Yaesu G-5500 Rotator Controller Repair

Back at the end of September, we had a rather strange occurrence at the GCARC Clubhouse. One of our members was at the Satellite station and found that the AZ-EL rotator was inoperative. The controller for this rotator is the Yaesu G-5500 model as shown in Figure 1. A little bit of rudimentary troubleshooting led to the discovery that the power inlet fuse, a 2-ampere Type 3AG 1/4” x 1-1/4” glass fuse, had gone open. He attempted to replace the fuse, and ended up getting a shock and also blowing the new fuse as well. As that was the only spare fuse of that type on hand at the Clubhouse, I came back the next day prepared with a few of the correct fuses with me. At a first glance, we (**Frank Romeo N3PUU** and I) found that the motor output wires on the back of the controller, especially for the Azimuth output, were loose and had been shorting to each other and to the controller chassis. We made the decision to change the “wire under screw head” arrangement that existed to a more orderly system of wire terminals designed to be secured under screw heads. I installed a full set of such terminals on both the azimuth and the elevation (which also turned out to have loose leads) wire lead sets. Thinking that I may have corrected the problem. I installed a new fuse and plugged the unit in. On plugging it in however, the fuse blew again immediately.

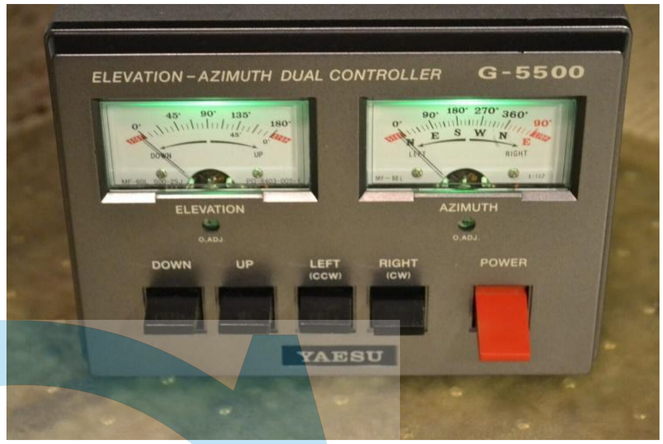

Figure 1 -- Yaesu G-5500 controller

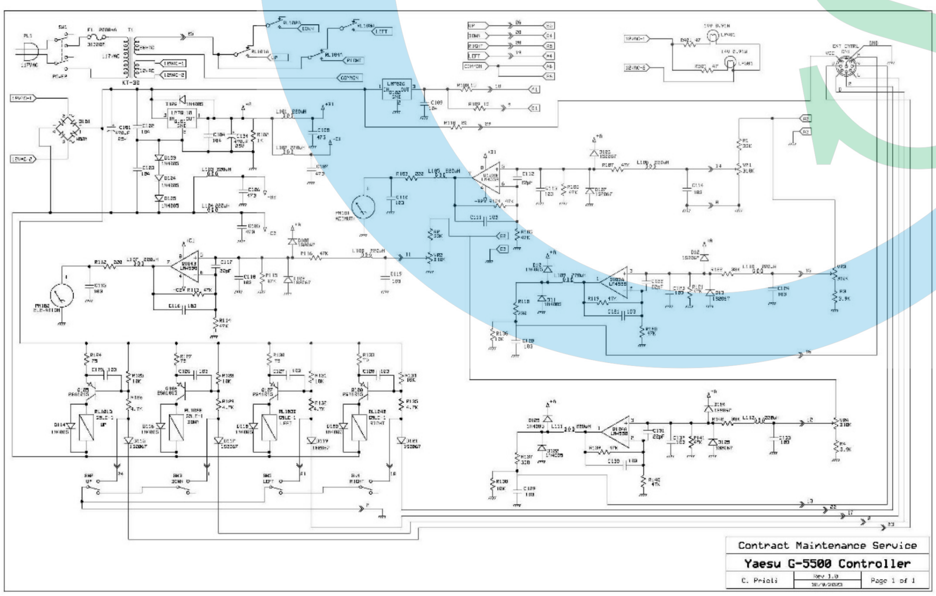

Figure 2 - G-5500 controller schematic diagram

At this point, I knew that we still had a problem, but I had no way of knowing just then if the problem was something internal to the controller or if it involved the harnesses to the motors or even one of the two the rotator motors themselves. I decided to narrow it down by disconnecting all of the external connections to the controller unit, which included the azimuth and elevation cable harness connections and also the external control cable. Once again, the controller blew its fuse immediately. This showed conclusively that the problem was internal to the controller. I brought the controller to my shop for further investigation.

One of the things that Frank and I had done was that we had taken a preliminary resistance measurement of the power transformer primary winding to see if we had a direct short circuit there, which we did not, though the resistance was very low at 0.8Ω. Not having any resistance specifications for the transformer windings, I did not want to condemn the transformer… yet… though we both suspected that the resistance reading obtained was too low. What I did instead was to disconnect the transformer secondary windings from their tie points into the controller circuitry, and then to try some substitution therapy. A quick look at the schematic (Figure 2) shows that the transformer has two secondary windings, with outputs of 12VAC and 26VAC respectively. The 26VAC output is used strictly to power the two rotator motors, being directed through the contact sets of the four SPDT control relays on the controller main printed circuit board (PCB), to manage the direction of motor rotation and which motor is active at any given point in time.

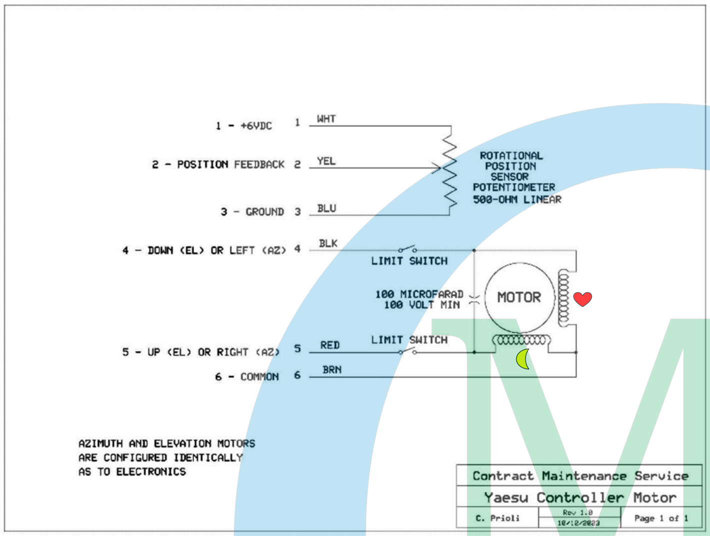

Figure 3 - Rotator motor electrical arrangement

A few words about the motor direction and how it is changed are due here. Unlike a DC motor in which we can change direction simply by reversing the polarity of the motor leads, with AC motors, it is not so simple. In this case, the rotator is actually equipped with four separate motor windings – or more accurately, with two motors with each motor having two separate windings. Figure 3 shows the electrical arrangement found in each of the rotator motors. The pair of windings in one motor changes the azimuth angle, while the pair of windings in the second motor changes the elevation angle. One winding of each pair produces motion in one direction, while the second winding provides the motion in the opposite direction. Let's call the motor windings AZ-forward and AZ-reverse, and EL-forward and EL-reverse. To move the antenna in the forward azimuth direction, we apply operating current to the AZ-forward winding in the azimuth motor. To move the antenna in the reverse elevation direction, we apply operating current to the EL-reverse winding in the elevation motor. In actuality, the windings are labeled as UP, DOWN, RIGHT, and LEFT, and each motor winding is controlled by a single relay that turns the current to that winding on or off. The 26VAC current flows through the relay contact sets, but the relay coils are controlled with current that is derived from the 12VAC secondary. Each axis of motion is equipped with a limit switch at each extreme of the motional range to cut off the motor current when the movement reaches the preset limit in that particular direction.

In reality, the directional control is a tad bit more complex than just one winding or the other, because in reality, *both* motor windings are energized when turning the motor in *either* direction. Refer to the Figure 3 diagram to follow along with this discussion. Let's assume that we are looking at the azimuth motor; the operation of the elevation motor is identical. When we want to swing the azimuth angle to the left, we engage the front panel switch marked "LEFT", which causes a relay to close and pass the 26VAC out to pin #4 in the Figure 3 diagram. Pin #5 is open at the controller end, as it too goes through a set of relay contacts which are in their open condition. Pin #6 is the common current return lead for the motor and is active when the motor is turned in either direction. The current flowing from pin #4 into the motor goes into the winding with the "heart" next to it. At the same time, current also flows into the circuit branch with the capacitor, through the capacitor, and into the winding with the "moon" next to it. However, the capacitor causes a phase shift of 90° between these two currents, meaning that the two magnetic fields created in the motor are *not* unified and in phase, but that one field leads the other. The phase difference causes enough of a lag between the two fields that it can be used to "steer" the direction of rotation. The difference in the timing of the current flow through these two windings is what causes the rotator to move in that direction. If the current, on the other hand, is applied to pin #5, we have a slightly different condition. At this point, pin #4 is open at the controller end because the relay contact points for that lead are open. The current enters the winding labeled with the "moon" symbol and simultaneously flows into the capacitor in the opposite direction and into the "heart" winding, again setting up a magnetic field that is offset in phase from the field of the "moon" winding. This time, however, the offset magnetic fields cause the motor armature to rotate in the opposite direction. This technique is known as *"split phase"* directional control.

Using a bench power supply with a 12.6VAC output, I provided the 12.6VAC directly to the leads that I had removed from the power transformer 12VAC secondary. If all was well with the controller circuitry, the relays would activate when the front panel switches were closed. What actually happened was that one of the two panel meter lamps illuminated, but the relays failed to operate at all. Some quick testing with a voltmeter showed that what should have been about 12VDC was actually quite low. When checked with an oscilloscope, the voltage was swinging widely from about +14.6VDC down to +5.5VDC at the output of the full-wave rectifier that starts the DC circuit. This voltage is also sourced to the relay control circuits as well as being the source for the two integrated circuit voltage regulators. In addition, it is used to generate the negative voltages required for powering the two operational amplifiers used in the controller.

This controller has several operating voltages in its circuitry, identified on the schematic as +A, +B1, +C1, -B2, and -C2 (see Figure 4). While none of these voltages are clearly identified on the schematic as to amplitude, it is clear that +A is +10VDC as it is directly at the output of the LM78L10 voltage regulator. The other positive voltages, which are simply highly-filtered +10VDC sources, are derived from that +10VDC source, while the negative voltages are derived from a diode stack. A quick look at the schematic shows that the two negative voltages are simply produced via three series diode drops of approximately 0.7V each, giving us roughly a negative 2-volt potential there. The two negative supplies are filtered and each is used for one of the two 4558 op-amps, supplying -2.0VDC to the negative rails of the op-amps. Taken together with the filtered +10VDC

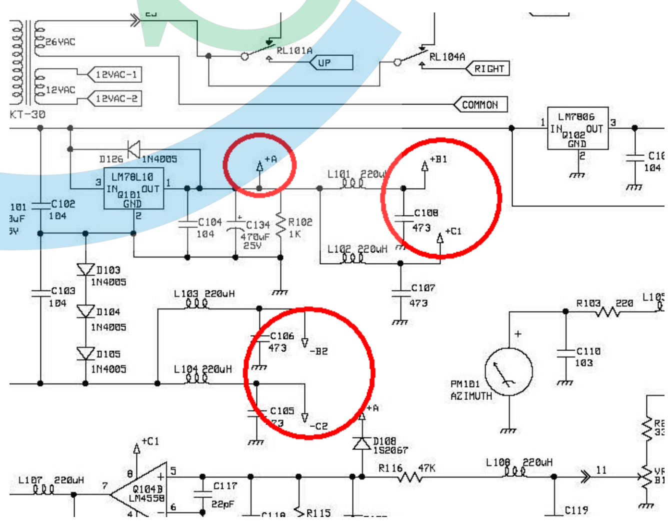

Figure 4 - Controller operating voltage sources

at the positive rails, we get a 12VDC operating voltage across each op-amp, rail-to-rail. It is unclear why Yaesu wanted separate filtered power inputs to the two op-amps, but they did, and that is how they did it. In addition, there is an LM7806 voltage regulator that provides a +6VDC supply used for the position-sensing potentiometer circuits at the rotator motors. A quick voltage check showed that neither the +10VDC nor the +6VDC supplies were present. Interestingly, even with the 10VDC supply defunct, the -2VDC supply was active, as it is not dependent upon the +10VDC supply as it originating source. Further, it was discovered that the 470µF/25V filter capacitor across the full-wave bridge rectifier output was open.

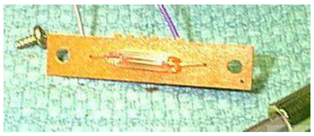
Figure 6 -Panel lamp

I replaced both of the voltage regulator IC's and the two 470µF capacitors on the board, and this restored full operation of the controller *when supplied by my bench power supply,* with the exception of the panel meter lamps, one of which was still burned out. My next job was to replace both of the panel meter lamps, going by the philosophy that they were of the same age and therefore the second one was likely to fail soon as well. That was a simple and straight-forward parts replacement job.

Figure 5 - Front panel rear view

The original panel lamps were of an axial or tubular design (Figure 5), having one wire lead coming out of each end of the tubular envelope. The lamps were supplied directly from the 12VAC secondary winding, and each lamp had a 47-ohm current limiting resistor wired in series with the lamp. I chose a T-1 type lamp with radial wire leads as the replacement, selecting a 14-volt 0.91-watt lamp for the replacement units. I could have converted these lamps over to LED's by adding a rectifying diode to each of the lamp boards, visible along the top of the controller front panel in Figure 6. The reason that I chose to install incandescent lamps again is that I found that it would be difficult to get adequate illumination directed downward onto the meter faces using LED's due to the directional nature of the light emitted by LED's.

The interesting thing is that although I found problems on the controller main board, I did *not* find anything shorted or likely to cause a fuse to fail. In other words, the unit repair was not yet complete. I next connected power to the unit with open connections at the secondaries of the power transformer, and it blew the fuse immediately. This told me that the transformer itself was defective and was the cause of the blown fuses.

The power transformer has three windings, a single (effective) primary and two secondaries, as already described. Figure 7 illustrates the power transformer used in this controller, with the terminals of the primary winding that are used in the 117VAC version indicated by the red arrows. In general terms, the higher a voltage to be expressed across a transformer winding will be, the higher that winding resistance will usually be. In the case of the Yaesu transformer in this controller, what I found initially was 0.8Ω across the primary winding, and 0.1Ω across the 12VAC secondary with 0.00Ω across the 26VAC secondary. These readings

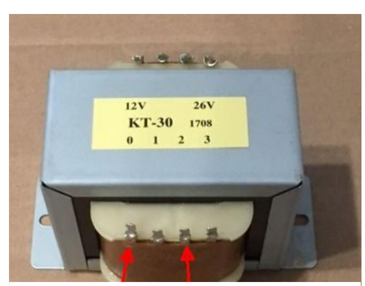

Figure 7 - Power transformer

were low enough that they were basically unreliable, so I decided to measure them again using my Ascel Æ20218 milli-ohmmeter. In this test, I measured 0.674Ω across the primary winding, 0.385Ω across the 12VAC secondary winding, and 0.128Ω across the 26VAC secondary winding. These readings, while quite accurate due to the nature of the Ascel Æ20218, reveal a bit of a problem. Following the conventional "higher voltage, higher resistance" logic, the 26VAC winding should have had more resistance than does the 12VAC winding. In addition, I believed that the primary winding resistance was considerably lower than it should properly have been. In theory, it should have been the greatest of the three resistances. I resolved to measure the winding resistances of the new transformer when it arrived, using the milli-ohmmeter.

On the day that the replacement transformer arrived at my shop, I spent a few minutes taking comprehensive resistance measurements with the Ascel Æ20218 milli-ohmmeter before doing the transformer installation. The results of those measurements are shown below.

Table 1 - Transformer resistance values

Primary Winding		
Connection	Resistance - Original	Resistance - Replacement
Pin 0 to Pin 1	0.624Ω	6.307Ω
Pin 0 to Pin 2 *	**0.674Ω**	**7.447Ω**
Pin 0 to Pin 3	0.788Ω	23.312Ω
Pin 1 to Pin 2	0.063Ω	1.149Ω
=Pin 1 to Pin 3	0.176Ω	17.032Ω
Pin 2 to Pin 3	0.112Ω	15.875Ω
Secondary Windings		
Connection	Resistance - Original	Resistance - Replacement
12VAC	**0.385Ω**	**0.374Ω**
26VAC	**0.128Ω**	**0.621Ω**

*This connection is the factory primary 117VAC input connection used in the G-5500 controller.

A quick glance at the table will show that the only winding of the original transformer that has a resistance measurement anywhere near that of the new (factory replacement) transformer is the 12VAC output secondary winding. In this table, those connections displayed in **bold** typeface are the connections that are used in this controller model. The values that are shown in **red** type are the failed values, while the **green** values are the acceptable values. Of course, *all* of the values in the "Replacement" column are acceptable values, as they are the values of the new transformer.

It is reassuring to note that the resistance measurements on the new transformer validated the "higher voltage, higher resistance" convention mentioned earlier. According to the Ascel Æ20218 measurements, the 12VAC, 26VAC, and 117VAC windings measured 0.374Ω, 0.621Ω, and 7.447Ω respectively. Clearly, the convention is alive and healthy here!

It is unusual for multiple windings to develop short circuits simultaneously *unless, of course, the failure of one winding was the direct cause of the failure of the other winding.* I believe that a cascade failure of that type is exactly what happened here.

Remember that one of the original findings was that the motor power leads were shorting at the back of the controller. I suspect that this short circuit caused excessive current draw through the 26VAC secondary winding, which in turn caused excessive current draw in the primary. I believe that it was the heat caused by this excess current that led to the failure of the transformer windings. At this point, I am left with the following failures, which may at first glance seem to be difficult to relate to the excess current…

- failure of the LM7806 6-volt voltage regulator;
- failure of the LM78L10 10-volt voltage regulator; and
- failure of the 470µF/25V filter capacitor that was installed across the full-wave bridge rectifier.

Figure 8 - Ascel Æ20218 milli-ohmmeter

Remember, however, that this capacitor had failed open, resulting in there being no smoothing of the DC pulses output by the FWBR. This would have had a strong effect on the operation of the voltage regulator IC's, especially on that of the LM78L10 10-volt regulator. The LM78L10 is a smaller low-current device and is less able to withstand the voltage swings. These three-pin voltage regulator IC's, as a device type, are dependent upon clean DC input power. The failure of the filter capacitor had the net effect of introducing unfiltered pulsating DC into the input side of the voltage regulators. This has a deleterious effect on the individual voltage regulator IC's, and in this case, it led to the failures of the LM78L10 and the LM7806 voltage regulators. The failure of the capacitor itself could well have been a function of age, accelerated by the heat of the excessive current. In fact, the only component failure not attributable to the root problem of the shorted motor leads is the single failed panel meter lamp. That failure was simply a function of time and operational age, which in turn is the reason that I replaced both of the meter lamps as well as the second electrolytic capacitor used in the controller.


Figure 9 - Kelvin lead set for Ascel Æ20218

I said earlier that the Ascel Æ20218 (Figure 8) is "quite accurate" in its results. This is partly due to the design of the meter itself, and partly due to the fact that it uses the Kelvin measurement technique, which removes all wire lead resistance from the reported results. In the case of a standard ohmmeter, the test meter leads are in-circuit and are therefore contributing their resistance to the reported value. The Kelvin system, which uses four test leads (Figure 9) instead of two and places a known and highly accurate current through the subject resistance, removes the resistance of the test leads from the equation. You can learn more about the Kelvin lead system by reading the explanatory article at https://storage.googleapis.com/production-domaincom-v1-0-0/180/1603180/ZMb5Nhvj/25e8a371f25642848308d72e18779604?fileName=Kelvin%20Resistance%20Measurement%20Method.pdf.

The graphic at Figure 10 illustrates the Kelvin four-wire resistance measurement system diagrammatically, providing an example of how the system works. While it is obvious that the wire leads used in making these measurements still have internal inherent resistance, that resistance is factored out by the fact that the voltmeter is connected in parallel and is a very high

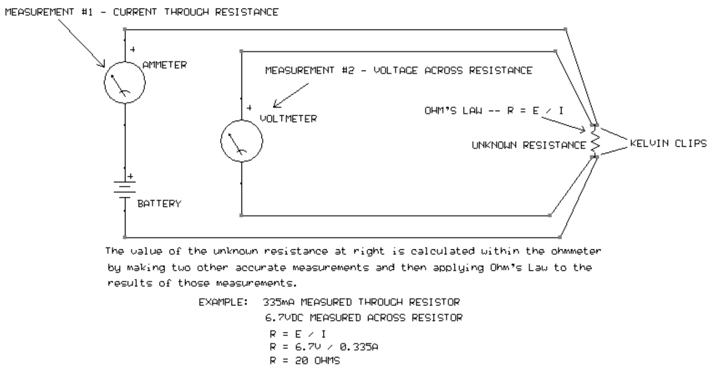

Figure 10 - Kelvin resistance measurement

input-impedance meter, meaning that circuit loading is at the lowest possible level. The Kelvin test clip is a special two-wire insulated clip where the current lead and the voltage lead are not connected at all until the clip is closed onto the lead of the target resistor. The results of the current and voltage measurements are used to calculate the resistance which is then displayed on the face of the Kelvin ohmmeter.

One of the problems with any resistance reading is the fact that there is some inherent error in almost any measuring device. When we get to values as low as these values are, a little bit of error makes a large difference. It was because of the apparent low values that I opted to measure the transformer resistances with the Ascel milli-ohmmeter.

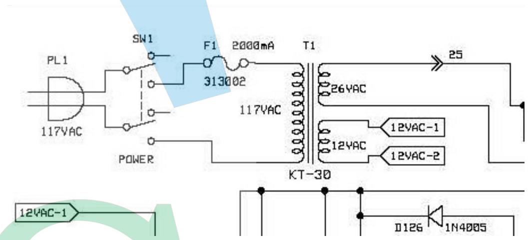

Figure 11 - Power inlet circuit

While I was waiting for the power transformer to arrive, I decided to verify the wiring to the transformer, completely on a whim and for something to do. In the back of my mind, I was thinking about the fact that the controller blew a fuse as soon as I plugged it in, when I thought that the power switch was in the off position. It was, as it turned out, a good thing that I did. What I had noticed previously, but did not think anything at all about, was that the power switch, a paddle-type switch, did not have a crisp "click" to its action, instead sliding easily from one position to the other. As I said, I did not think anything about it, assuming that that was the normal "feel" of that particular switch. However, when I started to verify the power transformer wiring, I discovered that the switch was, in fact, damaged internally.

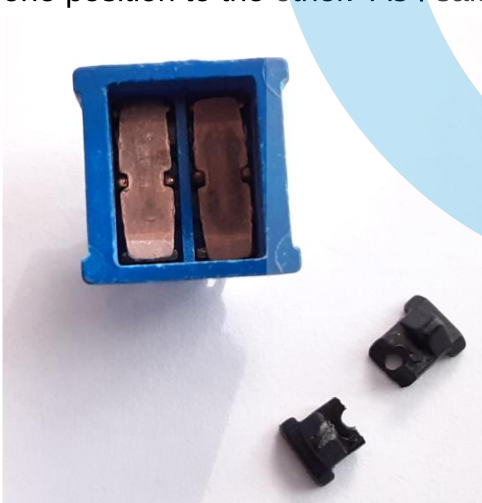

Figure 12 - Switch body and broken operating bar

The power inlet of this controller switches both the line and the neutral wires, using a DPDT paddle switch as the power switch (see Figure 11). The circuit has the power cord line side connected to the common on one half of the DPDT power switch. From the switched terminal of that side of the switch, the circuit goes to the fuse. From the fuse, the circuit goes through the primary of the power transformer. Coming out of the transformer primary, the circuit goes back to the switched terminal of the second side of the DPDT power switch. From there, the common on that side of the switch is connected to the power cord neutral. What I found was that while one pole of the DPDT paddle switch was switching, the other pole was not, and that pole was shorted (closed) to the active circuit. It was the fused (line) side that was shorted, meaning that even when switched "OFF", line current was available at the fuse and then at the transformer. To make things worse, the switch did not even switch that one pole each and every time the paddle was moved, giving a hit or miss action to the switch. The result was that even when the switch lever was in the was “OFF” position, sometimes the circuit was actually “ON”, which accounts for the fuse blowing as soon as I plugged the controller in with the switch “OFF”.

Being a curious cuss, I disassembled the paddle switch by prying open the retaining tabs that secure the switch body to its upper-half operating mechanism. Inside this switch, there are two teeter-totter contact bars that are supposed to rock back and forth between the opposite ends of the switch when the switch is operated. The single paddle lever is connected to a short toggle shaft, which is inserted into a plastic operating bar, which in turn slides along the teeter-totter contacts as the switch paddle is moved, thus rocking the contacts (see Figure 11). This plastic bar was broken into two pieces, and one side of the switch had the teeter-totter contact bar welded to the output terminal.

I was able to free up the teeter-totter contact bar by exerting a little bit of force on it, breaking the tiny weld. I then used some cyanoacrylate cement to glue the two pieces of the operating bar back together (Figure 13). Finally, I was able to re-assemble the switch, crimping the tabs back into place. Voilà! The switch worked as it should, with proper snap action as the paddle was moved. However, knowing that the switch was on borrowed time, I went ahead and ordered the replacement switch from Yaesu so that I would have it if and when the switch failed again.

Figure 13 - Repaired operating bar

With all of the failures considered together, it is difficult to determine *definitively* which failure was causal and which failures were collateral damage, and what the precise failure sequence was. Obviously, that failed panel meter lamp was just a function of time and use, as already stated. Any incandescent lamp will eventually burn out. However, the welded power switch is probably a result of the failed power transformer drawing excessive current long enough to damage the switch. At the same time, that high current is most likely not directly responsible for the failed voltage regulators. On the other hand, how much of the voltage regulator damage was a result of the open electrolytic capacitor? There is really no way to know the whole story. All that we can do is make some educated guesses, as I have done.

One final interesting point. When reviewing the schematic, it is obvious that the full rectified voltage of 12VDC or so is supplied to the transistor-controlled relay coil circuits. This is done because the manufacturer chose to use 12VDC-rated relays as the motor current switching devices. These circuits were apparently unharmed by the loss of supply voltage filtration.

This job is a prime example of my position that the repair is not complete until *all* of the problems are solved. I looked into the power switch purely out of the power of a whim. In reality, my subconscious probably knew that there was something wrong with the switch just because of the feel of the switch when operated and the way the fuse blew with the switch “OFF”, and that may well be what prompted the whim. Pay attention to the little things like that as you approach any repair, as it may make all the difference between a complete repair and a partial job. Listen to your subconscious and at least think about any “whims” that strike you. They could be driven by deep-seated knowledge of which you are not even aware.