SHV coaxial feedthrough RCR filter

Eric L. Martin

February 23, 2022

Triangle Universities Nuclear Laboratory, Durham, NC 27708, USA

Abstract

This filter is intended for use biasing germanium detectors for the LEGEND experiment, where the load current is expected to be < 1 nA and a large series resistance is acceptable. The final filter characteristics are 100 MΩ input resistance, 100 MΩ output resistance, and 16 nF capacitance to ground. The expected capacitance between input and output is 0.13 pF. The filter is constructed to minimize radiation power transfer by keeping the input on the same axis as the output and keeping the ground current symmetric about the output axis so capacitor radiation is emitted perpendicular to the output axis and cancels. The entire filter is contained in a sealed tube that can be filled with oil and mounts on a front-side nut SHV bulkhead jack. The SHV jack uses a gasket seal and is suitable for use in an oil filled application. The final diameter is 3/4 inches with a length behind the bulkhead of 3-1/2 inches to the output cable. The mounting hole is a common 1/2 inch D shaped standard.

Parts:

- 1 SHV bulkhead jack, TE Connectivity AMP Connectors 5225059-3.
- 1 3/4 inch OD 0.032 inch wall copper 101 tube cut to 3.16 inches.
- 6 2.7 nF 6 kV ceramic capacitors, Vishay Vitramon HV2225Y272KX6ATHV.
- 1 11/16 inch OD 1/4 inch ID copper washer. Hillman 44142.
- 1 M4 brass standoff in 6 mm hex, 5 or 6 mm length.
- 2 100 MΩ 7.5 kV axial lead resistors, Ohmite MOX1125231006FE.
- Epoxy, Loctite Hysol EA 0151.[1]
- 20 mL of silicone oil, Super Lube 45NA65.
- Section of high voltage cable for the output.
- Section of wire braid to shield the output cable.
- Copper tube to cover resistor to output cable joint, cut piece of AWG 20 wire terminal crimp connector.
- Electrical tape.
- M2.5 washer, or something similar to use as a temporary spacer.
- 4 mm grommet, printed part.
- Tube jig, printed part.
- Capacitor jig, printed part.

Assembly

1 Assemble the input resistor and SHV jack

1.1 Prepare the SHV bulkhead jack

The nickel plating on the SHV jack body is difficult to solder to while the underlying brass is far easier. It is a thin layer and will take little effort to remove.

1

1. The epoxy needs to be able to withstand high enough temperature to solder the SHV jack housing with the pin installed, this will heat the epoxy to somewhere around 200 C for a few minutes depending on the solder used. Most epoxies can handle such temperature for a short time. The epoxy should also be able to handle short term exposure to isopropyl alcohol and long term exposure to silicone oil.

1. Tape over the opening in the SHV jack body to prevent any metal from getting into the connector. Stray bits of metal can cause discharge problems later.

2. Remove the nickel layer around the largest diameter surface of the SHV jack body with a file, this is where the tube will later be soldered. See figure 1.

Figure 1: Left: SHV jack body with openings taped over. Center: some of nickel plating filed off revealing underlying brass. Right: all nickel from surface to be soldered removed, also showing the dust of all the material that was removed.

3. (Optional) Tin the uncoated surface of the SHV jack body to ease making a good solder connection with the tube later.

   (a) Use a tip that will provide good heat transfer and set the soldering iron to it's highest temperature.

   (b) The entire SHV jack body will be heated to near the solder melting temperature, use something that doesn't conduct heat well to manipulate it, like a bunch of paper towels.

   See figure 2 for tinning the SHV jack.

      i. Apply a small blob of solder to the uncoated surface of the SHV jack body.

      ii. Spread the blob of solder around the surface until it covers the entire surface where the nickel was removed.

      iii. Remove any excess solder with fluxed solder wick.

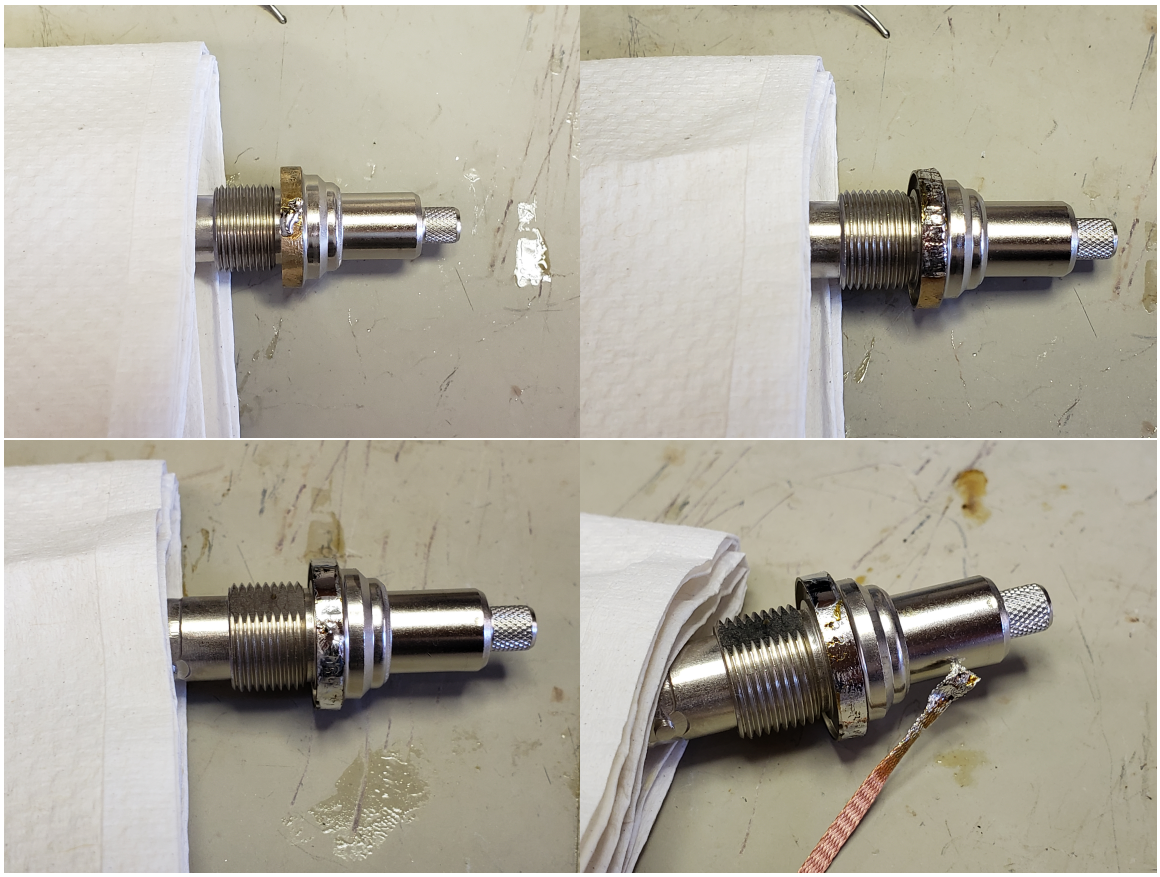

Figure 2: Top left: a small blob of solder applied to edge of SHV jack body. Top right: spreading the solder around the edge. Bottom left: extra solder after covering entire edge. Bottom right: SHV jack body after excess solder wicked away.

1.2 Install SHV pin on resistor

1. Check that the resistor end which will have the pin fits freely in the connector, for the Ohmite MOX1125231006FE resistors most easily fit in the connect, but one was found that wouldn't fit without being sanded down. It needs to have enough of a gap that oil can easily flow in. If one end doesn't fit try the other end or a different resistor (some resistors are a little thicker than others) and use the wide resistor for the output of the filter. If no resistors fit the bulge can be sanded down to be even with the rest of the resistor.

2. Cut the fit tested lead of the resistor down to the central conductor length in the connector trim recommendations, 6 mm for TE Connectivity AMP

Connectors 5225059-3.

3. Solder the pin on the lead.

   See figure for 3 soldering the pin on the resistor.

   (a) Tin the lead, there should be enough solder that will fill the gap in the pin but not so much it comes out of the pin once assembled. If there's a solder bulge on the lead large enough that it can't be pushed into the pin then it's enough to ensure contact with the pin once reheated and inserted.

   (b) Heat the pin with the lead held against the opening of the pin until the solder melts and the lead slides into the pin, no solder should flow out the escape hole in the pin.

   (c) Let the solder cool then ensure there is a good connection by gently pulling on the pin and resistor to be sure they doesn't come apart.

Figure 3: Left: solder blob on resistor lead ready for insertion into SHV pin. Center: inserting resistor by heating SHV pin. Right: Assembled SHV pin and resistor held with paper towels because the pin is still hot.

1.3 Install resistor and SHV pin in SHV jack.

1. Assemble the parts in a clean room or wear gloves at a minimum. Any residual oil from hands can lead to excessive leakage currents on high voltage components.

2. Clean the SHV jack and the resistor with the SHV pin well with isopropyl alcohol.

3. Prepare for epoxy application. If a centrifuge and/or vacuum chamber will be used make sure they are ready to go so the epoxy can be rapidly degassed and applied while it still flows easily. Read the rest of the instructions in this section ahead of time.

It is recommend to degassing the epoxy in a centrifuge to remove any bubbles that formed during mixing that could cause partial discharges.

(a) Fill a small syringe with the mixed epoxy, cap it, and place it dispenser side down in a disposable test tube. The tube is keep the centrifuge clean in the likely event some epoxy spills.

(b) Balance the centrifuge with an identical test tube and syringe filled with the same weight of water.

(c) Run the centrifuge at 1000 rpm for 3 minutes, too high and it will separate back out.

(d) Keep the syringe pointed down so the air bubble stays at the plunger until ready for application.

4. Hold the SHV pin and resistor pin side up so any epoxy that flows during application will coat the resistor and not the pin. Apply a small amount of epoxy to the region where the pin meets the resistor. It only needs to be enough to keep oil from leaking through the pin hole, it is not necessary to pot the connector with epoxy. Don't get any epoxy past the chamfered ridge a little further from the pin tip than center, that's the mating surface for the SHV connector.

5. Fully insert the pin into the SHV jack then invert the SHV jack and set it pin side down while the epoxy cures, so the epoxy can flow around the pin and form a good seal.

It is recommended to vacuum degas the epoxy to drive out any small bubbles that could cause partial discharges. Only do this if it can be accomplished within a fraction of the working time of the epoxy.

(a) Place the SHV jack pin side down in a clear vacuum chamber.

(b) Place the remaining epoxy in a small dish inside the same vacuum chamber. If the vacuum is too low it will boil the epoxy and cause bubbles instead of remove them.

(c) Draw a vacuum of 29 in Hg, if the epoxy in the dish is boiling reduce vacuum. Wait 2 minutes.

(d) Slowly vent the vacuum chamber, this is to collapse any bubbles that rose to the surface. Agitating the chamber can also help burst bubbles.

(e) Repeat this cycle of drawing a vacuum then venting until there are no bubbles forming in the epoxy in the dish. Then leave the epoxy to cure under atmospheric pressure. If possible, cure under a pressure of 60 psig to compressed any remaining bubbles.

Figure 4: Resistor installed in bulkhead jack.

6. (Optional) Tape over the gap between the resistor and SHV jack body to keep dirt out until final assembly.

2 Preparing the tube

1. Measure the section of tube using the tube jig and cut to length with tube cutter. See figure 5.

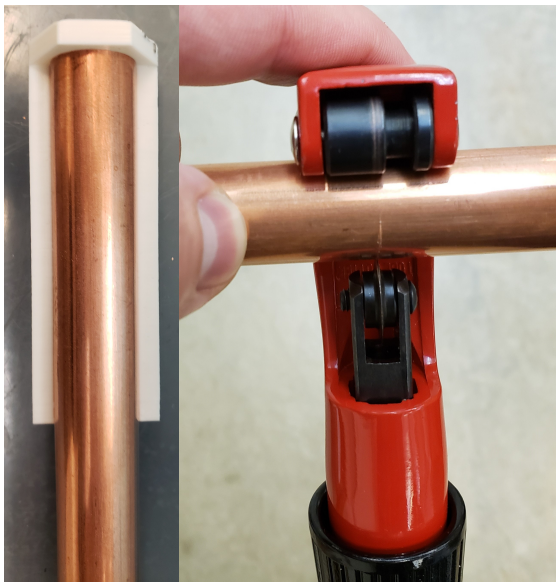

Figure 5: Left: measuring tube with jig. Right: cutting tube with tube cutter.

2. Place the cut tube in the jig and drill the 3/32" fill hole and 1/16" capacitor solder joint holes. The 3/32" hole is on both sides of the jig but only one is necessary. All six capacitor holes are desired for six capacitor, if installing fewer capacitors then space the holes evenly about the tube. Only install a number of capacitors that can be spaced such that the radiation to the output from any current flowing radially through the capacitors will cancel. This allows two, three, four, or six capacitors but not one or five capacitors.

Figure 6: Top: tube in jig ready to be drilled. Bottom: half of jig removed after drilling holes.

3. File any burs off the drill holes, be sure to get the interior side of the tube as the capacitors will catch on any burs.

4. Test fit the SHV jack in the tube, remember that a small gap is necessary for solder. The tube will likely need to be bored out, if so it is helpful to bore to the desired insertion depth so the connector easily inserts then stops in the desired position. The connector should be flush with the end of the tube, or slightly less inserted than flush so that the sealing ring can still be fully compressed. See figure 7.

5. (Optional) Tin the SHV jack end of the tube in the same manner the SHV jack was tinned. Check the fit again, if it doesn't go in there's probably a solder blob that needs to be wicked away.

Figure 7: Left: tube bored out to allow connector to fit. Center: tinned tube. Right: connector resting on shoulder in bored out tube.

6. Solder the washer to the cable end of the tube. For the chosen washer and tube it should be a press fit. If it can't fit into the tube it can be soldered over the end, if it falls through it can be secured with Kapton tape to hold in place during initial soldering. The cable shield will be soldered here later so a large solder excess is fine. Make sure all gaps between the tube and washer are sealed as this is an oil boundry.

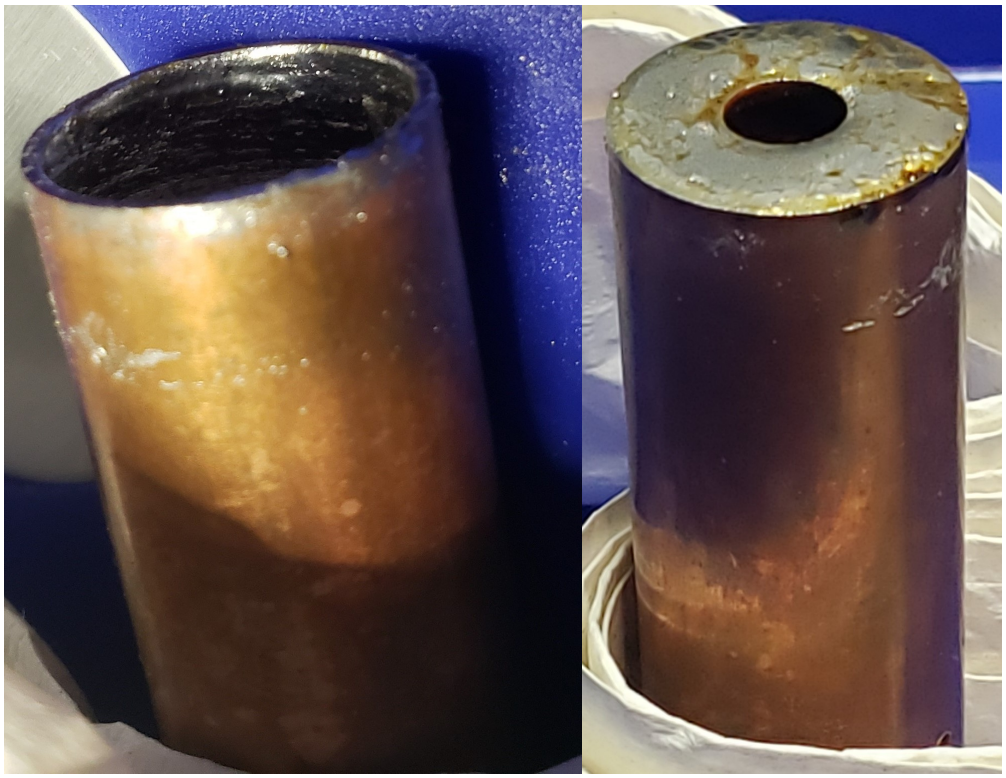

Figure 8: Left: cable end of tube tinned for a press fit washer. Right: washer installed in cable end of tube.

3 Assemble the resistors and capacitors

3.1 Assemble the capacitors

1. Place the capacitors and standoff in the jig. If using a 5 mm standoff place an M2.5 washer under the standoff for a spacer. Lightly tighten the bolts to hold the capacitors in place. The spring in the plastic jig will push the capacitors fully against the standoff when soldering without requiring significant deflection. Once tight, remove the washer.

2. Test fit the capacitors to ensure they can be inserted in the tube, they will protrude slightly from one side of the jig. Some filing of the standoff or tube may be necessary. **Do not file the resistors.**

3. Heat the standoff while applying additional solder to the capacitor to standoff joint until the solder flows. Then apply sufficient solder to fill the center of the standoff. Solder should flow along all the capacitors while spreading around the standoff.

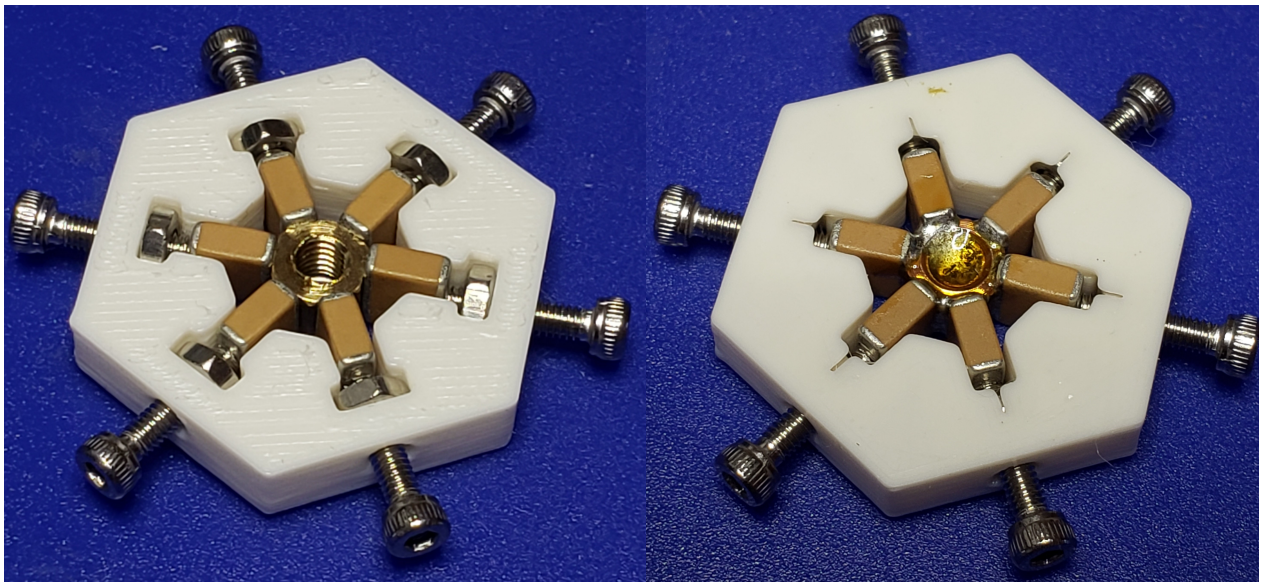

Figure 9: Left: capacitors and standoff in jig before soldering. Right: bottom of capacitors and standoff in jig after woldering, showing the solder flowed along the standoff to connect all along the capacitors.

4. Take the capacitors out of the jig and make sure the can slide into position in the tube. It is likely some filing of the tube will be required.

5. Place the capacitors back in the jig to keep them assembled while soldering the resistors.

3.2 Asemble the SHV jack, resistors, and capacitors

Don't start this step unless the epoxy used to seal the SHV jack center pin is cured enough to handle.

1. Trim the resistor leads that will go in the standoff down to less than the standoff length, leaving at least a couple millimeteres for a solder connection. The leads can be bent so they miss each other in the hole.

2. Solder the resistor lead from the SHV jack and resistor into the center of the standoff. Try to keep the resistors well centered, good alignment will minimize the radiative energy transfer bypassing the filter.

3. Support the SHV jack, resistor, and capacitors assembly by resting it on the SHV jack. Support the assembly with a wide part with a hole to help keep it from tipping.

4. Solder the output resistor lead into the center of the standoff.

5. Remove any solder flux.

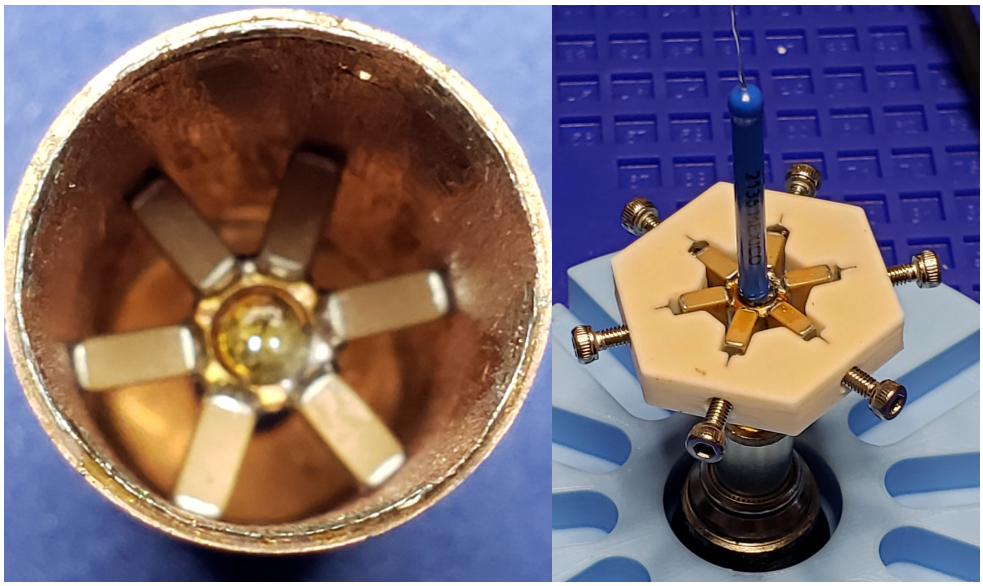

Figure 10: Left: capacitors test fit in tube. Right: SHV jack, inpout resistor, capacitors, and output resistor supported by SHV jack for soldering.

4 Attach the cable and tube

4.1 Attach the cable

Assembly differs if the cable has a connector already that prevents adding the tube after the cable is already attached. If the cable doesn't have a connector on the end then not adding the tube until after the cable is attached makes it easier to handle.

1. Cut a few millimeters of AWG 20 furrule and trim the resistor lead and cable center conductor to fit inside the furrule.
2. Tin the resistor lead and cable center conductor, leave a large solder blub so it will fill the furrle.
3. The furrle has a copper body but is nickel plated, which is hard to remove from inside the tube and makes it hard to solder to. However, the solder joint between the resistor and wire should be good.
4. Slide the furrule over the resistor lead while heating the furrule until the solder melt and the furrle slides on fully.
   (a) If the cable has a connector already, slide the cable through the grommet and tube first.

5. Heat the furrule and slide the cable all the way into the furrule.
6. Gently tug on the cable to ensure it made a good connection.
7. Ensure there are no solder points that might cause discharges. No solder is required on the exterior of the tube, whcih should minimize the liklihood of pints. If the solder is hot enough before the heat is removed it will form a smooth surface before solidifying. If there is excessive solder on the tube exterior forming points, wick it away.
8. Clean the solder flux off the filter, this is the last chance to do so before the tube prevents easy access to the filter internals.

4.2 Install the tube

1. Remove any protective tape inside the filter and slide the tube into place. Ensure the capacitor pads are visable through the holes in the sides of the tube.

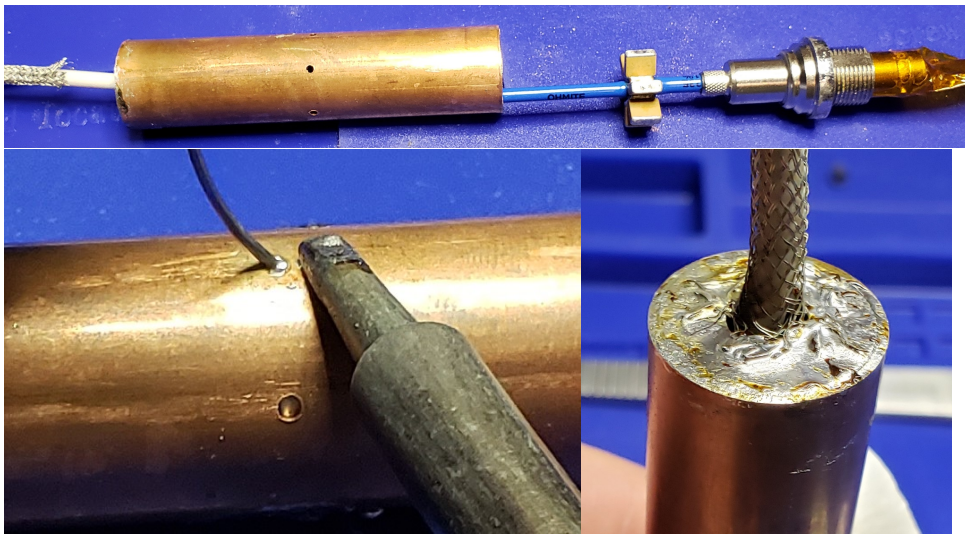

Figure 11: Filter assembly just before tube is slide into position.

2. Heat the tube right next to the holes and feed solder into the hole until it flows in and joints the tube to the capacitor. Make sure the holes are filled, these are oil boundries.
3. Solder the SHV jack to the tube. Ensure there are no gaps as this is an oil seal.
4. Solder the end of the braid to the washer, make sure no stray wires go into the hole that could cause discahrges. This gap will be filled with epoxy.

5 Sealing the cable connection

1. Hold the filter connector end up and flow isopropyl alcohol in through the fill hole, letting it drain out the gap between the washer and cable.

   (a) This is the last chance to clean the filter by flushing fluid through the filter. Unless an optional drain hole is added to the output end of the filter it can only be cleaned by filling and draining through the same hole, which won't be as effective, once the cable connection is sealed.

2. Mix some epoxy and apply it generously to the gap between the washer and cable. It isn't critical to keep the expoy from flowing into the filter but the point is to seal the gap, not pot the filter.

3. Slide the cable grommet into position to hold the epoxy in while it cures. Any voids in the epoxy on the filter exterior side of the washer will not be exposed to high electric field and are of no concern for discharges.

4. Tape around to grommet to ensure the epoxy remains in place while it cures.

5. Hold the filter connector end up so the epoxy flows into the gap and seals as it cures.

Figure 12: Grommet taped to end of filter to hold epoxy in place while it cures.

6 Fill the filter with oil

1. Turn the filter on its side so the fill hole is up.
2. Use a syringe with a blunt needle to dispense oil into the fill hole.
3. Tilt the filter to ensure oil flows into crevices in the connector end as well as the cable end. It should be as full as reasonably achievable.
4. Cover the hole in tape. Pull the tape tight and wrap it all the way around the filter to ensure it doesn't come loose.
5. Keep it connector side down for a day to ensure there are no voids in the oil near the high voltage pin of the connector. After this any small voids in the oil will flow to regions of the filter that are adjacent to the tube of the connector and not be a problem.

Figure 13: Finished filter with electrical tape wrapped around entire length.