QFilter Manual

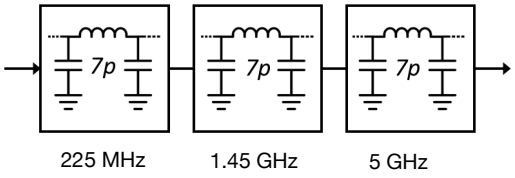
The QFilter is a compact multi-stage low-pass filter which rejects noise and ensures millikelvin electron temperature in up to 48 signal lines going to your quantum electronics devices and other sensitive cryogenic circuits. The QFilter is the result of several years of development at Harvard University and the University of Copenhagen on achieving the lowest possible noise and electron temperatures in quantum devices. The standard QFilter contains two filter banks, one with RC circuits and one with LC circuits, but combinations with two identical banks are also supplied.

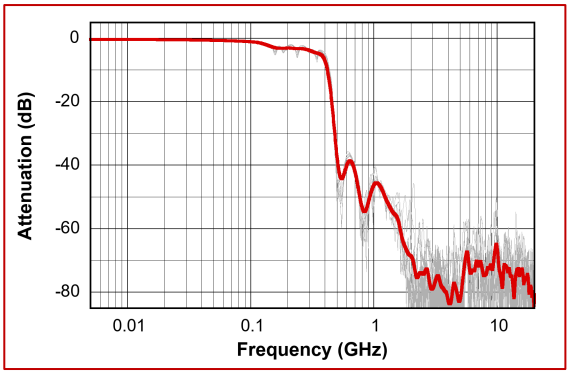
Features

- One audio frequency (RC) and one radio frequency (RF) filter board with 24 low-pass channels each.
- Designed for easy mounting on the mixing chamber plate of common dilution refrigerators.
- Sturdy design makes it possible to stack multiple filters for higher channel counts.
- Signal lines are thermally anchored to non-magnetic gold-plated copper brackets.
- Compatible with low temperatures and high magnetic fields.
- Non-magnetic shielded 25-pin microD connectors, female input, male output.
- Pinout compatible with Cinch connectors used in most dilution refrigerators.
- Optimal performance is achieved by connecting the RC and RF lines in series.
- QFilters can be stacked or mated in-series to save space or cables, respectively.

Radio frequency low-pass filter bank (RF)

- Three reflective 7-pole Pi filter stages, individually shielded.
- Attenuates above 225 MHz.
- Total resistance (room temp.): 2.0±0.5 Ω.
- Isolation to ground and other channels[1] > 2 GΩ.
- Maximum current 10 mA.

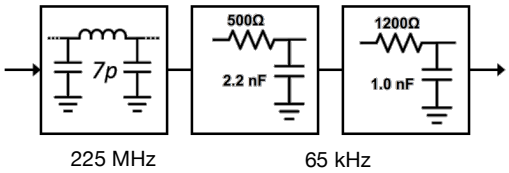


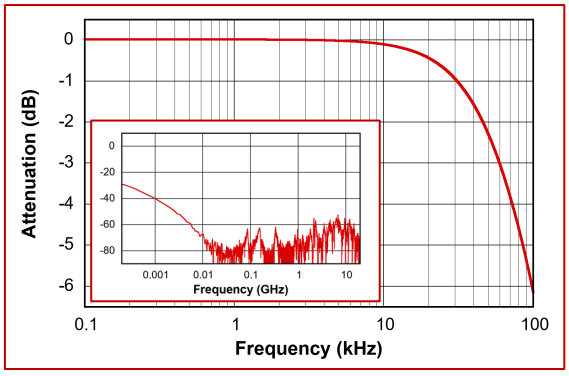


Typical attenuation vs. frequency of the RF filter bank measured using a 50 Ω referenced Rohde & Schwartz ZNB-20 vector network analyzer at room temperature.

Low frequency low-pass filter bank (RC)

- One reflective 7-pole Pi filter stage and two dissipative RC filter stages, individually shielded.
- Attenuates from 65 kHz or lower.
- Total resistance (room temp.): 1700±10 Ω
- Isolation to ground and other channels[1] > 2 GΩ.
- Maximum current 6.5 mA.





Typical voltage attenuation vs. frequency of the RC filter bank, measured with a Stanford SR830 lock-in Amplifier at room temperature. The insert shows attenuation in 50 Ω measured using a vector network analyzer.

[1] QDevil warrants a ground isolation of all QFilter lines ≥ 2GΩ below 4K. Should this ever fail during the lifetime of the QFilter, QDevil will repair the filter free of charge, unless the failure is caused by external circumstances like water damage etc.

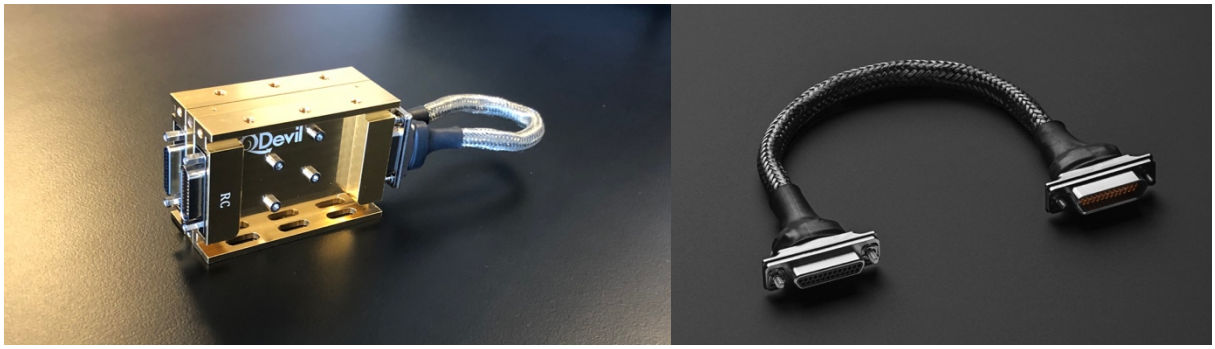
QFilter configurations

Q015 standard RC+RF combination

The standard filter assembly (Q015) is configured with one 24 channel RC filter bank and one 24 channel RF filter bank. For optimal noise reduction and thermalization, these are connected in series using a short jumper cable. For this, a shielded 6″ microD jumper cable is supplied. A 12″ version of the jumper cable is also available, e.g. for connecting the QFilter to the cryostat break-outs or to the sample insert. It is always recommended to use a shielded cable at the output of the QFilter in order to avoid noise pickup.

Q016 and Q017 RC+RC and RF+RF combinations

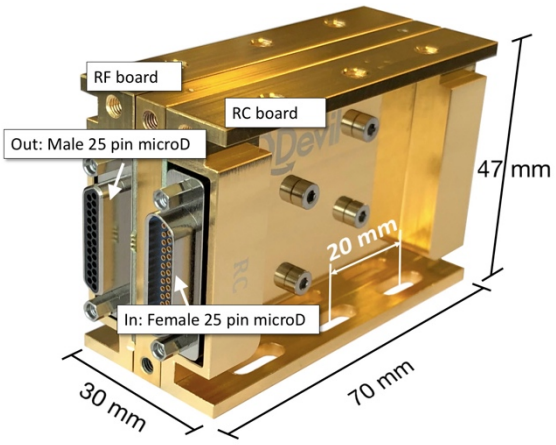
The QFilter can also be delivered with two RC banks or two RF banks, which can be mated in series (*piggy-tailing*) without the need for a jumper cable. See details on page 4.



The standard QFilter (Q015) with the optional 6 inch jumper cable connecting the 24 channel RC and RF filter banks in series. The wires in the shielded jumper cables are pairwise twisted and connected to the microD connector pins as (1-14), (2-15), … (12-25). The wire connected to pins 13 is unpaired.

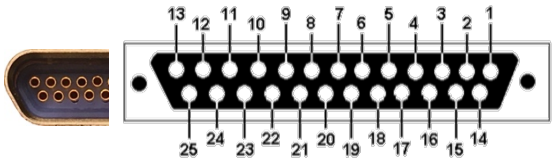
Dimensions and pin-out

The microD connectors have 25 pins, whereas the QFilter has 24 channels. As standard pin 13 of the microD connectors is not connected (consistent with most fridge manufacturers). Modifications are possible on request. Note that an early version of the QFilter had pin 25 floating, in case you have one of those.

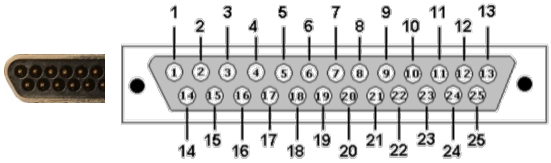


The QFilter dimensions. The mounting hole distance is 20 mm both along the length and the width of the filter. Shown is a standard Q015 RC+RF combination filter assembly.

Female connector front view:



Male connector front view:



The QFilter has 24 channels whereas the microD connectors have 25 pins. On standard QFilters, pin 13 is not connected. On special request, a strap can be mounted, connecting pin 13 to pin 25.

Installing the QFilter

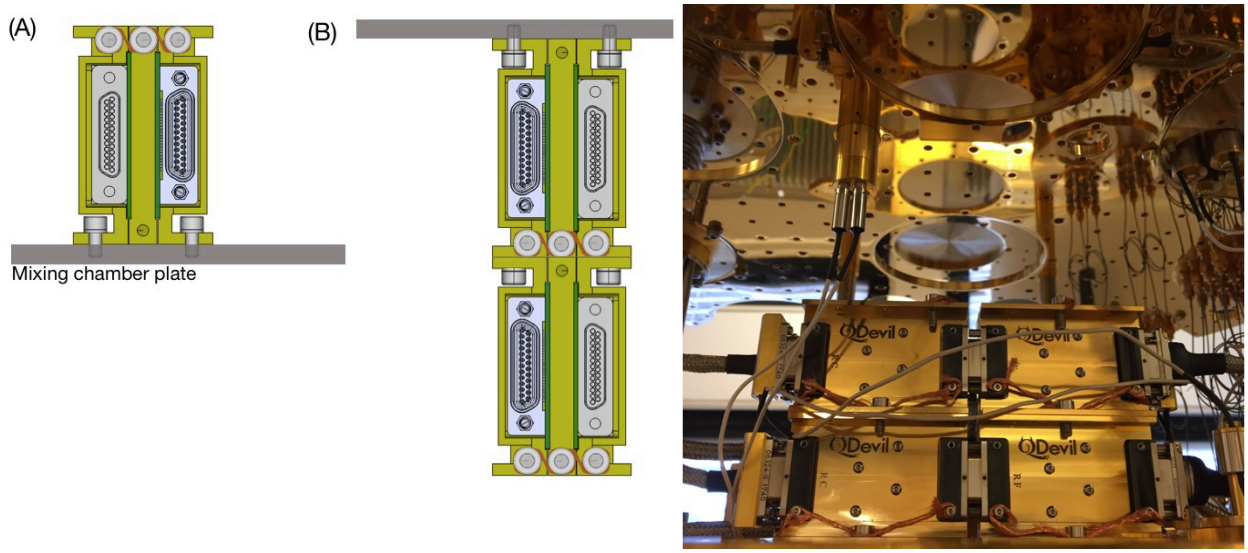
As phonon-electron interactions become very weak at millikelvin temperatures it is a significant challenge to ensure that electrons in the signal lines, which go all the way from room temperature to the sample through multiple thermalization stages, are as cold as the sample holder when reaching the sample.

High-frequency noise transmitted from room temperature or being picked up by the wiring down to the cold space not only reduces the signal-to-noise ratio but is also a source of heat, dramatically disturbing measurements.

The noise environment in each cryostat differs from lab to lab, depending on equipment nearby, electro-magnetic noise, vibration levels and wiring details. In addition, different quantum devices respond differently to electrical noise in terms of their transport characteristics. Nevertheless, here we provide a few general comments that will help getting the best performance out of your filters.

By mounting the QFilter, firmly onto the coldest plate of the cryostat it will both thermalize the electrical leads and electrons to the sample and filter out electrical noise from about 65 kHz to tens of GHz.

QFilters are normally placed directly on the mixing chamber plate (A) but can also be stacked onto each other either on the top of the mixing chamber plate or hanging below (B).



Middle segment thermalization

The middle segment of the filter assembly does not make direct controlled thermal/electrical contact to the mixing chamber plate or to the side brackets. It is therefore thermalized through a piece of copper connected to the two adjacent side brackets.

Screws

For best thermalization of the filter assembly use as many mounting screws as possible (at least one per side). In the QFilter Accessory bag you find Titanium screws and washers for mounting the filter assembly onto the cold plate. Titanium can be tightened rather strongly and is 100% non-magnetic.

If you for some reason, e.g. due to shortage of threaded mounting holes on the mixing chamber plate, you can only use a few screws, then stainless steel screws are another possible choice because they can be tightened very strongly. However, they may turn somewhat magnetic over time when exposed to high fields. Brass screws are also a good choice as they contract more during cool down compared to stainless steel. But as they cannot be tightened as strongly without breaking, you need to have many mounting holes available.

Maximum ratings and testing at room temperature

Maximum current rating

The maximum currents (at low temperature) is up to 10mA for the RF filter bank and 6.5mA for the RC filter bank. However, as the QFilter is meant to thermalize electrons and for being mounted on the coldest plate in the fridge, it is recommended to keep the current in the micro Ampere range in order to avoid the dissipation of too much heat at the mixing chamber. 25μA in a single line will generate about 1μW in the 1700 ohms of the RC filter stages, which should be compared to the 15-30 μW cooling power at the mixing chamber plate of a typical dilution refrigerator.

Maximum voltage rating

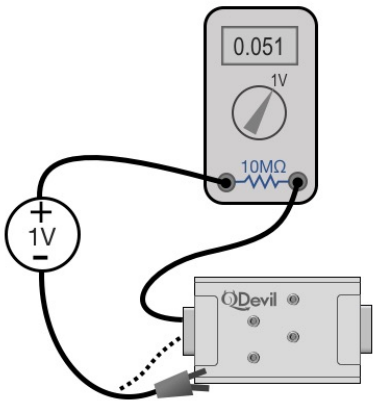
The QFilter is rated to ±10V at temperatures below 77K. At room temperature it is recommended not to apply voltages higher than 1V for longer times as some of the components are quite vulnerable and may develop leak to ground (in the order of MΩ). Note, should the filter develop a small leak to ground at room temperature, it will in most cases disappear when the filter is cooled down.

Testing the QFilter lines at room temperature (be careful)

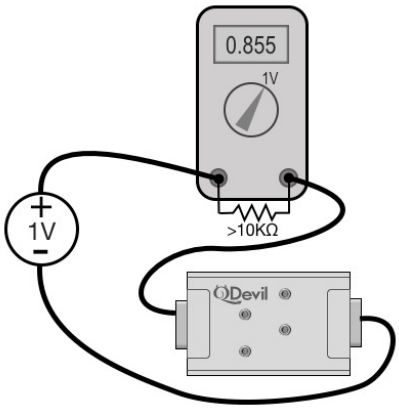
All units have been tested before shipping. If you need to test the lines before cooling down the filter, we recommend the following procedures:

To test leak to ground, use your (handheld) DMM in DC voltage measurement mode (1V range) and use the input impedance (e.g. R_{MM} = 10MΩ) as a series resistor. If you use a high impedance DMM, place a 10MΩ resistor across its terminals. Connect the positive terminal of the DMM to a 1V source and connect the negative terminal to the QFilter line(s) you want to test. Connect the negative terminal of your voltage source to the QFilter metal (ground) - not to microD connector shell. The voltage reading across the internal DMM resistance is a direct measure of the leakage between the lines or to ground: $R_{leak} = R_{MM} \times (1V / V_{MM} - 1)$. If you want to measure the leak between lines, use the same procedure but connect the negative terminal of the voltage source to the other QFilter line instead of to ground.

To test line resistance, place a resistor, R_{series}, of minimum 10kΩ across the terminals of the voltmeter and connect the negative terminal of the voltmeter to the input of the selected line of the QFilter and the negative terminal of your voltage source to the output of the line. $R_{line} = R_{series} \times (1V / V_{DMM} - 1)$.



Measuring leak to ground or between lines using a voltmeter. Common handheld multimeters have an internal resistance of 10MΩ (R_{MM}): $R_{leak} = R_{MM} \times (1V / V_{MM} - 1)$. If your DMM has a larger unknown impedance place a 10MΩ resistor across its terminals



Measuring line resistance using a voltmeter. Place a resistor, R_{series}, of minimum 10kΩ across its terminals to limit the voltage and current over the QFilter line: $R_{line} = R_{series} \times (1V / V_{MM} - 1)$.

Grease

If you mount our gold-plated filters onto gold-plated cooling surfaces of your mixing chamber plate (< 1K operation), we do not recommend the use of thermal grease. Instead, clean the mating surfaces with a mixture of IPA/water to remove any dust or grease prior to mounting.

For mounting at higher temperatures or on different materials, the use of Apiezon grease may be beneficial, depending on the surfaces and mounting forces used. See for example Sec. 2.6.4 TO GREASE, OR NOT TO GREASE? of Experimental techniques for low-temperature measurements by Jack W. Ekin (Oxford University Press, 2006).

Shielding

Unshielded twisted-pair copper looms have been used to connect the QFilters on the mixing chamber plate with the sample space under the cold finger end piece with good success. Depending on the noise environment in your cryostat, you may benefit by shielding this loom using a non-magnetic metallic braid for EMI shielding. If you use a braided shield, we recommend making a tight seal between the shield of your loom and the QFilter body, possibly using copper tape to ground and thermalize the shield appropriately. Always use a shielded loom/cable from the QFilter to the sample space.

Connecting the QFilter

When inserting the microD connectors of a loom or jumper cable into the mating connectors on the QFilter it is important to insert the connectors fully into each other to ensure stable contact.

Piggy-tailing QFilters

Not only can QFilters be stacked, they can also be mounted in series (piggy-tailed). This gives optimal filtering for 48 channels on the footprint of two QFilters, with the wo inputs in one end, and the two outputs in the other end of the filter train. When routing looms and cables in the cryostat this is often more convenient than combining two standard Q015 filters in the same way, where you will get inputs and outputs in both ends of the filter train.

If you have a pair of Q016 (RC+RC) and Q017 (RF+RF) filter assemblies, connect the RC filter in front of the RF filter, so that the RC filter is connected to the loom coming from room temperature and the RF filter is connected to the sample space. In order to mate the filters to each other in series, the threaded mounting posts on one of two mating the connectors (see photo, circled in red) will need to be removed. When buying pairs of Q016 (RC+RC) and Q017 (RF+RF) filter assemblies this is usually done from the factory and the unmounted jack posts are placed in the Accessories Bag. You can unmount the posts yourself by turning them counter clockwise using a wrench. **When connecting the two filter assemblies in series, it is important to insert the connectors fully into each other to ensure stable contact.**