Federal Agency for Cartography and Geodesy

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Wir geben Orientierung.

Cryogenic systems and receiver maintenance

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Content

The following topics will be covered and partly demonstrated by video

- Introduction
- Topology of a cryogenic system
- Basic maintenance: Adsorber change (Video)
- Top level design characteristics
- Basic maintenance: Cold head exchange (Video)
- Basic maintenance: Purging the helium circuit (Video)
- Important practical suggestions

Introduction

Why receiver noise temperatures are important?

The power of the incoming signal (measure in units of Jansky $[10^{-26} \frac{W}{m^2 \times Hz}]$
from the astronomical radio source is by far much smaller than the noise contribution from:

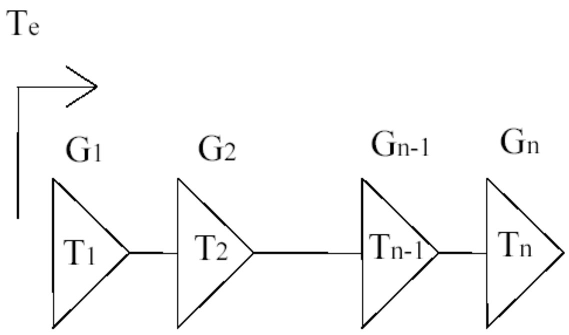
- Receiver
- Environment (antenna side lobes, spill over)
- Atmosphere

First amplifier element of the receiver signal path contributes a significant amount to the system noise power

Solution:
Cooling down to cryogenic temperatures (10's of K) lowers the self-generated noise of the amplifier element significantly

Introduction

Receiver noise factor is dominated by the first amplifier



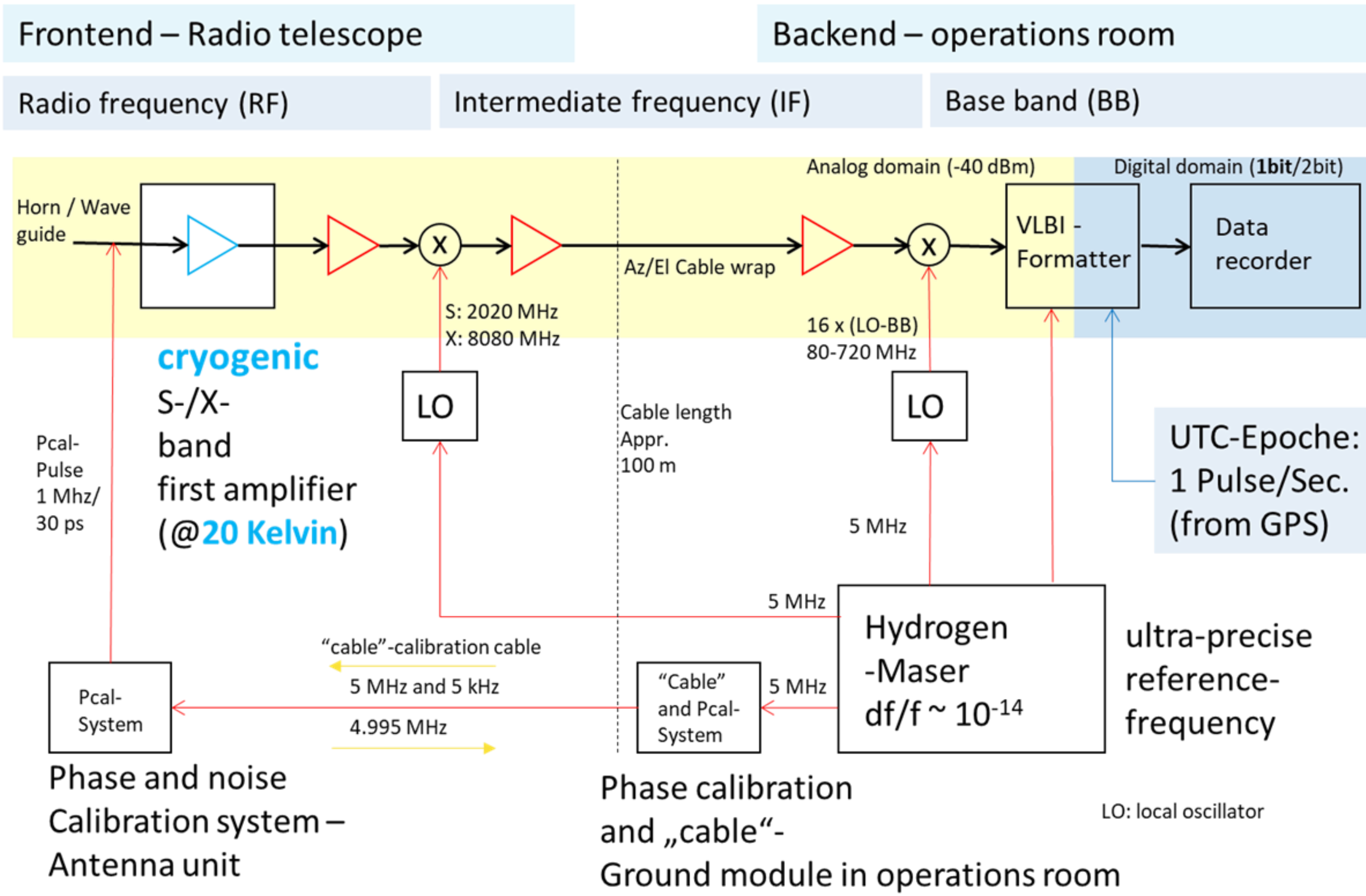
Friis formula for noise temperature:

$$T_E = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 * G_2} + \cdots + \frac{T_n}{G_1 * G_2 \dots G_{n-1}}$$

- Usage of Hyper Electron Mobility Transistor (HEMT) amplifiers enables very high bandwidth (> 10 GHz)
- Example: Cooled LNA: 15 K (@20Kelvin) versus 150 K (@300K)

➔ Keeping scheduled system equivalent flux density (SEFD) only with cryo-cooled LNA possible. Otherwise degradation of VLBI observation (SNR targets, number of scans, …)

VLBI block diagram, legacy S-/X-band system



Topology of a cryogenic system

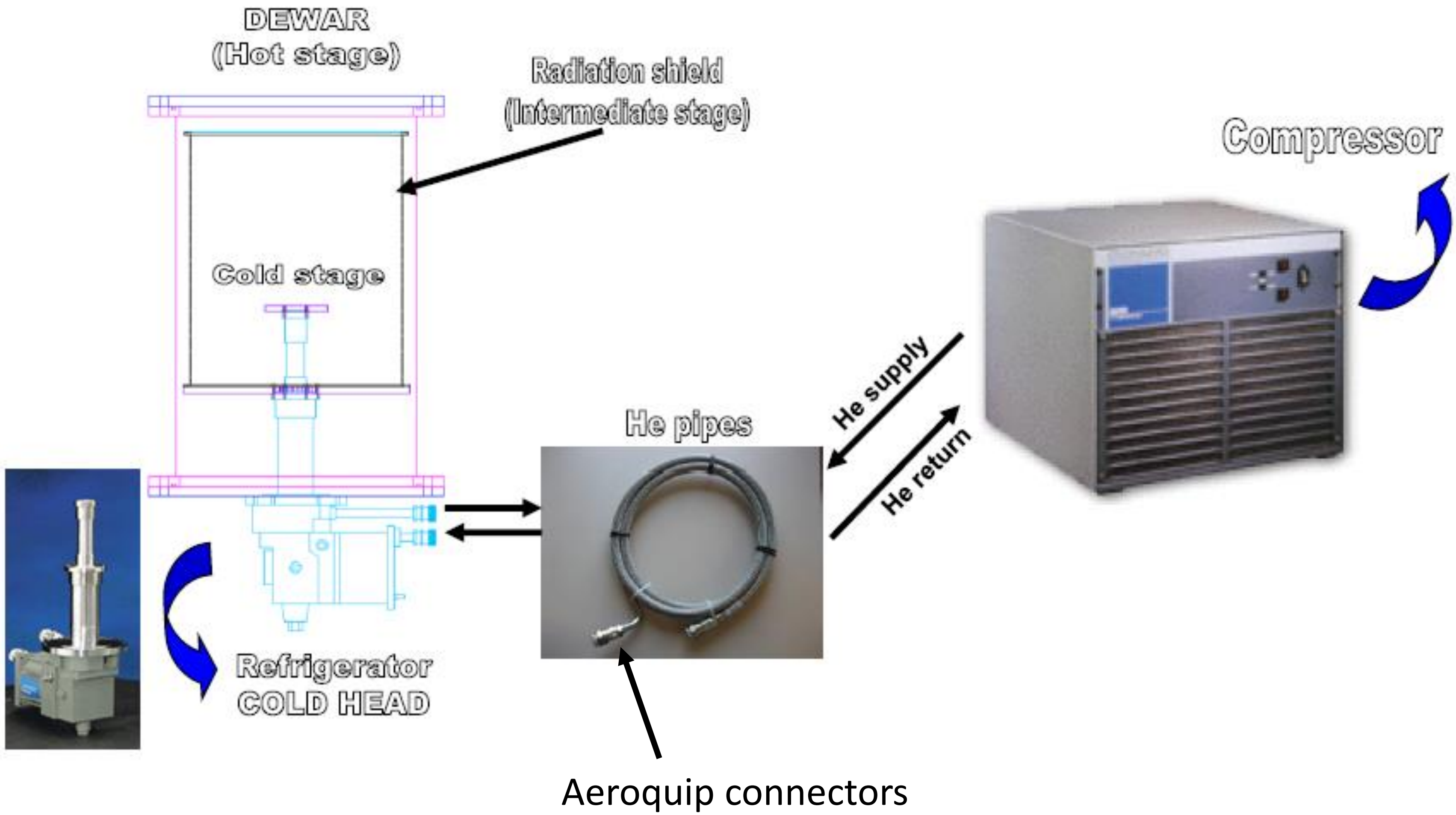
- Atmospheric gases (N, O_2) freeze at higher temperatures as the nominal operation temperature below 20 K. Helium gas as refrigerating medium used

- In general, a cryogenic system consists of a helium compressor, interconnecting high-pressure hoses, cold head (or cryo-cooler), vacuumized Dewar and related interconnecting cables

- The helium compressor compresses the helium gas, extracts the additional heat by compression (heat exchanger) and raises the operating pressure of the helium gas supply to the cold head

- The helium gas moves from the compressor (high pressure or supply side) through the hoses to the cold head and flows back via the return line to the compressor. Thus, a closed helium gas circuit is constituted

Topology of a cryogenic system



Topology of a cryogenic system

Important for operation and maintenance:

- Correct Helium pressure range
- Ambient temperature range
- Replacement of Adsorber (typically after 1 year of permanent operation)
- Helium flex lines with areoquip connector in a good and clean condition
- Cooling fan works and is clean

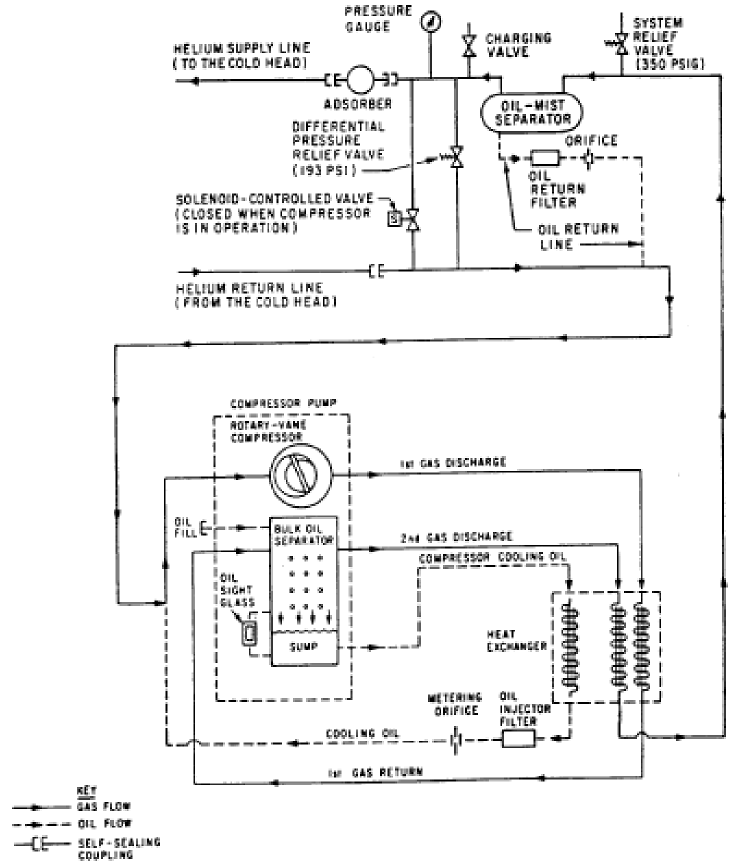
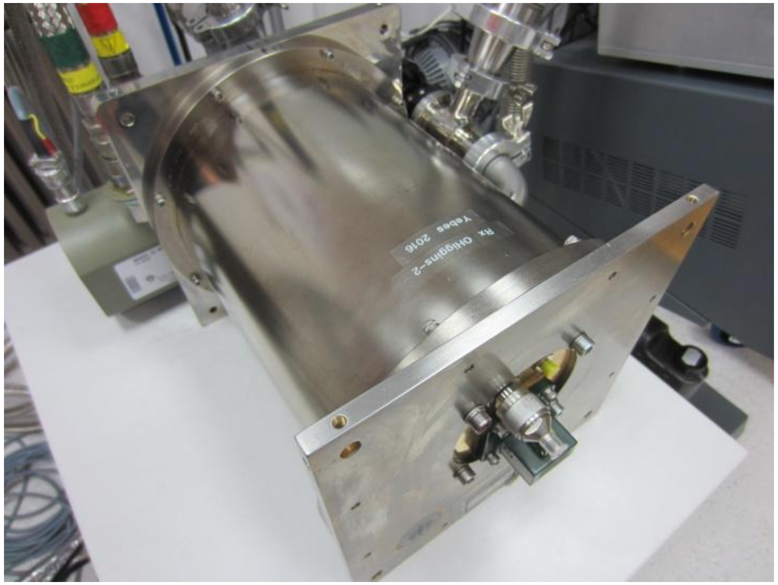


Figure 6-5: Flow Diagram of the 8200 (Air-Cooled) Compressor

Topology of a cryogenic system

In order to reach cryogenic temperatures, a vacuum chamber (Dewar), containing the LNA and related high frequency components, is evacuated to a very low pressure and a closed cycle cryo-cooler is used to remove the heat. The cryo-cooler acts as a cryo-pump, i.e. gas diffused inside is frozen and does not contribute to a rise in pressure level.



Example: VLBI station GARS O‘Higgins Dewar

Topology of a cryogenic system

Types of cryostats:

- Closed cycle:
  Using cold heads (He gas, 70K and 20K)
- Open cycle:
  (Liquid N: 77K, liquid He: 4K)
- Hybrid: „cold head“ + liquid He filling:
  0.35 K with He-3

For VLBI application:
Gifford McMahon (GM) cryo-cooler:

- Widely used for cryo-cooling
  the first LNA stages (as well as other RF components, e.g. filters, 90° hybrids)
- Temperature reached: < 20K

Design characteristics

Most important: **Cooling capacity**

Thermal conduction and radiation loading at the intermediate and cold stage

Convection is negligible, if pressure is better than 10^{-5} mbar

Total cooling power:

$$Ptot = Pcond + Prad + Pgas + Pdiss$$

- *Pcond*: thermal power transmission by solid material
- *Prad*: thermal power transmission by thermal radiation
- *Pgas*: Thermal power transmission by gas medium
- *Pdiss*: Electrical power induced by active electronic components (LNA)

Design characteristics

Thermal load due to conduction: $P_{cond} = \frac{A}{l} * \lambda * (T_2 - T_1)$

- A : cross section area of the conducting element
- L : conducting element length
- λ : Thermal conductivity of the material

  (between T_2 and T_1)
- T_2 : Hot stage temperature
- T_1 : Cold stage temperature

Conclusion:

Material selection with low thermal conductivity, small cross section and sufficent length (e.g. stainless steel, phosphor-bronze wire)

Design characteristics

Thermal load due to radiation: $\text{Prad} = \text{Fe} * \text{FF} * \sigma * A_1 * (T_2^4 - T_1^4)$

- Fe : Emission factor [$\varepsilon_1, \varepsilon_2$: emissivity of the surfaces

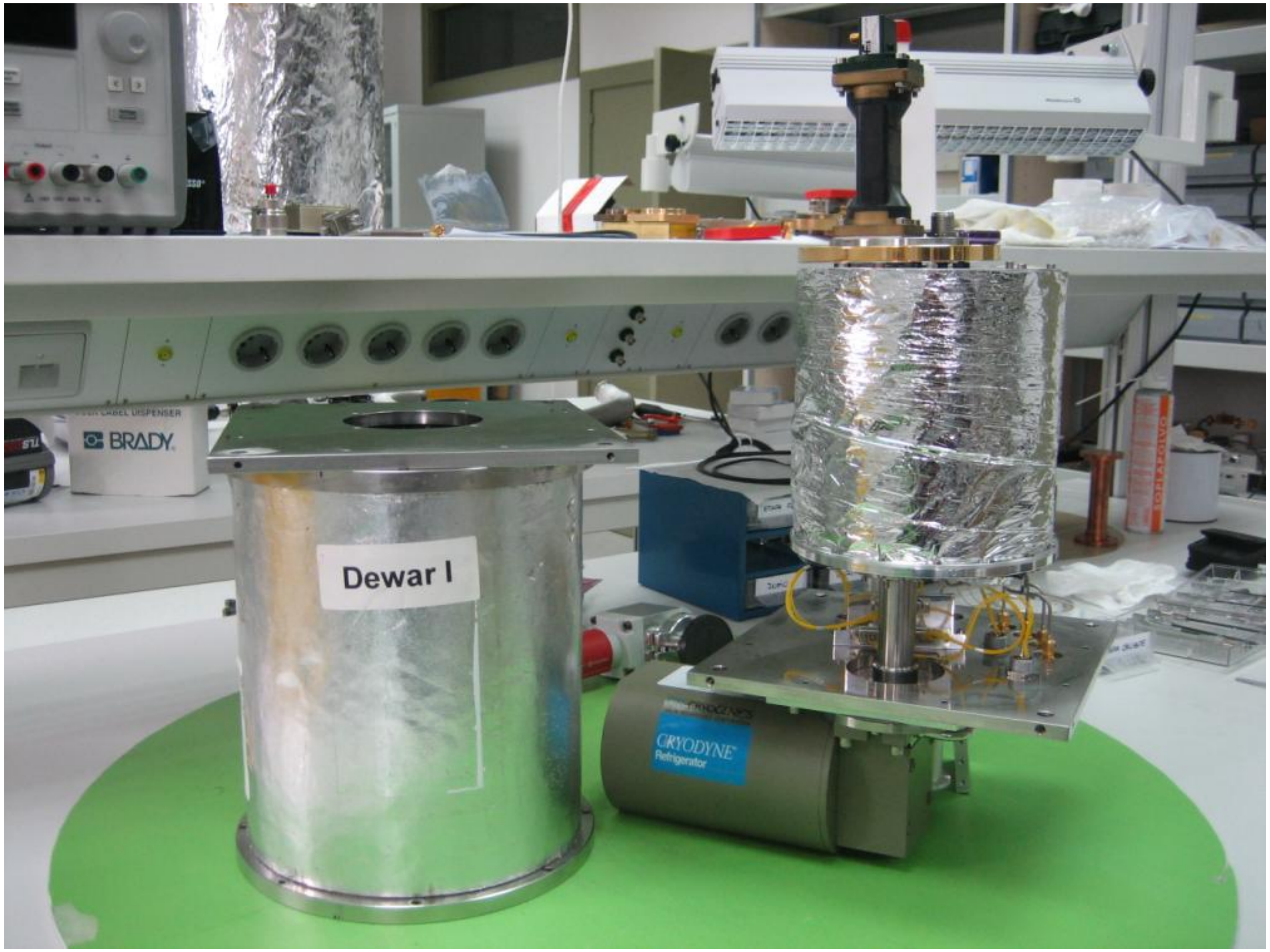
  (effectiveness in emitting energy as thermal radiation)]
- FF: Configuration factor (depends on geometry)
- σ: Boltzman constant
- T2: Hot stage temperature
- T1: Cold stage temperature
- A1: Area of inner surface
- A2: Area of outer surface

Conclusion: Polished surfaces with low emissivity of the surfaces, use of radiation shields

Design characteristics

Example:

- 20 m RTW Wettzell Dewar with removed outer cylinder.
- The radiation shield is visible (very thin metallized coated film)



Cold head replacement

If cold head fails or cold head reached operational lifetime (>2 years) the **preferred option** is to exchange the complete coldhead displacer cylinder or you can dismantle the coldhead displacer from the cylinder:

Important!
Delicate task. Working with gloves (e.g. Nitril). Avoid finger prints (grease contamination).

Demonstration Video:

1. Attach the charging adaptors to both helium ports.
2. Open both adaptor valves to discharge the pressure from the refrigerator. Remove charging cylinder.
3. Remove the four #10 Hex head screws securing the refrigerator to the cylinder and withdraw the refrigerator, thus removing the displacers from the cylinder.
4. Perform steps 1 through 3 on the replacement unit.
5. Carefully place the second stage seal suppressor over the seal on the replacement unit.

Basic maintenance, repair and replacement of Cryogenic parts cold head replacement

6. Clean the inside of the cylinder in the Dewar with a suitable solvent (petroleum ether is preferred, however, alcohol can be used). Make sure that the cylinder is completely clean and dry before proceeding.
7. Clean the “O” ring grove on top of the cylinder and install a new “O” ring coated very lightly with apiezon grease.
8. Carefully insert the displacers into the cylinder until the crosshead mates with the cylinder and bolt in place using a crossed pattern tightening procedure which insures that the bolts are tightened evenly.
9. Perform steps 1 through 6 of the system purging procedure.

Maintenance - Purging and pressurization procedure

Once this procedure is performed the helium gas contained in the compressor, hoses and refrigerator will be of the high purity
(better than 99.999%, Helium 5.0)
Read your manual of your cold head and compressor!

Example procedure:

1. In order to get a successful purge of the system the helium lines must be removed from the refrigerator when the system is as cold as possible. Trapping the contamination in the refrigerator. Disconnect while running the supply line and then immediately the supply line to the compressor.
2. Allow the refrigerator to warm to room temperature before proceeding.
3. Attach purging and charging adaptors to both the supply and return helium lines on the refrigerator.

Maintenance - Purging and pressurization procedure

4. Attach a regulated supply of ultra pure helium to the charging adaptor on the supply side of the refrigerator and adjust the regulator pressure to 50 PSI.
5. Apply electrical power to the refrigerator by attaching the cable from the compressor and turning on both switches on compressor.
6. Open the valves on both charging adaptors and allow helium to flow through the refrigerator for at least one minute.
7. Close the exhaust valve on the return side of the refrigerator and allow the pressure in the refrigerator to equalize.
8. Close the valve on the supply side of the refrigerator, the supply valve on the helium tank and remove the charging adaptors.
9. Return the normal helium line connections to the refrigerator and begin a normal cool down cycle as the refrigerator is now ready for use.

Important rules

- Make sure that the Helium gas is of highest necessary purity
- Observe rigorously the purging procedure for all gas connections and manifolds used when connections are made
- Keep gas and vacuum fittings clean
- Dirt (e.g dust, hairs, fibres, other debris) on connectors and vacuum surfaces could cause leaks and malfunction
- Use dust caps or similar always to protect open connectors and fittings
- Before assembly inspect visually connectors and fittings
- Clean the connectors and fittings with lint-free material wipes
- Wear gloves (e.g Nitril gloves) when handling vacuum exposed surfaces and cryogenic components
- Avoid surface contamination

Important rules

- Never break a vacuum isolation (most probably unintended opening of the vacuum valve) of a cold system (could cause mechanical breaks)
- Store a Dewar under vacuum condition (prevent exposition to oxygen)
- The vacuum valve of the Dewar should never be touched unless the vacuum pump is connected (prevent steep rise in pressure)
- Start up the vacuum pump before opening the valve

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Thanks for your kind attention!

Questions?

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