⟨g|q|e⟩

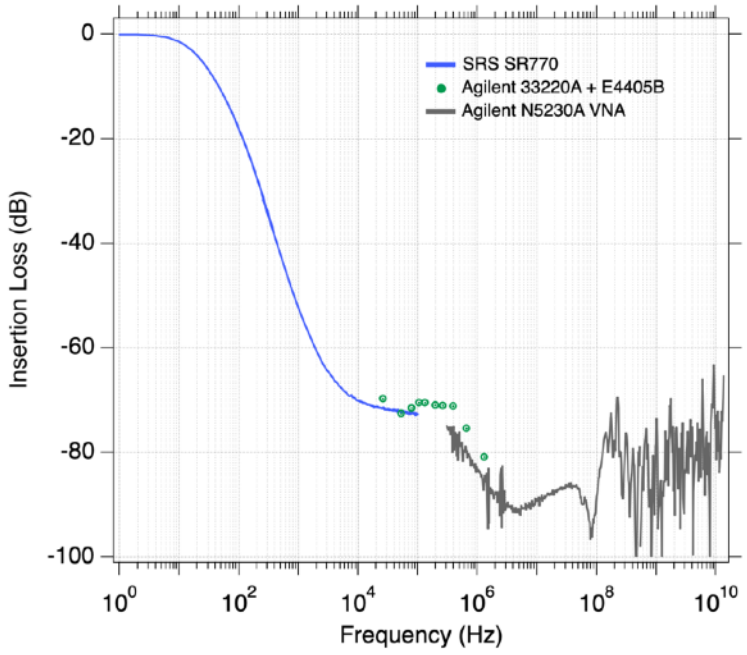
LPF

GQE-LPF-S low-pass filter

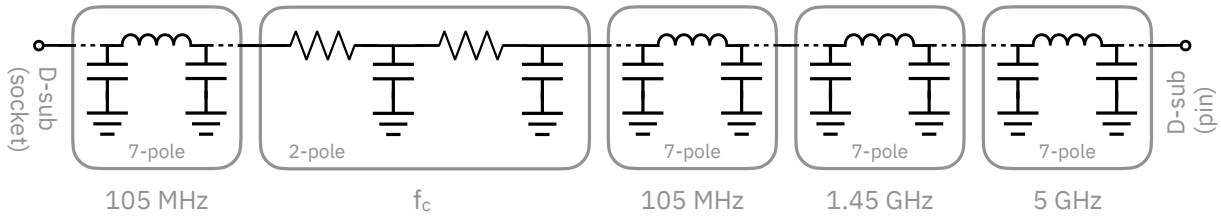
Highlights

- Combination of multi-pole RC and LC filtering for rejection of unwanted frequencies up to >20 GHz.
- Multiple RC configurations available to accommodate every use-case.
- Designed with thermalization in mind: gold-plated oxygen-free copper enclosures and ceramic circuit boards for maximum heat transfer at low temperatures.
- Mounts to most commercial dilution refrigerators in multiple orientations.
- Industry standard 25-pin micro-D connectors.

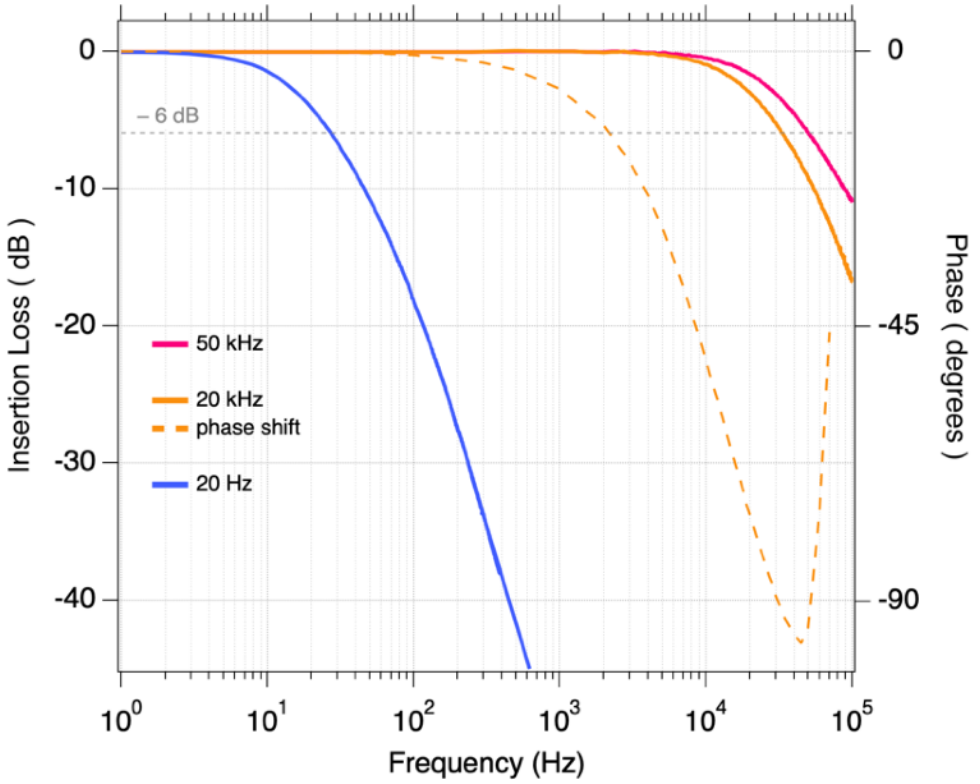
The GQE LPF was designed to reject high frequencies and thermalize DC wire sets to very low temperatures in dilution refrigerators and other cryogenic systems. As low temperature physicists we recognize there is no one-size-fits-all filter, which is why we offer multiple configurations with different cutoff frequencies and in-line resistances that can be customized to meet the needs of any experiment.



Typical attenuation of a 20 Hz filter from 1 Hz to 14 GHz



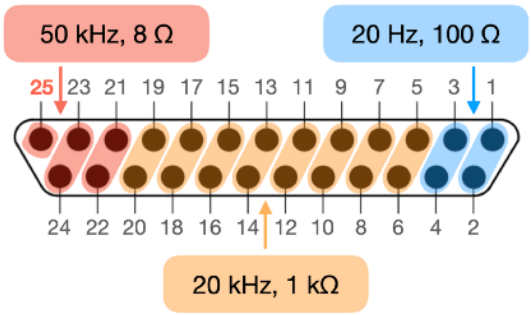
Cutoff and in-line resistance	Recommended applications	Operating limits
20 Hz, 103 Ω	Aggressive filtering of DC bias lines to qubits, quantum amplifiers, and other sensitive devices.	Max: 10 V, 50 mA
20 kHz, 1002 Ω	Low-frequency lock-in amplifier measurements.	Max: 25 V, 15 mA
50 kHz, 8 Ω	Designed for filtering connections to electromechanical switches and other high-current devices. Not recommended for transport measurements.	Max: 25 V, 250 mA



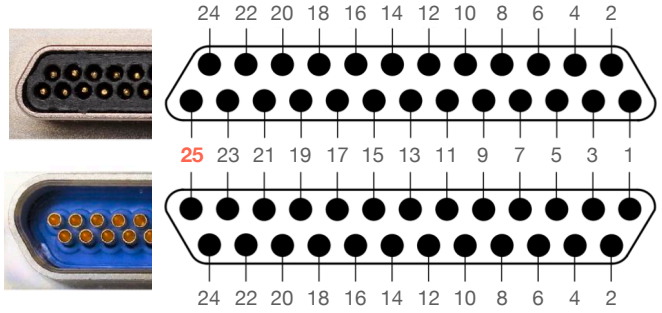
Low-frequency attenuation of standard filter configurations. Phase shift is shown for 20 kHz cutoff.

- GQE warrants ground isolation of ≥ 1 GΩ for channels with 20 kHz or 50 kHz cutoff frequencies.
- Cutoff frequencies may vary depending on load resistance.
- Operation at 4K is recommended for applications requiring significant (~mA) bias currents. For measurements requiring mK electronic temperatures, filter should be located on the mixing chamber plate and 20 kHz lines should be used.

GQE-LPF-S Configuration

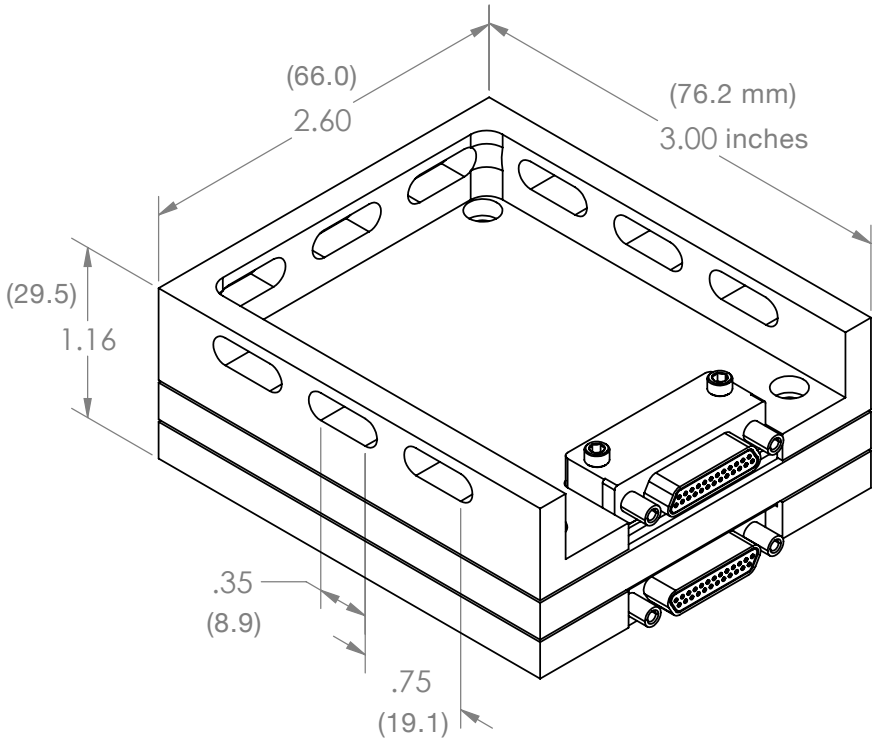


Line Indices



LC output (pin)

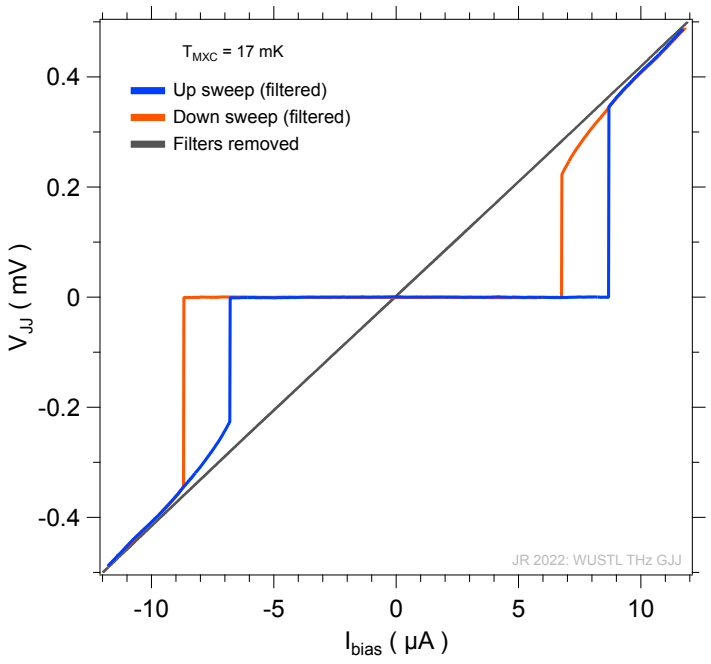
RC input (socket)



GQE-LPF-S specifications

- Standard (S) configuration features a combination of 20 Hz, 20 kHz, and 50 kHz cutoff filters to flexibly accommodate a variety of use cases.
- All lines feature 2-pole RC and four stages of 7-pole LC filtering.
- Input connector: 25-socket (female) D-sub micro
- Output connector: 25-pin (male) D-sub micro
- Insertion loss: > 60 dB for 1 MHz – 1 GHz, > 50 dB for 1 – 20 GHz (typ.)
- Lines 1-4: 20 Hz cutoff
  - Resistance: 103 Ω (typ.)
  - Insertion loss at 60 Hz: > 13 dB (typ.)
  - Operating limits: 10 V or 50 mA (max.)
  - Isolation from ground: > 100 MΩ (typ.)**
  - Recommended applications: Aggressive filtering of DC bias lines to qubits, JPAs, TWPAs, and other sensitive quantum devices. *Not recommended for transport measurements.*
- Lines 5-20: 20 kHz cutoff
  - Resistance: 1002 Ω (typ.)
  - Phase shift at 100 Hz: < 0.5 deg. (typ.)
  - Operating limits: 25 V or 15 mA (max.)
  - Isolation from ground: > 10 GΩ (typ.)*
  - Recommended applications: Low-frequency lock-in amplifier and transport measurements.
- Lines 21-25: 50 kHz cutoff
  - Resistance: 8 Ω
  - Operating limits: 25 V or 250 mA (max.)
  - Isolation from ground: > 10 GΩ (typ.)*
  - Recommended applications: Filtering connections to electromechanical switches and other high-current devices. *Not recommended for transport measurements.*

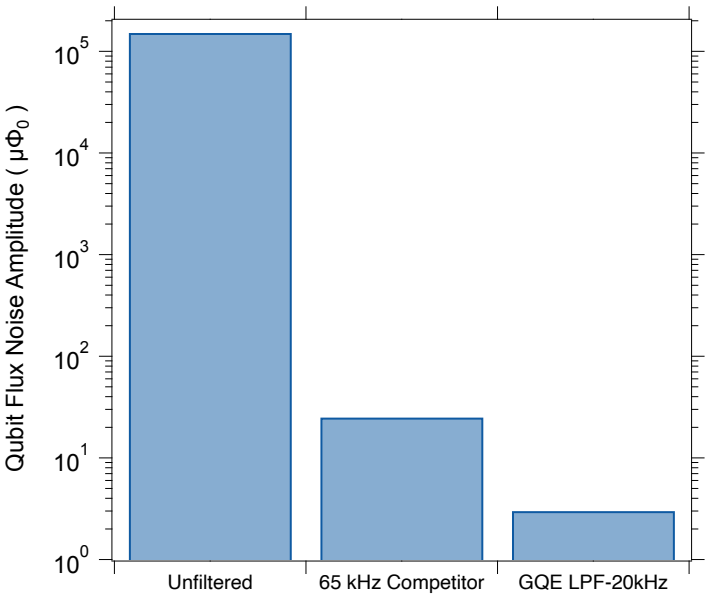
* GQE warrants ground isolation of ≥ 1 GΩ for channels with 20 kHz or 50 kHz cutoff frequencies.
** See note on ground isolation measurements in Handling & Operation.
- Cutoff frequencies may vary depending on load resistance.
- Operation at 4K is recommended for applications requiring significant (~mA) bias currents. For measurements requiring mK electronic temperatures, filter should be located on the mixing chamber plate and 20 kHz lines should be used.



An SNS Josephson junction (JJ) with a graphene weak link was measured in two configurations: unfiltered, and using the GQE LPF with 20 kHz cutoff. The filter was operated at 4K, with the sample on the mixing chamber at 17 mK. When filtered, the JJ demonstrated hysteretic switching behavior characteristic of an underdamped SNS junction (blue, orange). In the absence of filtering, purely ohmic behavior (grey) was observed. An effective junction temperature > 8 K is inferred in the unfiltered case.

Credit: Henriksen lab at Washington University in St. Louis

[1] *Resistive states of superconducting channels in an alternating electromagnetic field*, Low Temp. Phys. **27** (3): 165–184 (2001), V. M. Dmitriev, I. V. Zolochevskiĭ, E. V. Khristenko



The flux noise of a superconducting transmon qubit was measured [2] in three DC wiring configurations: unfiltered, using a commercial cryogenic low pass filter with a 65 kHz cutoff, and using the GQE LPF with a 20 kHz cutoff. Both filters were located at 4K. Flux noise was reduced by nearly four orders of magnitude by a competitors' cryogenic low pass filter, while the GQE LPF achieved a reduction of nearly five orders of magnitude.

Credit: Murch lab at Washington University in St. Louis

[2] *Characterizing and Optimizing Qubit Coherence Based on SQUID Geometry*, Phys. Rev. Applied **13**, 054079 (2020), Jochen Braumüller, William Oliver, et al.

Handling and mounting instructions

- While mechanically robust, the filter should be handled with care. **Avoid subjecting the filter to strong mechanical shocks or impacts. Avoid exerting unnecessary pressure on the D-sub plugs when making or breaking connections.**
- The filter can be mounted on its side or bottom using either M4 or #6 screws; using at least three screws is recommended if possible.
- Wearing rubber gloves will help to preserve the quality of the gold plating.
- The GQE-LPF is not particularly sensitive to electrostatic discharges, but it is advisable to employ standard ESD prevention measures when handling. **Never directly touch the pins of the input or output connectors.**
- **Do not disassemble or open the filter.** If you encounter issues, contact the manufacturer.

Testing notes and instructions

- Slight reductions in resistance will occur as the filter is cooled to 4K.
- Some measurements may show unusual behavior due to the large capacitance to ground on certain filter configurations, most notably those with 20 Hz cutoff frequencies. This unusual behavior will vary depending on the measuring instrument used.
    - **Testing the LPF with handheld multimeters is not recommended. These instruments can apply unknown voltages to the device-under-test. Always observe the operating limits given in Specifications.**
    - We recommend testing the LPF using a source-measure unit (Keithley 2400 or similar) configured to source a fixed voltage and measure resistance. We typically source 100 mV when measuring in-line resistance, and 1 V when measuring ground isolation.
    - Measurements of the resistance to ground on 20 Hz cutoff frequency lines will show unusual behavior associated with the charging of the large capacitors, manifesting as a resistance that appears to grow in time. Measurements made with a source-measure unit will show >10 MΩ to ground within a few seconds, and typically >100 MΩ if you are willing to wait.