SHV coaxial feed-through two stage RC filter with pulse line

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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 is a two stage RC filter with 100 MΩ resistances and 11.3 nF capacitance to ground. The expected capacitance between input and output is around 0.01 pF. The filter is constructed to minimize radiation power transfer by keeping the input on the same axis as the output and keeping the capacitors symmetric about the output axis so capacitor radiation is emitted perpendicular to the output axis and cancels. A pulse line connects to the final capacitor to allow applying a test pulse through the HV line and provide source termination to noise on the HV line. The entire filter is contained in a sealed tube that can be filled with oil and mounts with front-side nut bulkhead jacks.

Parts:

- 1 SHV bulkhead jack, TE Connectivity AMP Connectors 5225059-3.
- 1 BNC bulkhead jack, Amphenol RF 112234
- 1 3/4 inch OD 0.032 inch wall copper 101 tube.
- 6 3.3 nF 5 kV ceramic capacitors, Vishay Vitramon HV2225Y332KXMATHV.
- 6 0.47 nF 6 kV ceramic capacitors, Vishay Vitramon HV2225Y471KX6ATHV.
- 2 11/16 inch OD 1/4 inch ID copper washer. Hillman 44142.
- 1 M4 brass standoff in 6 mm hex, 5-6 mm length.
- 2 100 MΩ 7.5 kV axial lead resistors, Ohmite MOX1125231006FE.
- Epoxy, Loctite Hysol EA 0151.
- Conductive Epoxy, MG Chemicals 8330S. (optional)
- Section of high voltage cable for the output.
- Section of double shielded coaxial cable for pulse line, LMR-100
- Section of wire braid to shield the output cable.
- Section of heat shrink to cover shield braid. (optional)
- Tube jig, printed part.
- Capacitor jig, printed part.
- Resistor positioning jig, printed part.
- Jig stand, printed part
- Ground break insulator, printed part
- End cap, printed part.

Assembly

1 Assembly the Tube

1.1 Cut and drill tube

1. Measure a 61 mm section of tube with the jig and cut with a tube cutter.

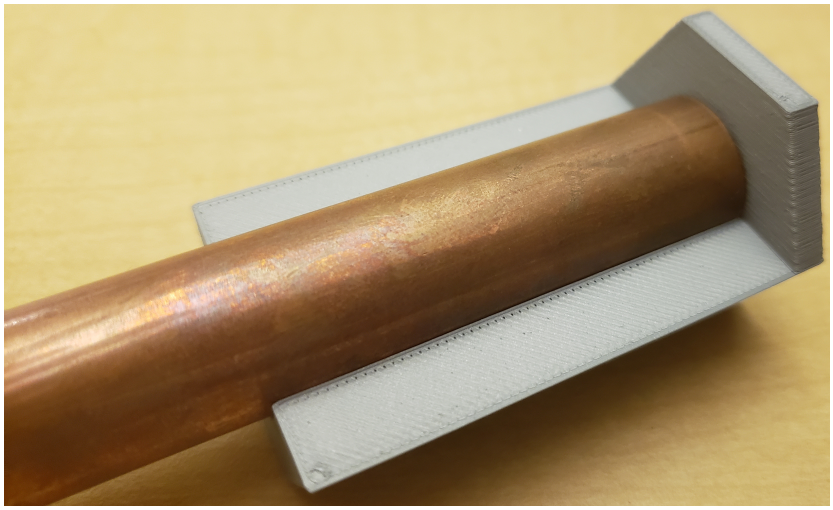

Figure 1: Tube jig used to measure the proper length of tube.

2. Use the jig to drill the smaller, 1/16 inch, holes in the tube.

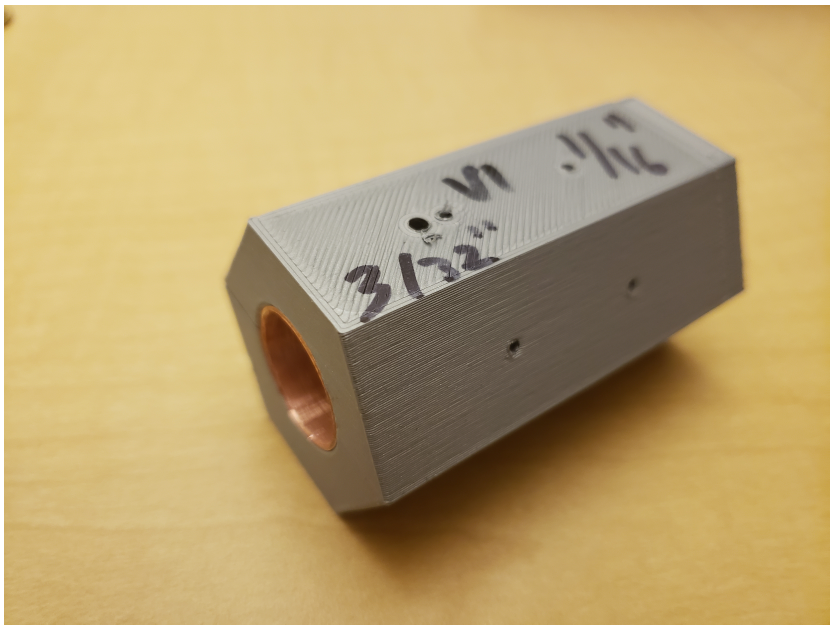

Figure 2: Tube in jig for drilled hole placement.

3. Rotate the tube 1/16 turn so two of the small holes line up with the seam on the jig on each side. Place the cover so the large holes are on opposite ends of the jig and drill out the large, 3/32", holes. This positioning of the holes allows cleaning fluid to flow through the filter and if bolts are used to seal an oil filled filter this keeps the ends of the bolts further from the capacitors.

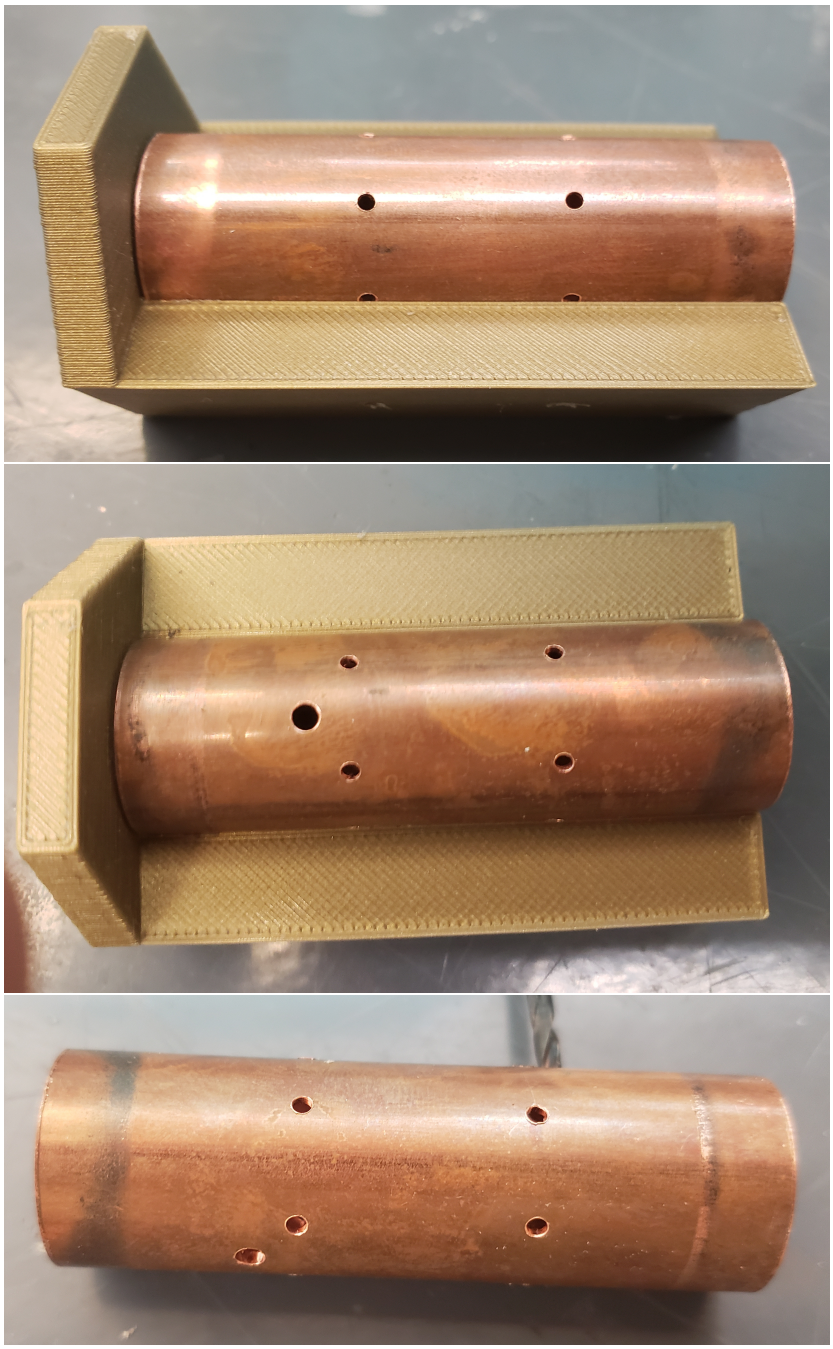

Figure 3: Large hole positions of tube.
Top: Tube rotated in jig to position large holes.
Middle: Large holes drilled, second large hole is under tube on right.
Bottom: Large hole positions, drill bit inserted in hole shows position of large hole hidden from view.

4. Bore out the inside of the tube on a lathe to fit the pulser PCB. It should be bored .04 inchs deep so the PCB protrudes slightly from the end of the tube. The end cap has a 0.4 mm high lip around the edge that will engage with the protruding PCB. Ensure the bored hole is wide enough the PCB easily slides in. The capacitors are very brittle and can easily get damaged if forcing the PCB into a tight fitting hole.

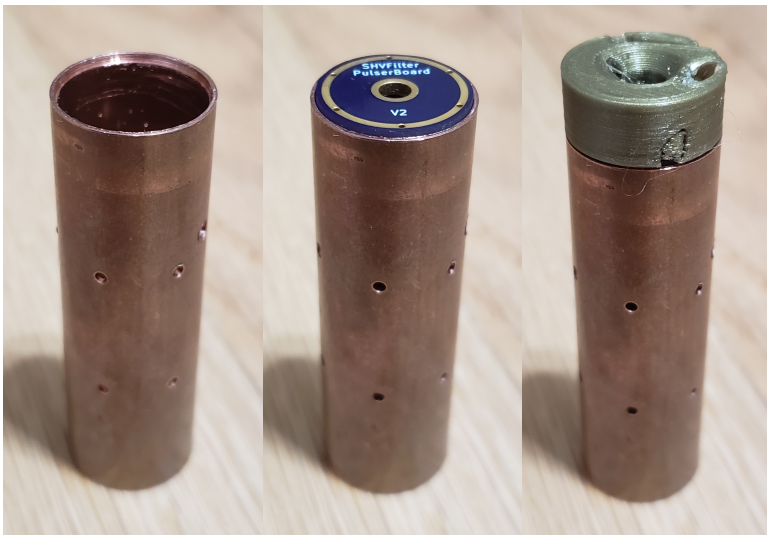

Figure 4: Test fitting the PCB in a bored out tube.

5. Deburr the inside of the tube with a rat-tail file and sand paper. If there are any burs the capacitors may catch later.

6. Place a copper washer on a flat head M4 bolt and tighten it against the head with a nut. Use a drill and file to turn the washer down until it slides into the tube.

7. *Optional*: File a notch in the edge of the washer to allow cleaning fluid to flow past the washer along the wall of the tube. When soldering the washer into the tube rotate the washer so this notch aligns with the large hole in the tube.

8. Put another washer on the end of the bolt sandwiched between two nuts. Position the washer so when it is inserted in the bored out portion of the tube the turned down washer is centered on the holes in the tube.

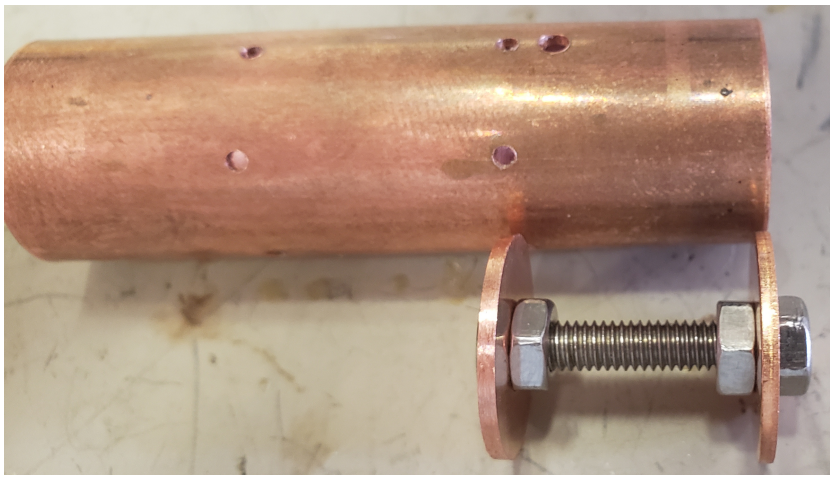

Figure 5: Copper washer and M4 nuts and bolt used as washer position jig.

9. Solder the washer into the tube. Be careful to handle the tube with a hot pad or some other thermal insulator — it will get very hot. Make sure there are no gaps in the holes in case it is later decided to fill the filter with oil.

2 Assemble the filter internals

2.1 Assembly the first stage capacitor array

1. Place three 3.3 nF and 3 470 pF capacitors and M4 standoff in the jig. Evenly distribute the capacitors so the values are alternating around the array, the slots in the jig are of different size for the different capacitors as well. Gently tighten the bolts to press the capacitors firmly against the standoff, but do not over tighten or the bolts will damage the fragile ceramic capacitors.

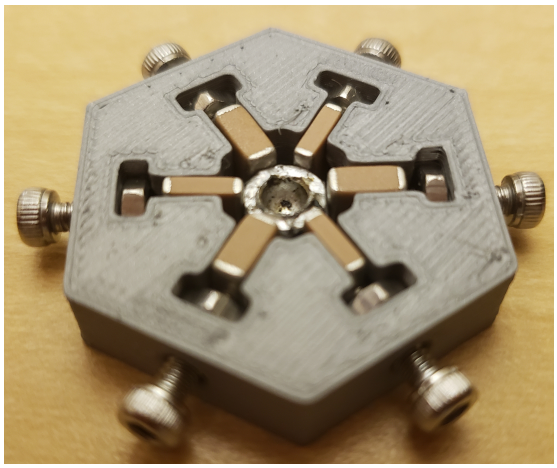

Figure 6: Capacitors in jig around an M4 standoff.

2. Solder the capacitors to the standoff. If the standoff fills with solder it will be a minor inconvenience later, but excessive solder can lead to high voltage breakdowns.

2.2 Attach input resistor to capacitor array

1. Select an input resistor and test fit the resistor to ensure it can easily slide into the SHV jack bulkhead connector. Due to manufacturing tolerances on the epoxy coating not all resistors will fit in the connector. If a resistor doesn't fit try the other end or use it for the output resistor instead.

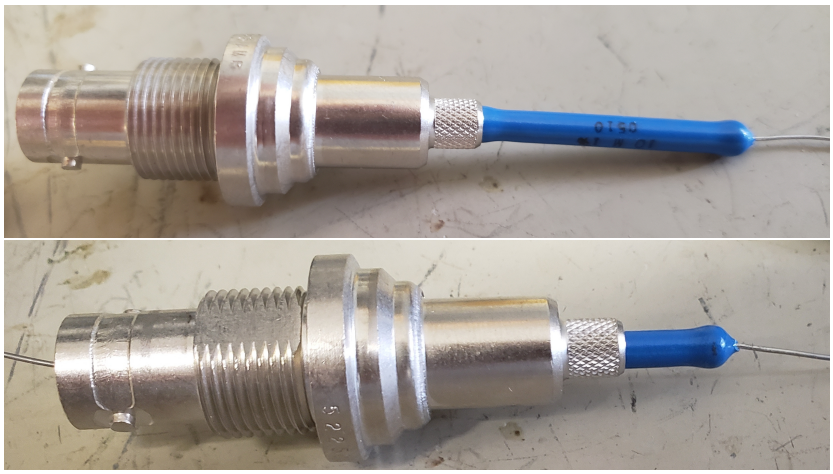

Figure 7: Resistor fit test.
Top: Resistor doesn't fit into connector.
Bottom: Resistor slides into connector.

2. Trim the lead on the input resistor that connects to the capacitor array down to $\sim$ 4 mm, leave the end that inserts into the SHV connector long for now.

3. *Optional:* Wrap Kapton tape around the mid section of the input resistor to provide additional insulation when inserted into the connector. Do not wrap around the bulge at the end of the resistor or it won't fit into the connector. The resistor epoxy should be sufficient to prevent discharges without this additional tape.

4. Assembly the resistor and capacitor jig with the input resistor lead that fits into the connector up. If the standoff was shorter than the width of the resistors, so that only one end is flush with the resistors, put the flush end up towards the input resistor.

5. Solder the input resistor to the capacitor array, gently push the resistor down so it is flush with the standoff in the center of the array.

6. Bend the lead that goes into the connector into a spring to keep the resistor held in place when the jig is inverted. See figure 8.

7. Select and trim one lead of the output resistor down to 4 mm and insert it in the jig.

8. Turn the jig over and insert the output resistor.

9. Solder the output resistor to the capacitor array. If the resistor was too large for the connect it may not fit well into the jig. If this results in a significant misalignment use a jig with a larger hole.

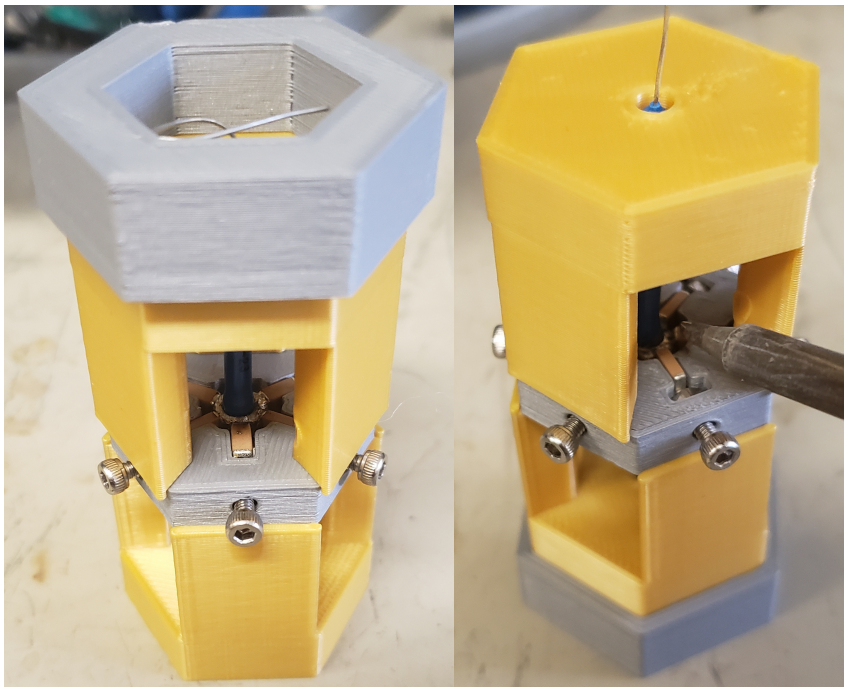

Figure 8: Attaching resistors using jig. Left: Input resistor in jig for attaching to capacitor array. Shown after soldering with lead bent into spring shape. Right: Output resistor in jig. Note the upper part of the jig doesn't quite rest flat against the rest of the jig because the resistor end doesn't quite fit the jig, but it's close enough.

2.3 Install SHV pin on resistor

1. Cut the fit tested lead of the resistor down to 6 mm, trim length for TE Connectivity AMP Connectors 5225059-3.

2. Put some solder flux on the resistor lead with the flux pen and solder a blob of solder to the resistor lead.

3. Gently pushing the pin onto the resistor lead, heat the pin until the solder melts and the pin slides fully onto the resistor lead. Make sure no solder protrudes from the side of the pin further than the widest feature of the pin.

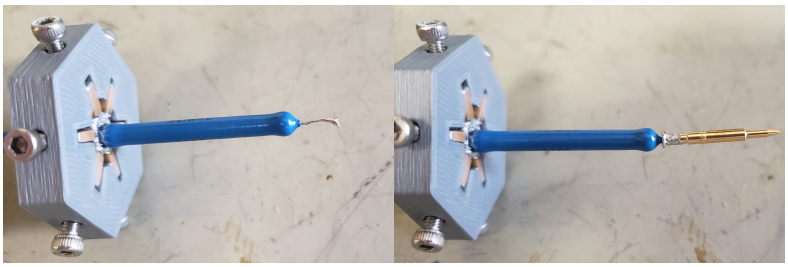

Figure 9: Pin soldered to input resistor.

3 Install the filter in the the tube

1. Carefully slide the filter components into the tube. The capacitors need to be rotated to align with the holes in the sides of the tube. If the capacitors don't easily slide into the tube then file down the tube a little to create tracks for the capacitors. Do not force the capacitors, they are brittle ceramic. Use the jig to ensure the tip of the pin is 29.8 mm from the end of the tube.The insertion of the capacitors will vary slightly depending on how the connector pin and capacitor array attach to the resistor, but it shouldn't shift enough that the capacitor pads aren't visible through the holes in the tube.

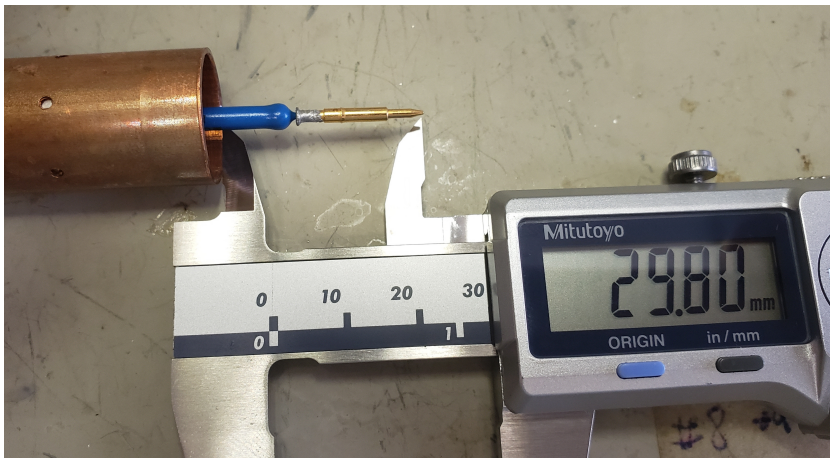

Figure 10: Distance of pin from end of tube measured with calipers. The position of the pin should be ensured using the jig. The rotation of the capacitors must be such that they can be soldered to the tube through the holes in tube, but the exact insertion of the capacitors in the tube isn't important.

2. Solder the capacitors to the tube. Be careful to handle the tube with a hot pad or some other thermal insulator — it will get very hot.

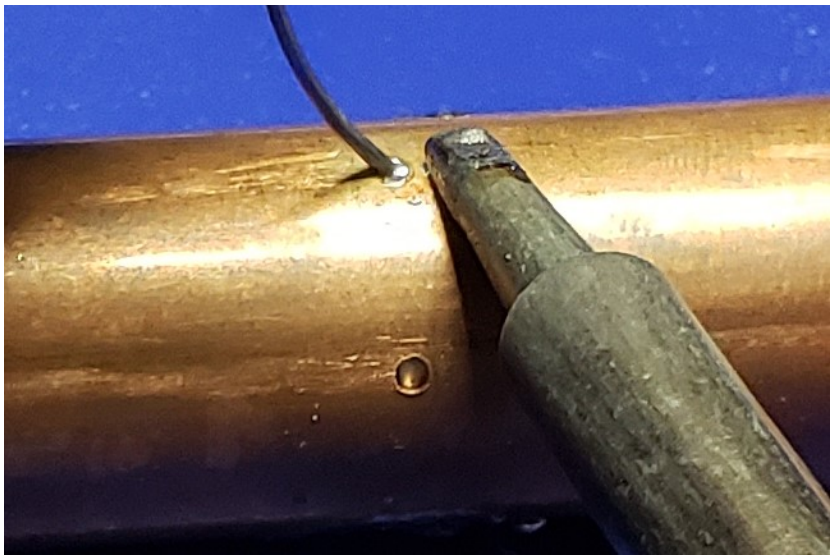

Figure 11: Soldering the capacitors to the tube.

3. *Optional:* Solder M2 nuts to the ventilation and cleaning holes in the tube to allow sealing the filter with an M2 bolt and gasket if it is to be filled with oil.

4. Thoroughly clean the filter and tube assembly with flux remover and IPA.

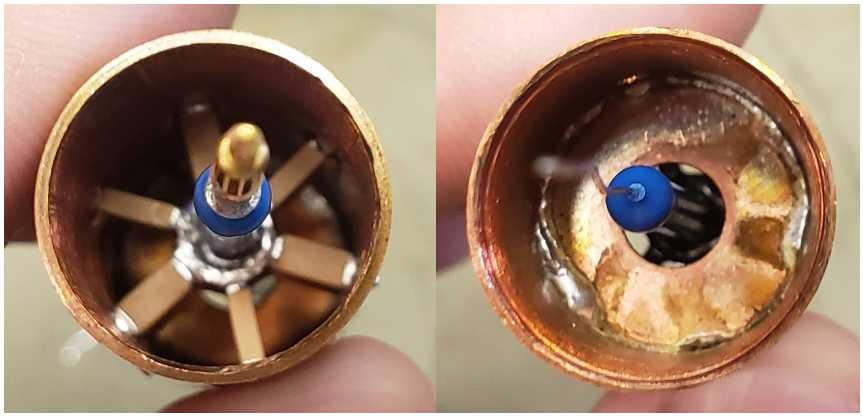

Figure 12: Inner parts of filter assembled in tube.
Left: SHV connector end view. Right: output end view.

4 Assemble the pulser PCB

1. Carefully solder three 470 pF and three 3.3 nF capacitors to the pulser PCB. Arrange the capacitors so they alternate values around the array. The capacitors shouldn't go over the hole in the center of the PCB, but can get arbitrarily close. The capacitors should be kept away from the sides so they just go on the pads, to keep as far from the tube wall as possible to avoid shorts.

Figure 13: Capacitors on pulser PCB. Note that the pads of these capacitors are damaged on one corner. This was caused by soldering down one end and then lifting on the capacitors, which easily broke. This particular filter board will not be used for high voltage.

2. Solder a lead of a 1 MΩ resistor and the pulser line to the PCB. The cable and resistor connections must be 180 degrees apart. It may be easier to feed the end of the cable through the filter end cap first.

3. Clean the PCB with flux remover and IPA.

5 Install the SHV connector

5.1 Install the ground break insulator on the SHV connector

1. File down a bit of the SHV connector to solder the resistor to the connector.

2. Solder one lead of the ground resistor to the connector, be sure there's enough lead remaining that the resistor fits in place around the insulator when installed. The insulator can be rotated to take up slack so err on the side of longer.

3. Slide the insulator section over the SHV connector and fold the resistor over, rotate the insulator as necessary to get the resistor positioned in a recess.

4. Once a good position is determined epoxy the ground break insulator in place.

   (a) Apply epoxy to the entire inner surface of the ground break insulator, this is potentioally an oil boundry.

   (b) Hold the assembly connector side down so epoxy flows into the gaps around the connector and tape around the joint to keep the epoxy from spilling out.

   (c) Keep the assembly held tight as it cures and ensure it is well aligned or the filter will be crooked when fully assembled.

   (d) The SHV connector assembly may be attached to the filter (next step) while the epoxy is still workable to more easily notice and correct any alignment problems.

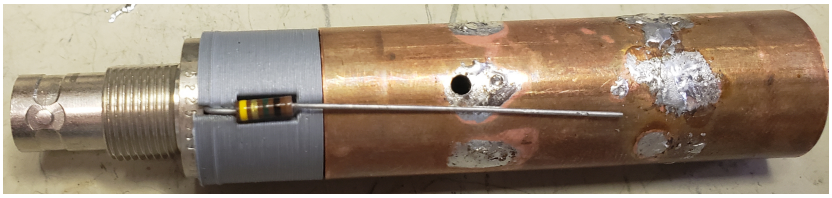

Figure 14: SHV connector, ground resistor, and ground insulator installed on filter.

5.2 Attach the SHV connector assembly to the filter.

1. Apply epoxy to the SHV pin around the joint with the resistor. Make sure no epoxy gets on the contact area of the pin for mating with a socket connector. There is a small barb-like ring around the connector that keeps it from pulling out of the connector, no epoxy should go past that. Keep the pin, resistor, and capacitor assembly oriented pin up, until inserted into the connector, to prevent epoxy from flowing along the pin towards the contact portion.

2. Generously apply epoxy to the ground break insulator. Coat the entire inner surface to add a second sealing layer in case the filter is filled with oil.

3. Insert the ground break insulator with SHV connector into the filter tube. The SHV pin needs to be centered so it slides into the connector and fully inserts into the SHV connector housing.

4. Keep the assembly oriented connector end down while the epoxy cures.

6 Install the pulser board and HV cable

1. Trim the second stage resistor lead so it reaches the middle of the pulser PCB capacitor array when inserted, this should be 3/16 inch from the end of the tube. Tin the lead.

2. Place a layer of Kapton tape in the end of the tube, long enough to insulate the second stage capacitors from the tube when fully inserted against the guard ring. 18 mm should work. There doesn't need to be an overlap in this strip, it prevents shorts between ground potentials, it doesn't stand-off high-voltage.

3. Roll of a piece of Kapton and insert it around the resistor. It should be long enough that it covers the guard ring when pushed against either the first stage capacitor array or the pulser PCB once installed, but doesn't interfere with installing the pulser PCB. 25 mm should be acceptable.

4. Push the end of the LEGEND cable through the pusler end cap and form a hole in the middle of the end of the LEGEND cable for the output resistor lead. Leave a gap between the pulser board and the end cap for heating the LEGEND cable.

5. Center the output resistor in the filter, use another PCB to assist in determining the center if necessary and insert pulser board, end cap, resistor, and cables assembly into the tube. The end of the output resistor should insert into the hole in the end of the LEGEND cable.

6. Solder the LEGEND cable end into the pulser PCB and to the output resistor. A small gap between the PCB and the cable insulation will be required to apply heat. The cable jacket can be slid up along the cable to expose more wire then slid back down after the joint is made.

Figure 15: Pulser board with resistor, pulser line, LEGEND HV cable, and end cap installed. The end cap is not yet slide down into place. Old version of end cap shown where resistor hole is same as cable hole.

7. Gently tug on the assembly to make sure it is connected to the output resistor.
8. Slide the end cap into place.

9. Mix some epoxy and apply it generously through the fill hole in the end cap. It is recommended to degas this epoxy first to remove voids that could later cause discharges as it will be up against the HV cable.

10. Tape around the end of the filter to hold the end cap and PCB in place and keep the filter connector end down while the epoxy cures.

7 Finishing touches

1. Install the BNC connector on the pulse line.

2. Install copper foil around the LEGEND HV cable. Foil can also be used to minimize the gap in the shielding at the ground break insulator and shield around the filter end cap. Kapton tape cover the resistor lead can prevent undesired shorts allowing the shield to be nearly complete.

3. Install shield braid around the LEGEND cable covering the entire length of the cable, including the connector, and extend up around to filter end cap to contact the tube. The braid can be bunched up to go around the filter tube and stretched out to be snug around the LEGEND cable.

4. Solder the ground wire with connector to the LEGEND connector end of the shield braid.

5. Use cable ties to hold the resistor leads, pulser line shield, and LEGEND cable shield tight against the tube. Conductive epoxy can be used to ensure a solid electrical connection, soldering would likely damage the ground break insulator or end cap.