Shumatech DRO Scale Power Noise Injection

Version 2

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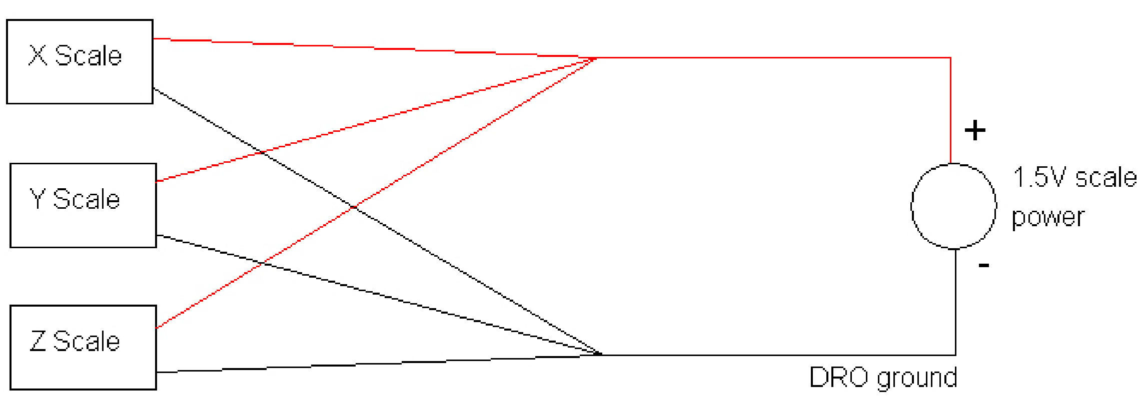
Abstract

The Shumatech Digital Read Out supplies 1.5V to its 3 scales. This voltage is generated on the circuit board that also holds the LED displays and digital circuits. It has been found that current flowing in the display and digital circuits also flows in the ground path of the 1.5V supply. The result is that an AC noise and DC offset voltage is placed in series with the scale's voltage supply. The filter capacitors at each scale suppress little of this AC noise. All of he DC shift is also evident. A simple modification to the wiring is offered that removes these extraneous voltages. Not enough data exists at this time to know if this injected voltage causes problems. It is, however, ugly and avoidable.

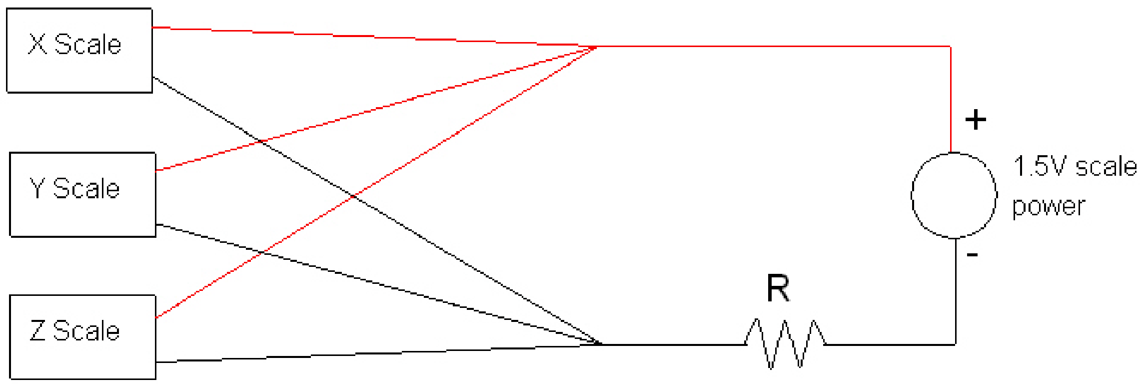
Overview

First, let's talk about the ideal case. We have an X, Y, and Z scale. Each scale receives power from the DRO. Inside the DRO we have a 1.5V scale power supply.



The negative side of the 1.5V scale power supply connects to the DRO's ground and also to the negative power input of each scale. The positive side of this power supply connects directly to each scale's positive power input.

In any real circuit, there is always some resistance. I have chosen to just show one resistance here because the other ones in the circuit do not contribute to the problem.

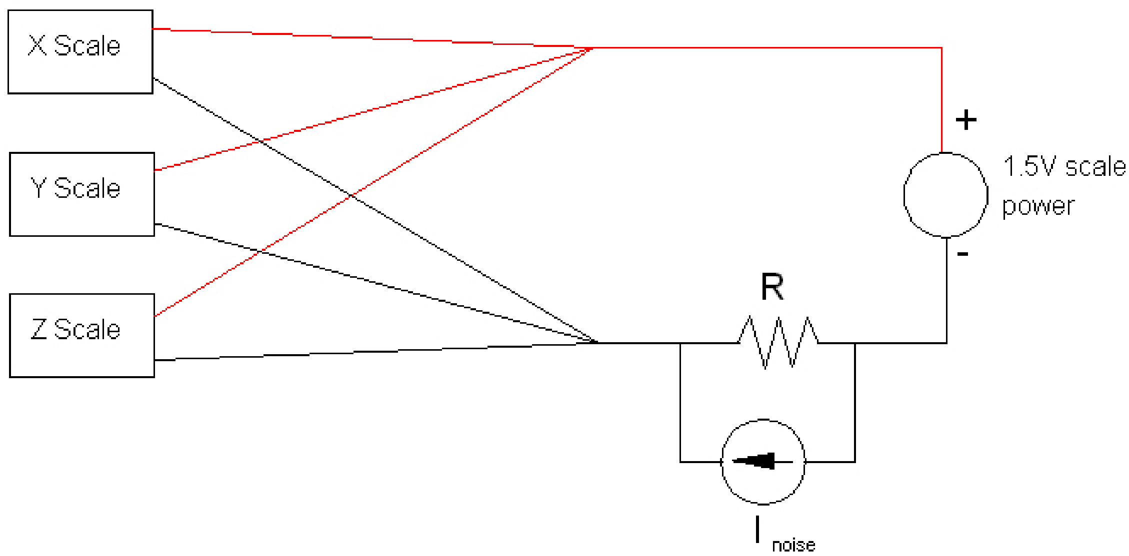


Well, it turns out that this resistance is rather small and the current flowing to the scales is extremely tiny. So if this was all there was to talk about, this resistance would not cause any mischief.

Note that I no longer have labeled the bottom of the 1.5V supply as DRO ground. That is because as we look closer at the circuit, it becomes progressively more difficult to decide what point should have this title*.

The next piece to this puzzle is what I will call I_{noise}. Think of it as a DC current source for now.

* The correct way to think about "ground" is that any one point in a system can have this designation. All other points are defined relative to ground. If a system is formed from parts, each with their own ground, it is common to talk about "datums". We really have a DRO datum plus a datum at each scale. In fact, the negative side of the scale power supply is the DRO datum and out at the scales, the positive input of each scale is a scale datum. Calling all of these points "ground" would be a disaster.



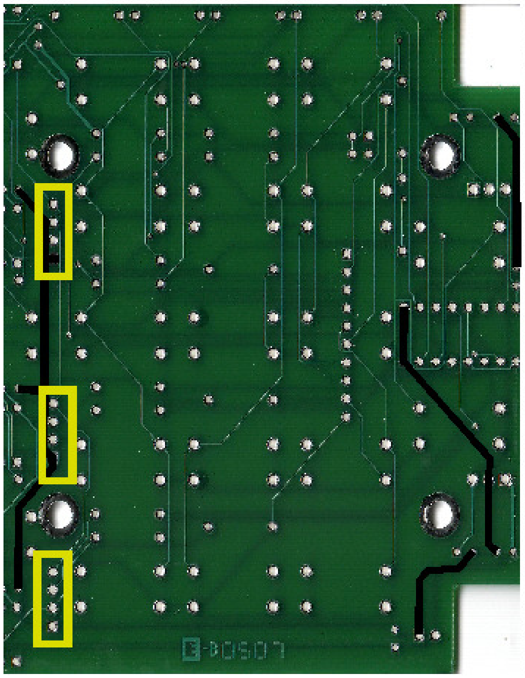
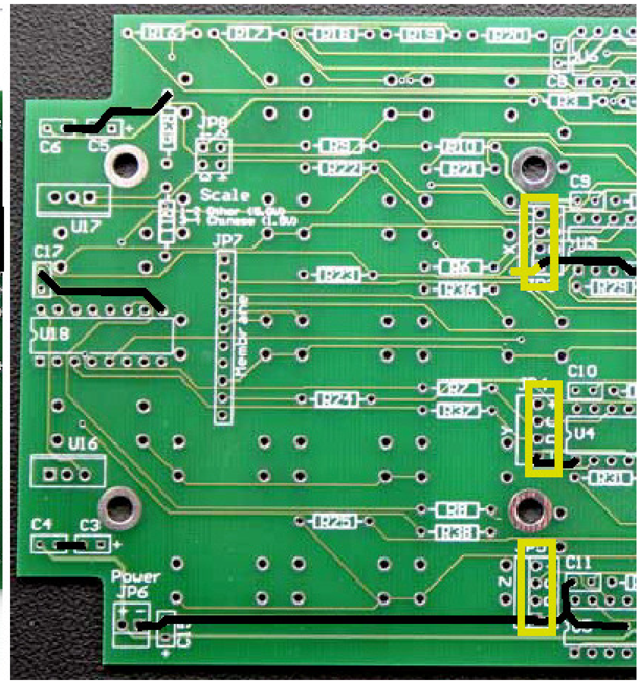
Essentially all of the current from I_{noise} will flow in our resistor "R" because R is a much easier path for the current than trying to flow in the scales. As I_{noise} flows through R, we develop a voltage which subtracts from our 1.5V supply.

Now that you see the theory, let's put a little reality into this model. Our resistor "R" is the resistance of circuit traces on the circuit board. The current source, I_{noise}, is current that flows through various digital circuits including the display. The result is a noise voltage that the scales see which is related to our digital circuits.

We can put even more reality into this model by pointing out that our resistor is really many resistors in series and our current source is really many currents flowing into the DRO's ground.

Rather than look at a more complex electrical model, lets look at the actual circuit board to gain a better understanding.

Here we have a close up of part of the DRO's circuit board. The left picture is the bottom surface and the right picture is the top surface. They have been arranged in a mirror image. I have drawn thick black lines to show where the ground path runs. The 3 yellow boxes show on each picture are the 3 headers that connect to the scale cables.

If you look very close, in the upper left corner of the right picture you will see C6 connecting to C5 with one of my thick black lines. This is where the 1.5V supply's negative terminal exists. The black line then goes to one end of R35 which is part of a pair of resistors that set the supply's output voltage. All of these connections are nice and close which is good.

In the left picture in the upper right hand corner you will see another black line. It too connects to a terminal of C5 and then runs vertically down to C17 before going to two pins on integrated circuit U18. From there the ground trace again goes vertically as can be seen along the right edge of the left picture. It connects to C4 and then C3 before reaching power plug JP6.

Here is where things get interesting. All power for the DRO comes in on this plug. Most of the ground current flows along the horizontal trace shown at the bottom of the right picture. The right end of this trace connects to our first scale cable header, JP5. The other two scale cable headers, JP4 and JP3, are connected by the vertical black line shown on the left side of the left picture. This ground current flows through the resistance of the traces and generates a rather tiny voltage. This voltage will be higher on the right end of the horizontal trace compared to the negative pin of the power plug. This means that the scales will see a reduction in voltage due to this ground trace voltage drop. That is exactly what we see. The voltage difference between scales is almost zero which implies that the vertical trace shown on the far left of the left picture carries relatively little current.

If you wish to see this voltage yourself, you will need a digital voltmeter able to read 1.5V with 2 or 3 places to the right of the decimal point.

Connect your voltmeter, set for DC, across the input capacitor of one of your scales. Set the DRO to standby by pushing FCN and then 9. The display will now be dark. Your voltmeter should read around 1.552V. This is the 1.5V supply voltage with I_{noise} set to almost zero.

Now, wake up your DRO by hitting FCN. Most of what this does is turn on your display which draws the majority of the current. You should see the voltage at the scale drop. To get the maximum effect, you want to light up as many display segments as possible. I do this by setting my filter values to all 0, set display intensity to 5[*], and set the display to HEX (hit FCN and then INCH/MM). You should see the entire display jitter.

Now read the voltage again. I got 1.524V, a drop of 28 mV. This is the total effect of all of those traces and the ground current flowing through them.

If you have an oscilloscope able to display 50 mV per division, you will get a more complete picture[**]. Before moving the scale wires, I saw a square wave across the scale's capacitor that was 30 mV peak to peak.

The sharp corners of this square wave tell me that I am looking at just the ESR of the capacitor being fed by a very low source impedance noise source. In other words, the filter capacitor is unable to stop this ground noise[***]. This wave shape changes as a function of the number of display segments lit.

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[*] Display intensity is set by duty cycle. With low intensity, the processor sends a pulse of current to the display less often than for high intensity.

[**] It is essential that the scope probe be attached to the bypass capacitor at the scale correctly. My scope probes have a removable tip. Under this tip is a copper ground ring with a small signal pin at the end. Fabricating a tiny socket that fits this ring and pin arrangement makes the best connection. It must solder directly to the cap's leads. My socket is less than 1/4" long.

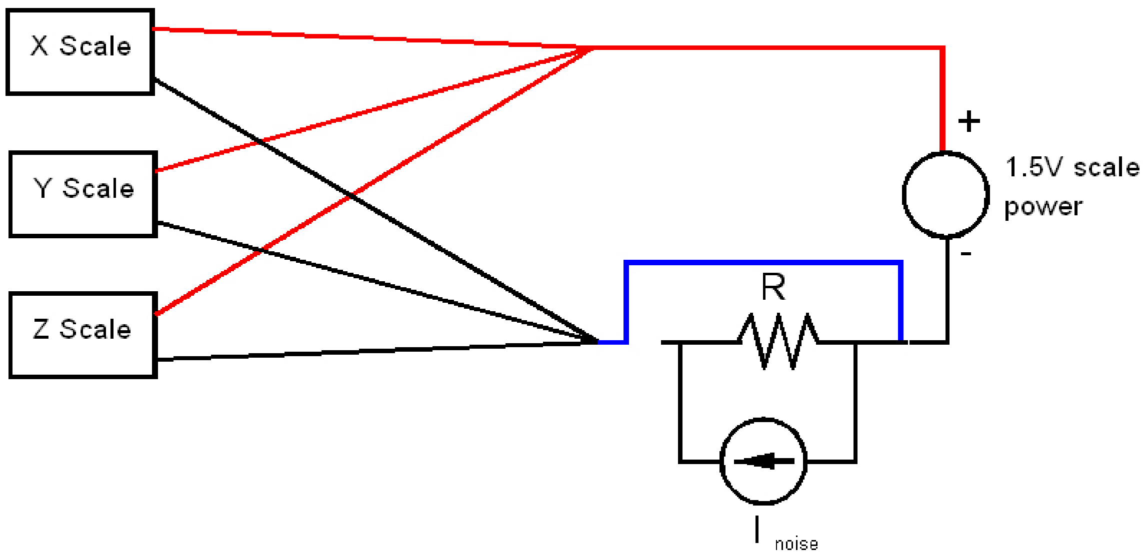
[***] A capacitor can be partially modeled as an ideal capacitor in series with an ideal resistor. At frequencies high enough to cause the ideal capacitor's impedance to be essentially zero, we will see just the ideal resistor. If this capacitor is driven by a voltage source with a source resistance equal to the ideal resistor's value, then half of the drive voltage will appear across the real capacitor and the ideal capacitor will have not effect.

When the ground wire is moved, I see a dead flat line both for AC and DC with the 'scope set to the same 50 mV per division.

Hit FCN and then INCH/MM to return to the normal decimal display.

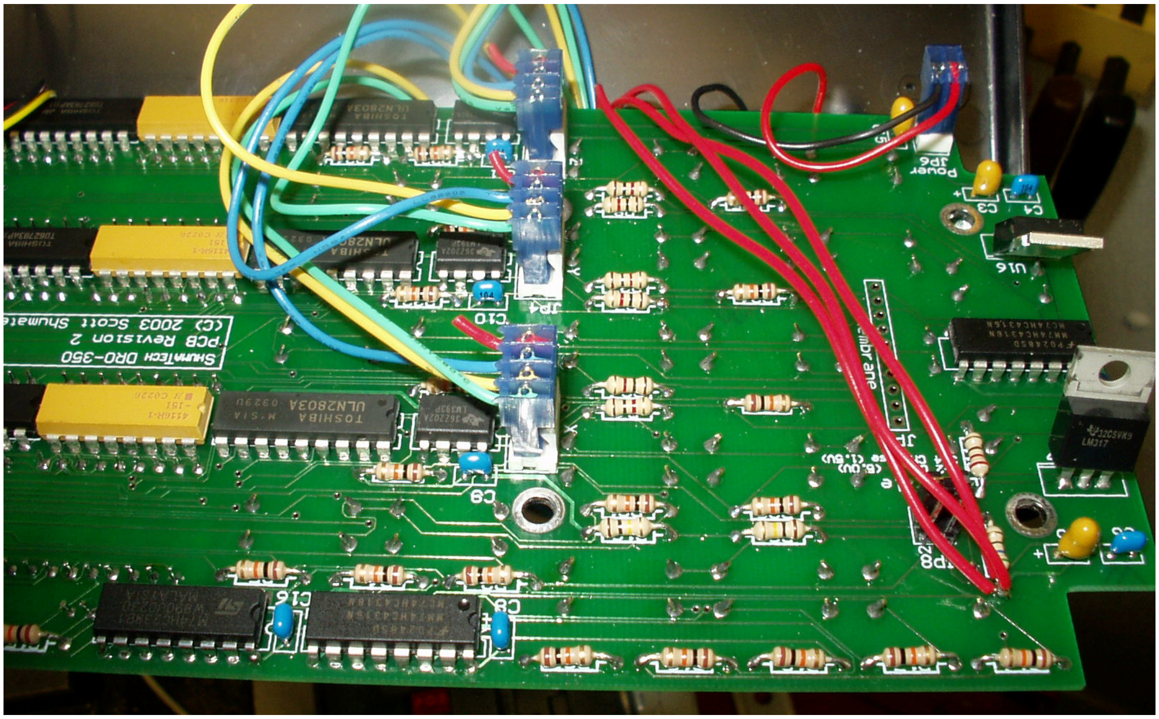
A simple Fix

If you don't want this ground noise, then just move the conductor so it is no longer in the path.



I have broken the connection between the resistor and current source and the scales. The three scale's negative power leads now go to the negative terminal of the scale power supply via the blue wire. It really is that simple.

Circuit Modification



Although it is possible to cut into the circuit board, I prefer to take the easy way out and move wires. I cut the negative voltage wires from the connectors plugged into JP3, JP4, and JP5 and soldered them to the end of R35 that also goes to C5.

Be careful if you do this since, at least on my DRO, the wires are red which is commonly reserved for the positive voltage rail.
This is not a pretty circuit modification but does get the job done. It is also easy to back out if it does not please you.

When I moved my wires, I saw a constant 1.552V regardless of DRO state.

So What?

By moving the wires to the ground at the scale power supply, we can eliminate the ground noise. But what does this do to help us? Well, I'm not able to see any reduction in scale jitter. I can probably reduce my filter capacitance but why bother? My filter value is now at 6 for each axis but works fairly well at all 4s. There is not a lot left to improve here.

If you do have your filter values set to above 10, then you may benefit from this modification. If you do try it, please let me know the outcome. More data is needed to assess the impact of this ground noise.

I would like to thank Larry Gill for duplicating my DC voltage tests and reviewing this text for clarity. Thanks to Shane for the very clear picture of the back side of the circuit board, Brian Pickett for providing guidance on the exact path of the ground, and Nick Müller for performing similar tests. I hope I have not left anyone out. This has certainly been a group effort.

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