current passing through the switches, the updated design drops this load to negligible levels: ~21.1mA steady-state through the ARM switch while LAUNCH is pressed, briefly rising to ~32.2mA during the Q1 gate-charging transient, and only ~1.11mA through the LAUNCH pushbutton after Q1's gate has charged.

As it relates to the added resistors, two of them (R2 and R4) ensure that the transistors turn fully off when the LAUNCH pushbutton is released; the other two (R3 and R5) are there to limit transistor gate inrush current. As the schematic shows, we can see that pulldown resistor R2 provides a gate capacitance discharge path to ground which ensures that Q1 turns fully off when the LAUNCH pushbutton is released. Similarly, Q2/R4 – the P-channel transistor Q2 needs its gate pulled high to ensure that it fully turns off.

Rounding out the analysis, control transistor Q1 draws ~2.36mA Drain-Source current through R4 when the LAUNCH pushbutton is pressed, a value well within Q1's operating range. And then, as a matter of good practice, a back EMF suppression diode is added to the output. Our long, 30' two-conductor 16AWG stranded copper wire Igniter Extension Cable presents a measured series inductance of 6.3μH, which, when the igniter suddenly burns out, can generate a negative spike of a few volts at Q2's Drain terminal. While the IRF4905 can safely withstand this (rated for -55V), we can't know what other external electromagnetic effects may jolt the controller during use, hence the added protective device.

Given the sizeable currents that can flow in this system, and the semiconductor device that controls them, one might raise the risk of a Q2 channel short-circuit failure mode – a fair question. That transistor, an IRF4905 P-channel MOSFET, has a max continuous channel current rating of 42A. But in our application the transistor has a discontinuous operation, with a firing current ranging ~10-12A (perhaps twice that when firing a cluster); this still leaves the part well within its rated operating window.

Quantitatively, we can estimate the part's overall probability of a random failure by using the MIL-HDBK-217F Notice 2 Part-Stress model for a low-frequency silicon FET, and the use factors the transistor is exposed to: here, we assume a 40°C junction temperature (i.e.: a hot outdoor ambient, not continuous use), a greater-than-2W power-device application, commercial plastic-package quality, and a Ground Benign environment. With these parameters the predicted overall failure rate for Q2 is approximately 0.53 failures per million operating hours. This corresponds to a calculated MTBF (Mean Time Between Failure) of approximately 1.9 million operating hours[4]. In normal club use, the controller may be energized for only a few dozen to perhaps one hundred hours annually, making the corresponding annual random-failure probability extremely small. So taken together, these considerations suggest that overstressing the control switches represents a greater life/performance risk than the possibility of a random transistor short, especially since the transistors are operating within range, while the switches (in the absence of the transistors) would not be.

With these additional components the original control circuit is now fully de-stressed, and we can expect years of reliable performance. Schematically, this update is relatively simple, and it's an update that can be easily applied to any launch system, including those that move firing control out to the pads.

[4] The failure rate estimate applies to the overall probability of a random device failure; the model does not predict what portion of the overall failure rate occurs as a consequence of drain-to-source shorts.

Other Considerations

One might wonder why this upgrade is a question worthy of discussion. After all, the analysis shows that even without the additional enhancements, there's a good chance the typical low-cost controller will still last longer than we plan to use it. And empirically, it's doubtful that many of us have had to replace a switch or throw a controller away because the switch stopped working. The answer becomes apparent when one considers the additional current capacity that clusters demand, and the correspondingly low impedance controller designs needed to properly support them, such as the design shown in our Figure 1. In contrast, a low-cost controller (e.g.: Estes Electron Beam) brings comparatively more current limiting to the firing circuit via its higher loop impedance, which can constrain its use with multi-motor models. It brings about two considerations:

- The Low-Performance Impact:

  Basic controllers typically utilize 4 AA alkaline cells and thin gauge wiring. Alkaline cells possess significant internal resistance. Under a short igniter load, the supply sags, and current is physically capped at roughly 2A to 3A. It's enough to fire the igniter if the batteries are fresh, and perhaps a couple in a cluster as well, but the batteries are soon depleted. The cheaper switch survives only because the system is incapable of delivering overstressing current.

- The High-Performance Implication:

  The controller pictured in Figure 1 utilizes a high discharge 3S LiPo battery and thick 16 AWG copper lines. This is a design for performance, something that can readily support large motor clusters, and features virtually no voltage sag. The loop resistance is about 0.3Ω, not counting the igniter. The igniter receives an unimpeded 10A+ current punch when fired. Routing this directly through a 5A switch without mitigation forces a severe 200% overstress scenario, hence the design enhancement.

So, one could say that the best, but performance-limited, value is offered by a low-cost controller; it's cost-effective and expedient, but not the best choice for clustered igniters. On the other hand, the best, high-performance value, something capable of firing large motor clusters, is a robust controller along the lines of the design shown in Figure 2.

Wrapping Up

This article shows an upgrade to a simple high-performance launch controller that protects and extends the life of the control appliances without impacting the performance of the unit. It's a modification that can be made within handheld units, and can easily be applied to remote controlled systems, like pad relay-based designs. I hope you found the article of interest, and as always, best of luck with your rocketry projects.