Electrical Noise and the

Chinese Scale/Shumatech DRO Interface

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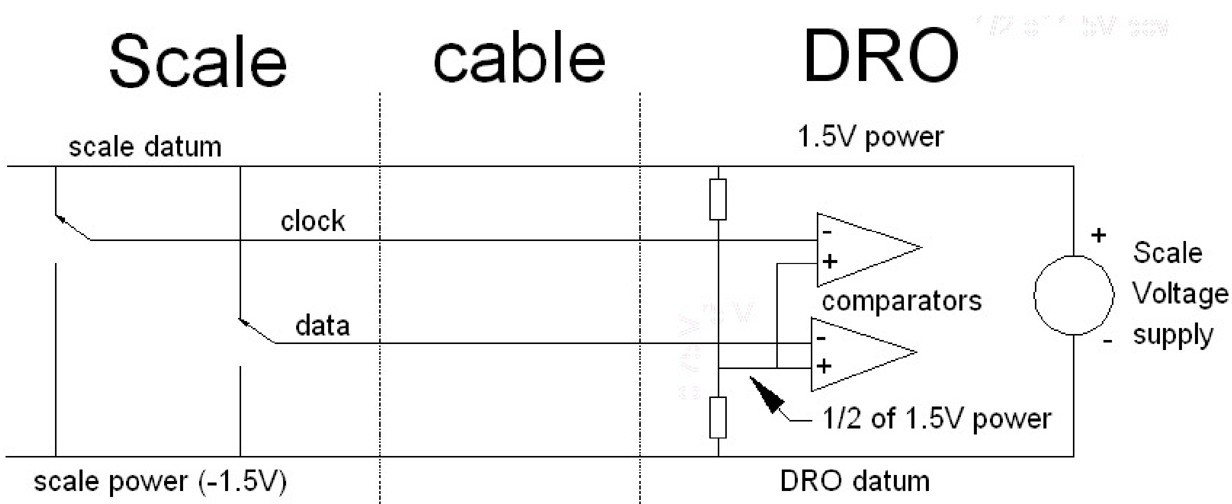
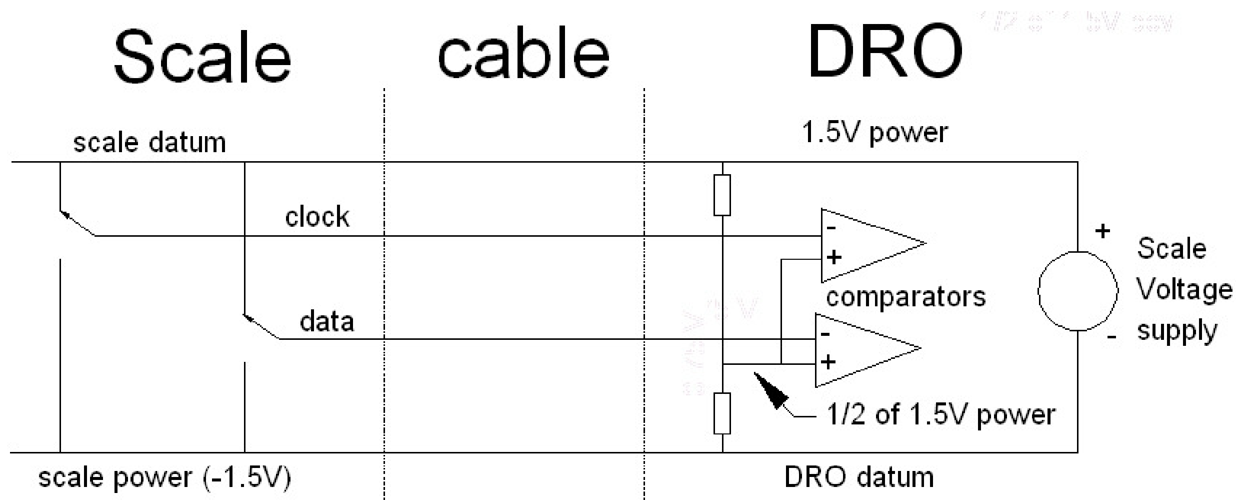
Much discussion has taken place about how best to wire up a Chinese Scale to the Shumatech DRO. Don't get your hopes up. I am not going to give you the definitive answer. Instead, I will attempt to explain, in layman's terms, some of the factors at play.

Here is a diagram showing the important elements. To the left are the important parts of the Chinese scale. In the center is our cable. On the right is part of the DRO.



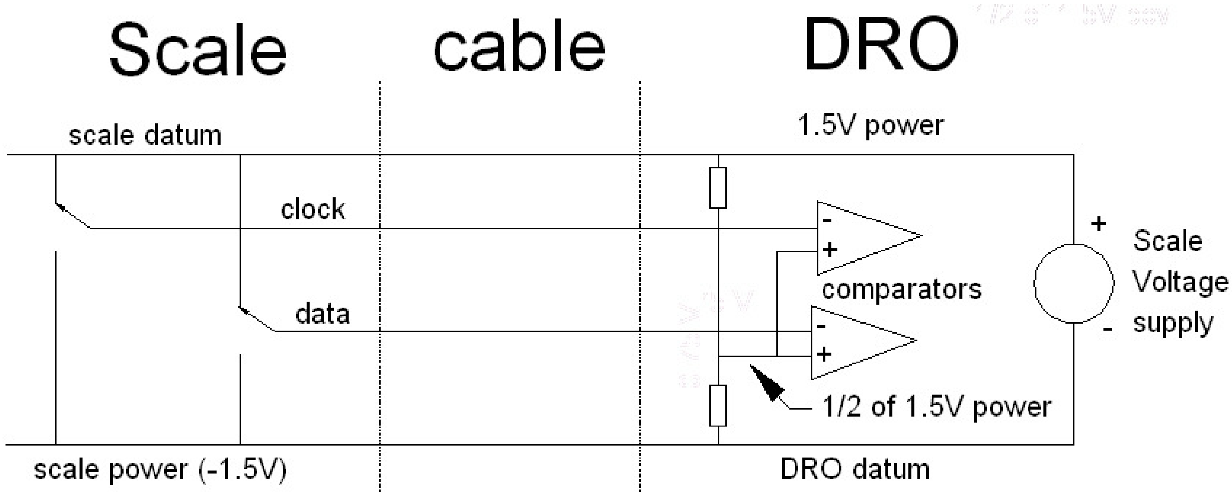
The first point of confusion is how things are named. Documentation related to the connections on the scale talk about +1.5V, ground, clock, and data. The +1.5V connection is also connected to the metal on the scale. It is standard practice to make the metal body associated with an electronics package the ground. Now, ground is a confusing term. In any system, you are free to define any single point as "ground". Ground is the reference point that is used to measure the relative voltage of all other points. Using the term "ground" here will lead to lots of confusion. Instead I will use the term "datum". A datum is a fancy term for a local common point. Note that the above picture has a "scale datum" and a "DRO datum". As long as I specify which datum is in question, there should be no confusion. The DRO datum does not connect to the ground pin of the power outlet. For safety reasons, the steel body of the mill or lathe should be connected to the ground pin of the power outlet. Note that if the scale datum which is also the metal of the scale is connected to the steel of the mill or lathe AND you were to ground the DRO datum, the scale voltage supply would be shorted out and all scales would go dead. Furthermore, if you cut the ground pin on the mill or lathe and at some later date the motor shorts out to its case, you may be exposing your beloved DRO to line voltage as well as risking your own life.

Back to the scale now. It is reasonable to assume that since the body of the scale is common with the plus side of the scale's battery, we should select this point as our scale datum. If I measure the voltage on the "scale power" wire with respect to scale datum, I will read - 1.5V as noted in the figure.



Now look at the clock and data switches and wires. The switches are actually in the electronics but showing plain switches does not diminish the accuracy in any significant way. These switches move up and down as pulses are generated. In the up position, these signal leads are connected to scale datum. In the down position, they connect to scale power.

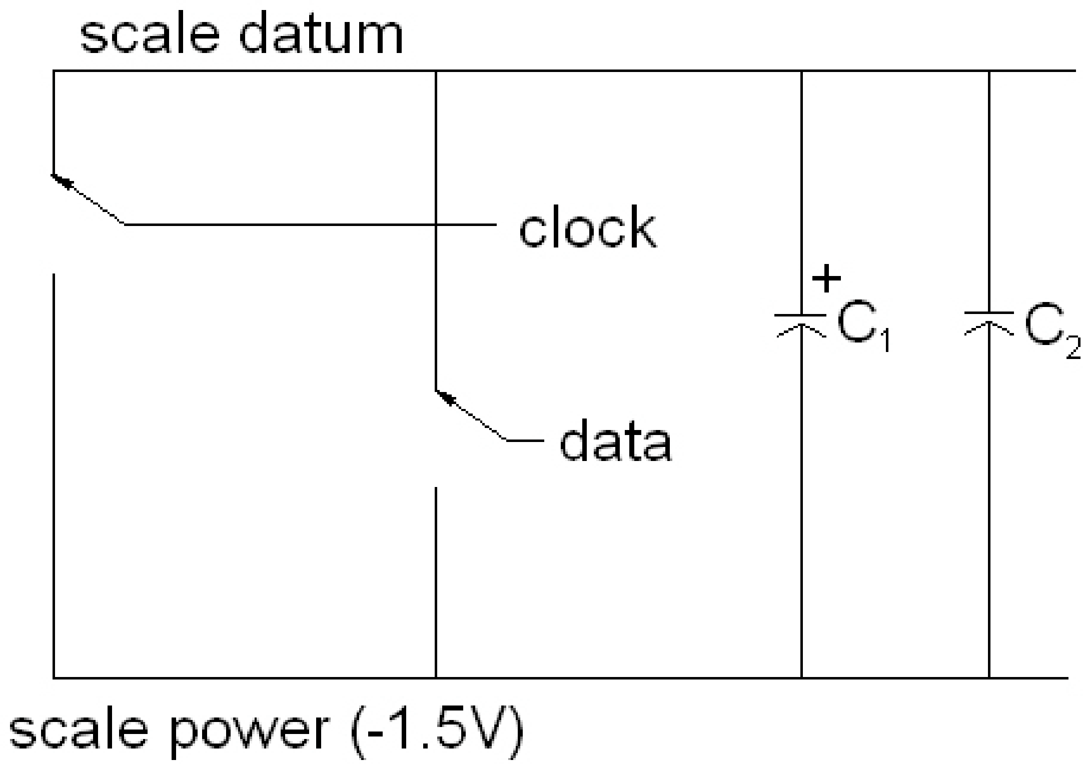
Now look over at the DRO end. Note the change in names. Instead of scale datum, we now call this node 1.5V power. Scale power is now called DRO datum. This means that if you measure the voltage of the 1.5V power wire with respect to DRO datum, you will read + 1.5V. The change in sign here reflects the change in the position of the datum. This is potentially confusing but necessary. We have no control over how the scale is built. Although there the developer had control of the DRO's circuit, it would be far more confusing if Scott did not redefine datum as shown.



In the DRO we have a comparator connected to the clock wire and another connected to the data wire. Their jobs are to take the signals from the scale and convert them to signals compatible with the rest of the DRO. They are also able to ignore a measure of electrical noise. Say the clock lead is at zero volts with respect to DRO datum. Any noise induced into this lead that is less than half of the 1.5V power supply will not cause the comparator to change state. We call this "noise margin". If the clock lead is at 1.5 volts with respect to DRO datum, the noise margin will be the same. A lot of noise can be induced into all 4 of these wires so additional means are used to reduce the effect on the DRO's displays.

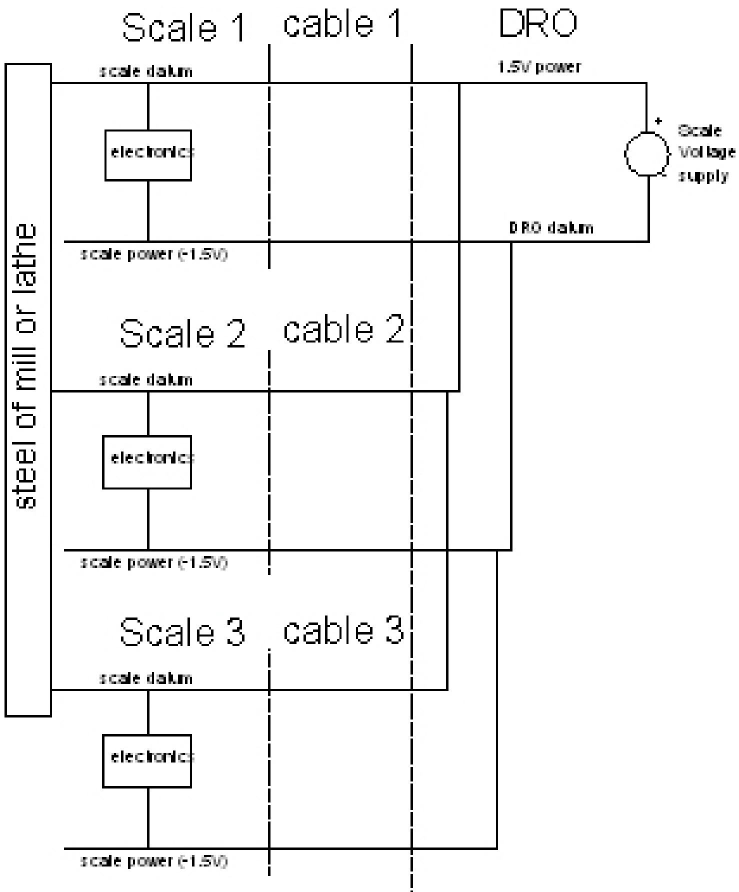
I am aware of two software techniques used in the DRO to reduce the effects of noise on the clock and data leads. The first is to read the number coming in from the scale three times before believing it. This does not slow down overall operation because the scale is configured to "fast mode" which causes it to send the number more often than the default mode. The second technique is a simple digital filtering technique. I have described this in the article at

http://rick.sparber.org/Articles/sb/sb.htm



Then we have the hardware approach to noise suppression. If enough electrical noise gets into the scale's power, the scale's circuit will get confused and start to send the DRO bad information. We reduce this problem by using capacitors at the scale. It is common practice among Shumatech DRO users to solder into the scale an electrolytic capacitor and a high frequency capacitor. The electrolytic, shown here as C_1, reduces low frequency noise at the scale's power leads. The high frequency capacitor, C_2, acts in a similar fashion. See the archives of the Yahoo group Shumatech for details on what values have worked well for people.

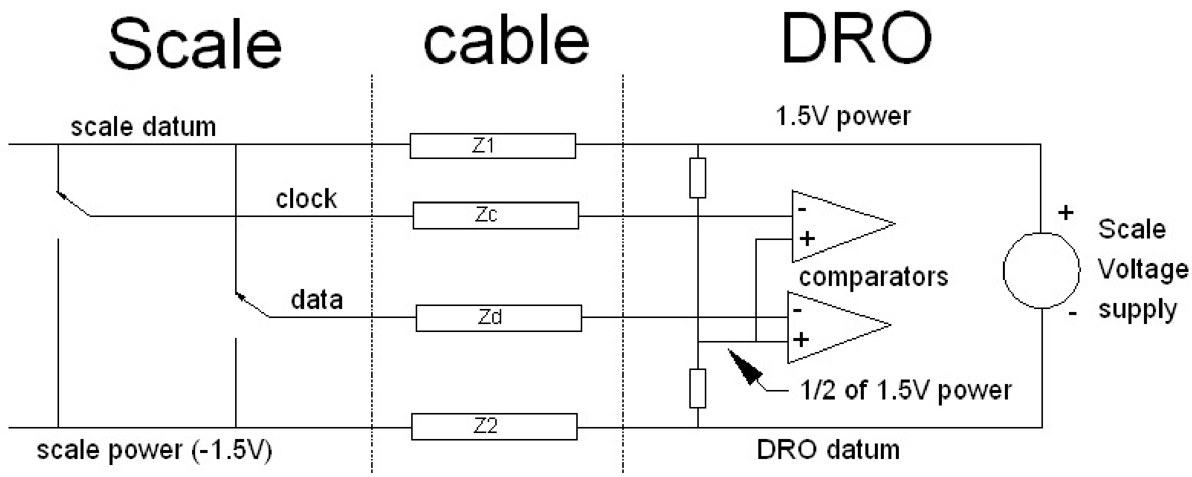
Life gets interesting when we consider the full system with 3 scales. I connect my scale bodies to the steel of my mill so that is what I have drawn here. Some have chosen to isolate their scales in the hope of gaining more electrical noise immunity.



I have used an ohmmeter to measure the resistance between various parts of my mill and see much less than one ohm. This is a bit surprising since there is oil between all moving parts. Anyway, that is my reality and probably yours too. The result is that the circuit gets more confusing. Note that all three scale datums are connected together through the steel. They are also connected together via cable to the point inside the DRO called 1.5V power. The resistance from one scale datum to another scale datum via the DRO is much larger than through the steel. From the DRO's viewpoint, it sees three wires that go from the steel to the 1.5V power point.

You will see later how these multiple connections can have strange effects when electrical noise gets into the scale datum and scale power wires of each scale.

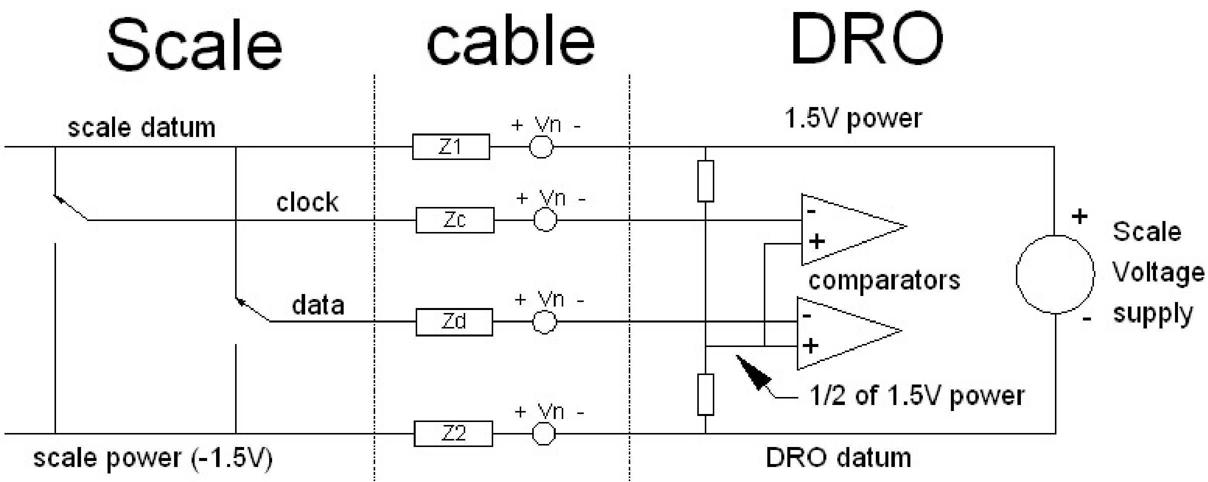
Let's return to the simplest case of one scale talking with the DRO but add some of the non-ideal characteristics of the cable. These characteristics will become part of a model that helps explain how the scales and DRO react to electrical noise.



Note the boxes labeled Z1, Zc, Zd, and Z2. If we are concerned with just direct current, then Z represents a resistance. If we are concerned with AC, then Z represents a resistor with an inductor in series. This means that as the frequency of the noise increases, the "impedance" gets larger. The larger the impedance, the easier it may be to get noise into our comparators. If all 4 conductors are in the same cable, all Zs shown here are equal.

Things are about to get a bit more complicated as we look at how noise effects these wires. There are two pathways for noise. The first is magnetic and the second is capacitive. At this time I will only discuss magnetically induced noise because I am not convinced that capacitvely coupled noise is that much of a factor.

When a magnetic field exists near the cable, an AC voltage is generated that will be in series with each wire. Call this voltage Vn. The same voltage is in series with each wire in the cable because the same magnetic field in coupling equally to each wire. This is an AC voltage but I show a + and - to indicate that all got positive at the same time and all go negative at the same time. We call this behavior being "in phase" and is essential to how our circuit is able to reject this noise.

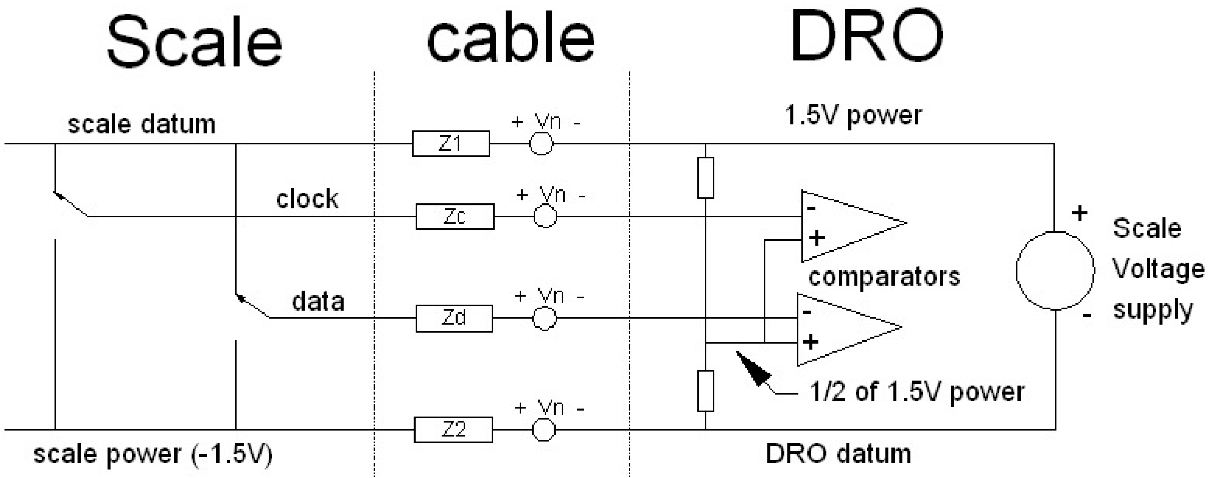


I will now demonstrate why Vn has no effect on the data signal when we have the above circuit.

First lets revisit how the circuit works when Z and Vn equal 0. Starting at the DRO we have 1.5V power. It connects to scale datum. At the scale we have the data switch in the up position so it too connects to scale datum. The voltage at scale datum passes through the data switch and is conducted back to the data comparator via the cable. In the DRO the comparator associated with the data signal will see a voltage equal to 1.5V with respect to DRO datum. This will cause the data comparator to output a logic 0 because the voltage on its negative input is higher than the voltage at its positive input.

Now consider the circuit with a Vn that is not zero. Leave all Zs zero for now. Keep in mind that all that matters is what the data comparator sees. Starting at the DRO's 1.5V power, we see a Vn as we go out to the scale datum. Note that it adds because the + sign of the Vn is facing to the left. This voltage is again passed through the data switch and back through the cable to the data comparator. But wait. In the cable we have another Vn voltage source. As we pass through it we must subtract its value. We added Vn as we went from DRO to Scale along the top conductor and subtracted Vn as we moved from scale back to DRO. The net result is that the noise induced in the top conductor was canceled by the noise induced in the data conductor. If you move the data switch so it connects to scale power, the same noise cancellation will be seen. Do you see that this scheme works regardless of the magnitude of Vn? In theory, Vn could be thousands of volts yet the comparator would not see it. In fact, this is how telephones are able to carry a tiny fraction of a volt of signal that represents your voice while power lines nearby induce over 100 volts of noise.

Next consider the effect of having non-zero cable impedance (Z1, Zc, Zd, and Z2).

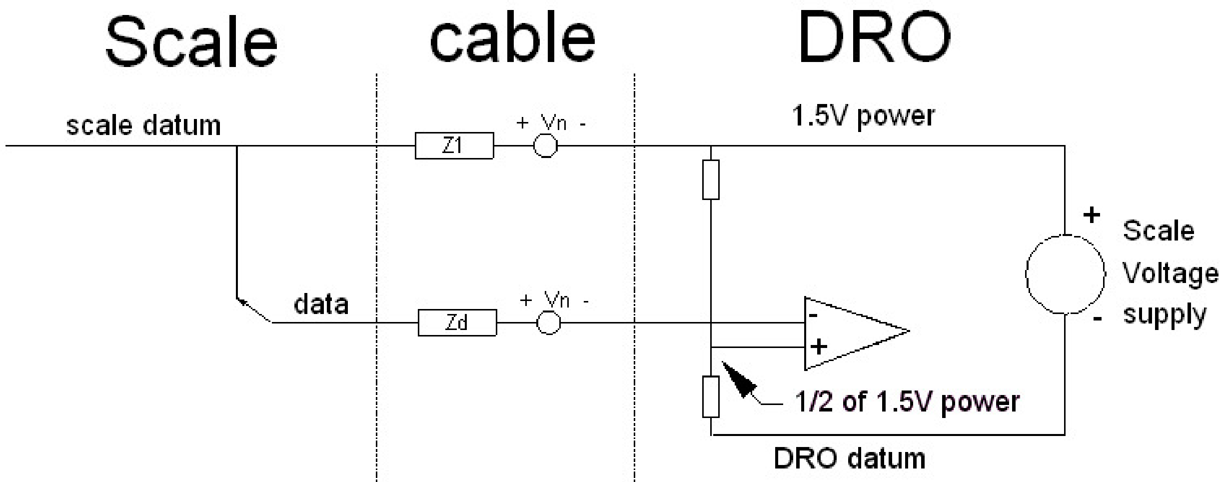


For the circuit shown here, cable impedance is harmless. We have no current flow due to Vn because the net noise voltage is zero. This means that no noise voltage is developed. They therefore have no effect on the signals seen by the comparators.

The picture does not change as we add the two other scales since each one has its own set of clock and data comparators and are only connected together at the DRO by their power and datum leads.

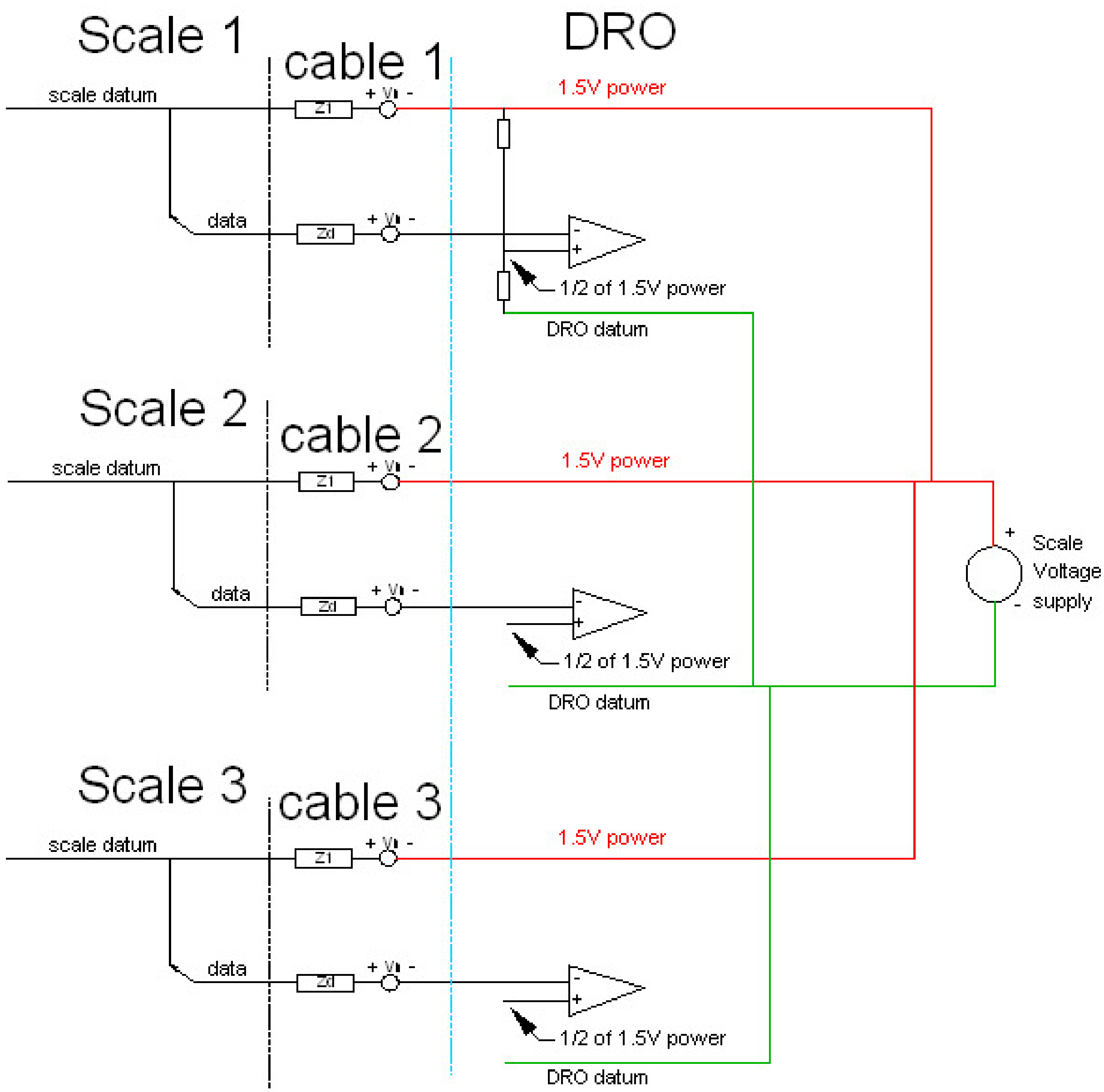
You will see later that when we connect scale datum to the mill or lathe, the values of cable impedance and Vn can effect our clock and data signals as seen by the DRO in potentially bad ways.

You may not agree, but my goal in the next section is to NOT confuse you. Towards this end lets strip away some of the above circuit and focus only on the data lead.



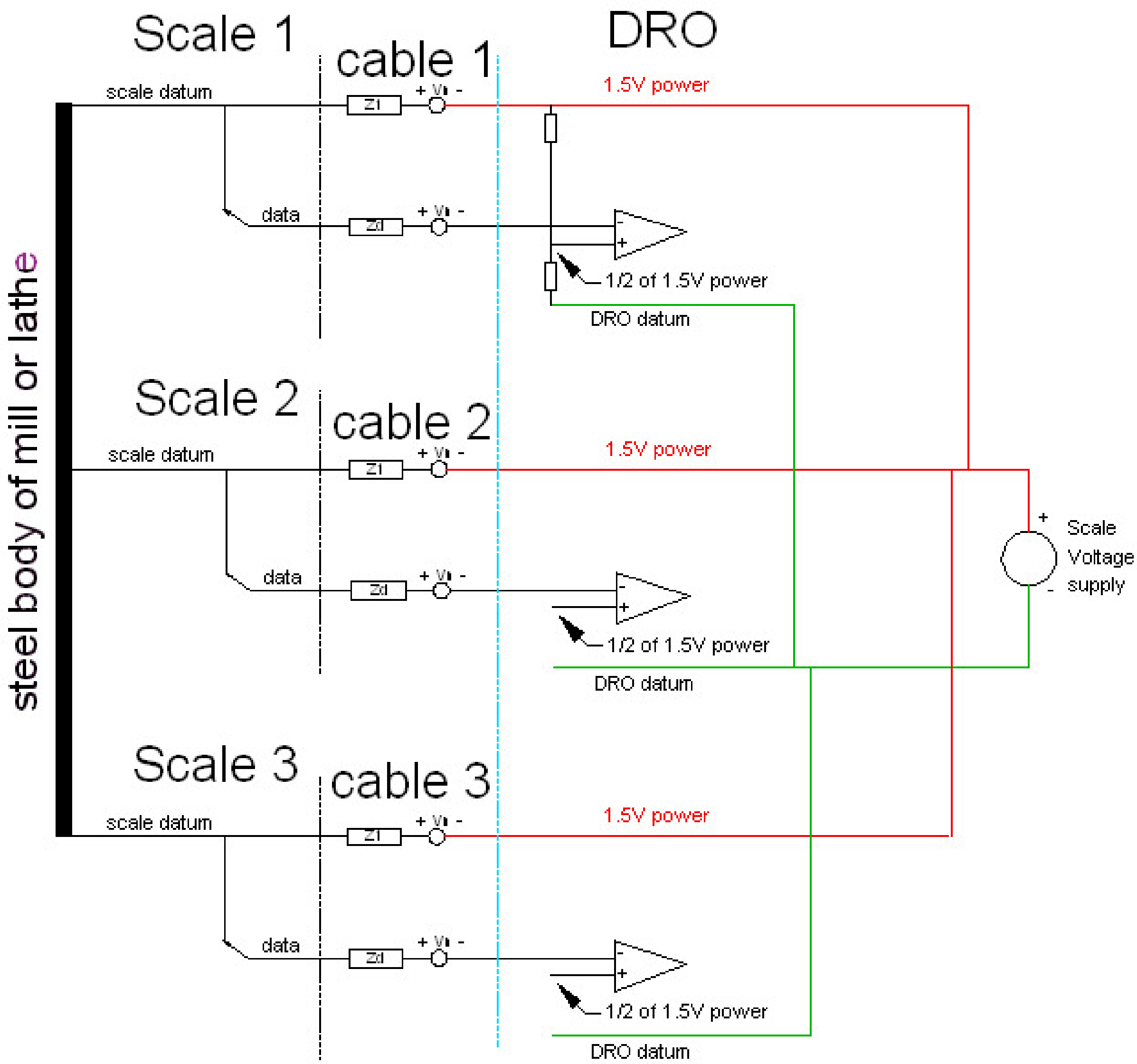
I hope you can still see that the voltage seen at the negative input of the comparator is immune to the noise voltage Vn.

Now it is time to expand our view and include all 3 scales. I am showing the 3 scales, each with its own cable.



Each cable can be a different length and have a different exposure to noise. This means that cable 1's Z1 and Vn may not be the same as cable 3's Z1 and Vn. It turns out that this does not matter. The noise associated with each cable is canceled as seen by the associated comparators as explained above. So having three independent scales is no different from having just one.

Brace yourself, we are about to take a very large step in complexity. Consider what is going on when we connect all three scale datums to your mill or lathe.



Making the electrical connection from each scale body to the steel of the machine greatly complicates how the system responds to noise but that does not mean it is a bad choice. I have all of my scales connect this way on my mill and it works fine. I have also heard of people who do not connect their scale bodies this way and who have seen problems. It all depends on how much noise your system must tolerate.

Consider the case of noise being induced into cable 1 but not into the other cables. Call this noise source V1n. Trace the path of current flowing due to V1n. Starting at the positive terminal, the current first flows through cable 1's Z1 (call it Z11). From there some of this current will flow through cable 2's Z1 (Z21) and the rest will flow through cable 3's Z1 (Z31). How this current splits is a function of these impedances. The shorter the cable, the lower the impedance, the more current it will pass assuming all cables are of the same type. As current flows through Z21, it will generate a noise voltage that is not present in scale 2's data lead. This means that the comparator associated with scale 2's data lead will see this noise. The same can be said for scale 3's comparator.

We can tell the same story for noise induced in cables 2 and 3 so we end up with noise at the input of each comparator that comes from noise induced in the other two cables.

One take home message here is to keep those cables short so the impedances are kept to a minimum and the exposure of the cable to noise sources is kept to a minimum.

Another thing to note is that high frequency bypass capacitors out at the scales does change this picture a little. Ideally, the scale datum and scale power nodes are connected together via this capacitor. Looking at cable 1, can you see that we have Vn on scale datum and scale power? We also have the same impedance on each of the wires. Inside the DRO we have a high frequency capacitor and one at the scale. This means that cable 1's Z1 and Z2 cable impedance are essentially in parallel. The result is a halving of the impedance fed by the noise voltage. It is hard to say if this is good or bad in the general case. It all depends on how much the noise voltage source acts like an ideal voltage source.

It certainly is good when you consider that the power applied to the scale must be as quiet as possible.

If Vn is an ideal voltage source, then the smaller the impedance across it, the higher the resulting noise current. This noise current flows in the other cables and is not good. On the other hand, if Vn acts more like a current source, then the current will remain constant independent of the impedance. In this case, the lower impedance will mean a lower resulting noise voltage.

I'm sorry to say that the bottom line is that changing the high frequency capacitor's value can make your noise problem better or it can make it worse. Not a very satisfying bit of insight…

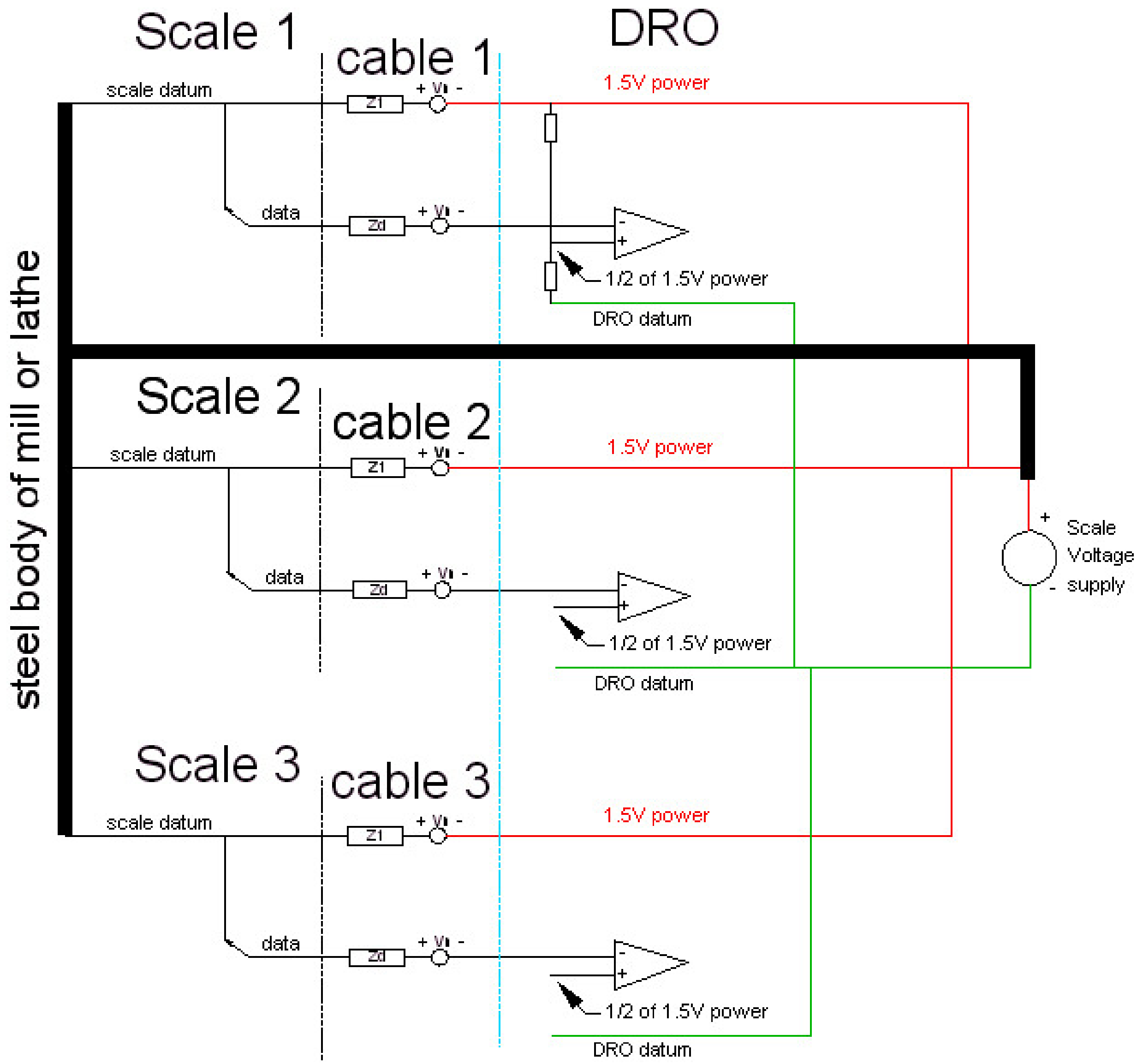
Another can of worms relates to using shielded cables. Some people ground just one end of the shield. In this way they form an electrostatic shield rather than a magnetic shield. An electrostatic shield will reduce noise coupled via stray capacitance. A magnetic shield will reduce noise from magnetic noise sources like a motor. You can only achieve a magnetic shield if you ground both ends of the shield. This is not such a simple task and I'm not convinced it is worth the trouble.

You may be able to see the DC effect of shielded cable from the above diagram. For starters, if you have your scale datums connected to machine steel, do not attempt to connect the shield to machine steel and to DRO datum. Doing so will short out the Scale Voltage supply.

This lack of useful insight underlines the fact that there are just too many variables to come up with a "cook book" answer to noise problems. My best advice is -

1. Review the Shumatech archives for things that have worked for others.
2. Keep you cables short.
3. Route your cables away from known continuous noise sources like motors. (Occasional noise sources like switches are probably harmless because the system will recover).
4. Do put low frequency and high frequency capacitors at each scale but experiment with different values to find what works best for your setup. Each scale may need a different set of values.
5. For what it is worth, in my set up I do ground the scale bodies, do not use shielded cable, do have my X and Y scale cables around 4' long, and do on very rare occasions have the dreaded jump in readings by 200 counts. I have low frequency capacitors of around 100 uF and high frequency capacitors of around .05 uF at each scale.

There is a circuit change that may help matters and is easy to impliment. Consider adding a heavy copper strap between the machine's body and the positive node of the Scale Voltage supply.



This will force the voltage on the scale datums to be the same as at the Scale Voltage supply's positive net. Any noise associated with Z1 in any cable will have no effect on the scale datum. You will still have to contend with the noise associated with the data lead. Noise from other cables will not effect this cable.

RUN TESTS AND FINISH THIS SECTION

These ramblings are already very long and I do not know if anyone will read this far. If people wish me to expand on any part of these notes, let me know and I will seriously consider doing so.

As always, I welcome comments and corrections. All of us are smarter than any one of us.

Peace,

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