# SHV coaxial feedthrough RCR filter

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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 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 0.75 inch OD 0.25 inch ID copper washer.
- 1 5.5 mm brass hex standoff cut to 0.25 inches.[1]
- 2 100 MΩ 7.5 kV axial lead resistors, Ohmite MOX1125231006FE.
- Epoxy, Loctite Hysol EA 0151.
- 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 for resistor to output cable, AWG 20 wire terminal crimp connector with plastic removed.
- Cable grommet.
- Copper tape.
- Kapton tape.

# 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. 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.

[1] 5.5 mm bare brass hex standoff in 0.25" length were unavailable.

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. 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.

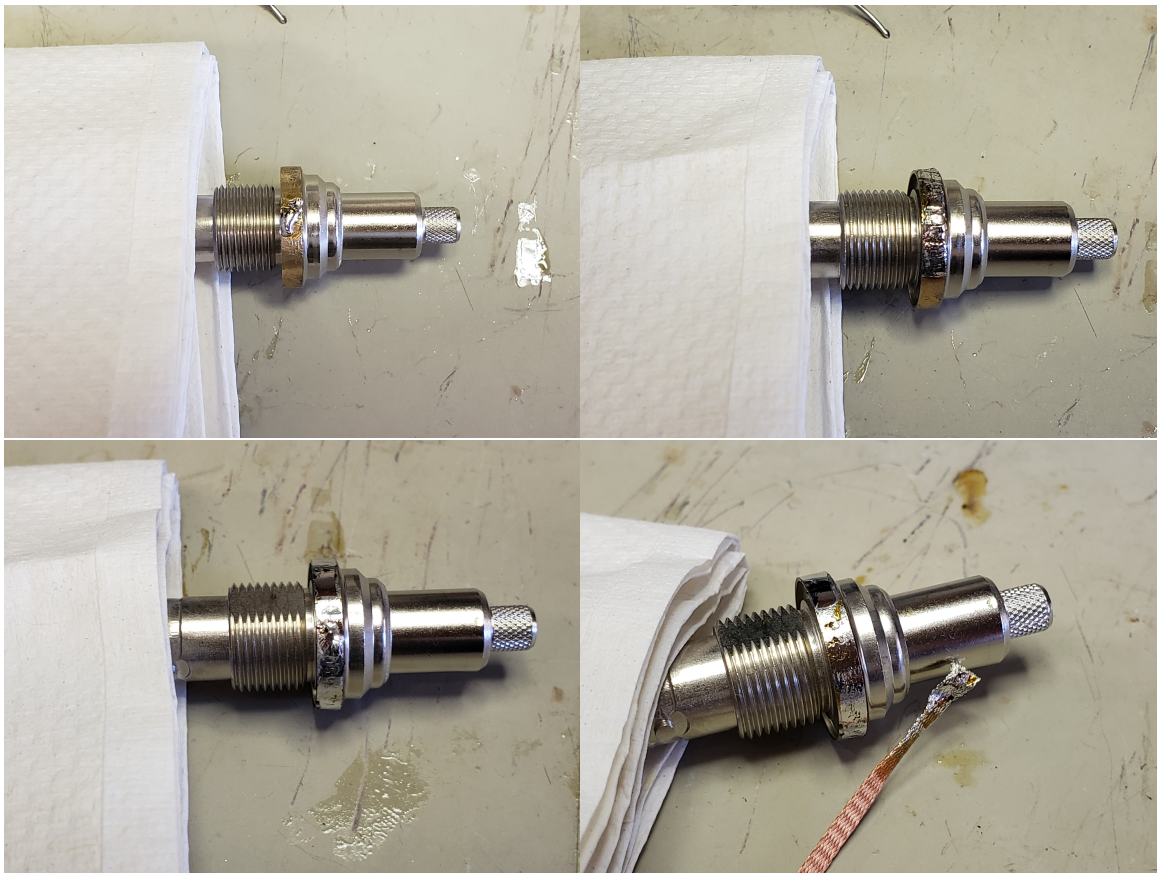

Figure 2: Top left: a small blob of solder applied to edge of SHV jack body. Top right: spreading the solder around the edge. Bottom left: extra solder after covering entire edge. Bottom right: SHV jack body after excess solder wicked away.

## 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 even in the same batch, 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, 0.234" for TE Connectivity AMP

Connectors 5225059-3.

3. Solder the pin on the lead. The pin is intended to be crimped on, but it's intended to be crimped to the signal wire of cables that are larger than the 0.020" lead of the Ohmite MOX1125231006FE resistor. Crimping also works well for stranded wire but not for solid wire. It is recommended to solder the pin on instead.

   **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.

4. Prepare some epoxy. 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.

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

   (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 syring pointed down so the air bubble stays at the plunger until ready for application.

5. 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.

6. 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 degass the epoxy to drive out any small bubbles that could cause microdischarges. Only do this if it can be accomplished within 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.

Figure 4: Resistor installed in bulkhead jack.

(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. Adjitating 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.

## 2 Preparing the tube

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

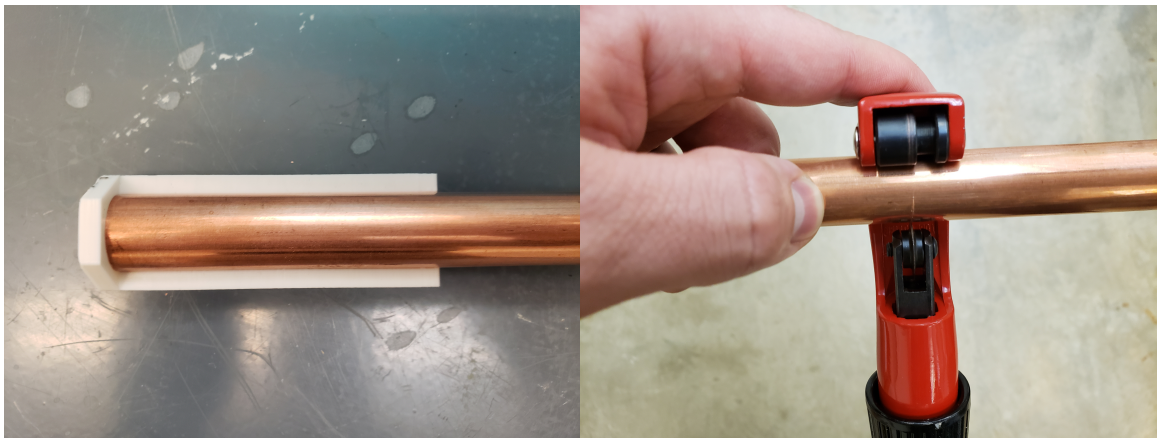

Figure 5: Left: measuring tube with jig. Right: cutting tube with tube cutter.

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. See figure 6.

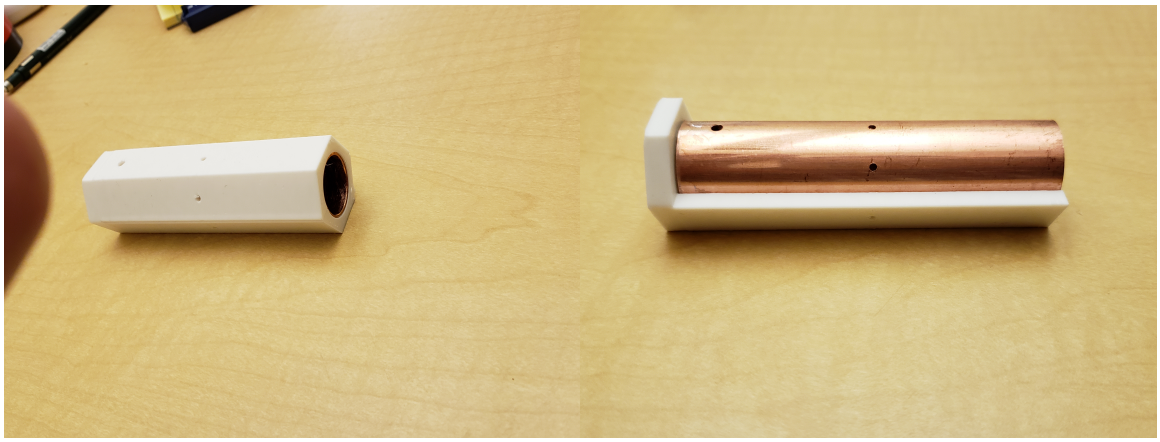

Figure 6: Left: tube in jig ready to be drilled. Right: half of jig removed after drilling holes.

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. Tin the 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.

# 3 Assemble the resistors and capacitors

1. Trim the resistor leads that will go in the standoff down to less than the standoff length, 0.25" for a single row of 2225 capacitors, leaving at least a couple millimeteres for a solder connection.

2. Tin the resistors and both contacts of the capacitors.

   (a) Remove any excess solder from the capacitor contacts that will mate with the hex standoff.

   (b) Leave a solder bulge to the capacitor contacts that will mate with the tube. Measure the size of the capacitors with the bulge so the assembled capacitors and standoff will just fit in the tube. For the 0.686 inch ID tube and 5.5 mm standoffs this leaves a nomial 0.234 inches for each capacitor, allowing for only around 10 mils for a solder bulge.

3. Cut the hex standoff to size, file off any sharp edges, and tin the standoff including the hole in the middle where the resistor leads will go.

4. Place the capacitors and standoff in the jig and 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.

5. Heat the standoff while applying additional solder to the capacitor to standoff joint until the solder flow. Then apply sufficient solder to all joint. Do not leave any protruding points that could cause discharges. If the solder is hot enough it will form a smooth surface when the iron is removed before it cools enough to solidify.

6. Check against the tube to make sure the capacitor contacts will be well ceneted on the holes in the side of the tube, it should be in the right position when the resistor body is flush with the standoff.

7. 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.

8. Put a piece of high temperature tape, like Kapton, over the output side of the standoff and capacitors. Cut a hole in the tape to expose the hole in the standoff. This is a dust mask in case filing is needed when attaching the output cable.

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

# 4 Assembly the cable and tube

## 4.1 Attach the cable

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

1. Trim the resistor lead and cable center conductor to fit inside the available tube, 0.315 inchs total for the AWG 20 furrule. Leave plenty of extra sheild on the cable to later solder to the washer.

2. Tin the resistor lead and cable center conductor.

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. Either ream the tube to remove the plating or apply a generous amount of high activity flux to the inside of the tube. It is possible to solder to nickel with agressive flux, no clean flux probably won't work.

4. Slide the furrule over the resistor lead and insert the signal cable into the furrule.
   (a) If the cable has a connector already, slide the cable through the grommet washer and tube first.
5. Pull the cable out slightly to expose some wire, heat the tube until solder flows to exposed wire, then fully insert the cable and resistor lead and remove heat.
6. Gently tug on the cable to ensure it made a good connection.
7. Ensure there are no solder points that might cause discharges. If the solder is hot enough before the heat is removed it will form a smooth surface before solidifying. It is best to avoid filing as the mask won't completely keep dust out, but if necessary file down any sharp points and clean away the dust.
8. Remove the dust mask tape from the standoff and capacitors.

## 4.2 Attach the tube and washer

1. Put some high temperature tape, like Kapton, around the end of the tube covering the fill hole. This is to prevent solder from not only getting into the hole but the entire surface where tape will be used to seal the hole, so the entire outer surface of the tube should be taped near the connector end to ensure it stays free of solder.
2. Slide tube section over filter, close to but not past the edge of the gasket groove. Rotate the tube so the holes are aligned with the capacitor contacts.
3. Solder the tube section to the SHV jack, ensure there are no gaps for oil to leak out of.
4. Solder the capacitors to the tube through the holes in the side. Look through the end of the tube to ensure they are connected. Ensure the holes are completely plugged with solder so oil can't leak out.
5. Solder the washer to the output end of the tube.
   (a) Use two crossed pieces of Kapton tape to secure the washer.
   (b) Solder the sections between the tape.
   (c) Remove the tape and solder all the way around, this is an oil seal and it needs to be free of gaps.
6. Solder the wire braid of the cable shield to the washer. Leave a small gap for alcohol to flow out for cleaning, the seal will be made with epoxy.

### 4.3 Sealing the cable connection

1. Remove the tape coering the fill hole and clean the solder flux out of the fitler. Hold the filter connector end up and flow isopropyl alcohol in through the fill hole and let 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. Degass some epoxy and apply it generously to the gap between the washer and cable. While it isn't critical to keep the expoy from flowing into the filter 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. Apply some additional epoxy to the grommet if desired, 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. This tape can be left in place afterward as a permanate part of the filter.

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

## 5 Fill the filter with oil

1. Turn the filter on its side so the fill hole is up.

2. Use a syringe with a need 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, wrapping the tape all the way around to 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.