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.

1 Parts:

1.1 Filter components

- SHV bulkhead jack, TE Connectivity AMP Connectors 5225059-3
- BNC bulkhead isolated jack, Amphenol RF 112252
- 3/4 inch OD 0.032 inch wall copper 101 tube
- 6x 3.3 nF 5 kV ceramic capacitors, Vishay Vitramon HV2225Y332KXMATHV
- 6x 0.47 nF 6 kV ceramic capacitors, Vishay Vitramon HV2225Y471KX6ATHV
- 11/16 inch OD 1/4 inch ID copper washer. Hillman 44142
- M4 brass standoff in 6 mm hex, 5-6 mm length
- 2x 100 MΩ 7.5 kV axial lead resistors, Ohmite MOX1125231006FE
- 1 MΩ resistor for ground isolation
- 51 Ω resistor for pulse line ground
- 2x M2 brass nuts
- Pulse PCB
- High voltage cable for the output, FTAPP094-10-48
- Ground break insulator, printed part
- End cap, printed part

1.2 Jigs and other equipment

- M2 bolt to use for attaching nuts to tube fill ports
- Guard ring positioning jig
  - M4 flat head bolt
  - 3x M4
  - 11/16 inch OD washer [1]
  - M4 washer
- Capacitor array jig
  - Capacitor jig, machined from aluminum or stainless steel

[1] A Hillman 44142 copper washer used for the guard ring will work for the jig as well, but a stainless steel washer would be better as it won't become accidentally soldered to the tube by stray solder.

  - 6x 4-40 nylon bolts
  - Capacitor jig removal tool, printed part
- Positioning jigs
  - 2x Resistor positioning jig, printed part
  - Resistor jig stand, printed part.
  - PCB positioning jig, printed part.
  - Short pin positioning jig, printed part.
  - Long pin positioning jig, printed part.
- Tray or other container for cleaning parts in IPA
- Two glass beaker for flux remover, one for filling syringe and one for waste
- Lab coat
- Safety glasses
- Ultrasonic cleaner
- Vacuum degassing chamber

1.3 Consumables

- Isopropyl Alcohol (IPA)
- 413 B heavy duty flux remover
- Acid brush for applying flux remover
- Syringes with 16 gauge blunt tip needles
- Rubber gloves
- Epoxy, Loctite Hysol EA 0151
- ~1/8" wide Polymide tape
- Electrical tape
- Conductive Epoxy, MG Chemicals 8330S (optional)
- Double shielded coaxial cable for pulse line, LMR-100
- Wire braid to shield the output cable
- Heat shrink to cover shield braid. (optional)
- Solder flux

- High temperature solder[2]
- Low temperature solder[3]
- Silicone rubber potting compound, Momentive RTV11 with supplied DBT catalyst or alternative for deep section curing (RTV9811) or slow curing (RTV9910) (optional)

[2]SAC 305 was used for the high temperature solder. SAC 305 melts at 217-220 C solidus-liquidus (not a eutectic alloy). Spreading solder in the plastic stage, where it had a consistency similar to acrylic paint, was found to be helpful in controlling temperature to a local area without melting off other components while distributing solder. This was followed by a reapplication of flux with a flux pen and a brief heating to above full melting temperature to ensure the solder made a good joint. This method was used to ensure a good seal around the M2 nuts on the tube fill ports, where solder had to be spread over a large area without melting the solder joint for the guard ring washer.

[3]60/40 Sn-Pb was used, which melts at 183-190 C and is not a eutectic alloy. 63/37 Sn-Pb, a eutectic alloy which melts completely from solid to liquid at 183 C, would likely work just as well as no spreading of solder around difficult components is necessary.

Assembly

2 Assembly the Tube

2.1 Cut and drill tube

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

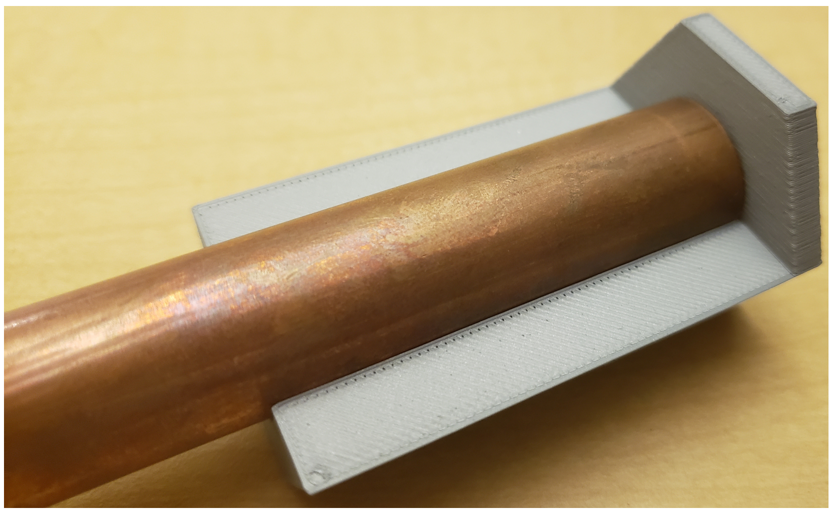

Figure 1: Tube jig used to measure the proper length of tube.

2. Use the jig to drill the smaller, 1/16 inch, holes in the tube. Do not attempt to drill through to drill two holes at once and do not keep using the same jig after the guide holes are worn, just print more jigs. Poorly aligned holes will make later assembly far more difficult and a few seconds spent here will save far more time later.

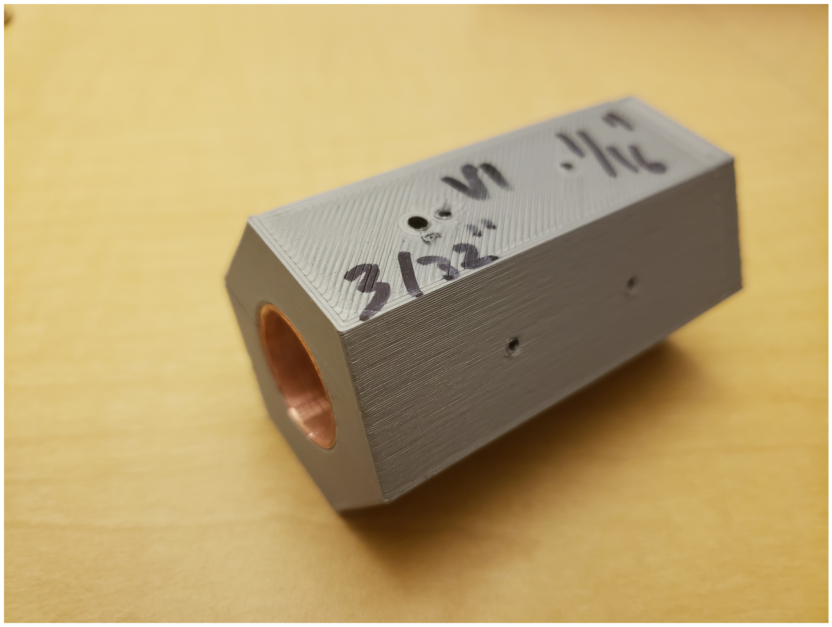

Figure 2: Tube in jig for drilled hole placement.

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 between capacitors more easily and if bolts are used to seal an oil filled filter this keeps the ends of the bolts further from the capacitors.

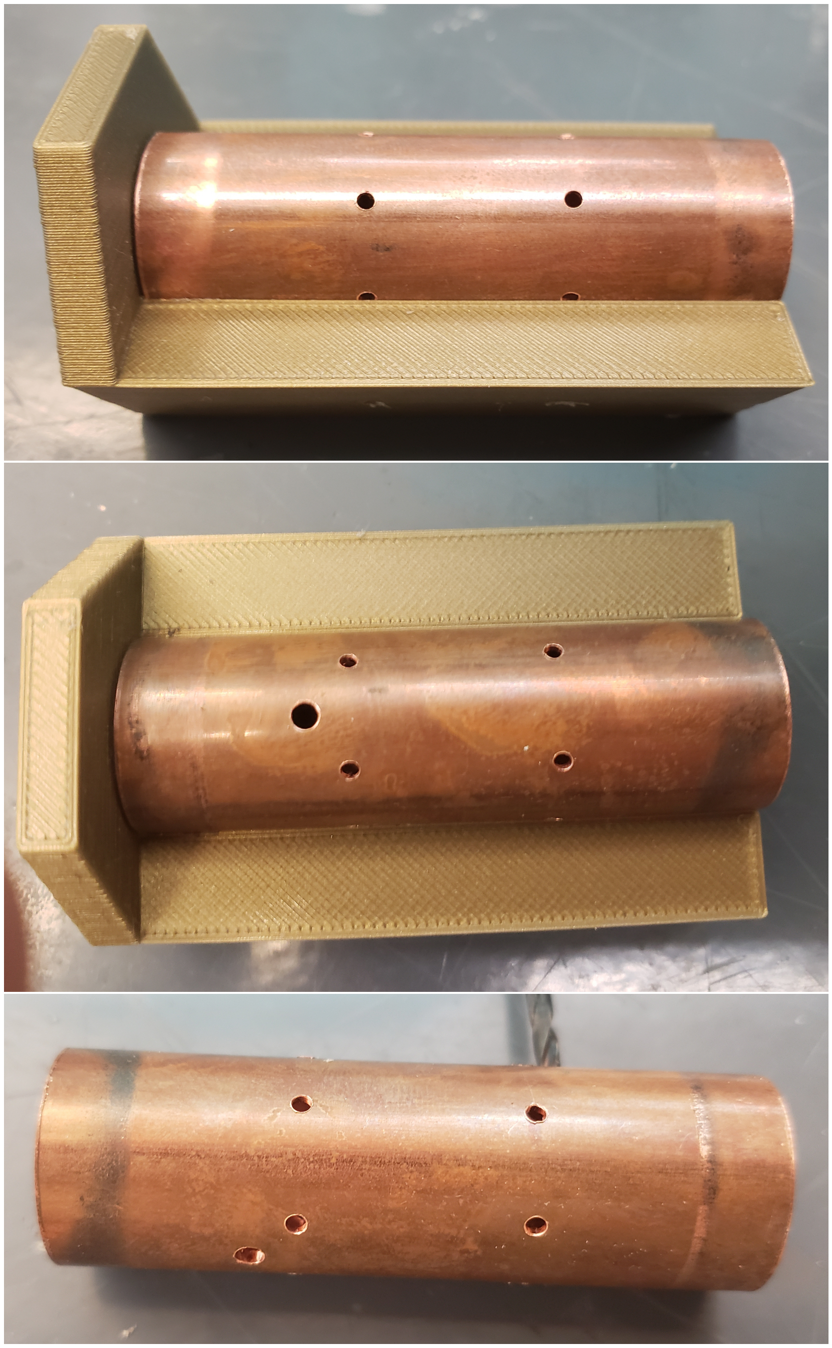

Figure 3: Large hole positions of tube.
Top: Tube rotated in jig to position large holes.
Middle: Large holes drilled, second large hole is under tube on right.
Bottom: Large hole positions, drill bit inserted in hole shows position of large hole hidden from view.

4. Bore out the inside of the tube on a lathe to fit the pulse PCB. It should be bored 1 mm (0.039 inches) 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 or a flap wheel. If there are any burs the capacitors may catch later. Finish with a fine file or sand paper and thoroughly clean.

2.2 Install guard ring washer in tube

Warning: be careful handling the tube after first application of heat. It will remain hot for quite some time.

1. 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.

2. File a notch in the edge of the washer to allow cleaning fluid to flow past the washer along the wall of the tube.

3. 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.

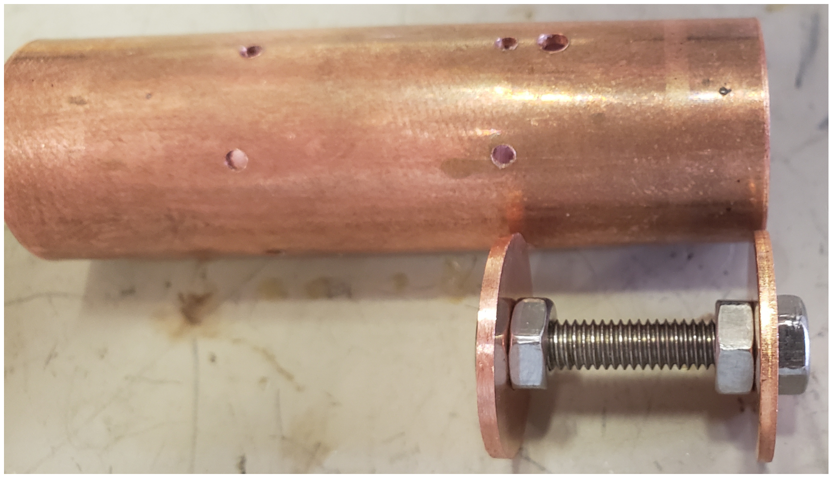

Figure 5: Copper washer and M4 nuts and bolt used as washer position jig.

4. Insert the washer into the tube and rotate the washer so the notch aligns with the large hole in the tube. Solder the washer into the tube using a high temperature solder. 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. When soldering apply heat next to the hole with a bit of solder on the tip to improve heat transfer to the tube. Once the tube is hot enough to solder blob will wet to the tube instead of pool on the tip. At this point solder can be fed into the hole and it will wet to the washer inside the tube. Be careful to keep the washer properly inserted as once the tube it heated it will easily melt all the solder joints, not just the one being worked on.

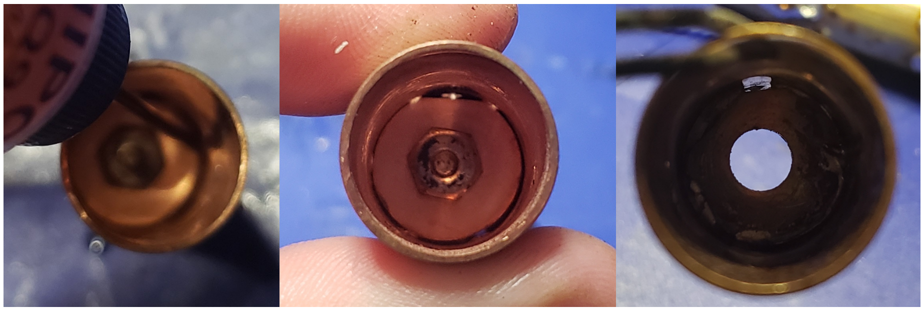

Figure 6: Left: Applying flux to washer inside tube.
Center: position of washer with notch towards fill port.
Right: gap after soldering washer. This particular washer was soldered with the gap down and too much solder for the final joints and excess solder flowed down and filled in the gap. It had to be reworked to remove excess solder and open the gap.

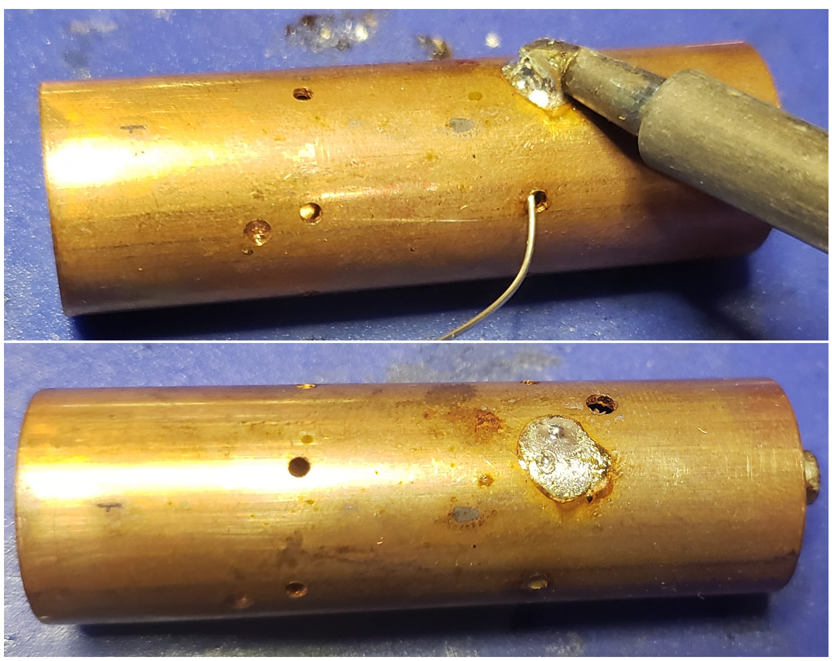

Figure 7: Top: solder being fed into a hole while the tube is heated from an adjacent hole.
Bottom: after heat removed and tube cooled the lower hole is plugged with solder.

5. Put a brass M2 nut on a stainless steel bolt and use it to solder a brass

M2 nut to the fill port. Brass can be difficult to solder to, be sure to use aggressive flux. Do this for both fill ports and use high temperature solder. See 2.

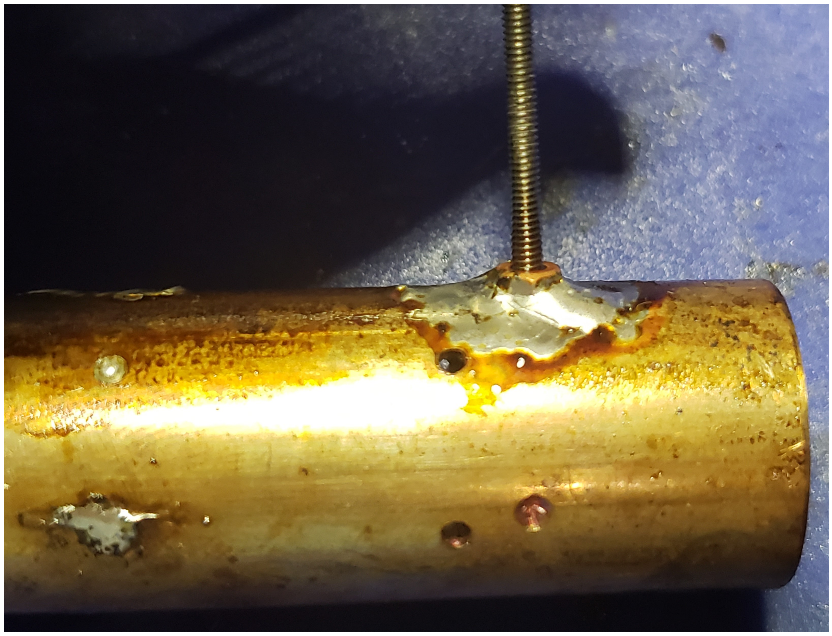

Figure 8: Brass nut soldered to tube using stainless steel bolt as aid.

6. Thoroughly remove all solder flux with heavy duty flux remover and an acid brush.

3 Assemble the filter internals

3.1 Assembly the first stage capacitor array

Warning: the ceramic capacitors are very brittle and will not hold high voltage if cracked or chipped. Be very careful handling the capacitors and do not attempt to use any capacitors that are cracked or chipped.

1. Place Kapton take on the sides of capacitors to protect them from the aluminum capacitor jig.

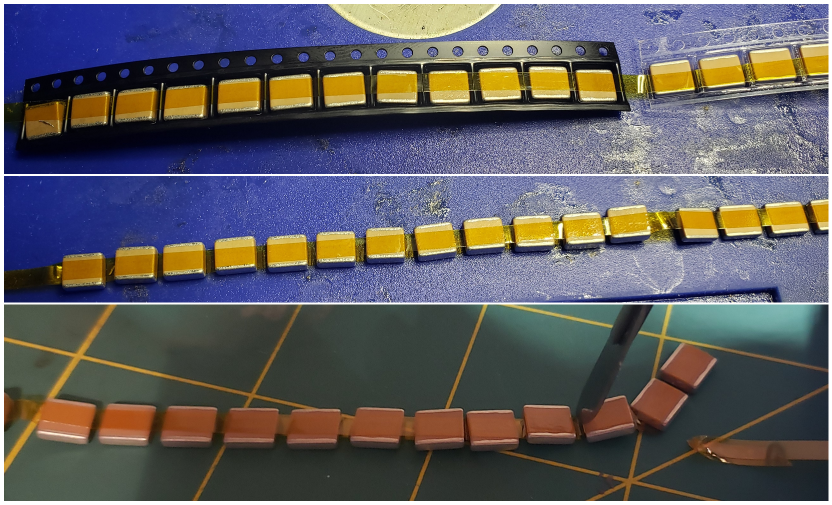

Figure 9: Top: Taping capacitors while still in strip.
Middle: Taping second side of capacitors once removed from strip.
Bottom: *Carefully* separating capacitors with scalpel.

2. Place three 3.3 nF and 3 470 pF capacitors and M4 standoff in the jig. Ensure there are no jagged edges on the standoff before installing, inspect under a microscope. 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. Gently tighten the bolts to press the capacitors firmly against the standoff.

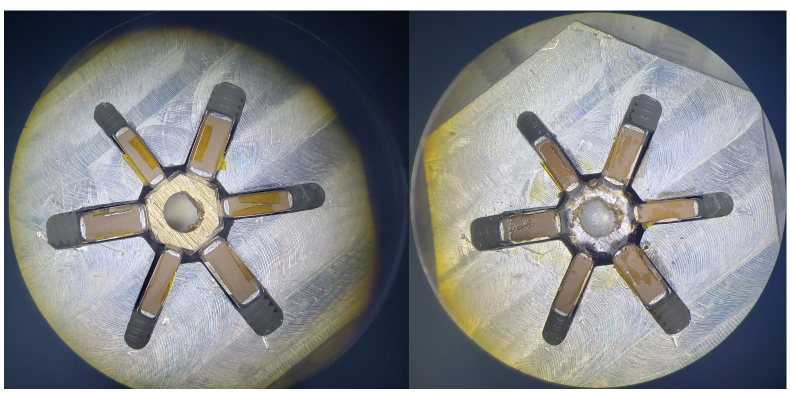

Figure 10: Capacitors in jig around an M4 standoff. Left: before soldering. Right: after soldering. Note that some of the capacitors are not well centered in their slots. This capacitor array was difficult to remove.

3. Press the capacitors and standoff down on a flat surface to get one side of

the capacitors flush with the standoff. Press on the jig so the capacitors stick out of both sides slightly.

4. Center the capacitors in their slots such that they aren't touching the sides of the jig on either side, this will allow them to be easily removed after soldering.
5. Solder the capacitors to the standoff.
   (a) Recommend starting on the side flush.
   (b) Apply some liquid flux so it flows across the face of the standoff and down the sides.
   (c) Heat the nut and apply solder to all the capacitor to standoff joints, allowing solder to flow down the sides of the standoff.
   (d) Flip the jig over and if done properly enough solder will have flowed along the capacitor to standoff joint that the joint is already soldered on the other end as well.

3.2 Install SHV pin on resistor

This can be done before or after attaching the resistors to the capacitor array. Doing it before is recommended.

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.

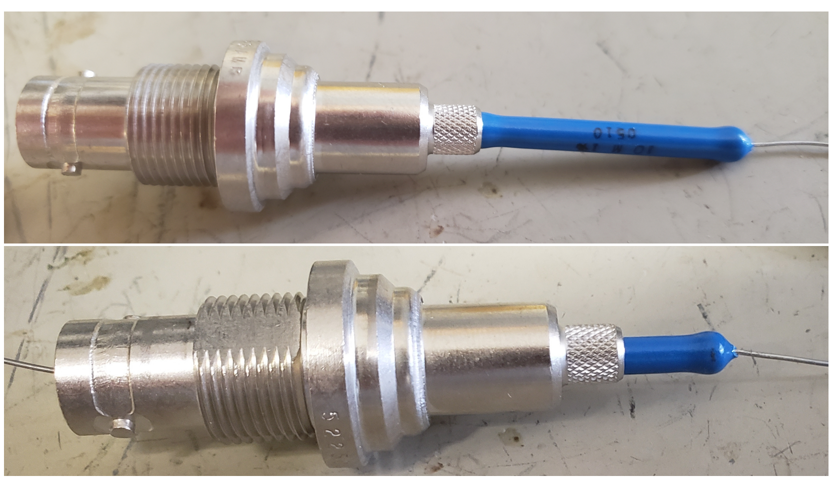

Figure 11: Resistor fit test.
Top: Resistor doesn't fit into connector.
Bottom: Resistor slides into connector.

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

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

4. 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.

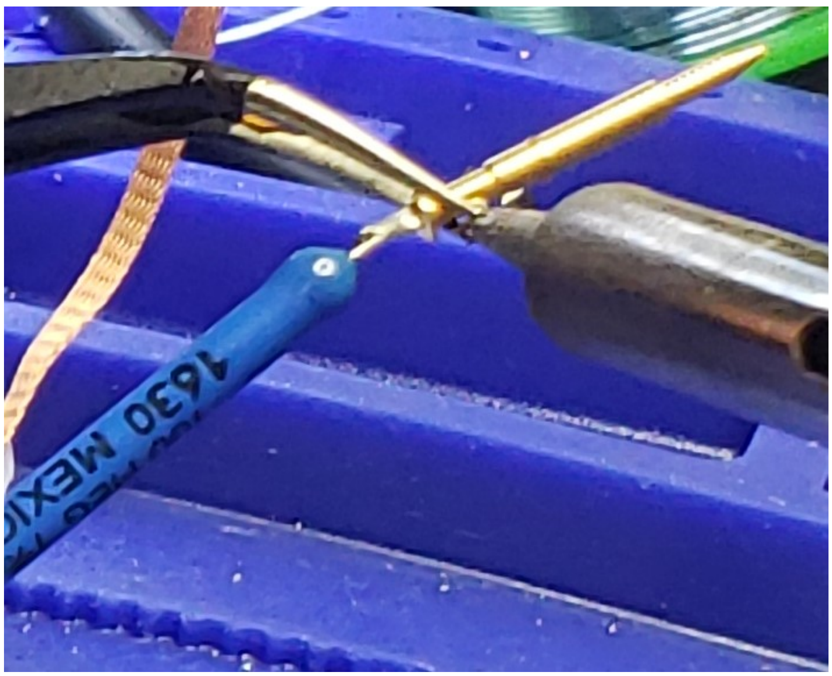

Figure 12: Soldering pin to input resistor.

3.3 Attach resistors to capacitor array

Warning: Be careful handling the capacitor array after the first application of heat, it will remain hot for quite some time. Be carefully handling the assembled capacitors and resistors, too much stress on the resistors can easily break the leads once attached with a zero length solder joint.

1. Trim the lead on the resistors that will connect to the capacitor array down to $\sim$ 6 mm. Bend a loop into the trimmed lead so it easily holds a solder ball. Make sure the resistor that will be used for the SHV connector end can fit in the connector. See figure 11.

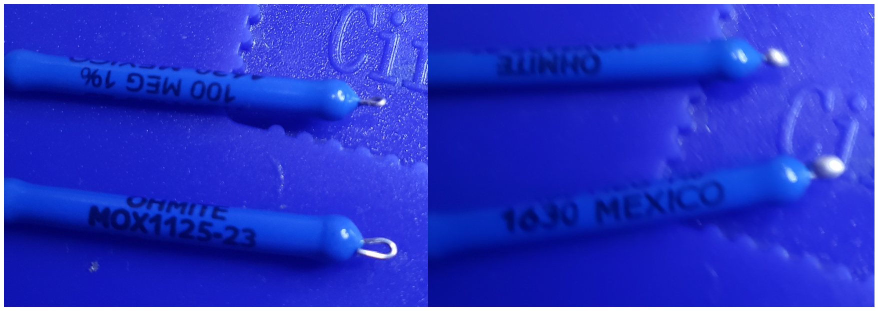

Figure 13: Left: loop on resistor lead to easily hold a ball of solder.
Right: solder ball on resistor ends prepared for installing on capacitor array.

2. *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. Do not do this if intending to pot the filter as it will restrict flow and lead to air gaps that can cause discharges. Experience has shown wasn't necessary in prototype testing, but the corner of the SHV connector is a field concentration concern.

3. Solder one resistor to the capacitor array, gently push the resistor down so it is almost flush with the standoff in the center of the array, leaving a little bit of room so it can be tilted. Put the flush end up towards the input resistor. Use the resistor jig to ensure it can be centered. It is possible to solder the resistor to the capacitors array while installed in the jig, just more difficult and if the resistor is installed carefully it should be well enough centered without the jig. Bend the other lead into a spring, this keep the resistor pushed against the standoff when the jig is inverted. If the input resistor already has a pin installed then the output resistor must be done first so the spring can be formed.

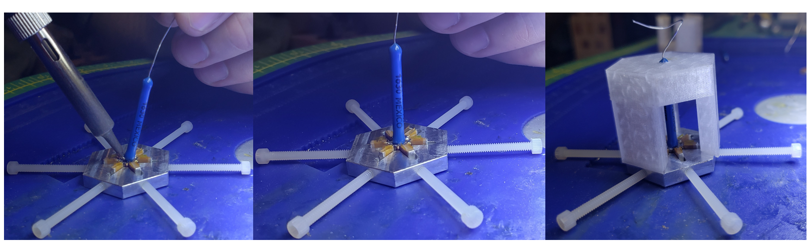

Figure 14: Installing input resistor on capacitor array.

4. Turn the jig over and place it on the resistor jig stand. Solder the second resistor to the capacitor array and check that it is centered afterwards

with the jig. There are two jig versions, one with a 4.0 mm hole and one with a 4.4 mm hole. The 4.4 mm hole may be required depending on the epoxy coating shape on the resistor.

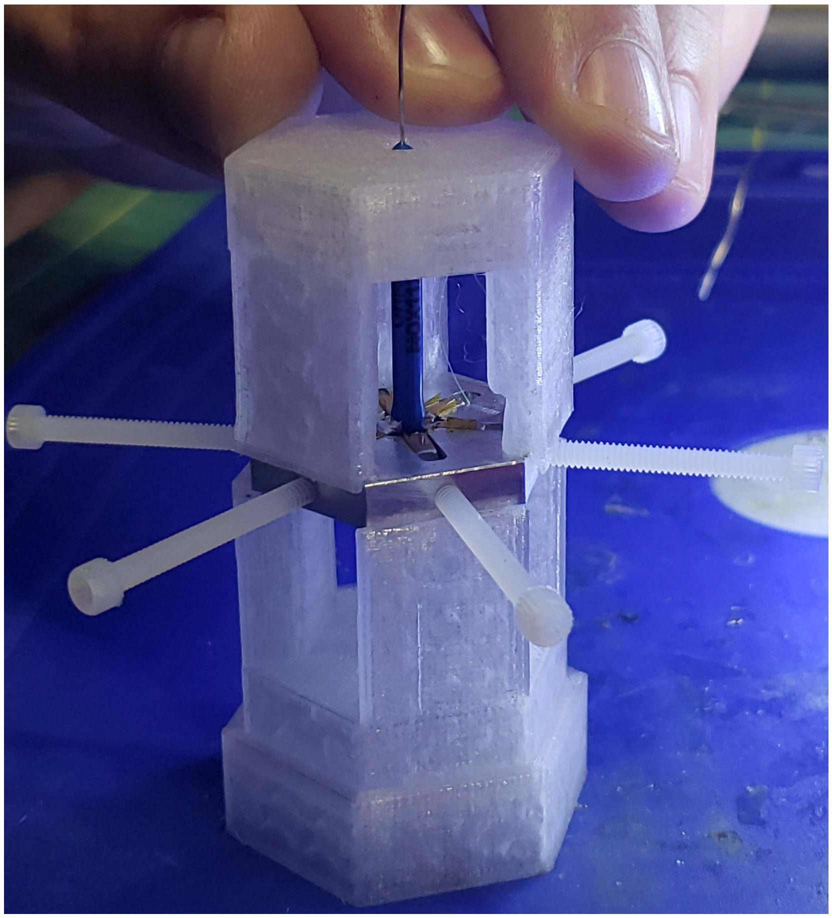

Figure 15: Checking the alignment of the second resistor with the resistor jig. The entire resistor jig assembly with two resistor jigs and a resistor jig stand is shown.

5. Loosen the nylon bolts. If the capacitor array doesn't easily come out of the jig do not attempt to apply significant force with the resistors or they will break. Use the capacitor array removal tool to gently push the capacitor array out of the aluminum jig. The jig has narrow and wide portions to match the narrow and wide resistors. Push from the side flush with the capacitors so if the capacitors are crooked they are assured to fit through the jig. Use both resistor jigs to get enough height to remove the resistors without hitting the table.

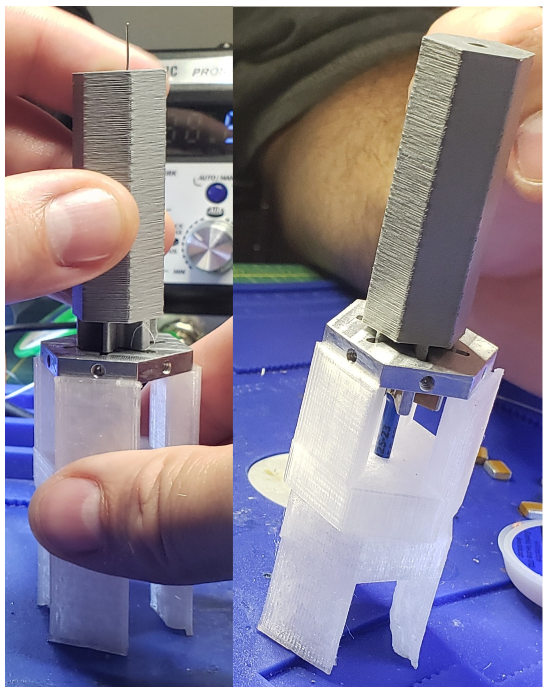

Figure 16: Removing capacitor array from jig using removal tool. Both resistor jigs were used to hold the assembly above the work table.

6. Remove the nylon bolts clean the jig and bolts with heavy duty flux remover and IPA to remove solder flux. The bolts will start to stick in the jig if it is not cleaned after every use.

7. Remove the Kapton tape from the filter internals and thoroughly clean all solder flux with heavy duty flux remover and an acid brush.

8. Inspect for any signs of damage under a microscope.

4 Assemble the pulse PCB

1. Carefully solder three 470 pF and three 3.3 nF capacitors to the pulse 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. Use a high temperature solder so the joints don't melt when additional components are attached to the PCB later. Recommend doing one capacitors at a time and soldering outside pad to position capacitor then solder inside pad. Do all three large capacitors first so smaller capacitors are added when space is limited. Add fresh flux and clean up solder joints after all capacitors are placed.

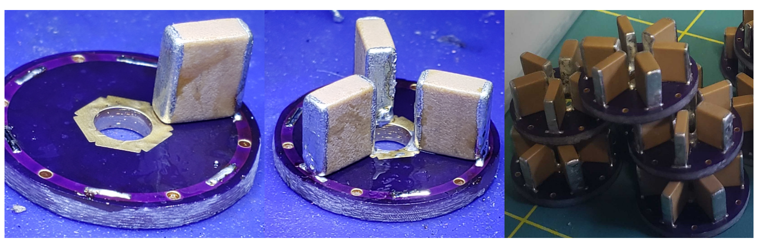

Figure 17: Capacitors soldered to pulse PCBs.

2. Clean off most of the solder flux with heavy duty flux remover but don't worry about removing it thoroughly. The PCB will need to be cleaned multiple times after this step but it is easier to remove most of the flux at this step while it is easier to handle. Pay particular attention to solder flux stuck under the capacitors, it will be much easier to clean under capacitors at this step and further steps won't apply flux directly to the area under capacitors.

3. Cut an 20 cm section of pulse line. Trim the cable down to the center conductor for ~2 mm on both ends, one end attached to the PCB the other is going to be used for continuity checks. Trim back the jacket and braid ~ 2 mm more. Trim off ~35 mm of jacket leaving either a bit of

jacket at the end to hold the braid together or place a bit of heat shrink on the cable.

Figure 18: Trimmed cable with section of jacket removed from middle to expose shield, but portion left at end to keep shield braid in place. Markings are in inches.

4. Trim down and solder a lead of a 51 Ω resistor to the pulse PCB. Solder the pulse line to a hole on the opposite end of the PCB.
5. Feed the HV cable pigtail through the 3D printed end cap. Do not forget this as it can't be installed once the cable is soldered to the PCB.

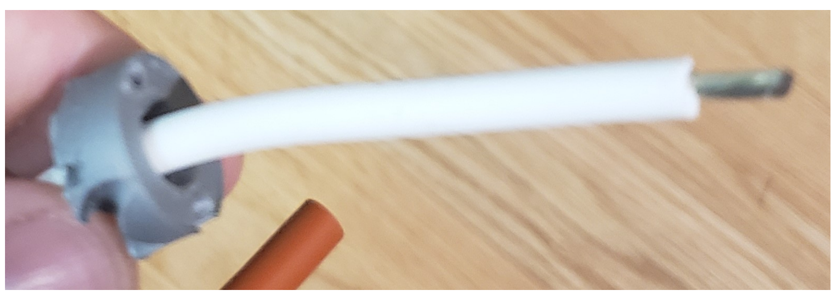

Figure 19: HV cable fed through end cap prior to attaching cable to PCB.

6. Trim the HV cable end so the conductor goes through the hole in the PCB but not too far up along the capacitors, there needs to be room to the resistor lead later. Feed the cable through the hole and spread the conductor strands out so they will solder bridge to the capacitors. Solder the HV cable to the pulse PCB with high temperature solder.

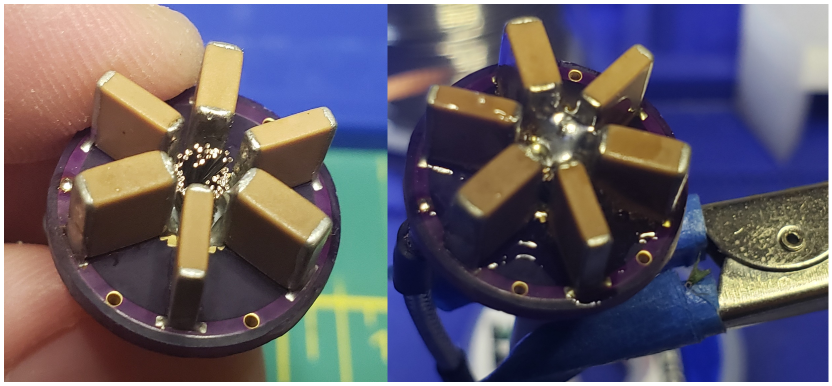

Figure 20: Soldering HV cable to PCB.

7. Clean off the solder flux again. The PCB will have to be cleaned again later, but it will be far more difficult as it will then be attached to the filter internal inside the tube and sticking only 1 cm out the end of the tube.

5 Install the ground on the SHV connector

1. File off a portion of the SHV connector body to reveal the brass underneath, this will make it much easier to solder to. Apply an aggressive flux to the revealed brass, it is still difficult to solder to brass.

2. Solder the end a 1 MΩ resistor to the SHV connector body. This needs to be positioned so that it can go through a hole in the ground isolation electric break and fit in a recess for the resistor. If the lead is too long it can be wrapped further around the SHV connector to take up slack, but if it's too short it needs to be removed and redone.

3. Remove the solder flux with heavy duty flux remover and a brush.

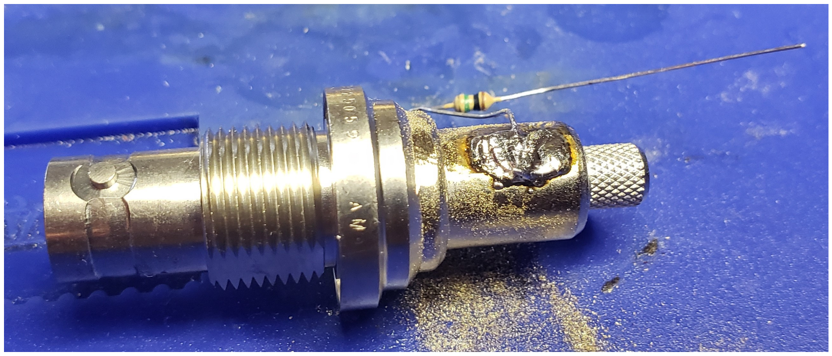

Figure 21: Soldering ground isolation resistor to SHV connector body. Note the nickel and brass residue from filing off some of the nickel plating to expose the brass connector body.

4. Allow the connector to cool then install the electric break on the SHV connector. Rotate so the resistor goes through one of the notches in the connector side and is fully contained in one of the recesses. Ensure the electric break is fully installed on the connector.

6 Install the filter in the the tube

1. Test insert the filter internals into the tube. They should have a small gap to the sides to ensure a good solder connection can be made, but slide in easily. If the capacitors stick on any obstructions remove the obstructions with a file or sand paper and clean the tube to remove resulting dust. **The capacitors are very brittle, do not attempt to force them past an obstruction.**

2. Use the short connector jig to position the pin 19.8 mm from the SHV connector end of the tube. The pin should protrude 1 mm from the end of the jig. This positions the pin 10 mm away from its final position and allows making a solder connection for the pulse PCB to the output resistor.

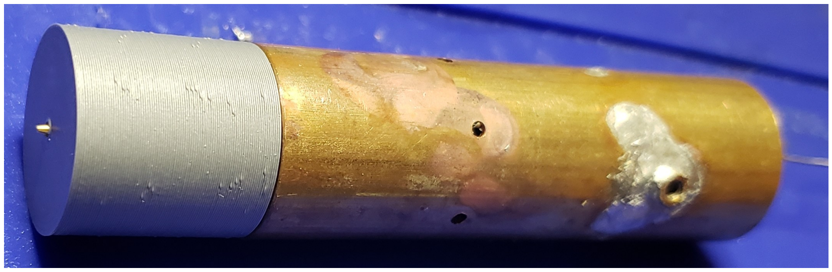

Figure 22: Short pin position jig installed on tube with pin sticking 1 mm through hole in jig.

3. Install the pulse PCB in the PCB assembly jig and attach to HV pigtail end of filter. The jig positions the PCB about 9 mm from the end of the tube which should allow it to insert 1 mm into the recess on the end of the tube later.

4. Check the position of the resistor for making the solder connection, then remove the jig and make a loop and add a solder ball to the end of the resistor. Position the loop so it can be soldered to the solder blob between the capacitors on the pulse PCB, which should be about in the middle of the capacitors.

5. *Optional:* Add a layer of Kapton film around the output resistor as added protection against discharges to the guard ring. Experience has shown this wasn't necessary in prototype testing but the edge of the guard ring is a field concentration concern.

6. Reassemble the jigs and solder the output resistor to the pulse PCB. Use a lower temperature solder to avoid melting the solder joints of the capacitors on the PCB.

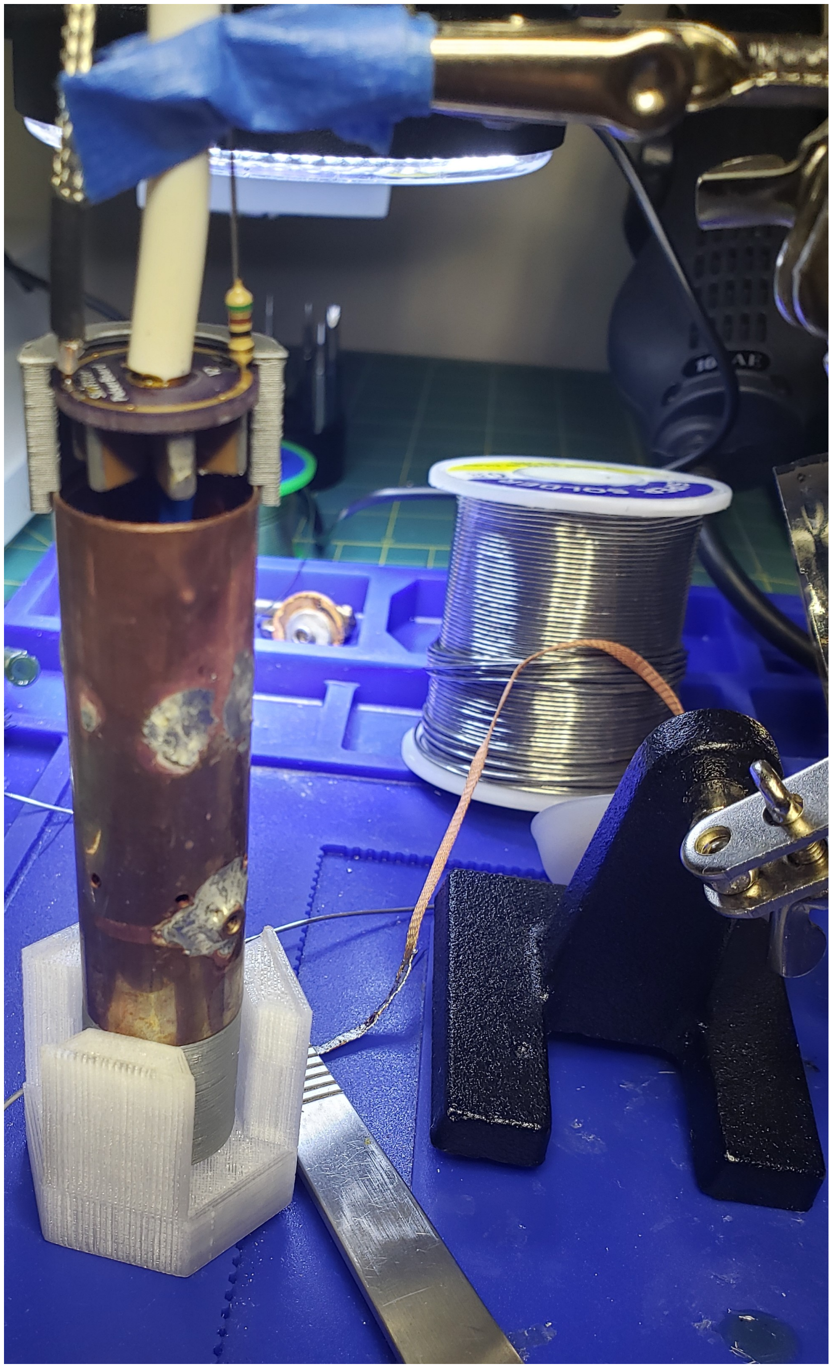

Figure 23: Soldering the output resistor to the pulse PCB.

7. Thoroughly clean the pulse PCB and connecting components with heavy duty flux remover. This is the last cleaning before the filter is assembled and no more solder is going to be used after this step. **The most common problem with these filters has been discharges attributed to residue left on the surface of the pulse PCB and coupling coupling capacitors, be thorough.**

8. *Recommended*: Add a strip of Kapton tape around the capacitors to avoid shorting the capacitors to the side of the tube later. While not strictly necessary if the capacitors and PCB are well positioned this will ensure no shorts are created by poor alignment. A short that occurs from a shift while epoxy cures would be difficult to fix and remove the ability to pulse through the filter.

9. 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. Use the longer pin jig to position the tip of the pin 29.8 mm from the end of the tube. The pin should protrude 1 mm through the hole in the jig. Tape the pulse PCB in place to ensure the capacitors stay put as they are soldered to the tube. Kapton tape will be easier to remove later. Vinyl electrical tape may be stretched to secure the PCB in position better, but will melt when heated and leave a difficult to remove residue. Do not try to install the end cap at this time, it will melt when soldering the capacitors in place.

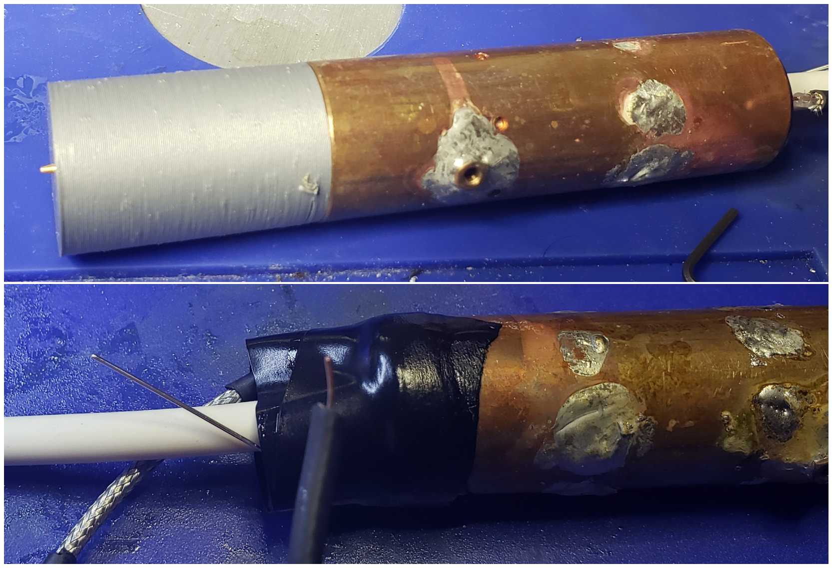

Figure 24: Top: the position of the pin should be ensured using the jig. The rotation of the capacitors must be such that they can be soldered to the tube through the holes in tube, but the exact insertion of the capacitors in the tube isn't important and may vary slightly depending on the length of the capacitor array standoff and solder joints for the resistors.
Bottom: PCB taped in place to mitigate shifting of capacitor array.

10. Check continuity on the pulse line and ground resistor, it will be difficult to correct problems once the capacitors are soldered to the middle of the tube. The center conductor of the pulse line should measure 51 ohms to the resistor lead and there should be an open between the pulse line or resistor to the tube wall. In the highly probable event of a short to the tube put a piece of Kapton tape around the resistors to separate them from the tube wall. There's no harm in adding the Kapton anyway, just in case.

11. Remove the jig and 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. Use low temperature solder to avoid melting other solder joints on the tube or the capacitors to the standoff at the center of the capacitor array. Be careful not to shift the tube around while hot enough to melt solder to avoid moving the capacitors. Soldering capacitors on opposite sides first can help mitigate the likelihood of inadvertently shifting the capacitors.

7 Clean

To ensure that all the flux is removed and does not contribute to the discharges, it is recommended to clean the solder components, especially the pulse board, with heavy duty flux remover. The compound used was 413B-liquid heavy duty flux remover. The liquid is highly flammable. Gloves and glasses must be worn at all time while handling the liquid, and care must be taken to not breathe in the fumes. Use only a small amount of liquid at times. The flux remover contains acetone and ethyl acetate, which can dissolve both PLA and PETG, thus one should try to not let the liquid touch the 3D printed end-caps and ground break insulator if cleaning with these parts installed. Incidental exposure will not rapidly damage the plastic if it is cleaned up quickly. Cleaning is easiest to perform before installing the connector and end cap, but the filter can also be cleaned after full assembly using only the fill ports. This will make it more difficult to drain solvents, but is otherwise similar.

1. Check the syringe needle will fit through the M2 nut on the fill port. A 16 gauge needle should barely fit.
2. Pour a small amount of 413 B flux remover into the beaker.
3. Draw flux remover into the syringe.
4. While holding the filter with the pulse board on the bottom, put some flux remover into the filter using the small port holes. 2 mL of liquid will fill the filter to about the mid way between the top of the puler board capacitors and the fill port.
5. Swirl for a few seconds then drain the flux remover into a waste beaker.
6. Repeat until all flux is removed as indicated by drained flux remover running clear.
7. Wipe down liquid around the filter
8. Leave the waste liquid to evaporate in a well ventilated area, ideally under a fume hood or outside.
9. Clean the entire filter thoroughly by complete submersion in IPA.
10. Use an empty syringe to purge the filter several times with air. This will help dry out remaining liquid.
11. Let the filter dry overnight before applying high voltage, potting, or sealing with epoxy.

Figure 25: Filter taking an IPA bath before final assembly.

8 Install the end cap

1. Remove the electrical tape around the PCB and slide the end cap down on the PCB. Feed the resistor and pulse line through, folding the resistor over in its groove and the pulse line through its groove.

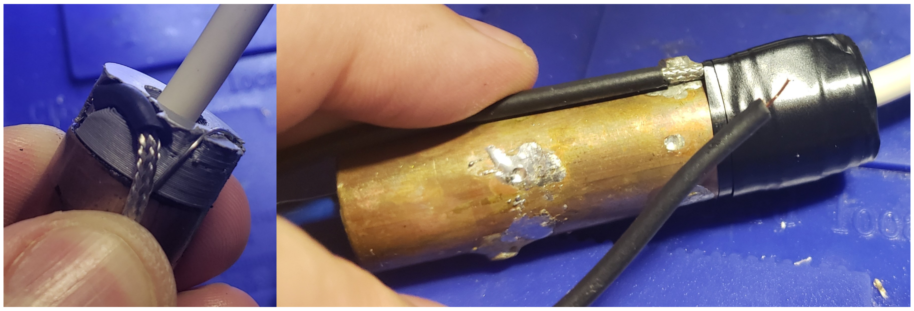

Figure 26: Left: end cap slid into position with resistor and pulse line fed through grooves.
Right: end cap taped in position, covering ground resistor and hold resistor lead and pulse line shield against tube.

2. *Optional*: Apply conductive epoxy to the pulse line shield and ground resistor to ensure good electrical connection to the tube. Do not attempt to solder these to the tube, the plastic end cap will melt.

3. Tape the end cap to the tube. Ensure the pulse line shield and ground resistor lead make good contact with the tube before applying tape.

9 Inspect

This is the last chance to make sure there are no problems before applying epoxy. Disassembly for repair will be difficult after application of epoxy.

1. Look in the end of the tube to ensure the capacitor solder joints to the tube are good.

2. Test the electrical connections.

   (a) Between pulse line center conductor and tube should be 51 ohms. This ensures the connection between pulse line to pulse PCB, pulse PCB to 51 ohm resistor, and resistor to tube.

   (b) Check the pulse line shield is shorted to the tube.

   (c) Check capacitance between output and tube is about 11.3 nF. To connect to the output do not force a multimeter probe into the connector or it may rip. Use a short piece of metal like a hex wrench.

   (d) Check capacitance between the standoff in the middle of the capacitor array and tube is about 11.3 nF. If the electrical connections are clearly good on visual inspection this isn't necessary.

   (e) Check resistance between SHV pin and output is 200 MΩ, many multimeters can't go up to this high a resistance.

10 Attach the SHV connector assembly to the filter

1. Check pin insertion depth.

   (a) Check the pin protrusion from the end of the tube. The ground break insulator is designed for a 29.8 mm protrusion to fully insert the pin in the connector and the pin positioning jig should result in the pin being close to this value.

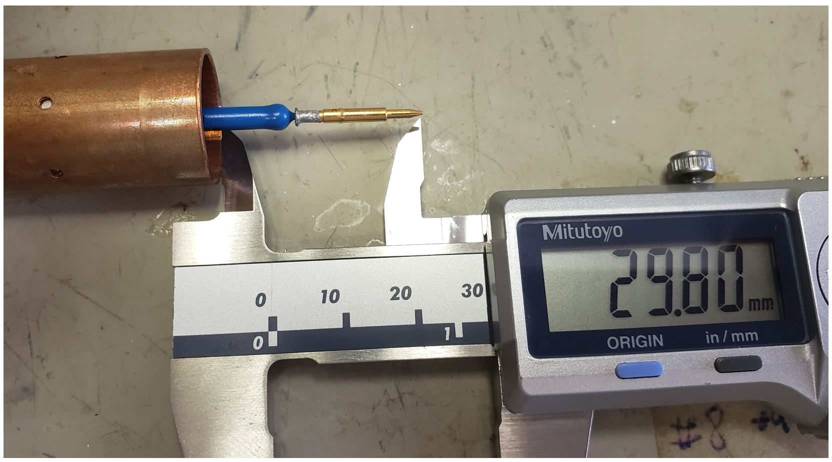

Figure 27: Nominal distance of pin from end of tube measured with calipers.

   (b) Place the connector with ground insulator on the end of another piece of tube and check to distance from the end of the tube to the end of the connector.

   (c) MIL-STD-348B specifies the allowable pin position. Measure the depth of the dielectric in the connector and use the measurements of the pin and end of connector from the end of the tube to determine if the pin will fall in the acceptable range. Pin depth in dielectric = connector end distance from tube - pin distance from tube - depth of dielectric from connector end, which must be between 4.78 mm and 5.28 mm (S in figure 28). If the pin position falls outside this range print a ground isolation electric break with a different length to adjust the pin position.

2. Apply epoxy.

   (a) 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

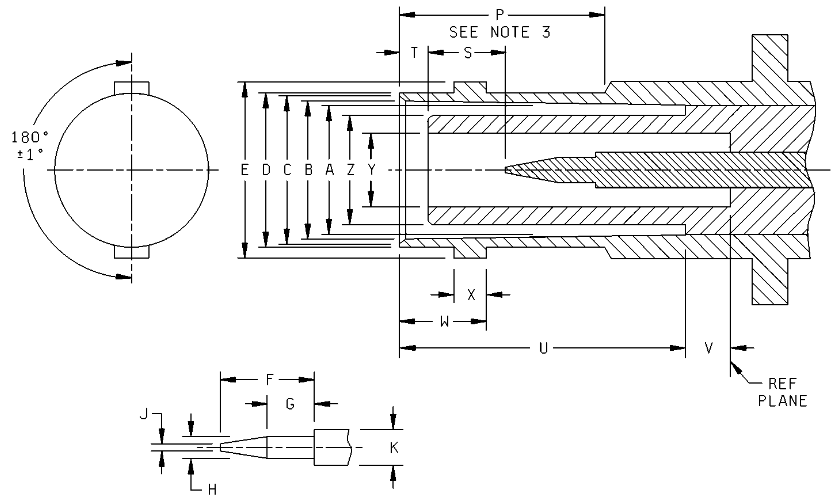

Figure 28: MIL-STD-348B_CHG-3 page 89. S = 4.78-5.28 mm, T = 1.55-1.98 mm.

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. *If the filter will be filled completely with silicone rubber or never filled with oil this step (but not the next step) may be skipped. This is only to ensure the filter won't leak if filled with oil.*

(b) Generously apply epoxy to the area between ground break insulator and connector. Coat the entire inner surface to add a second sealing layer in case the filter is filled with oil. Also apply epoxy to the top of the electric break where it will insert into the tube. This epoxy is not going to be exposed to high voltage and doesn't need to be free of bubbles.

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. If the pin stops before the ground break insulator is fully inserted in the tube do not force it further and risk breaking the filter. There should be little enough gap that the insulator inserts part way in the tube and it can be kept aligned with tape until the epoxy cures or the filter is filled with silicone rubber.

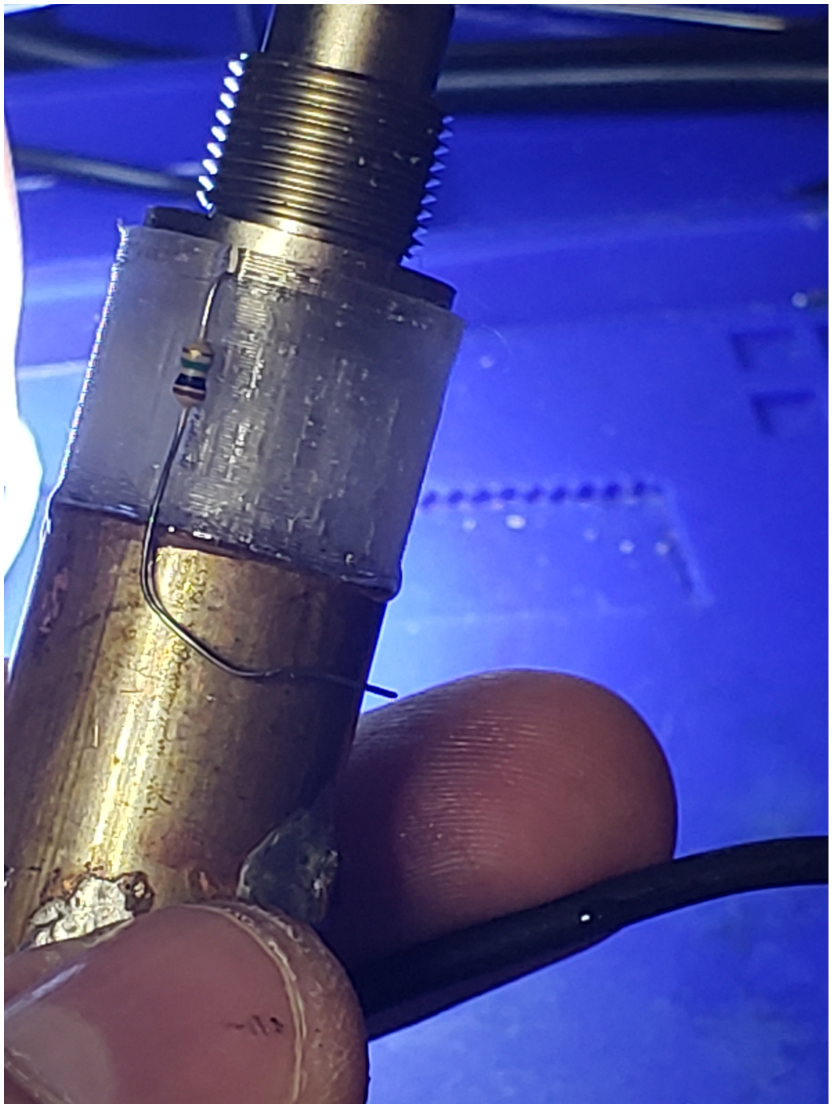

Figure 29: Epoxied SHV connector and ground isolation electric break installed on tube. Note the resistor lead is bent to wrap around the tube, this is to ensure good electrical contact when the joint is taped over with electrical tape.

4. Check the series resistance again from SHV pin to filter output, it should be 200 MΩ. This checks if something was broken when the connector was installed and gives a chance to take it apart before the epoxy cures.
5. *Optional:* Use conductive epoxy to ensure good electrical connection between ground isolation resistor and tube. Do not attempt to solder this connection, the printed parts will melt.

6. Tape over the joint with electrical tape and keep the assembly oriented connector end down while the epoxy cures or until the filter is filled with silicone rubber. Make sure the ground isolation resistor makes good contact with the tube when taping it down.

11 Potting

Potting shouldn't be necessary, but many filters have had discharge problems when filled with air mostly due to soldering residue on the pulse coupling capacitors. The solution that has proven most effective is to fill the filter with silicone oil, however oil is not allowed at LNGS so filling with silicone rubber can be done instead. If silicone rubber will be used with a pulser PCB that has slots in it then epoxying the endcap to the filter can be skipped as the silicone rubber and tape will hold the filter together. This will also allow air to escape as the filter is filled with silicone, thus epoxying the end cap to the filter is not recommended if the filter will be filled with silicone rubber.

11.1 Potting the endcap with epoxy

If not filling the filter entirely with silicone rubber the endcap should be epoxied. If the pulse PCB has slots significant epoxy will flow through the slots before it cures, if there are no slots there will be insignificant loss of epoxy through the vias and gap between the pulse PCB and filter tube. If the filter will be filled completely with silicone rubber and the pulse PCB is slotted then it is recommended to only epoxy the edge of the pulse PCB to the tube and endcap so the filter is held firmly together by a strong and rigid epoxy bond while leaving the slots and hole in the endcap open for air to escape while filling with potting compound.

11.1.1 Complete potting

1. Pot the HV pigtail connection to the pulse PCB by filling the end cap with degassed epoxy through the end cap fill port. Keep the filter oriented with the SHV connector end down while the epoxy cures if using a PCB without slots or seal the fill port and keep the filter oriented connector end up so the epoxy doesn't drip into the filter instead of curing in the endcap. This will also seal the tube so it can be filled with oil if desired.

Figure 30: Fill port for potting HV pigtail connection. Fill port is the small hole next to the cable.

11.1.2 Structural epoxy only

1. Generously apply epoxy to the outside edge of the pulse PCB. There needs to be enough epoxy to firmly attach the pulse PCB, tube, and endcap together and so long as the epoxy doesn't seal the slots in the pulse PCB it won't interfere with air escape later.

2. Tape around the epoxied area to hold the filter together while the epoxy cures.

3. Keep the fitler oriented SHV connector end down while the epoxy cures. If some epoxy drips into the filter as it cures it should end up on the inner wall of the tube and not be a problem, if it drops into the endcap and seals the hole air can't escape later during potting.

11.2 Filling with silicone oil

1. Use an oring or cut a gasket for two M2 bolts.
2. Seal one fill port with an M2 bolt and gasket.
3. Fill the filter completely with oil, covering the fill port and tilting it to ensure oil flows into voids then adding more oil.
4. Seal the second fill port with an M2 bolt and gasket.

11.3 Filling with silicone rubber

11.3.1 Partial fill

The most common discharge problem occurs at the pulse coupling capacitors as these are most difficult to clean. Potting only the pulse coupling capacitors is usually effective and can be done after the fitler is epoxied together without risk of adding problematic air voids. This procedure is based on the deaeration procedure specified in the RTV11 technical data sheet.

1. Place a filter that has been epoxied together in a jig so it stands connector end up.
2. Mix RTV11 with the minimum amount of catalyst to maximize the working time for degassing and minimizing voids. For the DBT catalyst included with the RTV11 0.1% catalyst was used by adding one drop to 20 grams of RTV11.
3. Use a syringe and 16 gauge needle to inject 2 mL of potting compound through the fill port by the pulse PCB end of the filter. This will fill the filter to about half way between the fill port and the top of the pulse coupling capacitors.
4. Place the filter on jig in a vacuum degassing chamber along with any remaining mixed potting compound in a separate open container so any frothing that occurs can be observed in the remaining potting compound.
5. Draw a vacuum of 33 mBar to degass the potting compound, leaving the compound under vacuum for at least 2 minutes after frothing ceases.

11.3.2 Complete fill

A complete fill is best performed on a filter where the endcap and pulse PCB are attached to the filter with epoxy only around the edge of a slotted pulse PCB, this allows air to easily escape while potting.

1. Place a filter that has been epoxied together in a jig so it stands connector end down.

2. Mix RTV11 with the minimum amount of catalyst to maximize the working time for degassing and minimizing voids. For the DBT catalyst included with the RTV11 0.1% catalyst was used by adding one drop to 20 grams of RTV11.

3. Use a syringe and 16 gauge needle to inject 3.5 mL of potting compound through the fill port by the SHV connector end of the filter. Do not draw more potting compund into the syringe than necessary as it needs to be left in the mixing container to be degassed.

4. Place the filter on jig in a vacuum degassing chamber along with any remaining mixed potting compound so any frothing that occurs can be observed in the remaining potting compound.

5. Draw a vacuum of 33 mBar to degass the potting compound, leaving the compound under vacuum for at least 2 minutes after frothing ceases. There is an air void in the SHV connector between the input resistor and connector body, this step is also to fill this void.

6. Filling the rest of the filter depends on if air can escape out the end cap.

   (a) If the pulse PCB is slotted and air can escape out the end cap then fill the filter the rest of the way through the SHV connector end fill port until potting compound comes to the top of the hole in the end cap.

      i. Seal the fill port by the end cap with an M2 bolt and leave the port near the SHV connector open.

      ii. Seal the fill port with an M2 nut and keep the filter oriented connector end down as the potting compound cures.

   (b) If the endcap is sealed and air can only escape out the fill port.

      i. Fill with an additional 10 mL of compound, this puts the level of the potting compound at about the guard ring and ensures the void between the resistor and SHV connector is filled while continuing to fill the filter.

      ii. Seal the fill port by the SHV connector with an M2 bolt and tilt the fitler on it's side so the end cap side fill port is up. Continue to fill through the end cap end fill port to the maximum extend possible. Keep adding more potting compound as it settles and the air void shifts to the side with the fill port.

      iii. Seal the fill port and tilt the filter so the SHV connector end is elevated at a 30 degree angle with the connector end fill port down. There is a slot in the guard ring on the fill port side and this will keep an air void remaining from easily moving past the guard ring. Any air voids along the tube wall by the guard ring will be in a region of minimal electric field. Any air void on the SHV connector side of the guard ring will move to the space between the SHV connector body and the tube, which is another region of low electric field.

12 Finishing touches

1. Install the BNC connector on the pulse line.
2. Install copper foil around the HV pigtail. 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 HV pigtail 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 cable. Conductive epoxy can be used to ensure a solid electrical connection to the tube for contact the shield braid around the HV connector pigtail. Do not attempt to solder connections to the tube or the 3D printed plastic parts will melt.
4. Solder the ground wire with connector to the HV pigtail connector end of the shield braid.
5. Label the filter and record any details. Is there Kapton tape around the input resistor? How about a film around the output resistor? Is it potted?