I recently discovered I had a voltage regulator that was not regulating. This sent me on a quest to find a new one or someone who could repair it. The former seems to be answered by Lamar, who appear to make the only suitable replacement, and I never found the latter. Somebody gave me a contact at Electromech but they never responded, so I was on my own.

It turns out a hangar neighbor went through the same thing on his F Bonanza some time ago and went the Lamar replacement route. He happened to still have his old broken regulator, which was the same part number as mine, and offered it to me to dissect. I decided to see if I could fix his and mine, purely for the intellectual challenge and not to install back in the airplane because, of course, I am not a certified avionics shop.

The regulator is a mix of discrete components on a single layer PCB in an aluminum box. The electrical/mechanical/thermal design is, at best, mediocre, the construction quality fair to poor, although this might be an overly harsh comparison given what I am used to working with in the day job. I can say whoever designed and built this thing was not a perfectionist.

The VR input/output function is pretty simple--- bus voltage goes in and a field voltage approximately equal to the bus voltage comes out until it hits the desired regulation voltage (nominally 28.5V) at which point the field voltage goes to zero which, in turn, causes the alternator output voltage to lower, which causes the regulator to increase the alternator output, etc, in a continuous loop. The Vin/Vout curve has a bit of a knee, albeit a sharp one, and, since the alternator generates an output voltage proportional to the field, the end result is the alternator is kept in regulation right at the knee.

There is also an overvoltage trip function that opens up a NC relay to cut the output when the bus goes above 32V. Once tripped, bus voltage has to be removed in order to reset the relay.

For the equally curious, attached are pictures of the board, as well as the PCB trace and schematic created by backwards engineering the traces. The schematic is in two pages: the one page is the overvoltage portion and the other page is the regulator portion. Both pages might have some minor inaccuracies and/or incompleteness since the focus was to draw just the overall circuit topology.

A simple circuit explanation--

The overvoltage circuit passes the bus voltage ("battery" pin) through a relay, whose output is labeled "switched voltage", and on to the regulation circuit. The OV circuit has two PNP transistors; one has a base voltage picked off of a divider that follows at about 70% of the bus voltage, the other has a base voltage that is kept around 10V less than the bus by the zener diode. These two voltage lines intersect (i.e., when $0.7x = x-10$) at $x = 32V$, as fine tuned by the trim pot. The two transistors are like a see-saw, either one is conducting ("on") or the other, teetering around the trip point. Until the trip point is reached, the zener-fed transistor is on because its base voltage is lower, and the divider-fed one is off. The reverse is true after the trip point; turning on the divider-fed transistor after the trip point applies a gate voltage to the SCR (or thyristor), which then conducts and energizes the relay coil. This opens the relay and interrupts the voltage being fed to the regulator circuit, killing the field and therefore the alternator. The SCR will continue to conduct and keep the relay open even if the transistor turns off and stops supplying the gate voltage (which it will do once the alternator is off and bus voltage goes to the battery voltage), and is why the batteries have to be turned off to reset the VR after an OV trip.

The regulator portion operates in a similar manner in that it has an NPN transistor with a base voltage that is about one third of the bus, and an NPN with base voltage set by a zener, which keeps the base at a constant ~9V. In this case, the two lines intersect around 28.5V, also adjusted by the trim pot. When the voltage is below the adjusted regulation point, the zener-fed transistor is on because its base voltage is higher, which turns on a slightly bigger transistor to drive the even bigger 2N3055 that supplies the field. Above the regulation point everything turns off and there is no field and no alternator output.

Also included here are some simulated voltage traces on the various transistor points. In both cases you can see the zener/divider base voltages and how things change when they intersect (note that in the simulation the resistors were set to some nominal value and were not tweaked to force the cutoff points to exactly 28.5 and 32.0 as they would be on an airplane).

I should mention that my hangar neighbor's bad regulator is a -3 and my bad one is a -5; they might be superseded to something else now, I forget. The only difference I could see between our two was an additional capacitor between the SCR gate and ground, bitch soldered to the back of the board (like I said, not the most impressive design or quality).

The results---

On the first regulator, the field voltage on the bench followed the bus voltage up to 32V and tripped, i.e., there was no regulation of the alternator and in flight the voltage eventually increased until it hit the OV trip point. My regulator did the exact same thing, as shown in the attached JPI download. I will spare the debug details except to note that, when testing on the bench, the field output will not behave properly with an open circuit, i.e., you have to load the field so the 2N3055 emitter can dissipate instead of floating. I picked the fattest resistor I had handy, which I think was a couple watt, 1k resistor. It turns out in both bad regulators the field drive transistor, the familiar 2N3055---coincidentally the same one that drives our panel lights---was shot. A replacement brought both my and his regulator back into working order. The fix was that simple.

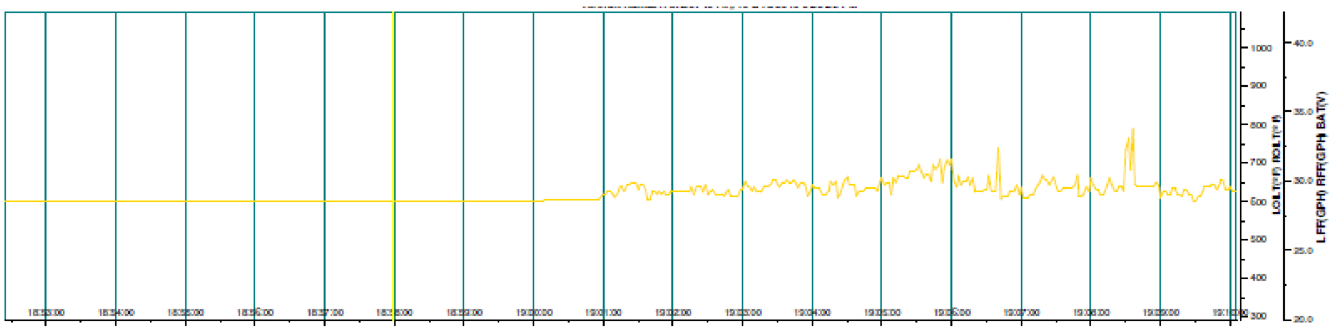
On my regulator the OV trip function was also not tripping consistently, something I noticed in the JPI download and verified on the bench. On the bench, sometimes the relay would click when the input voltage was above 32V, sometimes not, and by accident I discovered the OV circuit would work when the back of the board was randomly touched. Not regulating and also not tripping is A Bad Thing. Looking with an eye loupe I found what appeared to be a cold solder joint (the board was hand soldered) as well as a PCB trace that had been scraped off to the point of, I suspect, causing an intermittent circuit. The scrape occurred at the board edge, on a pad closest to where the board slid into a slot in the aluminum housing. From the width and characteristics of the scrape, it looks like the assembler initially put too much solder on the pad and the board edge could not fit into the housing slot, so s/he scraped off the pad until it did fit. Unfortunately, s/he also scraped off the underlying PCB trace. I do not know if either the cold solder joint or the scraped trace was the cause of my OV circuit not working (they were both on the SCR gate leg), but once retouched with an iron it all works fine.

If anyone is similarly replacing their 2N3055 transistors for their VR or, for that matter, their panel lights, replace them with 3055H. The H suffix is a slightly more robust version compared to what you used to be able to find in Radio Shack. The H also happens to be the official number called out by the parts book for the panel lights.

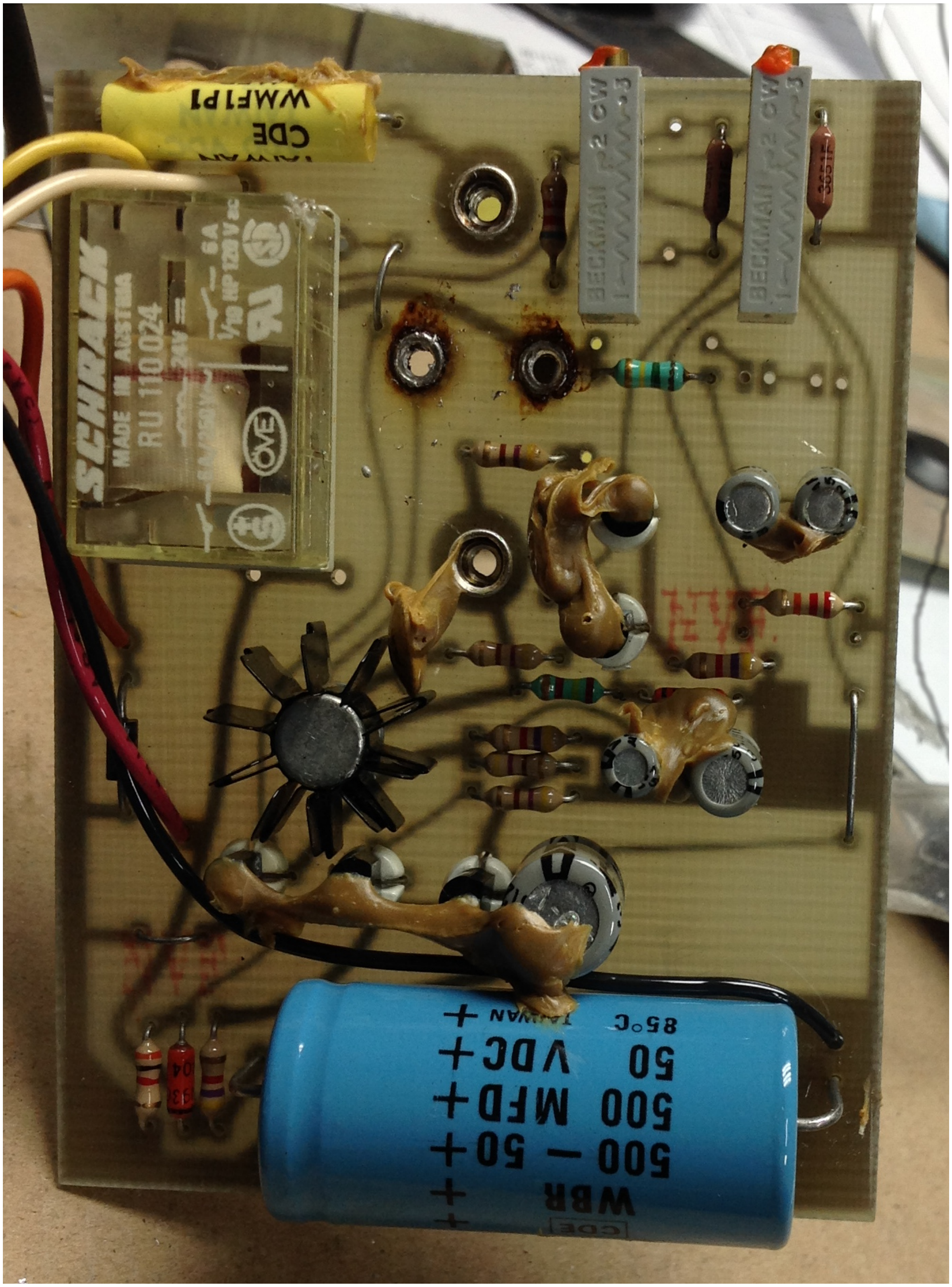
I guess the answer to "How to fix a voltage regulator" is "It depends". In two cases it was the drive transistor, yet someone else I know had trouble with an older 12V version and in that case it was a corroded trim pot (one of the old wire wound types, no longer used). The attached documents should at least give you a good head start to find whatever ails yours, especially if it is one of the same Electromech versions.

Have fun experimenting!

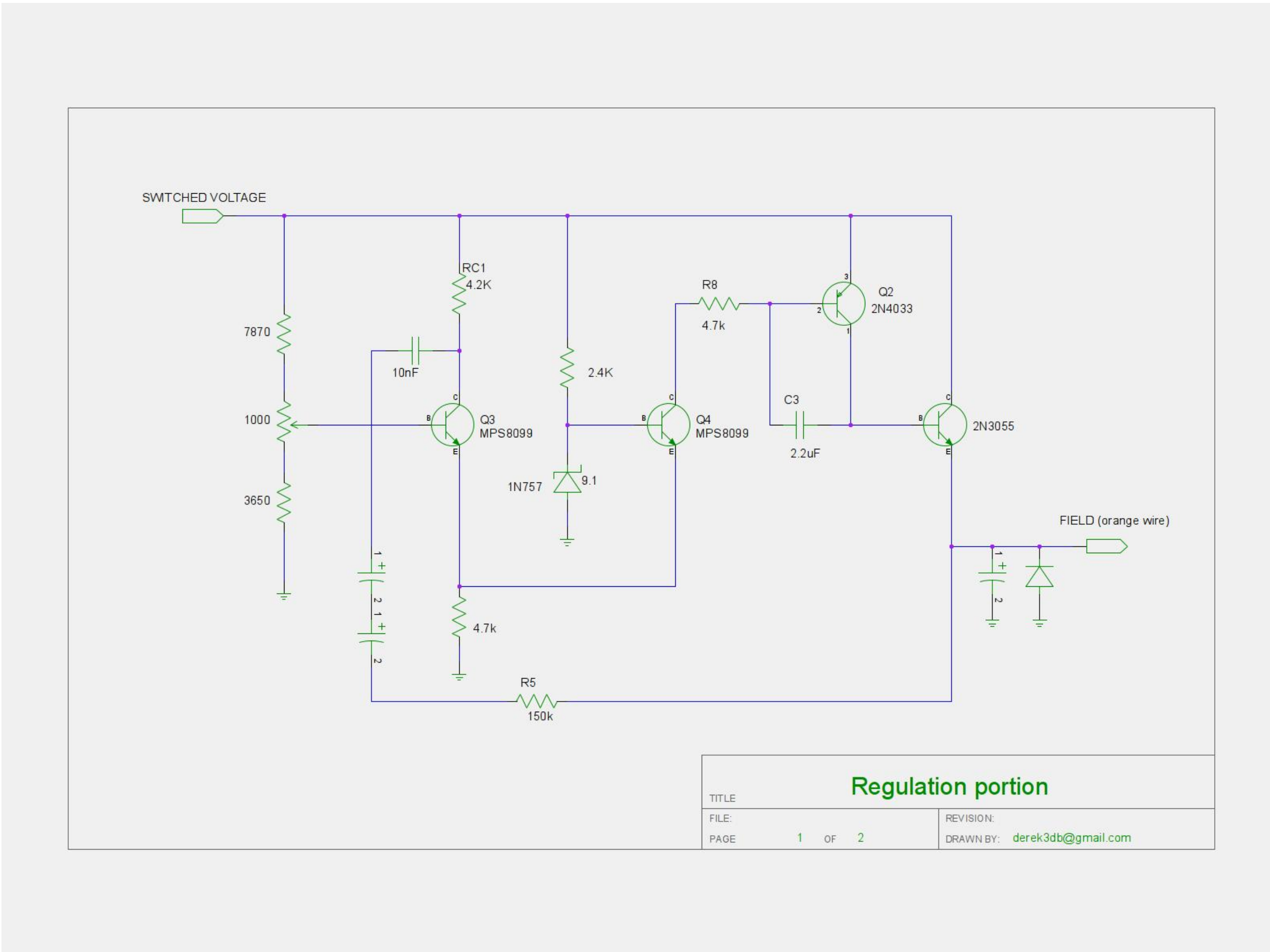
Here is what a bad VR looks like-- this is my JPI download showing bus voltage during one of the first flights after installing a JPI in my new to me airplane, by which time I suspected I had a bad VR because the alternators would every once in a while go off line. I had isolated it to VR#2 (my habit is to switch before every startup) and on this flight I switched from VR#1 to VR#2 around 19Z to get the data. It regulated OK for a minute or so before losing grip (I think this might have been coincident with turning on the landing lights). At ~19:08:30 it actually went to 33.8V but did not trip off. Engine RPM was constant the whole time.



Picture of the board. The empty holes are where the 2N3055 gets soldered & screwed in. It is mounted externally.



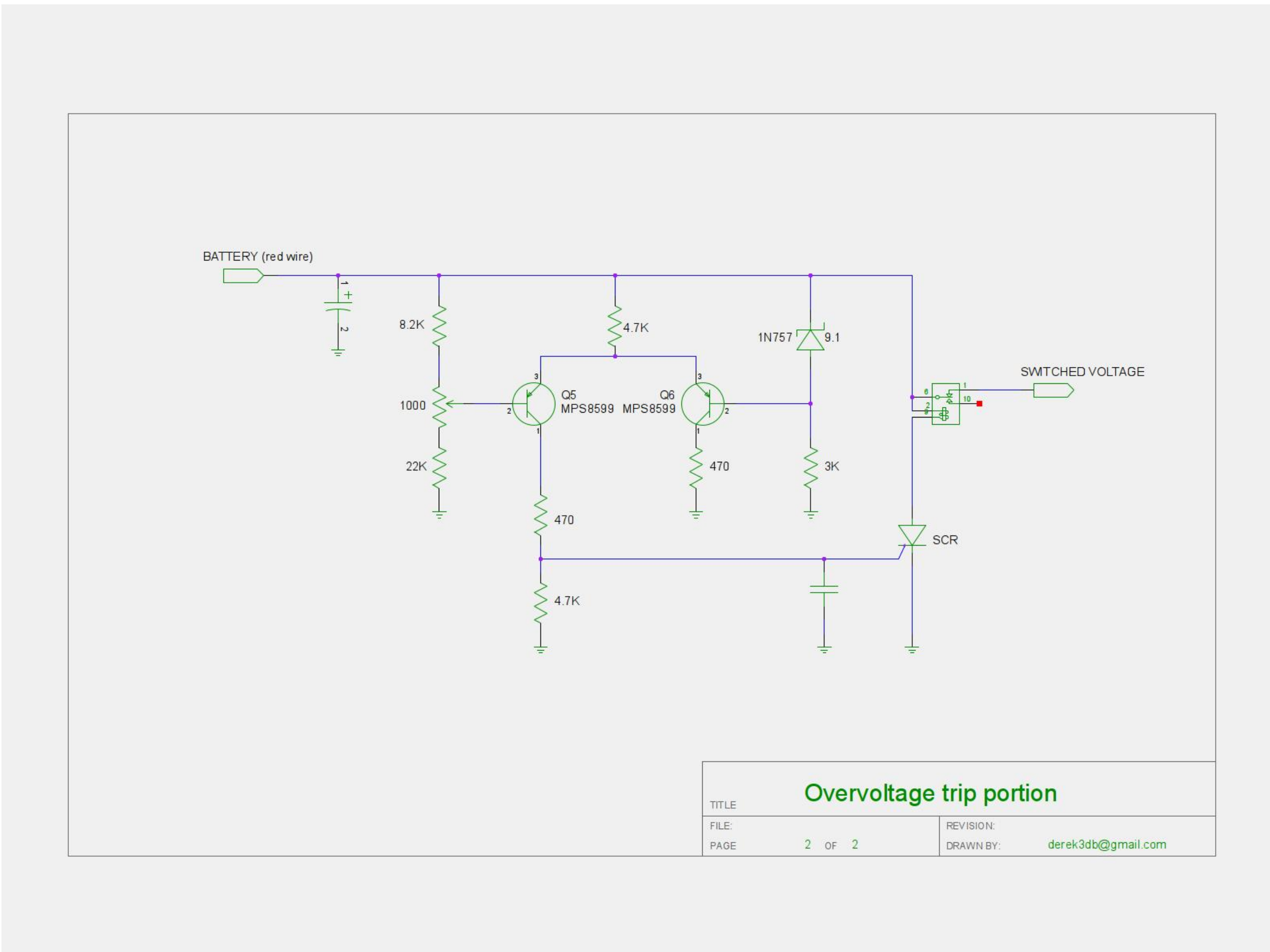
Regulator portion of the schematic.



Overvoltage portion. The input ("Battery") is synonymous with bus voltage.

The -5 version has another capacitor in parallel to the one already shown on the SCR gate. The one here might be drawn wrong, instead I think it's electrolytic, value unknown; I wasn't paying close attention to caps.

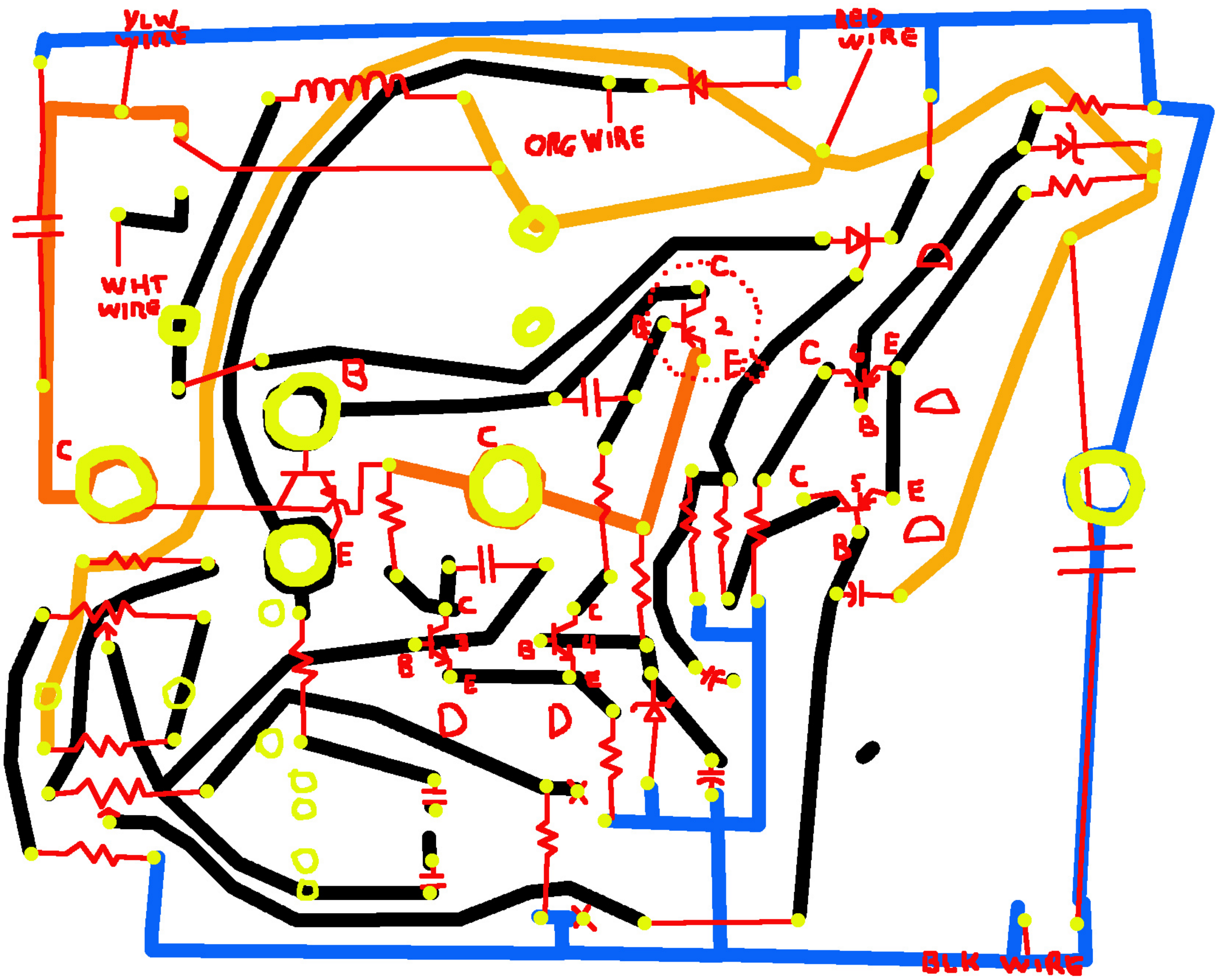
The schematic does not show it, but there is a white wire going from the unused relay output (arbitrarily labeled pin 10 here) to pin D on the VR connector. The VR labels it "overvoltage indicator" but it is not used, at least on the Baron.



PCB traces as viewed from the backside of the board, with the components as connected on top.

Blue is the ground plane, light orange is the bus voltage trace, dark orange is the switched voltage trace. Yeah, the the traces should have been colored to be consistent with the wires connected to them, but you can't get good help these days.

The yellow wire is not on the schematic but is labeled “OV latch”. It goes to pin G on the connector and is unused on the Baron.

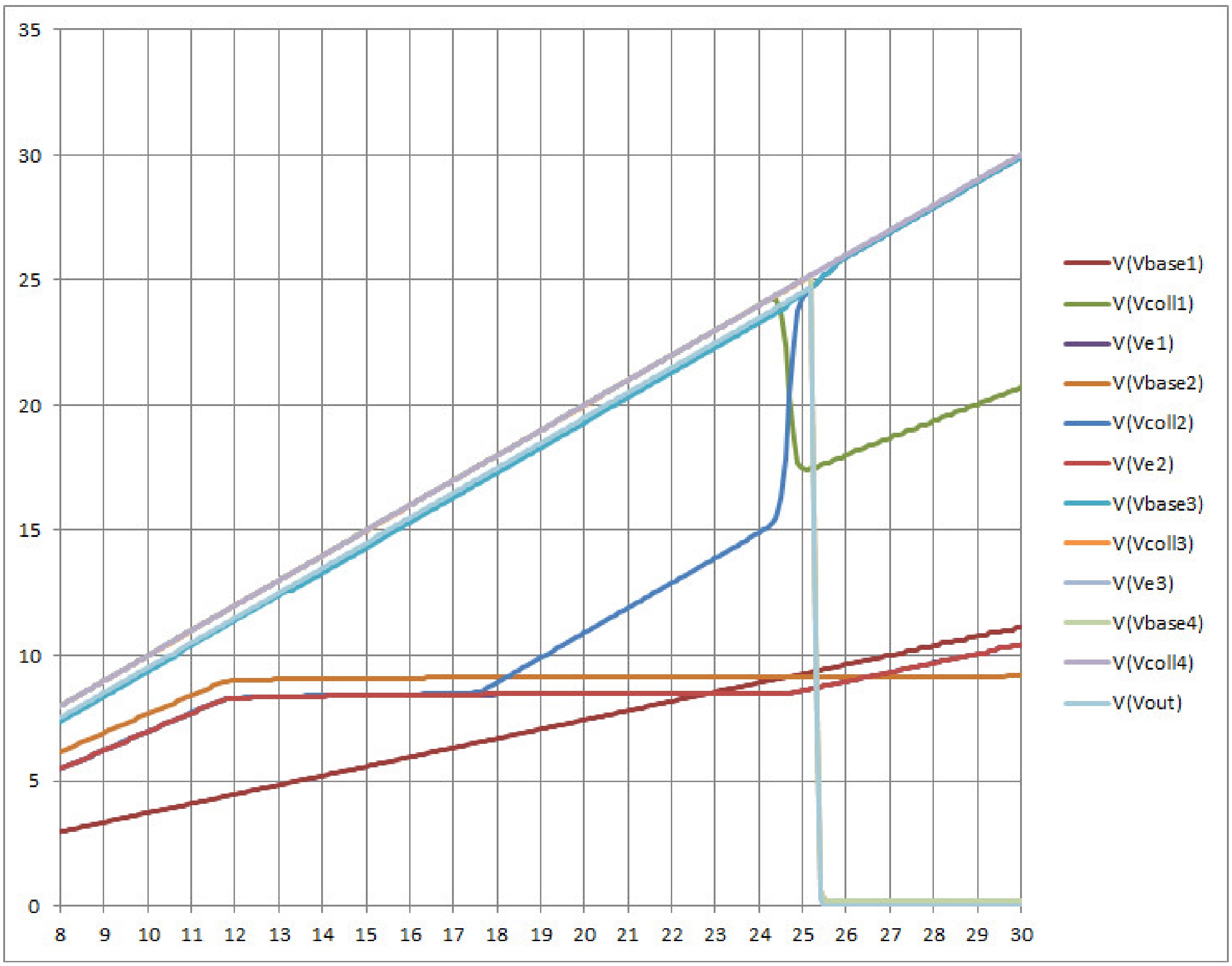


Plot of voltage traces of the regulator transistor EBCs.

The same jackwagon who screwed up the PCB trace colors also numbered the Qs in this simulation and they do not match the schematic. V1 to V4 in the plots corresponds to Q3/Q4/Q2/2N3055, respectively, in the schematic.,

The x-axis is regulator input voltage. When installed on an airplane, input voltage will not go below 24V due to the battery.

The plots shows the regulator cutting off at ~25.2V because I just lumped the trim pot and divider resistances together in the simulation. The trim pot changes the slope of the Vbase1 line (lowest line at the start) and the intersection of Vbase1 and Vbase2 normally occurs somewhere around 28.5V. In practice, the actual cutoff voltage isn't adjusted, the output of the alternator is. On the Baron, this is done with the left engine running (both VRs sit in the nose) while measuring bus voltage.



Overvoltage circuit plot of the transistor base voltages and SCR gate voltage. Q1 and Q2 in the plots are Q5 and Q6, respectively, in the schematic. As with the regulator circuit, the trim pot changes the slope of the blue voltage line, and therefore changes the intersection point of the two voltages.

I also lumped the trim pot resistance here, so the cutoff in the plot occurs at ~34V. A properly adjusted regulator will trip at 32V.

The SCR will start conducting, causing a trip-off, when the gate voltage is a fraction of a volt.