

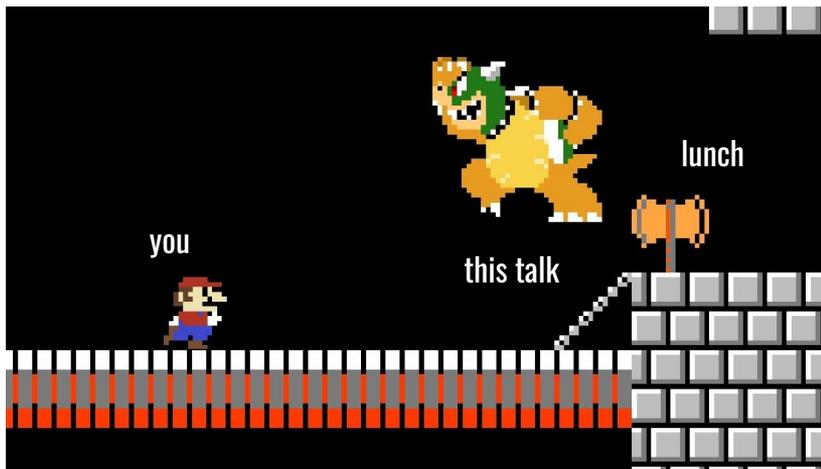
Introduction to Cryogenic RF Components (for SQUATs)

Qubit Sensing Workshop
Taj Dyson — 10/28/2025

Introduction

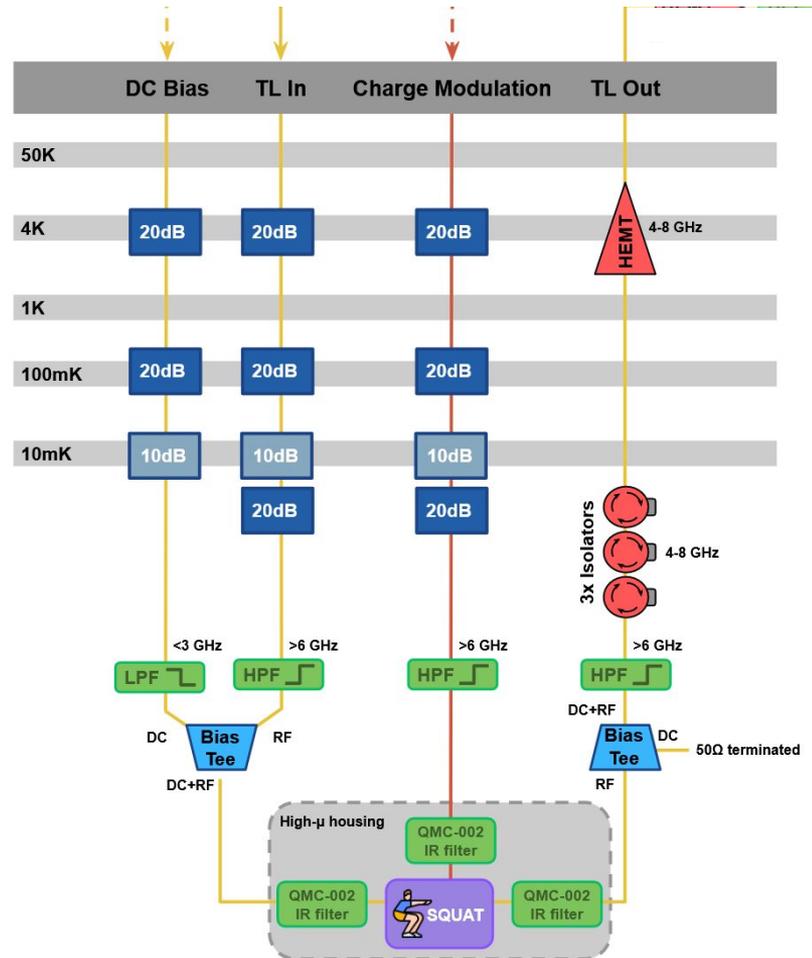
This talk aims to be two things:

1. An educational refresher or introduction to common RF components
2. A brief walkthrough of a successful SQUAT RF chain as a baseline for future discussions



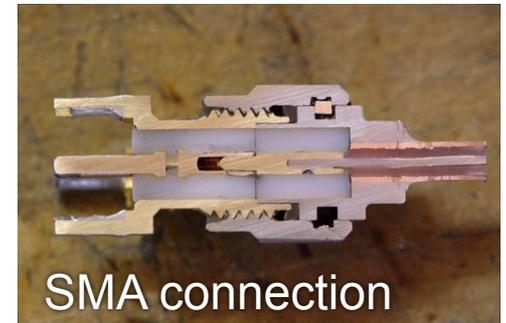
This is the SQUAT RF chain in BFG.

We'll walk through it as an example implementation of most of the components discussed.



Cables & Connectors

- Transmit signals between components
- Materials affect loss
 - Stainless steel is relatively lossy. Used on input lines and after amplification
 - NbTi is near lossless. Used between device output and first amplifier.
- Connector type affects cutoff frequency
 - SMA works up to 18 GHz, sometimes 26 GHz. Dielectric is usually PTFE.
 - 3.5 mm goes up to 34 GHz. Dielectric is air.
 - SMK (a.k.a. 2.92 mm) supports up to 40 GHz. Dielectric is air.
 - All these connectors are mechanically interoperable. However, the SMA pin engages the 3.5/2.92 socket before the threads engage, leading to damage if not carefully aligned when connecting.



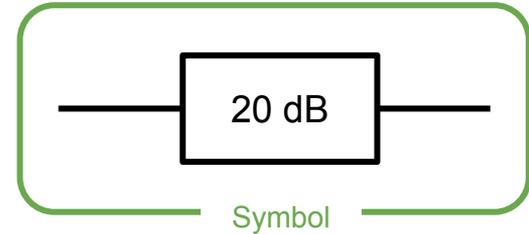
Attenuators

- Attenuate a signal by a factor typically quoted in dB
- As with any component, emits Johnson–Nyquist noise with voltage spectrum ($R = 50\Omega$)

$$S_{VV}(f; R, T) = 4k_BTR \frac{hf/k_B T}{e^{hf/k_B T} - 1}$$

$$T_{eff} = T_A \left(1 - \frac{1}{L_A}\right)$$

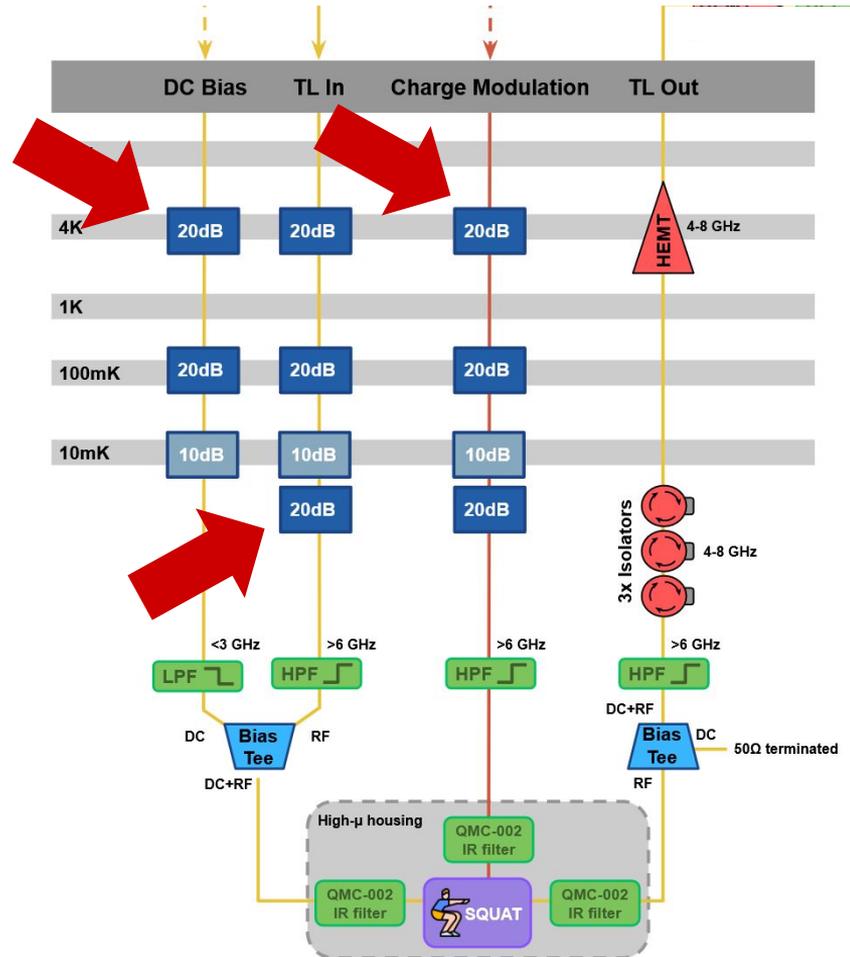
- Under the hood, a network of resistors



Attenuators

- Used primarily to attenuate thermal noise from the hotter stages
- Calculate effective noise temperature for each attenuator,

$$T_{eff} = T_A \left(1 - \frac{1}{L_A} \right)$$



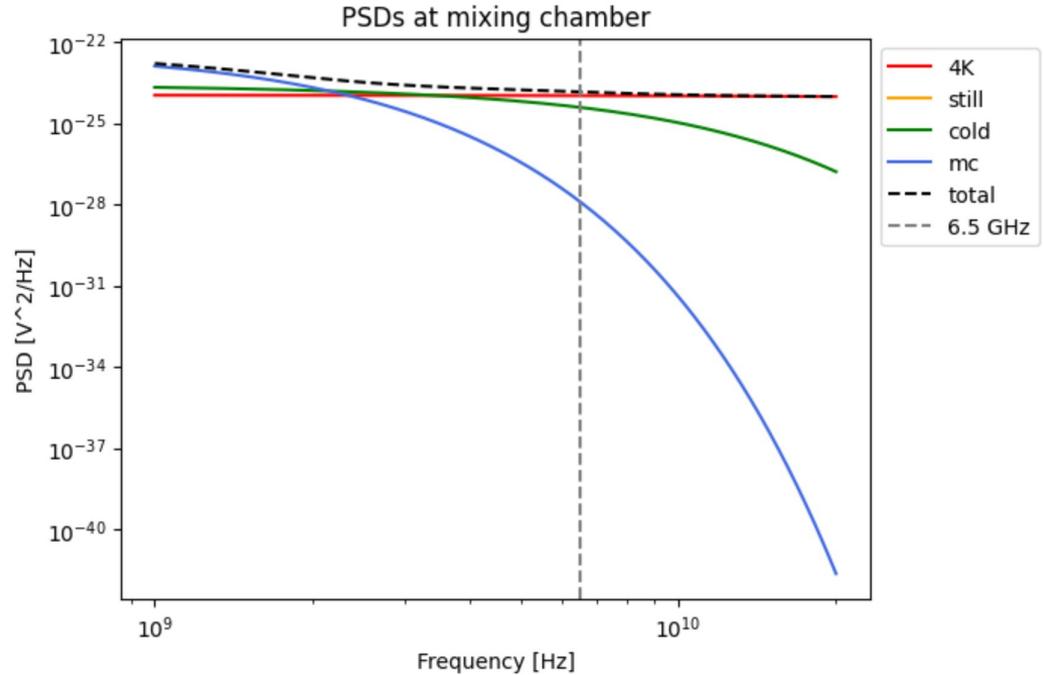
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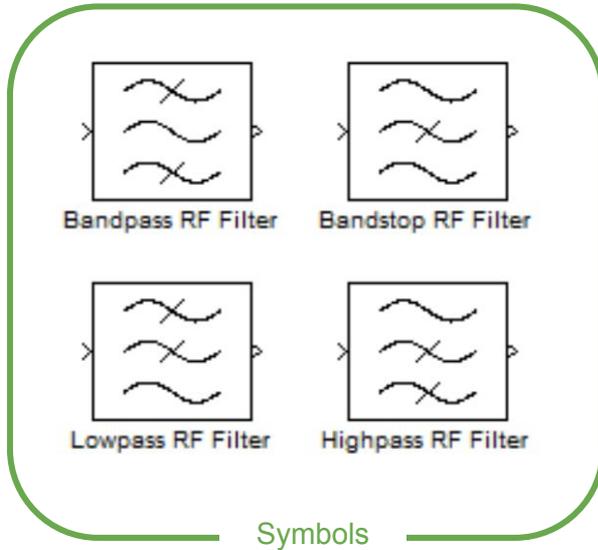
$$T_{eff} = T_A \left(1 - \frac{1}{L_A} \right)$$

then calculate their S_{VV} 's and sum them for the total noise voltage spectrum



RF Filters

- Used to transmit power in a particular frequency range, reflecting the rest
- A few varieties
 - Lowpass
 - Highpass
 - Bandpass
 - Bandstop

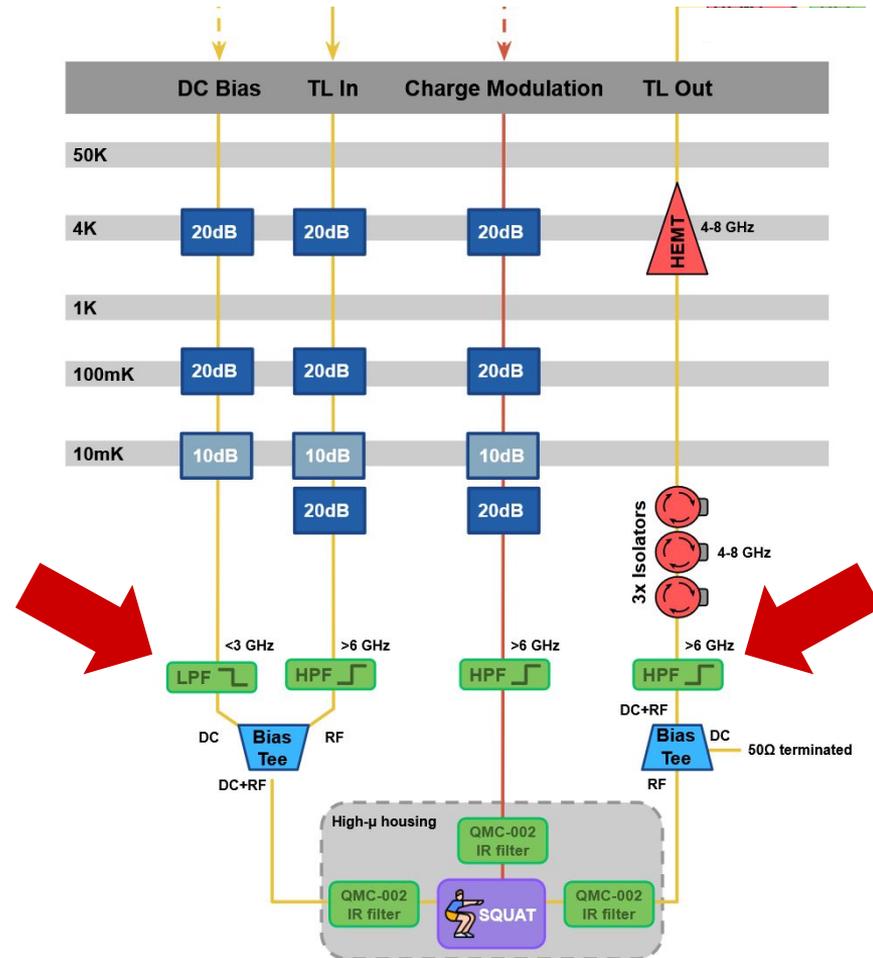


(Sometimes a little cartoon of their transmission spectrum instead)



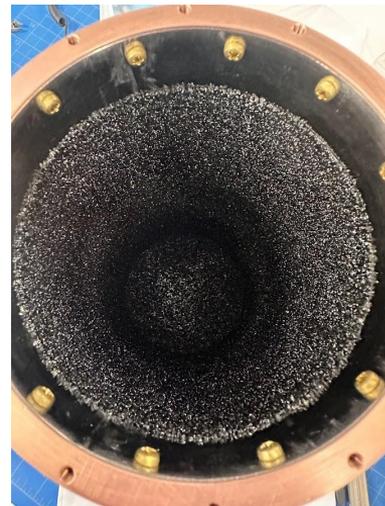
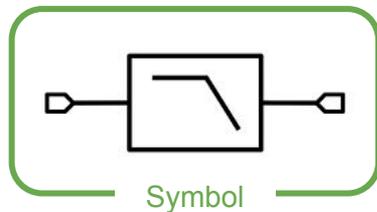
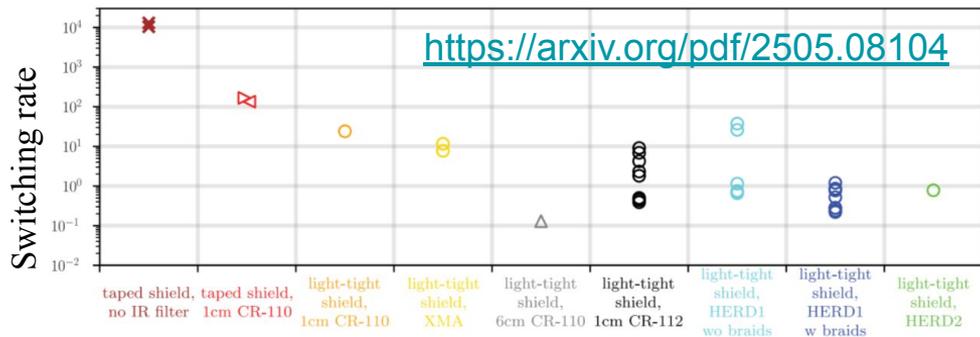
RF Filters

- Filters are chosen based on known signal frequencies
- Filters reject noise and avoid amplifier saturation



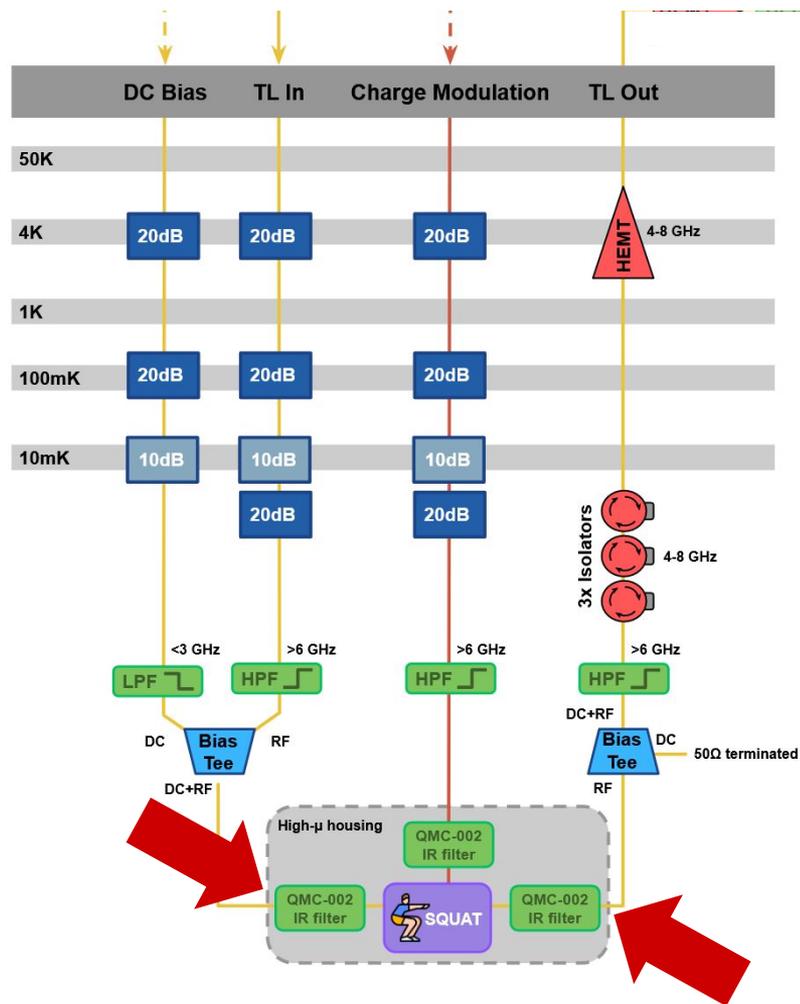
IR Filters

- Infrared photons hurt device performance (e.g. transmon parity switching)
- Two types of mitigations
 - Inline “eccosorb” filters on input
 - Light-tight cans with eccosorb coating
- Proper IR filtering can reduce switching rate by orders of magnitude
- Must protect all ports of the device, even the “output”



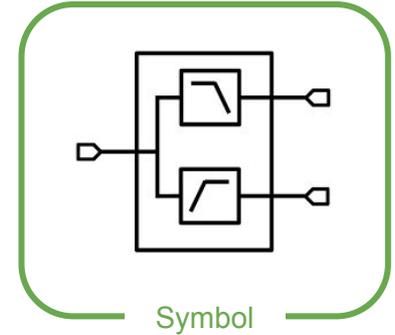
IR Filters

- Currently using QMC-004's on input lines and a high-energy radiation drain (HERD) filter on the output (contrary to diagram)
- ◆ QMC-004: better IR mitigation
 - ◆ HERD: lower insertion loss (~0.1 dB)



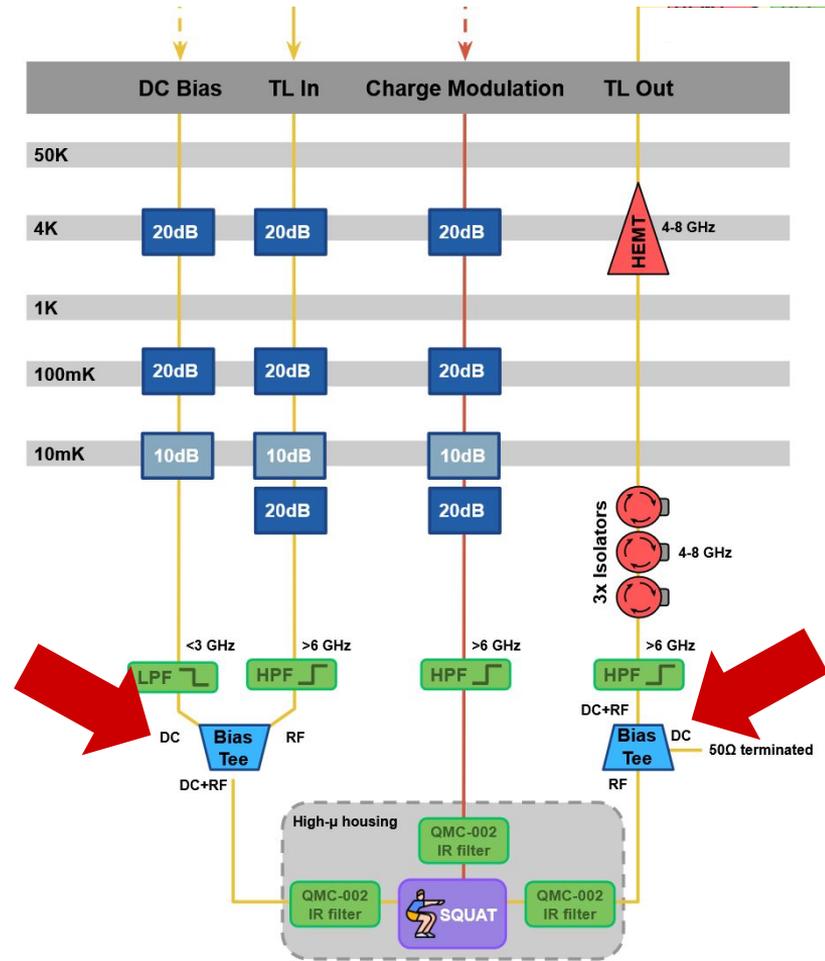
Diplexers

- Used to split or combine signals of different frequencies
- Useful for adding the pump tone for parametric devices, especially when the pump is high-power, since they're not inherently lossy
- If the low band is ~DC, it's called a bias tee.



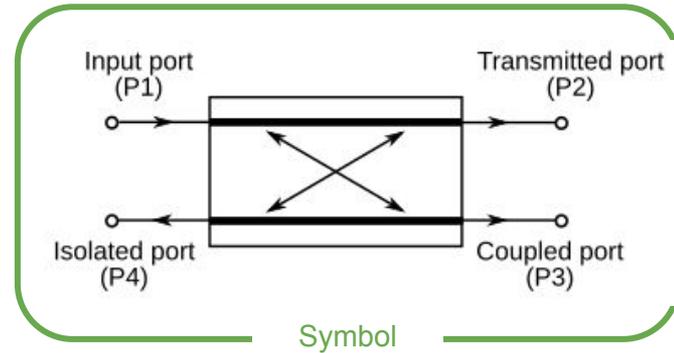
Diplexers

- Bias tees are used to combine the signal with the DC charge bias, and remove it before it impacts the HEMT amplifier



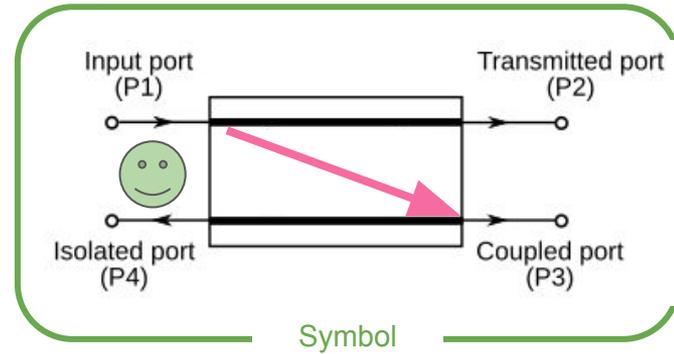
Directional Couplers

- Similar to the diplexer, used to split off or combine signals
- Characterized by coupling ($P3/P1$) and isolation ($P4/P1$), quoted in dB
- Usually sold with a terminator permanently connected to the isolated port ($P4$).



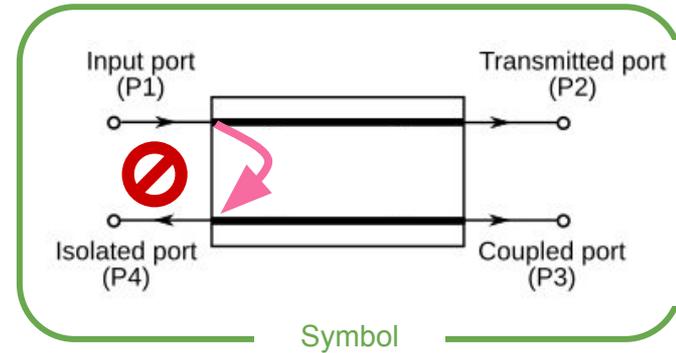
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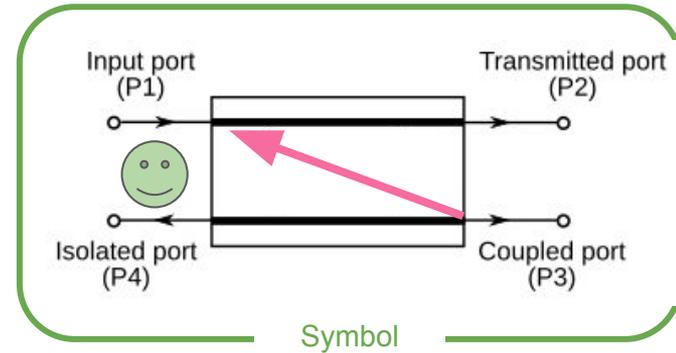
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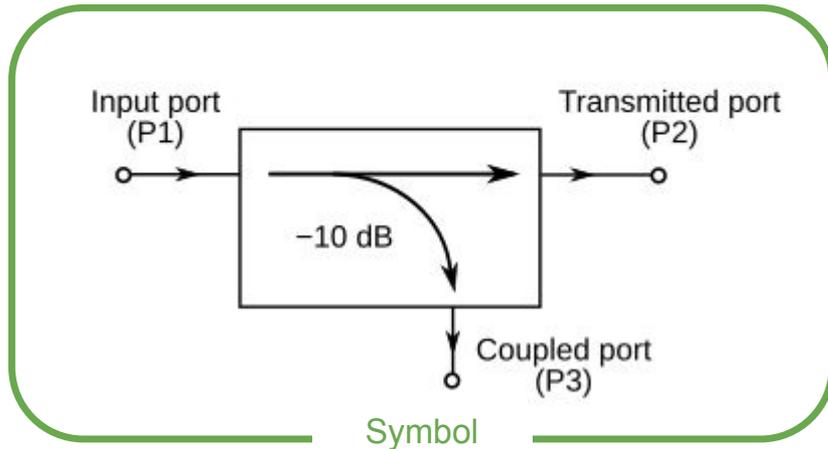
Directional Couplers

- Similar to the diplexer, used to split off or combine signals
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- Usually sold with a terminator permanently connected to the isolated port ($P4$).
- “Directional” in the sense that power from $P1$ goes to $P3$, but not $P4$. However, power into $P3$ will go through to $P1$.



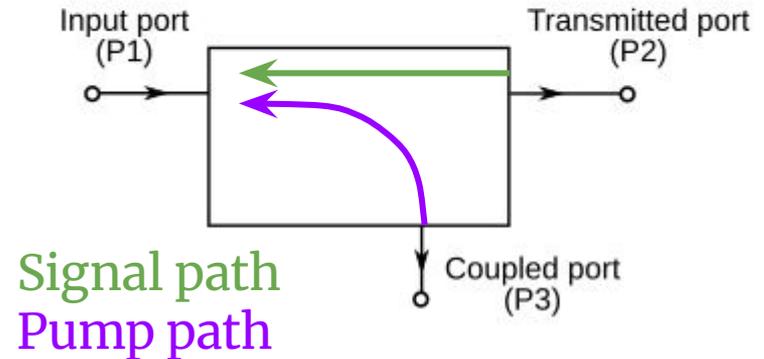
Directional Couplers – pump connections

This is a variant on the symbol, since P4 is often terminated.



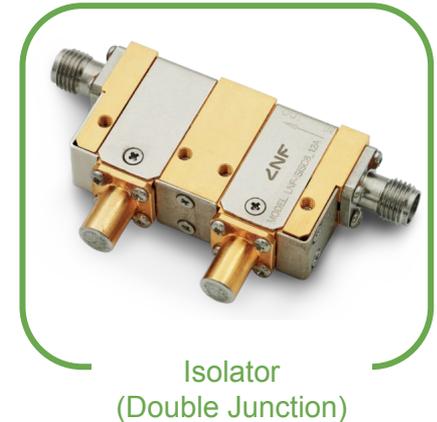
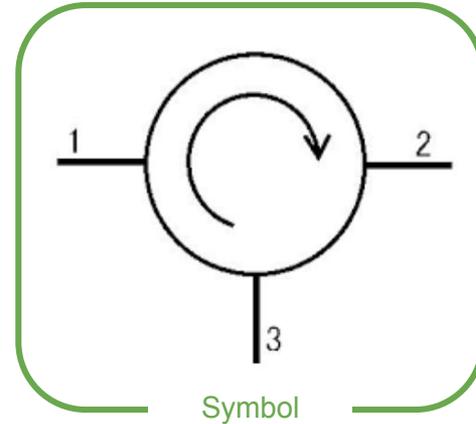
Beware!

The arrows are reversed if you want to couple power *in*, rather than out.



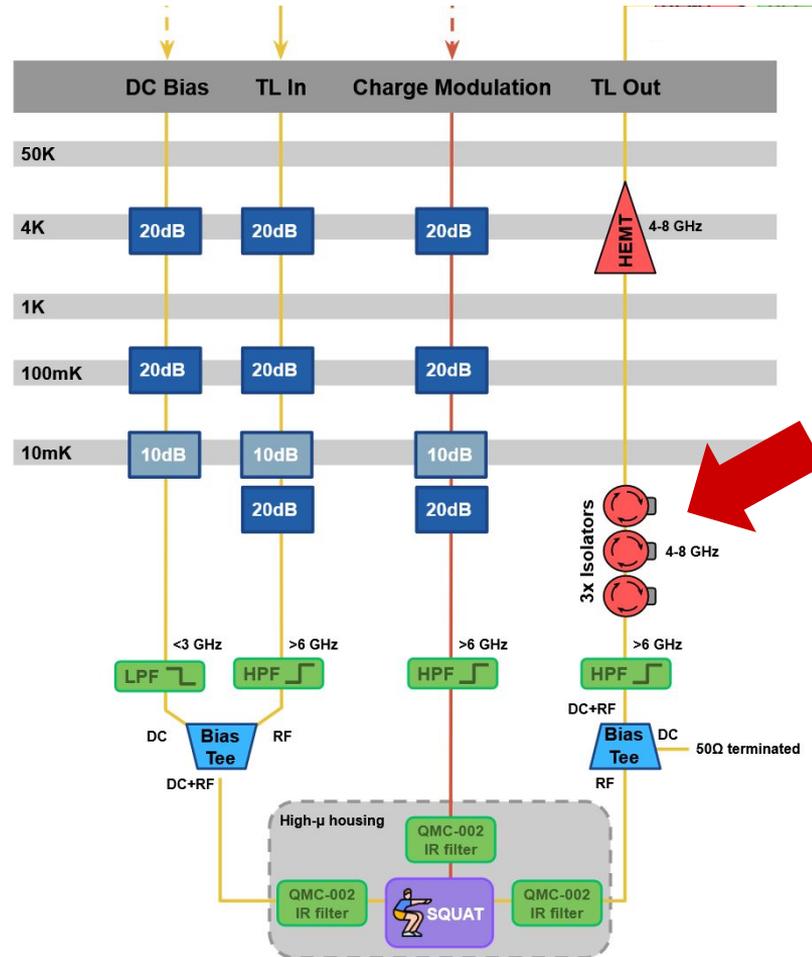
Circulators & Isolators

- Incoming signals transmitted to the next port number only
- Useful for isolation (suppress standing waves) and to turn a reflective device like a JPA into a through-line device (in port 1, bounce off 2, out port 3)
- Can be sold with a terminator permanently connected to port 3 as an “isolator,” even cascaded
- Contain magnets, so are often shielded to protect sensitive devices



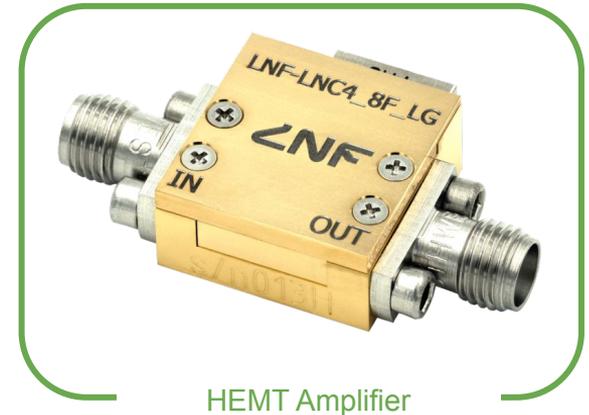
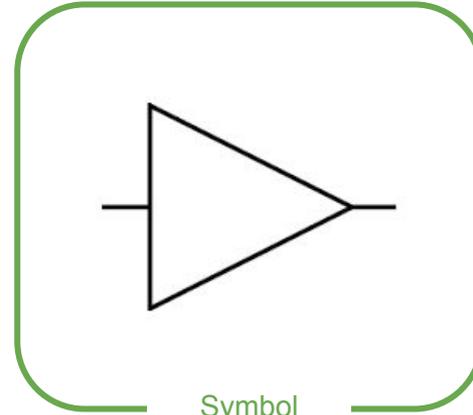
Circulators & Isolators

- Using LNF triple-junction isolators between the device and the HEMT
- Using LNF-provided magnetic shielding



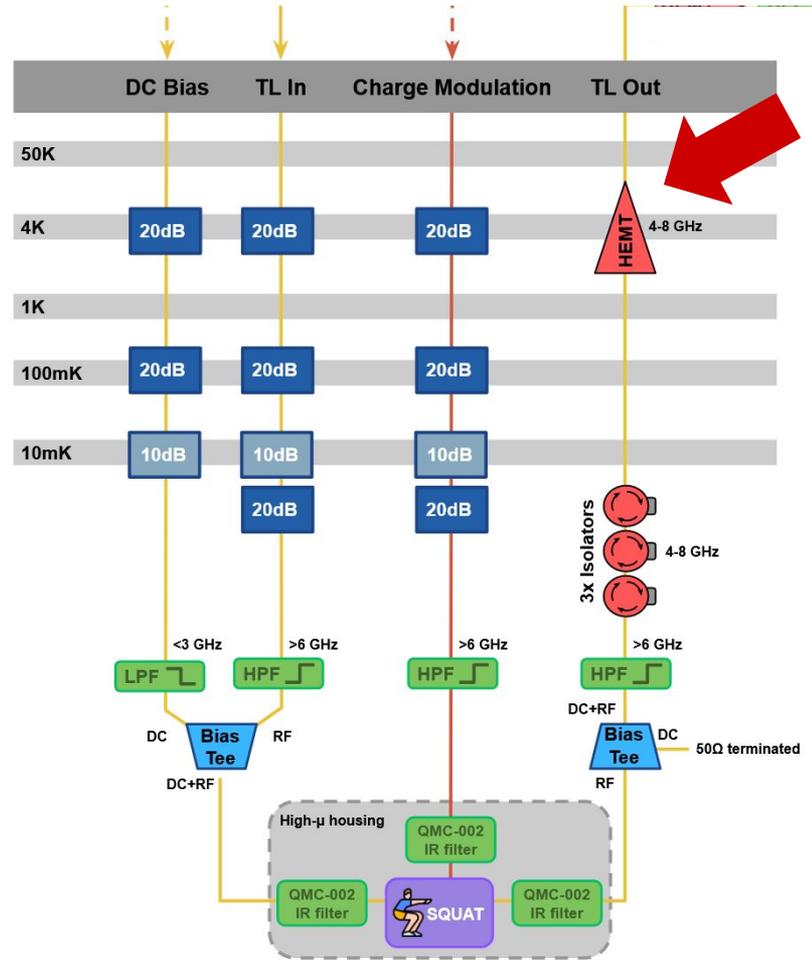
Amplifiers

- Amplify the signal so it is detectable by 300 K electronics
- The first stage of amplification is usually a HEMT at 4K
- Must be DC biased to a given operating current
- Highly sensitive to voltage spikes (ESD, bad grounding)
- Amplifiers are characterized by noise temperature (as if Johnson noise). HEMTs have $T_N \sim 1.5 \text{ K}$



Amplifiers

- Using the LNF 4-8 GHz HEMT
- An additional room-temperature amplifier is not shown



Thank You!

And Discussion..?

