Competition Launch Control System

Flickering Continuity Indicator Investigation

PITTSBURGH SPACE COMMAND

October 2024

Introduction

I've spent some time revisiting the continuity circuits within the Club's Competition Launch Control System. You may recall we observed a problem during CMMF-X (2021) where pressing a continuity check pushbutton on the Control Console would also cause the indicator for an adjacent inactive pad to flicker. I was able to come up with a fix for this, based on an assumption as to what was happening, but I wasn't able to spend the time then to actually find the root cause. Despite resolving the flicker issue the source of the problem has plagued me since. So, I've done some testing here to find the actual root cause, the results of which are summarized in this report. While the root cause is now clear, the good news is there's no need for further adjustments to the system. The fix from 2021 remains valid.

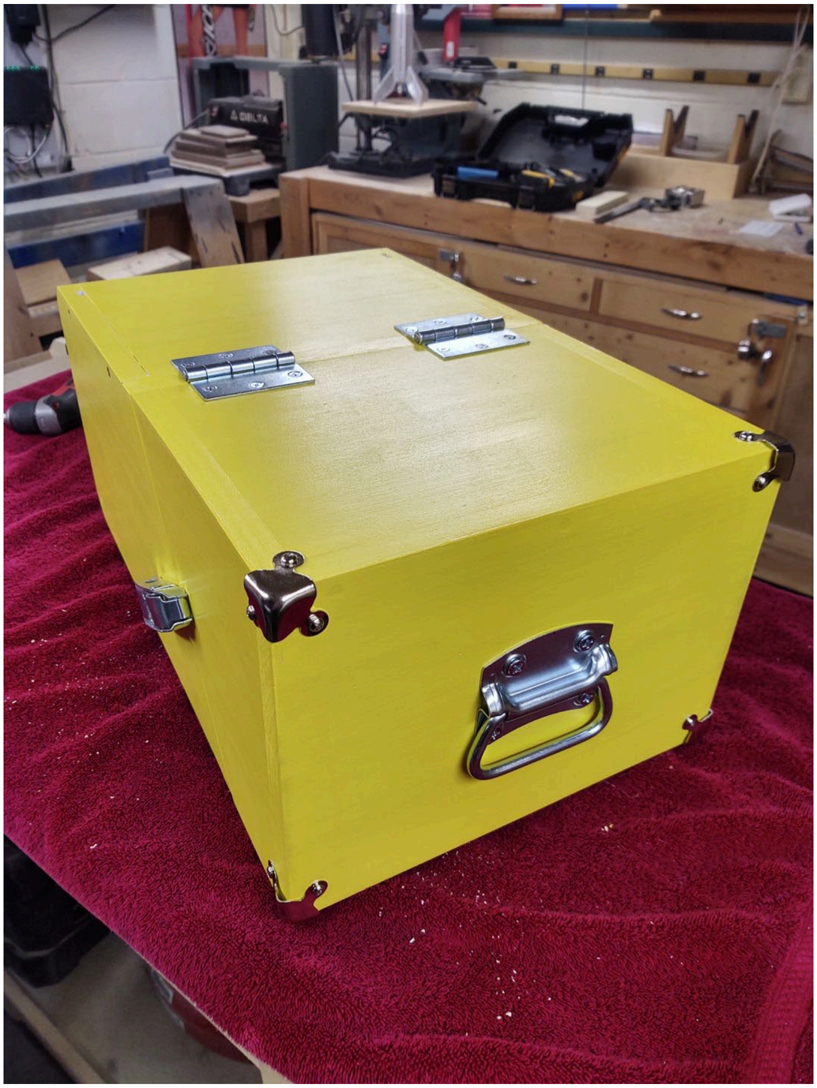
Some Background

First, a few words about the system itself. Let's recall that our Competition Launch Control System was designed and built in 1997 by Tim Zibrat. It's worked very well over the years, and you longer serving club members will remember the old control console.

Old Control Console

It featured some very hard to see incandescent bulb continuity indicators, some Pad Select rocker switches that could be inadvertently left in the "ON" position, and a momentary toggle switch that was used as the launch button.

While the system proved to be reliable over the years, the plywood control console cabinet was starting to show its age, and Chuck was kind enough to craft a much-needed new cabinet.



New Control Console Cabinet

At Rod's request, I changed out the old Pad Select rocker switches for Pad Enable momentary pushbuttons; this has made the operation of the system much safer, as it now takes two control actions to launch a rocket. It's no longer possible to forgetfully leave a pad turned on.

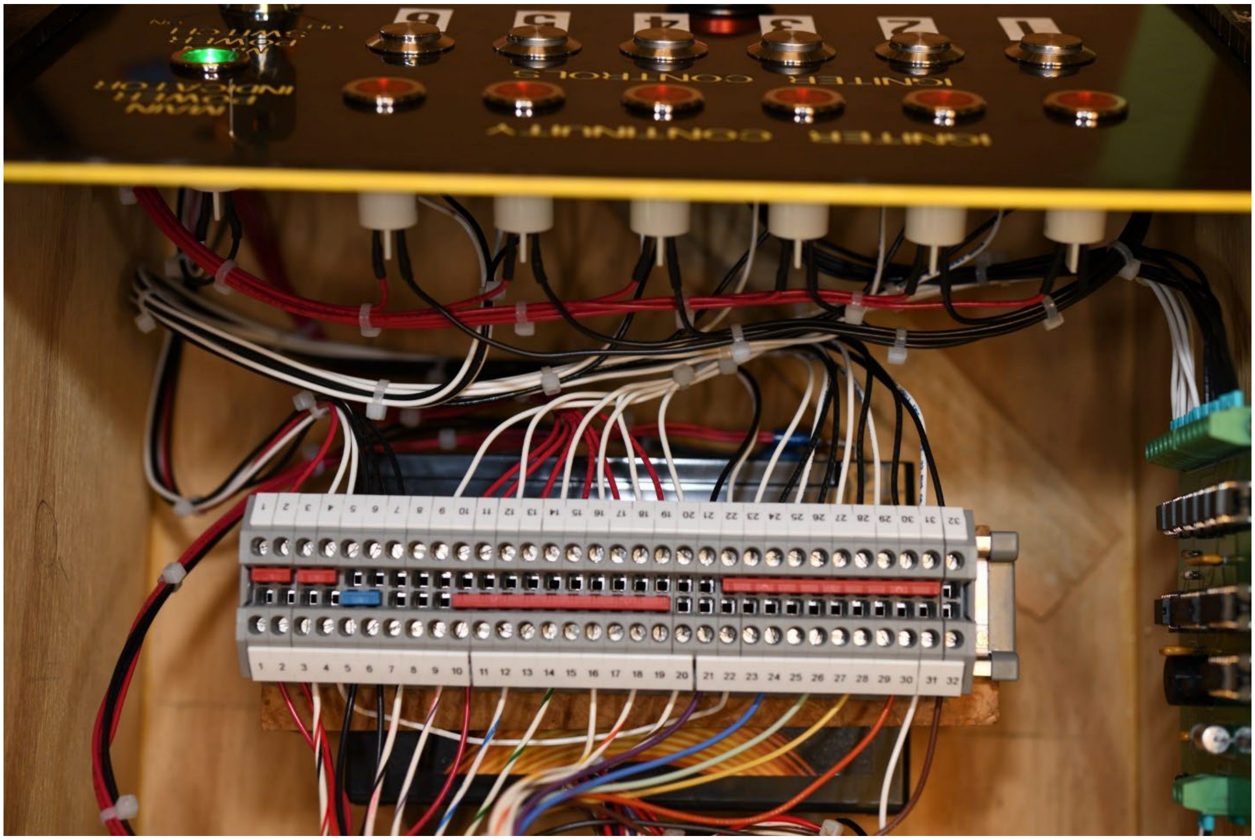
I also changed out the old red incandescent bulb indicators that were used to display continuity. These 12V indicators were hard to see in bright daylight, and as well, each one used quite a bit of current, something in the order of 100mA or so, as I recall. These were changed out to high brightness LED indicators, each one using less than 20mA of current.

Then finally, the old momentary toggle switch launch button was replaced with a big, environmentally sealed, red pushbutton. Fortunately, we were able to retain the old control panel while making these appliance changes, as getting a new one made and engraved would have been a significant undertaking.

New Controls and Indications

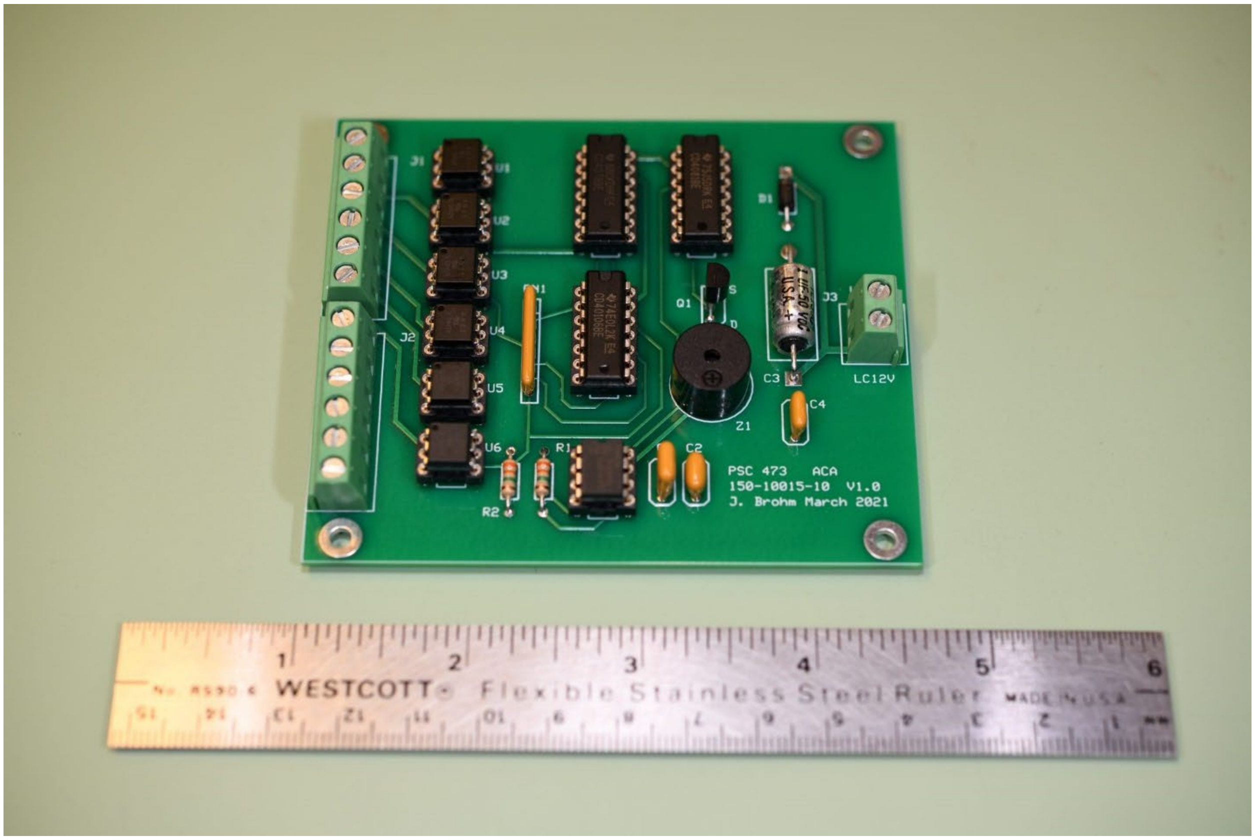
While planning these upgrades I also decided to make the console much more maintainable. Tim had wired the old console with point-to-point wiring, which meant wires got shorter with each repair. One would also have to de-solder a few adjacent parts and wires to get the failed one out, which meant a lot of extra work.

I wanted a system that would allow any individual control or indication appliance to be replaceable, so I decided to add an internal Terminal Block that every control and indication would land on individually.



Terminal Block

I also designed and added a PCB that would provide an audible continuity alert in conjunction with the visual indicators on the front panel. You can see that board installed on the right side of cabinet in the photo above.



Audible Continuity Alert PCB

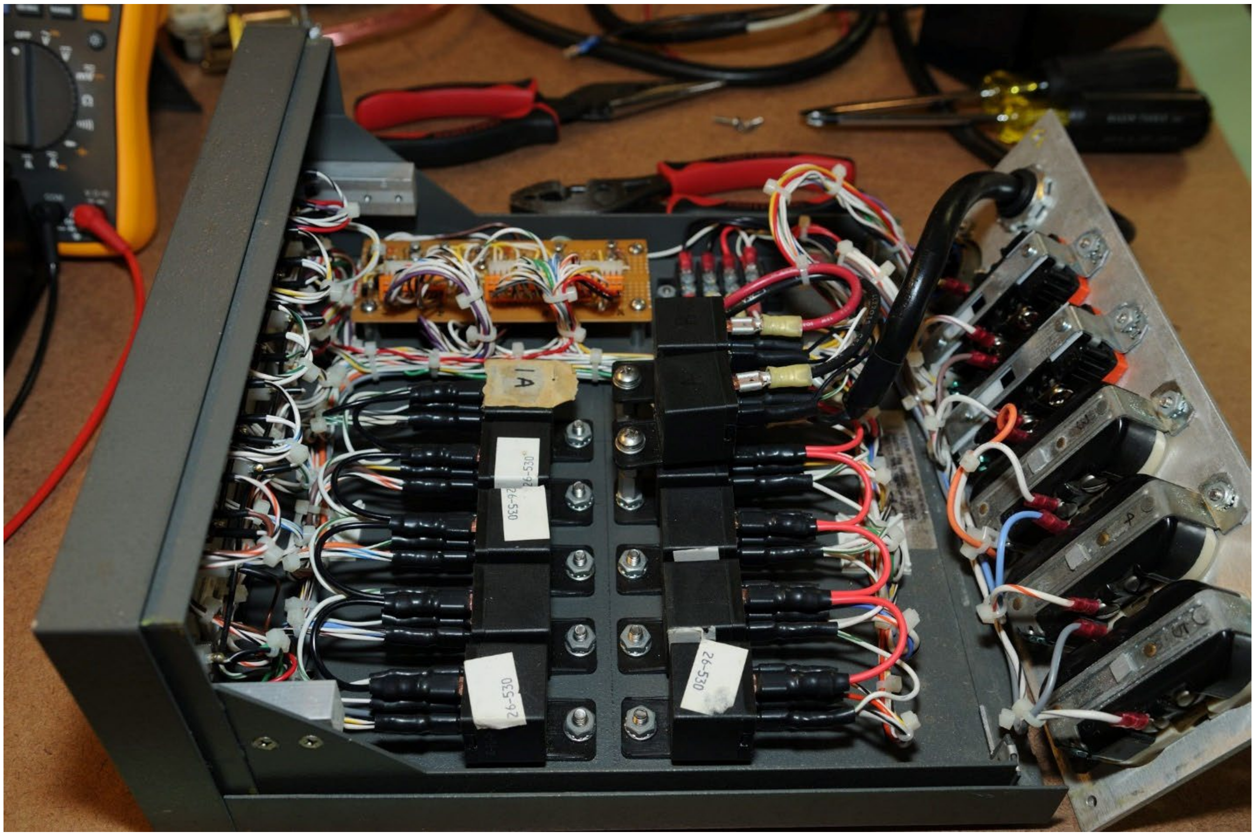
With all these changes we arrived at a safer control console that provides better, more effective continuity indications, all captured in a fresh new box.

The Yellow Relay Box

As many of you know, the Control Console interfaces to the pad-located relay box (the Yellow Relay Box) by way of a 19-core cable.

The Yellow Relay Box

That Yellow Box is the magic part of the system, and after all these years I still find Tim's vision for, and fabrication of, this part of the system just amazing. He packed a ton of stuff very efficiently into quite a space-optimized package.



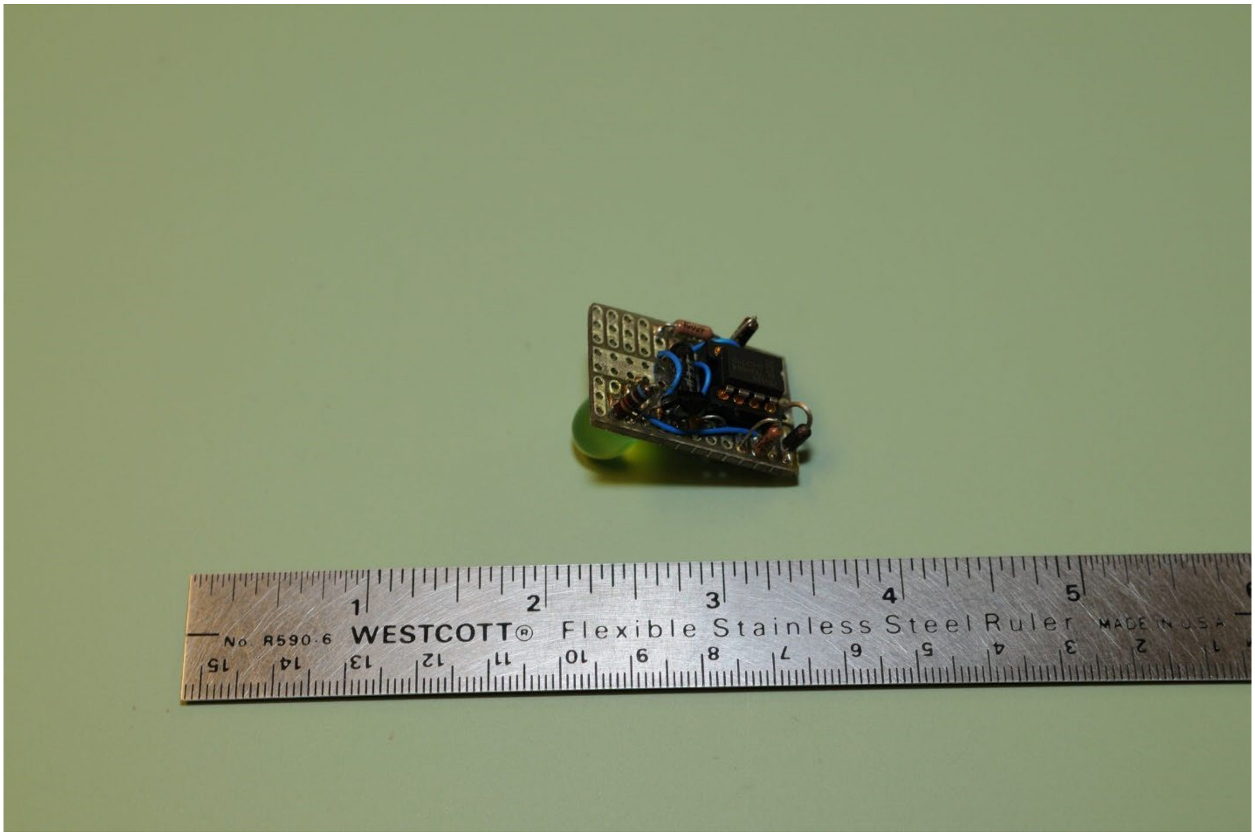
Original Yellow Relay Box Internals

The photo above shows the original internals. On the right are five duplex receptacles, mounted to the back panel. This is where the igniter extension leads are plugged in. In the middle are the five pairs of pad control relays; each pad has a pair of relays so that the power to an igniter is conveyed by way of a double-break circuit. Both the positive and the negative leads are switched in this system. At the far end of the row is a pair of stacked relays – these are the power control relays, and they route power to the pad relays when the system is turned on.

On the left is the inside of the front panel; that's where the local continuity check pushbuttons are located, together with their corresponding local continuity check indicator LEDs, and the Pad Active LEDs.

Referring to the prior Yellow Relay Box photo, one sees on the right of the front panel the circular connector that allows the system to be extended to a separate Pad 6 Away box for HPR operation. On the left side of front panel is the Pad Safe Indicator.

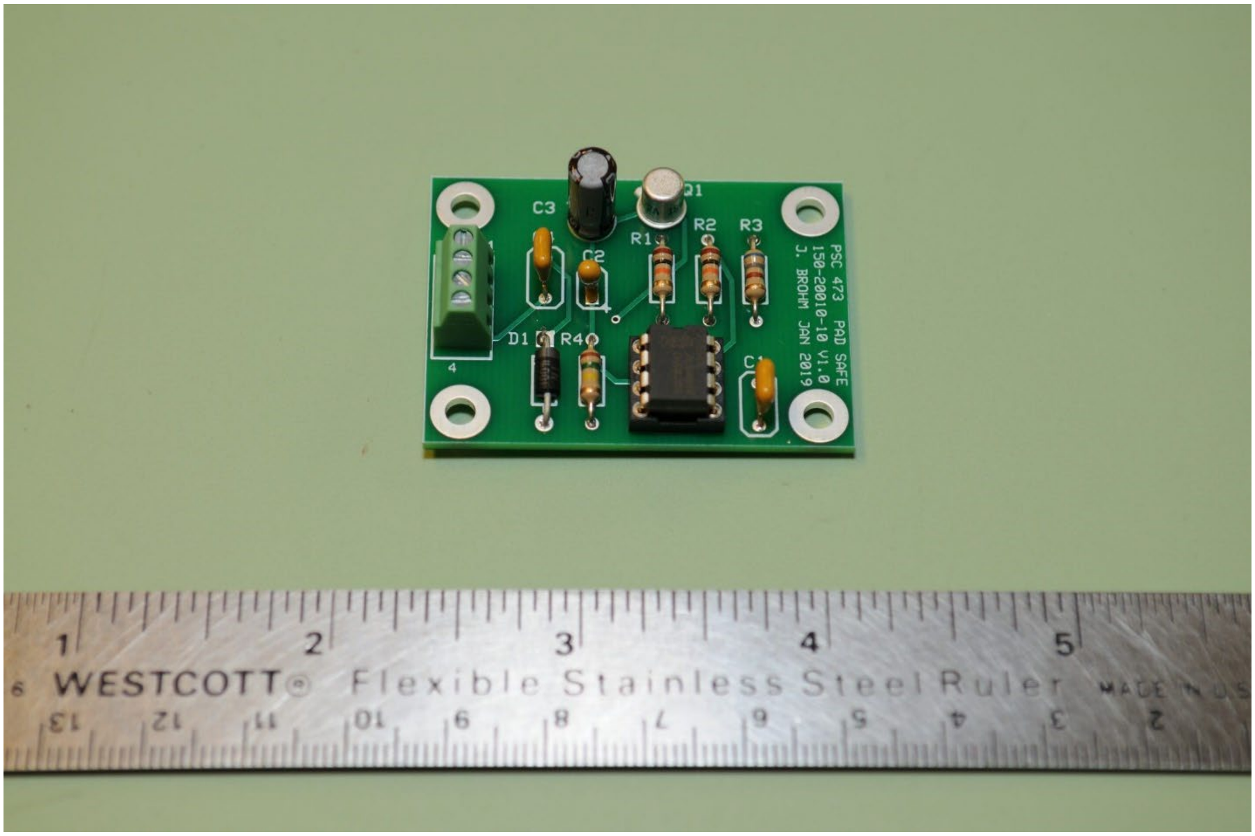
The old Pad Safe Indicator was handcrafted on a small piece of perf board, and it housed a low frequency (about 6 Hz) oscillator circuit that would flash the large LED on the left of the front panel when the Yellow Box was OFF, or SAFE. When the box is turned on, the flashing LED turns off, indicating the system is live. It's kind of a reverse logic, but Tim designed it this way to accommodate possible power problems. For example, if the power was stuck on, or the LCO forgot to turn the system off (i.e.: the system is still live), then the indicator would be OFF. The system is only SAFE when the LED is flashing. The following photo shows the old Pad Safe Indicator Board.



Old Pad Safe Indicator Board

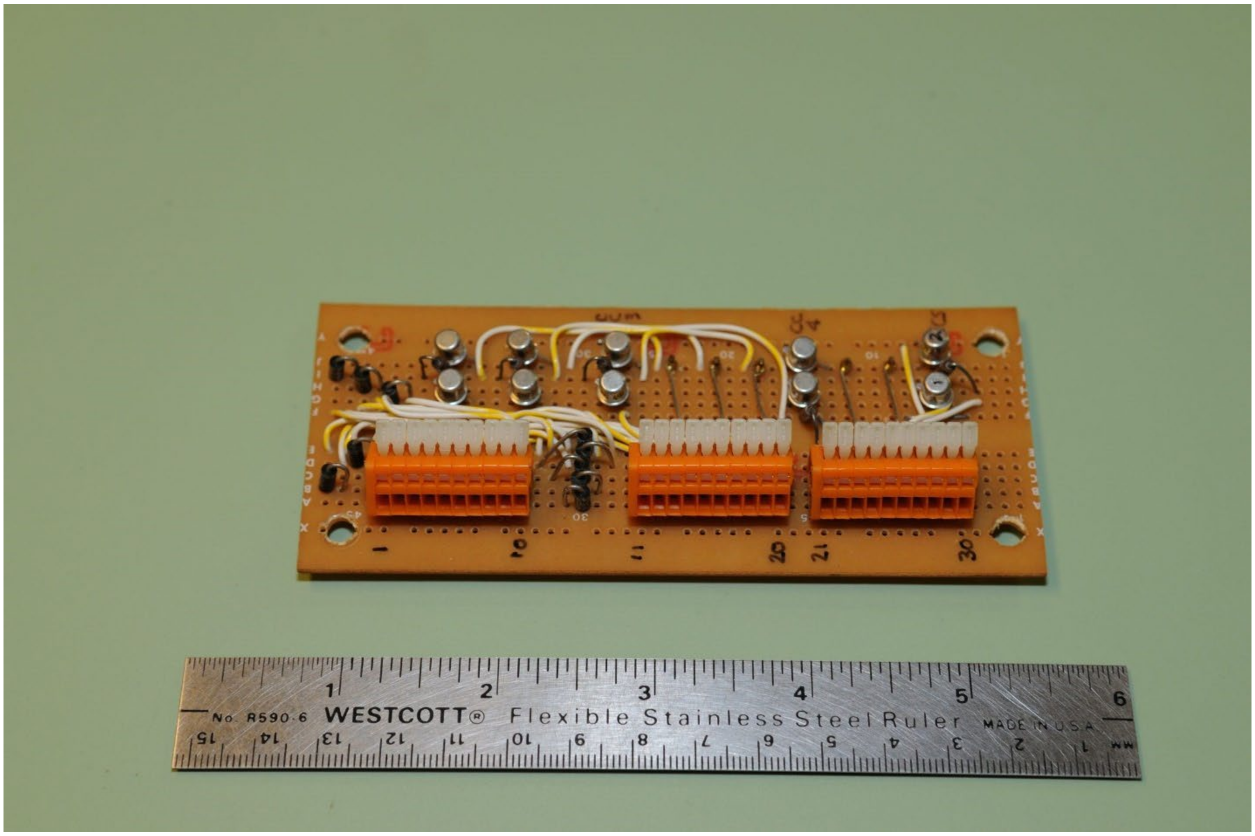
A few years ago, I refurbished the internals – all of the relays were replaced with new ones, the old white duplex receptacles were replaced with safety orange ones, and I replaced the old Continuity and Pad Safe Indicator boards with new ones.

There were two problems with the old Pad Safe Indicator circuit – first, the LED indicator was a low brightness Green LED, and it was hard to see from the LCO desk. Second, and more problematic, the Pad Safe board would fail at virtually every launch. The way it was designed to interface with power left it exposed to inductive kickback from the relays, and the timer circuit would eventually fry. So I took Tim's timer circuit design as it was, but added some power protection and corrected the way it interfaced to power. I also replaced the old Green LED with a new, high brightness Blue LED. With these changes the Pad Safe Indicator is now easily visible from the LCO location and we haven't had a failure since.



New Pad Safe Board

If we look back one more time at the photo of the internals, one can see at the top of the photo the old handcrafted Continuity Board; Tim built this on an old Radio Shack perf board, the kind one would use for breadboarding a quasi-permanent circuit. The following photo provides a closer view of this board.



Old Continuity Board

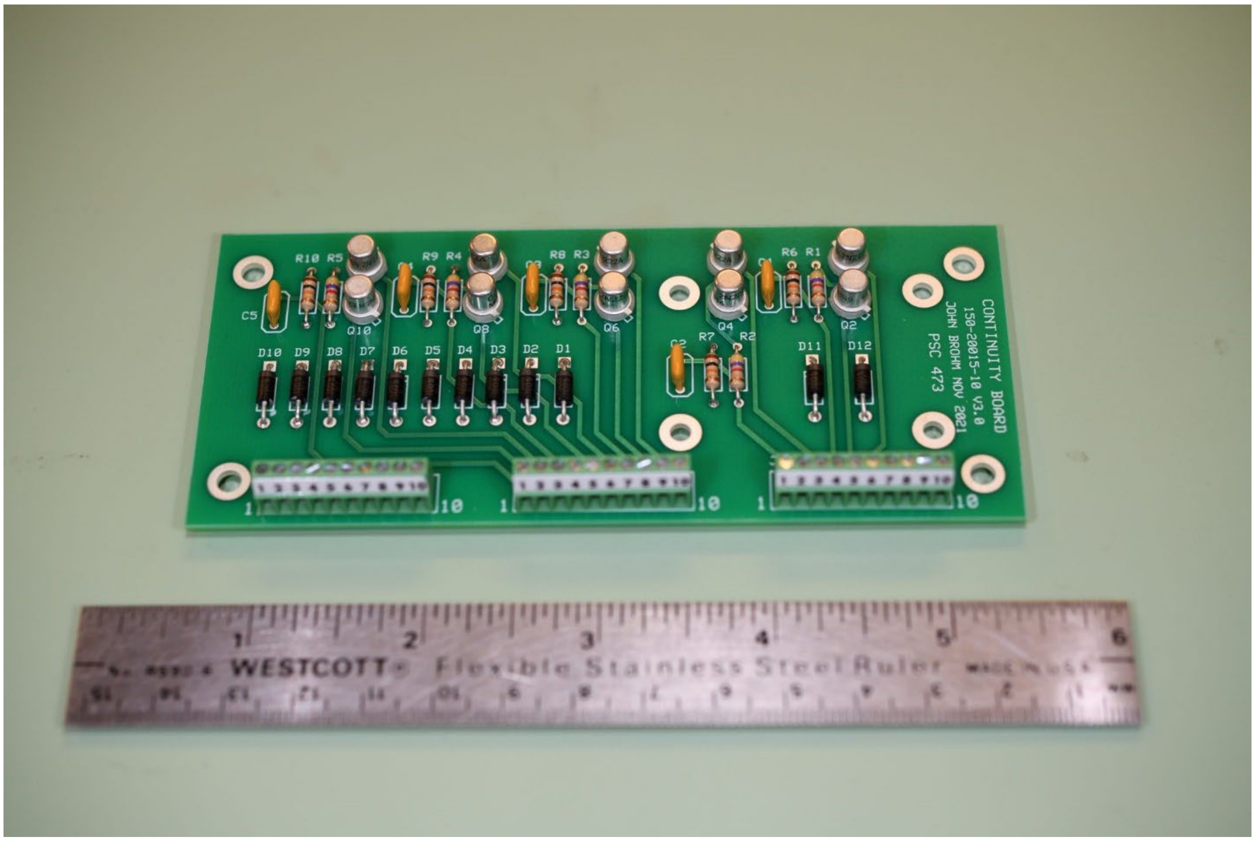
Tim's continuity check circuit is an elegant design; its concept relies on the use of a transistor as the check current source. Doing so allows one to reduce the check current to very low levels, an important consideration when the system could be confronted by all kinds of igniter types, from high current Aerotech First Fires to Quest Q2G2s and electric matches. As originally designed by Tim, the check current was limited to 1.2mA; compare this to a typical Estes Electron Beam controller with the old incandescent continuity check bulb: that controller passes a 200mA check current.

The check circuit was duplicated on the board for each of the pads; each circuit consisted of two transistors – one to drive the Continuity Indicator back on the LCO Console, and one to drive the local continuity LED on the front panel of the Yellow Box. Looking at the photo of the Old Continuity board, one can see a total of five pairs of transistors, one pair assigned to each pad.

When I refurbished the Yellow Box, I took the opportunity to layout Tim's continuity circuit on a new PCB. I also made a couple of adjustments to the circuit. As we'll see in the schematic provided later on in this note, I added a pull-down resistor to the input of each transistor pair. Even though Tim's circuit usually worked properly, his design left these inputs floating when an igniter wasn't present in the circuit. Under the right temperature and humidity conditions, this can cause the transistors to pass a small leakage current, giving rise to a faulty continuity indication. Adding an input pull-down resistor ensures each transistor pair is fully turned off when the corresponding pad isn't active/enabled.

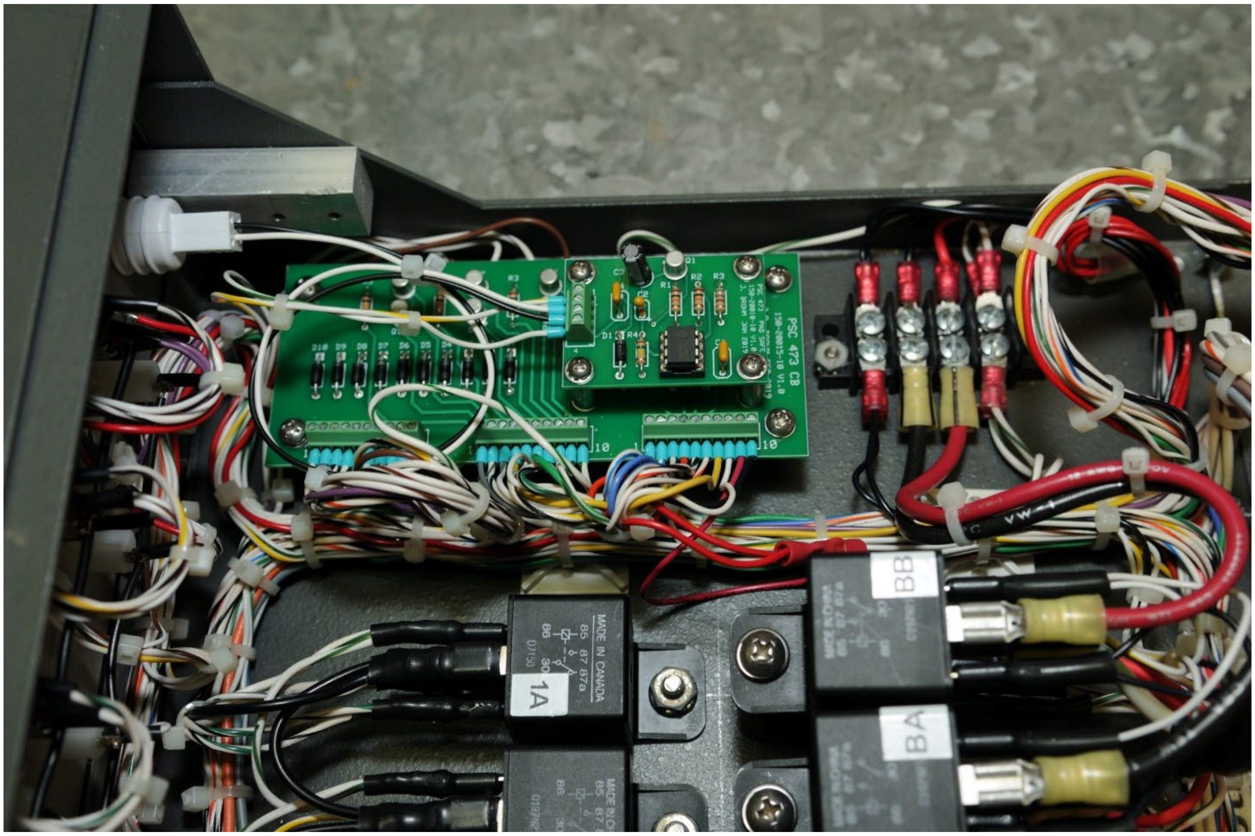
I also reduced the value of the check current limiting resistor. Tim's design produced a check current of 1.2 mA; this in turn was split between the two transistors comprising each pair – a somewhat marginal arrangement. I wanted to make sure that when turned on, each transistor was saturated; that would ensure the transistors would be fully "ON". Reducing the check current limiting resistor value ensured the transistors were biased for this operating mode. These changes increased the check current to 3.5mA.

With these changes the new Continuity Check Board now looks like this:



New Continuity Check Board

Given the premium on space inside the Yellow Box, I designed the two new boards so that they would stack. The inside of the Yellow Relay Box now looks like this:

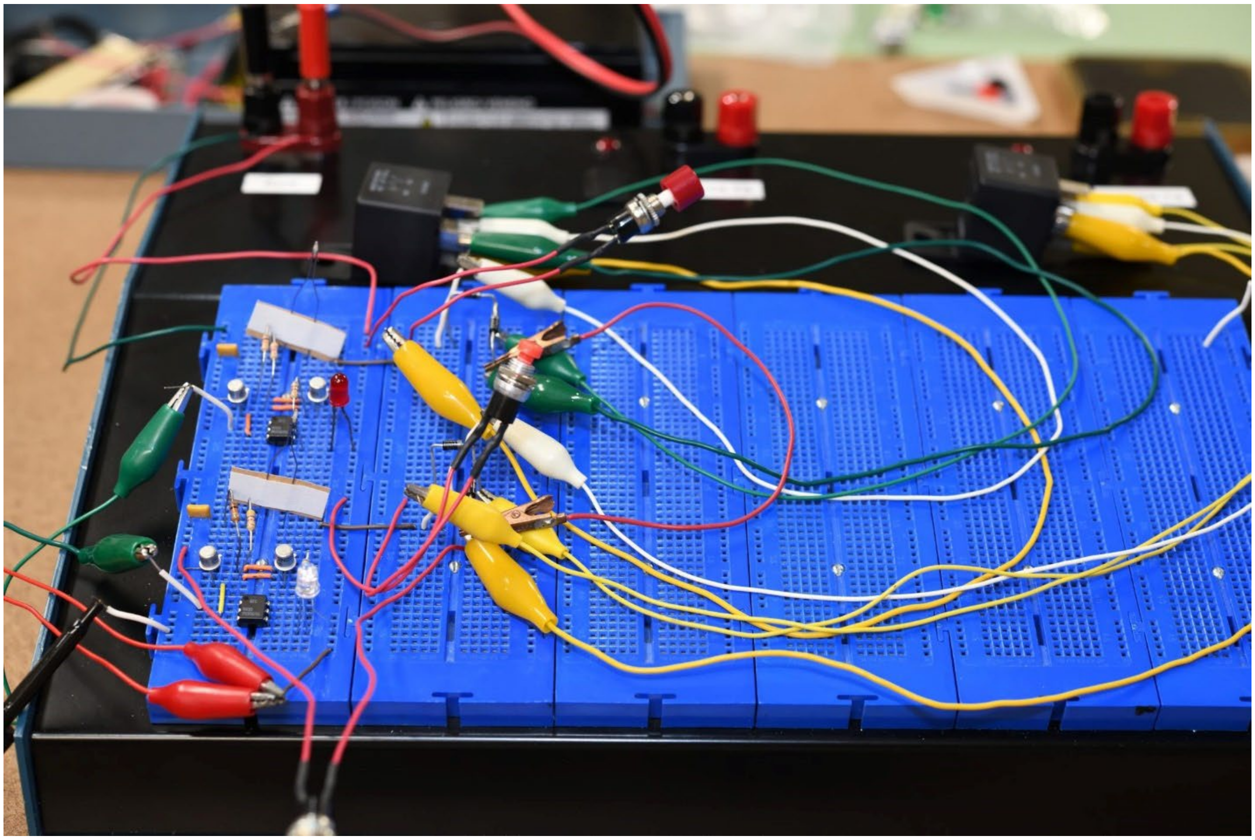


New Insides

Other than the changes to the check current limiting and input protection, all the circuits were exact copies of Tim's original design, implemented on modern professional printed circuit boards. And since these updates were made the system has performed reliably, at least until that fateful day in October 2021. What was causing the adjacent LCO Continuity Indicators to flicker? How come the flickering wasn't apparent/wasn't noticed in the operation of the old system?

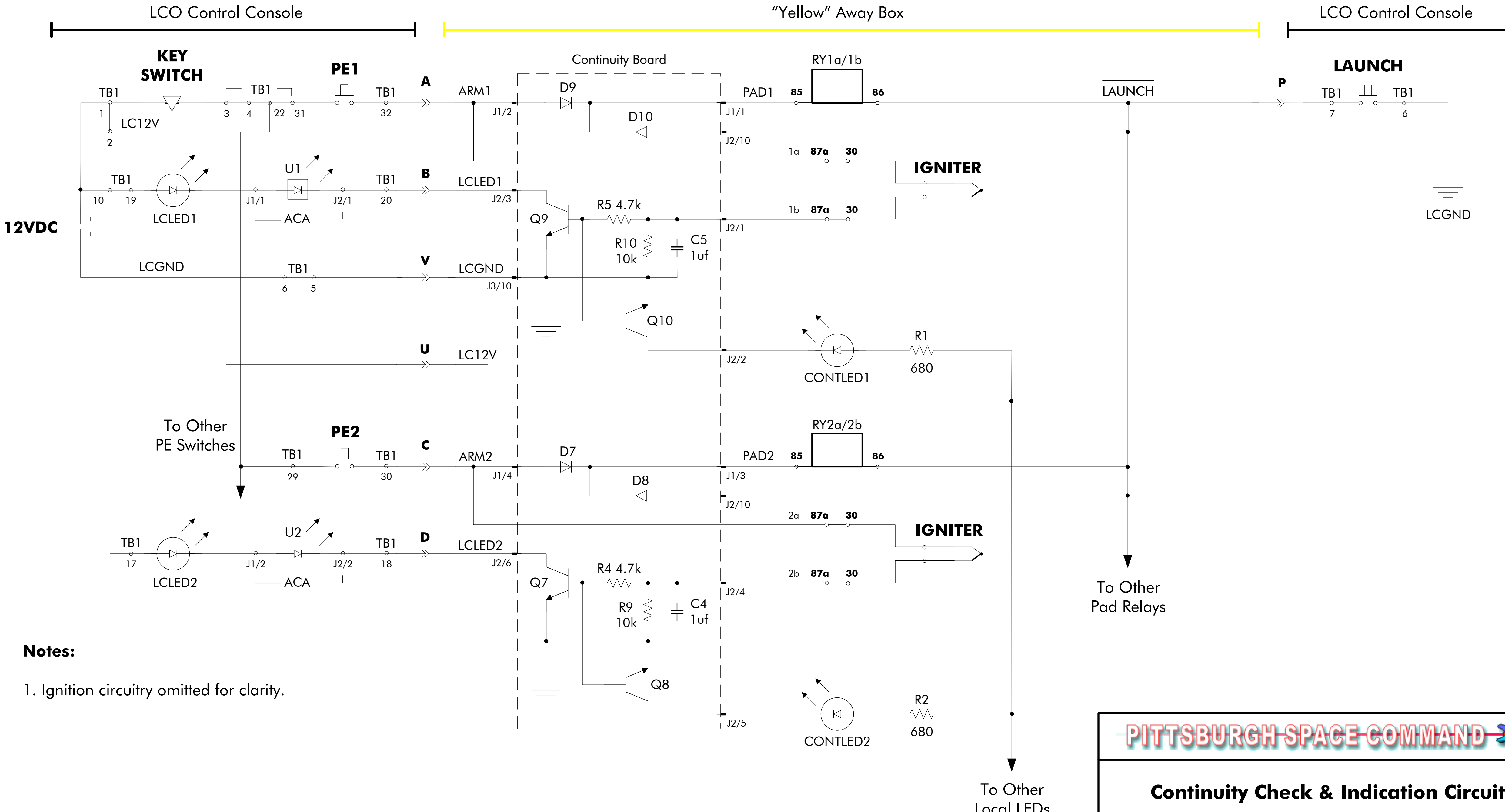
Testing the System

Back when the problem was first noticed, I set up a pair of continuity circuits on my breadboard so they could be tested and experimented with. The following photo shows the setup. There are two circuits on the breadboard, let's call them Pad 1 and Pad 2, and the circuits include both an LCO Continuity indicator and a Local Continuity indicator. I used the exact same LCO indicators as installed in the console; they are sitting on the left, just outside of the photo.



Breadboard Test Circuits

These circuits correspond to the actual system, and are shown schematically in the following drawing.



Notes:

1. Ignition circuitry omitted for clarity.

PITTSBURGH SPACE COMMAND

Continuity Check & Indication Circuits

PROJECT: PSC Competition Launch System	Approved: John Brohm
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With the circuits powered up and igniters connected, what I found was that indeed, pressing the Pad Enable (PE) pushbutton for, say, Pad 1 would fully illuminate the continuity check indicator for Pad 1, but would also cause a momentary, dim pulse or flash to occur on the indicator for Pad 2. The same would occur in reverse, that is, if I pressed the PE for Pad 2 – a momentary pulse would show up on Pad 1's Continuity Indicator.

My immediate thought was perhaps there was some kind of inductive kickback or pulse occurring from the relays, causing a brief pulse to leak through to the transistor inputs. I experimented with several values of input damping capacitors and found that a 1μf capacitor placed at the input of each transistor check circuit would damp out the pulse. No more flickering. I updated the PCB layout to include these capacitors, soldered up a new board, and that's the one you see in the earlier photo. The added capacitors are the small yellow rectangular components located beside each set of resistors and transistors.

With that update the system has been working fine. But the problem has continued to nag me, because how there can be an inductive kickback when the relays were never picked? The flickering would occur when the LCO was just checking for continuity; the relays weren't energized, so no back EMF could be occurring. Plus, as the schematic shows, each relay circuit is isolated by a blocking diode – D9 in the case of Pad 1, and D7 in the case of Pad 2. So there could be no active current sneak path. So I pulled out the breadboard and revisited the circuits.

Regarding the possibility for a sneak current path, it's the reason why Tim included blocking diodes in his design. All of the pad control relays share a common return to ground; that's the LAUNCH wire one sees on the right side of the schematic, tied back to the Launch pushbutton on the control console. If diodes like D9 and D7 were absent, then pressing (for example) PE1 would also cause the continuity indicator LCLED2 for PAD2 to illuminate (so long as an igniter was present at PAD2), even though pushbutton PE2 was not pressed. That's because the control relay coils aren't polarized; they function just like a piece of wire, and would pass current to a neighboring continuity indication circuit unless something was inserted to stop the current flow. That's what D9 and D7 do, as do the similar diodes in the other pad control circuits.

To give some dimension to the effectiveness of the blocking diodes, the control relays need about 160mA to pick, or activate. A blocking diode is just a regular diode inserted backwards in the current flow direction, and so it is reverse-biased in this direction (that's why its cathode, the bar part of the triangle symbol, is facing the relay – current can only flow through the diode from the other direction, anode to cathode). When these diodes are reversed biased, as they are in this circuit, they can pass only a very tiny leakage current, in the area of about 50 nano-amps. That's six orders of magnitude less than the activation current of the relays, and about two to three orders of magnitude less than the activation current of the transistors. So these diodes do a good job of keeping each of the control and indication circuits isolated, even though the relays share a common return.

But what about the adjacent indicator flickering problem? To get a better idea of the effect, I configured the continuity circuit on my breadboard exactly as Tim originally had it – no damping capacitors (C4/C5 removed), no input pulldown resistors (R9/R10 removed), and the check current limiting resistor value restored to the original 10k ohms that Tim had (R4/R5). In this configuration I found the adjacent indicator flickering to be even more pronounced/more visible than what I had observed before I added the pulldown resistors and the damping capacitors. I also observed the flickering occurring with the associated local Yellow Relay Box continuity indicators as well.

I then removed the common return LAUNCH line between relays. No flickering. I reconnected the common return but removed the igniter from the adjacent circuit; again, no flickering. Reconnecting everything and the adjacent indicator flickering returned once a PE button was pressed. So even though the blocking diodes were stopping any kind of significant reverse current, the presence of the common return was still providing some kind of electrical path for this issue.

Semiconductor devices can build up a small internal charge owing to how the physics of their internal electronic junction works. The junction can work as a tiny capacitor, and since I was seeing only a barely visible, short flicker, I thought perhaps the blocking diode was the culprit. So I pulled D9 and pressed PE2 – again, I observed a momentary, barely visible flicker on LCLED1. So D9 wasn't the issue, and it made sense, as that junction capacitance is very small and I was skeptical to begin with that this would be the factor.

The importance of pulling D9 must be underscored; doing so completely isolated the PAD1 continuity check circuit. PE1 was open, and removing D9 removed the electrical path through RY1. Yet pressing PE2 would cause LCLED1 to flicker. Things were now pointing to the relay itself.

So next, I pulled the wire that connected the igniter to relay contact 30. No flicker. I replaced this wire and then pulled the wire from relay contact 87a to D9. The flicker returned. Now the problem was localized.

The investigation implicates the relays themselves as the source of the momentary pulse that causes the flicker to occur. But as the relays are open ended when not selected (supposedly electrically isolated), how can this happen? Well, what the testing implies is that when igniters are hooked up and a pad is selected (i.e.: a continuous circuit), let's say PE2 is pressed, the 12V battery potential is immediately connected through D7 and the relay coil in RY2 to the common return line. That sudden rise in potential also lands at the back end of the relay coil in RY1, and like any inductor (which is what the relay coil is) that sees a sudden rise in voltage, it generates a brief spike which in turn is inductively coupled to the relay contacts, given their close proximity with the relay package. It's a very brief and very small spike, and very little in the way of an actual induced current, but the induction is enough to ripple a spike to the input of the Q9/Q10 transistor pair.

I found that adding the 10k pulldown resistor back in to the input circuit reduced the intensity of the flicker; adding the damping capacitor eliminated the problem entirely. The damping capacitor acts like a short circuit to a sudden short duration spike, so the spike never gets to the transistors, thus eliminating the flicker.

I have to say I wouldn't have imagined this to be the mechanism that caused the flicker. When I first looked at this issue a couple of years ago, I just assumed there was some leakage current or back EMF occurring. Typically, it's these kinds of issues that cause problems like this in circuits. It was only after thinking about this some more that had me second-guessing those possibilities.

All this leaves one unanswered question: how come we didn't see this effect in the old system? That answer lies with the old incandescent bulb indicators. The inductively coupled spike was indeed occurring, but because it's so brief and so small in energy, there was never enough juice to fire up the elements in the bulbs. So the spike, even though it was occurring, would never be seen.

And I think that's why Tim may have added the incandescent bulb indicators. His original design shows LEDs on the control console, not bulbs. I'm speculating that Tim may have seen this flickering problem when he first put the system together, and solved it by switching to an indicator that wouldn't show the flicker. When I reverted the system to LED indicators, the problem then had a platform to reveal itself.

Anyway, the conclusion is the original fix remains valid, and the adjacent indicator flickering problem is resolved. Any new issue would point to a new problem, and we'll deal with that should it arise.