Power Supply Considerations for Measuring Lower Working Voltage Limits

By
Martin Catt

Probably the single most useful and basic measurement for a quartz analog movement is the lower working voltage limit. To put it simply, you are seeing just how low can you reduce the battery voltage to the movement until it can no longer function. By comparing the reading you get with the manufacturer's specified limit, you can quickly evaluate the overall condition of the movement and determine whether only a battery change is all the watch requires, or whether a complete service is indicated.

Exactly how you measure the lower working voltage limit can affect the result you get. Using the wrong variable voltage source can give you a false reading, resulting in unnecessary overhauls and charges to your customers. Consider what happens if the customer goes somewhere else and has the cell replaced, and the watch continues to work just fine for the next two years. You may get the reputation for wanting to overhaul everything that comes into your shop. You need to be able to provide fast, accurate answers to the condition of the watch to be able to provide good service to your customers.

Testing equipment has changed considerably since the first electronic watches appeared in the 60's, and the results you get with an old Citizen analog watch meter will differ considerably from the results you get with a state-of-the-art Witschi Q-6000. This last statement can cause considerable discussion among watchmakers, because after all, volts are still volts, and amps are still amps. True, nothing has changed as far as units of measure, but what ***has*** changed is how the test equipment supplies the variable voltage for testing.

A modern watch tester such as the Q-6000 uses a digital to analog converter, called a **DAC**, to provide a voltage that can be varied in precise .05 volt steps to a buffer amplifier. This amplifier provides a layer of isolation between the movement under test and the DAC, so that any load caused by the movement under test does not affect the voltage provided by DAC. The buffer amplifier simply looks at the voltage from the DAC, and sets its output voltage to match. Backed up by a transformer powered by the AC power line, the buffer amplifier can provide a constant voltage at current levels up to the point where the built-in short circuit protection kicks in. Figure 1 shows a simple block diagram for a modern digital test power supply.

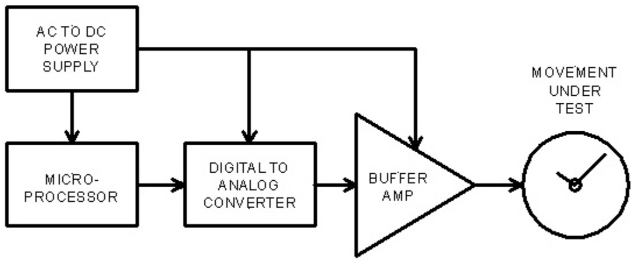

Figure 1: block diagram of a modern digital quartz power supply.

Older analog test equipment use a simple resistive voltage-divider setup to produce a variable voltage, as shown in Figure 2. Typically, a 5000 ohm variable resistor is connected across a 1.5 volt "D" cell. The movement under test is connected across the slider of the variable resistor and the negative terminal of the cell. By turning the variable resistor to different positions, any voltage between zero to 1.5 volts can be provided to the movement under test.

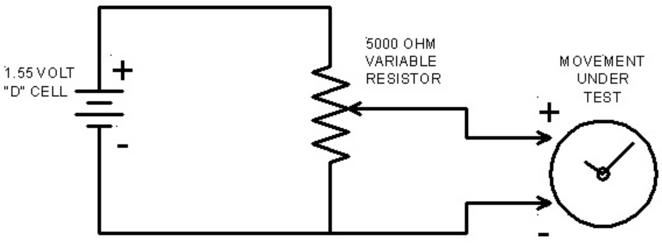

Figure 2: block diagram of the older variable-resistor voltage divider power supply.

On paper, both methods appear equivalent. Each can produce a variable voltage. The major difference is in what happens when a movement is hooked up to the supply. A quartz analog movement provides a considerable load on the power supply. What's worse, a quartz movement is a dynamic load, not a static load. The current required is constantly changing over time as the step motor pulses. Between each pulse, the current demand falls to levels of a microampere or less, while the current demand can rise from several hundred microamperes to the milliampere range when the coil fires. Depending on the movement, the current demand can change five to ten times a second for a chronograph, to once a minute for non-sweep movements that pulse once a minute.

In a modern digital test set, the buffer amplifier takes care of any changes in loading caused by the movement under test. For the older analog test equipment, this is not the case. Resistive voltage dividers are extremely sensitive to the load placed across their output, and the voltage will drop under a heavy load.

The reason for the voltage drop under load requires looking at how the resistive voltage divider works. As stated before, a quartz movement represents a complex load on the power supply. The electronic circuitry itself provides a small but fairly constant current load, while the step motor coils provide resistive, inductive, and capacitive loads. Trying to take ALL of these combined loads into account becomes a real head-splitting mathematical nightmare (which I welcome anyone with a PhD in physics or electronics to explain). Instead, let's just look at the resistive load of the step motor coil and see how it affects the output voltage from the divider.

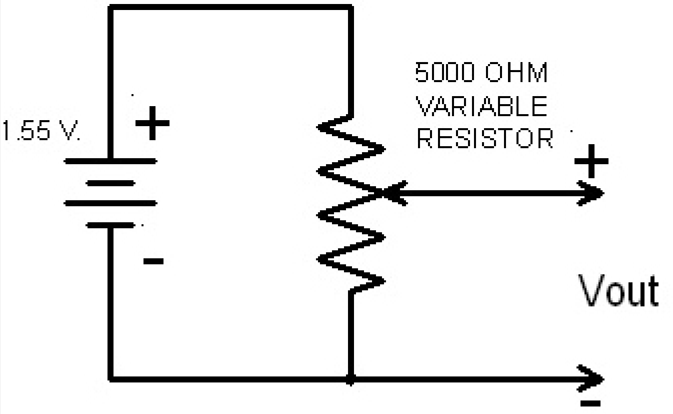

Figure 3A: Voltage divider with variable resistor.

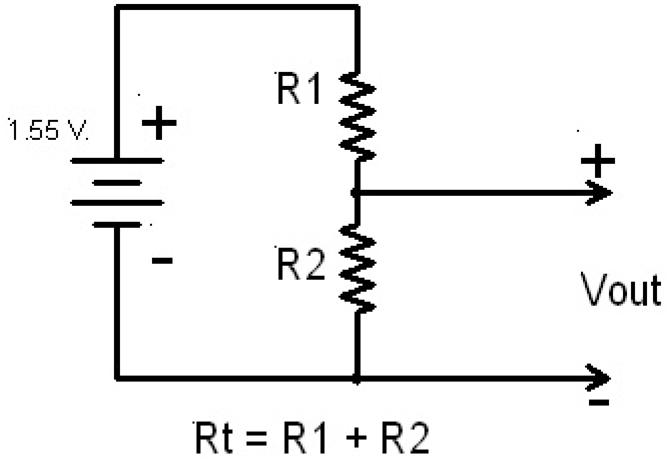

Figure 3b: Voltage divider shown as two fixed resistors.

Figure 3A shows the basic voltage divider circuit using a variable resistor, while Figure 3B shows the voltage divider as a pair of fixed resistors, with each resistor representing the amount of resistance on either side of the variable resistor's slider.

The output voltage from the divider can be calculated using Equation 1:

Vout = (R2/Rt) * Vin (1)

Where:

Vin is the input voltage from the battery
R2 is the resistance of the lower leg of the divider in ohms
Rt is the total resistance of the divider, which is R1 + R2

Using a 5000 ohm (5K) variable resistor for the voltage divider, we need to set the voltage divider to put out 1.2 volts from a 1.55 volt cell. Since we know Vin, Vout, and Rt, rearranging equation 1 to solve for R2 gives:

R2 = (Vout * Rt) / Vin (2)

R2 = (1.2 *5000) / 1.55

R2 = 3870 ohms, or 3.87 K

R1 is found by subtracting R2 from Rt:

R1 = Rt – R2

R1 = 5000 – 3870

R1 = 1130 ohms, or 1.13 K

Therefore, Figure 3B can be redrawn using the values for R1 and R2 to show a voltage divider circuit that will put out 1.2 volts from a 1.55 volt source, as shown in Figure 4. This is the No Load, Open Circuit output voltage for the divider shown in Figure 4. I picked 1.2 volts for this example because this voltage is a common ***go/no-go*** value used for testing quartz movements. If the movement will run at 1.2 volts or less, it is generally considered to be in good condition and doesn't require a complete service. If the movement fails to run at 1.2 volts, then a complete service and cleaning is indicated.

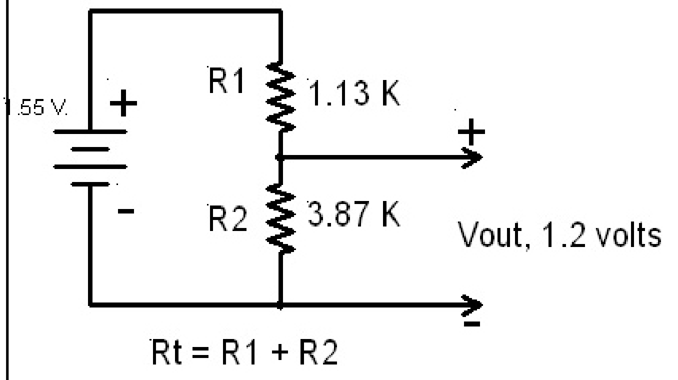

Figure 4: Voltage divider with fixed resistor values to give 1.2 volts from a 1.55 volt source, where Rt = 5K (5000) ohms.

Note that the calculations above are for the voltage divider alone, with nothing connected to the output. Now, let's look at what happens when a movement is connected, and how it affects the output voltage. Figure 5 shows the voltage divider with a quartz movement attached to the output. The circuit inside the dotted lines is a simplified version of a movement. Rc represents the step motor coil resistance, which for this example is set to 1200 ohms, or 1.2K, which is a fairly common value for most coils. Switch S1 represents the transistor used to pulse the step motor coil. As stated before, we are ignoring the small load placed on the power supply by the quartz circuitry and the inductive and capacitive loads from the coil, and just considering the resistive load.

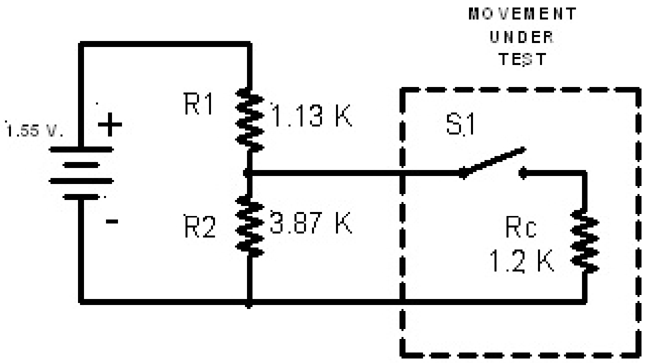

Figure 5: Voltage divider from Fig. 4 with a movement attached. S1 represents the transistor that controls the current to the coil, while Rc represents the resistance of the motor coil.

Now, as long as the coil remains disconnected from the circuit, the output voltage from the divider remains at 1.2 volts. When the switching transistor in the movement fires and connects the coil to the circuit, suddenly we have the coil's 1.2K resistance in parallel with R2, as shown in Figure 6. This changes the resistive values in the voltage divider, where the total resistance Rt is now equal to R1 plus the combined parallel resistances of R2 and Rc.

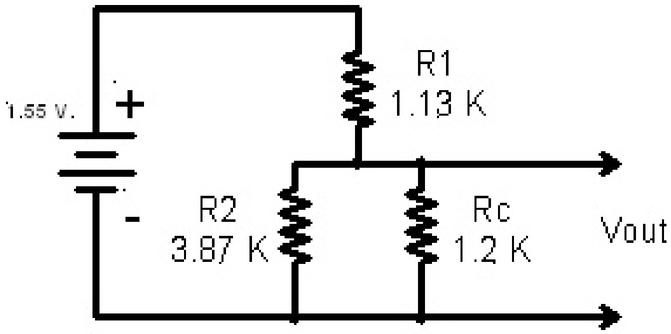

Figure 6: When the transistor fires, the coil resistance Rc is placed in parallel with R2.

The combined resistance of the two resistors in parallel is found with Equation 3:

Rcb = (R2 * Rc)/(R2 + Rc) (3)

Rcb = (3.87 * 1.2) / (3.87 + 1.2)

Rcb = 0.92K, or 920 ohms

This new value is less than a third of the original value for R2 needed to produce a voltage output of 1.2 volts. Figure 7 shows the equivalent circuit with resistance values. So how does this affect the output voltage?

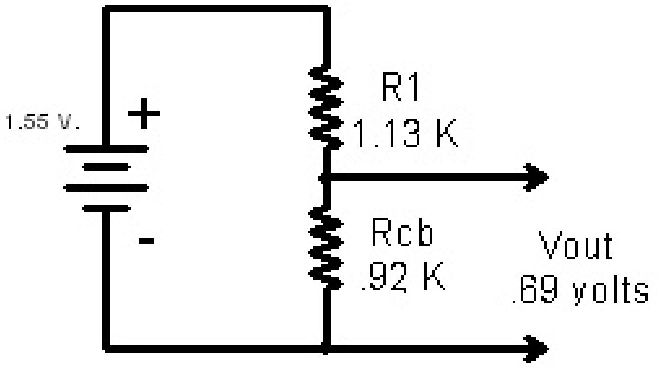

Figure 7: Combining R2 and Rc gives an equivalent resistance Rcb of .92K. This new value drops the output of the voltage divider from 1.2 volts to .69 volts when the coil fires.

First, recalculate the value of Rt, substituting Rcb for R2:

Rt = R1 + Rcb

Rt = 1.13 + .92

Rt = 2.05 K, or 2050 ohms.

Now, plug the new values for Rt and Rcb into Equation 1 to get the output voltage:

Vout = (Rcb/Rt) * Vin

Vout = (.92 / 2.05) * 1.55

Vout = 0.69 volts

So what this means is that when the step motor pulses, the output voltage -- which *was* at 1.2 volts -- drops down to less than seven-tenths of a volt, ***exactly at the time when the full 1.2 volts was needed the most***. After the step motor pulses, the coil's resistance is removed, and the voltage jumps back up to 1.2 volts.

This drop in voltage is so brief that it would not register on most analog or digital voltmeters. At best, you might see the needle flicker slightly, or perhaps a slight bobble in the lower digit of a digital meter. You think you're testing the movement at 1.2 volts, but you're actually testing the movement at considerably less. The result is a lot of apparently "bad" movements, resulting in a lot of unnecessary full services.

Modern testing equipment is pretty much immune to the effects of circuit loading. The buffer amplifier bases it's output on the voltage level it sees at it's input, and, backed up by the AC line transformer, can supply more than enough power to make up for the change in the load when the step motor fires.

In the past, using a resistive voltage divider wasn't a problem. Everyone used voltage dividers for testing, even the manufacturers, so the published lower working voltage limits were determined using the old method. Everybody was on the same page, so to speak. Over time, the technology improved and the testing standards moved to more complicated power supplies that weren't affected as much by circuit loading, and the new lower working limits listed by the manufacturers used the new testing methods.

So what this means to you is that if you're testing movements using the old Citizen watch meters, or any other test setup that uses a resistive voltage divider, then your numbers will not match the rest of the world, and you'll be doing a lot of unnecessary repairs. It's time to move up to a more modern power supply for testing. In the next installment of this article I'll show you how to make such a unit for less than twenty-five dollars.