Bundesamt für
Kartographie und Geodäsie

Cryogenic Systems and Receiver Maintenance

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Objective

Provide basic knowledge of a typical Cryogenic system with a low noise receiver used in geodetic VLBI

- Why a low noise receiver is required
- Cryogenic system necessary to operate amplifiers in low noise operating region
- Operation and maintenance of low noise receiver
- Practical suggestions for maintaining cryogenic low noise receivers

Agenda

The following topics will be discussed:

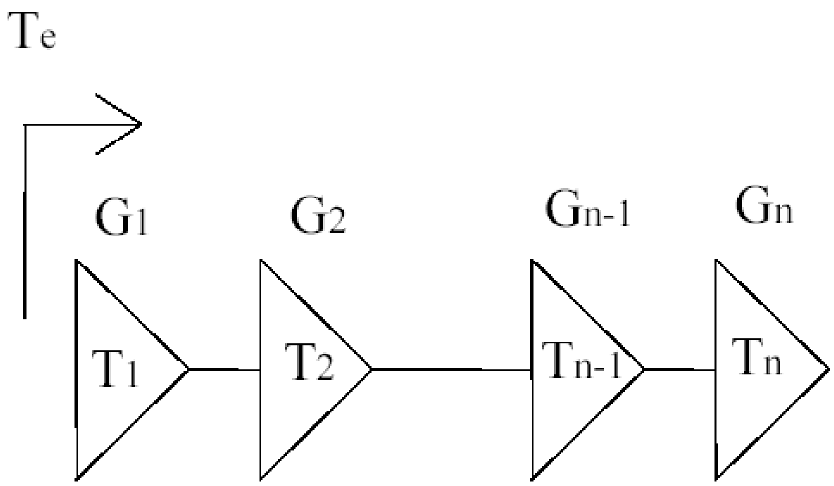
- ✓ Why accurate measurements of receiver noise temperatures are important
- ✓ Noise diodes and calibration of the receiver system
- ✓ An overview of the Cryogenic system within the VLBI system
- ✓ Basic maintenance, repair and replacement of Cryogenic parts

Introduction

Why receiver noise temperatures are important?

- The incoming signal from the astronomical radio source is much smaller than the noise from:
  - Receiver
  - Background
  - Atmosphere
- First amplifier element of the receiver signal path contributes the greatest amount of the system noise power

Introduction
Cascaded amplifiers – Signal to noise ratio



Friis formula for noise temperature:

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

Introduction
Cascaded amplifiers – Signal to noise ratio

- Receiver noise factor is dominated by the first amplifier
- Usage of HEMT amplifiers
- HEMT: Hyper Electron Mobility Transistor
- Very high bandwidth possible

Introduction
LNA

- By using cryogenic HEMT LNA’s we achieve the lowest receiver noise contribution,
  e.g. 15 K (@20Kelvin) versus 150 K (@300K)
- Extremely low power levels of received signal, a small percentage of the receiver noise contribution
- The typical LNA used in VLBI and Radio Astronomy usually detects broad band Gaussian noise signals from very distant sources such as quasars

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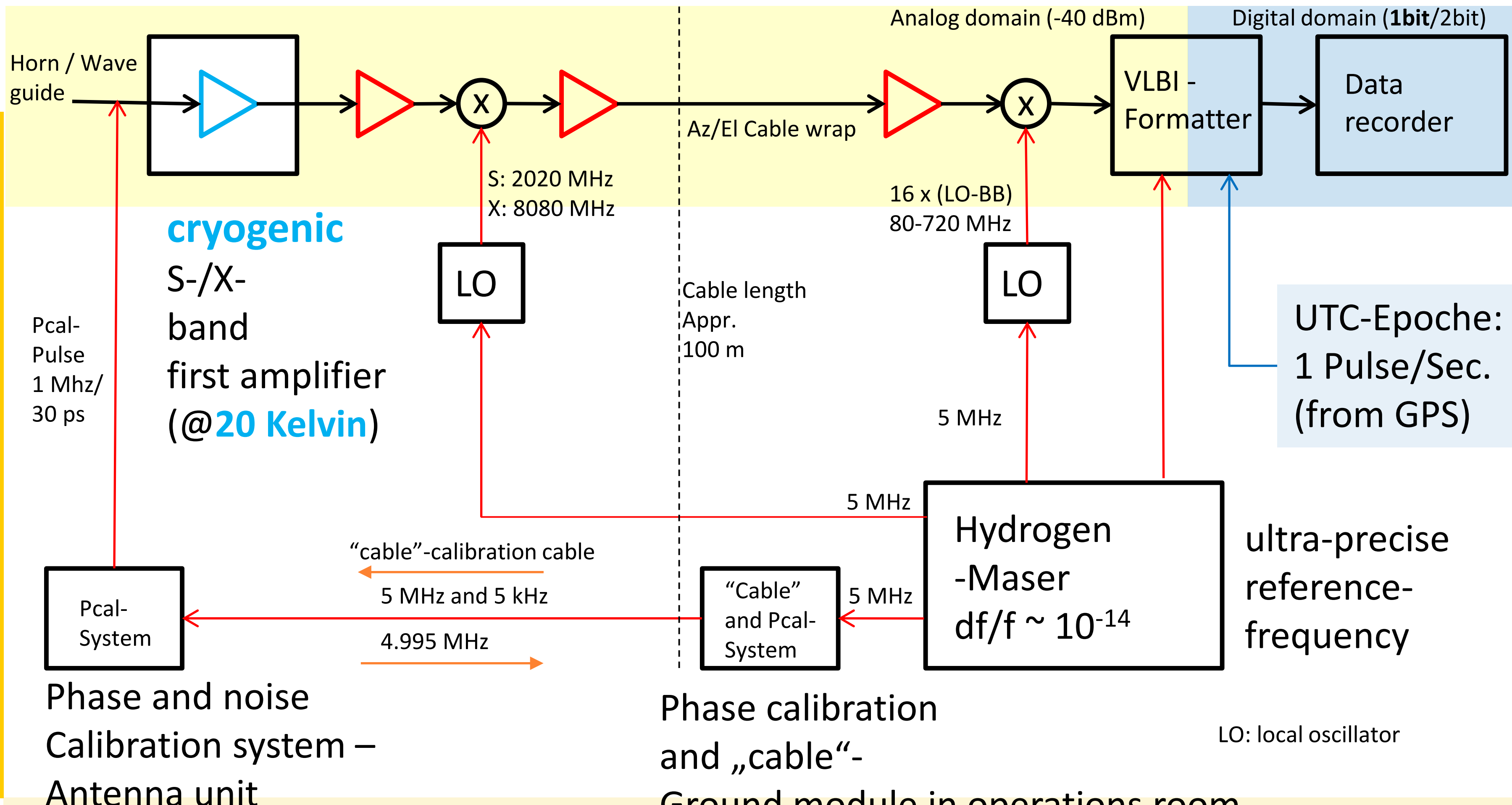
VLBI Scheme
Analog S-/X-band System

Frontend – Radio telescope | Backend – operations room

Radio frequency (RF) | Intermediate frequency (IF) | Base band (BB)



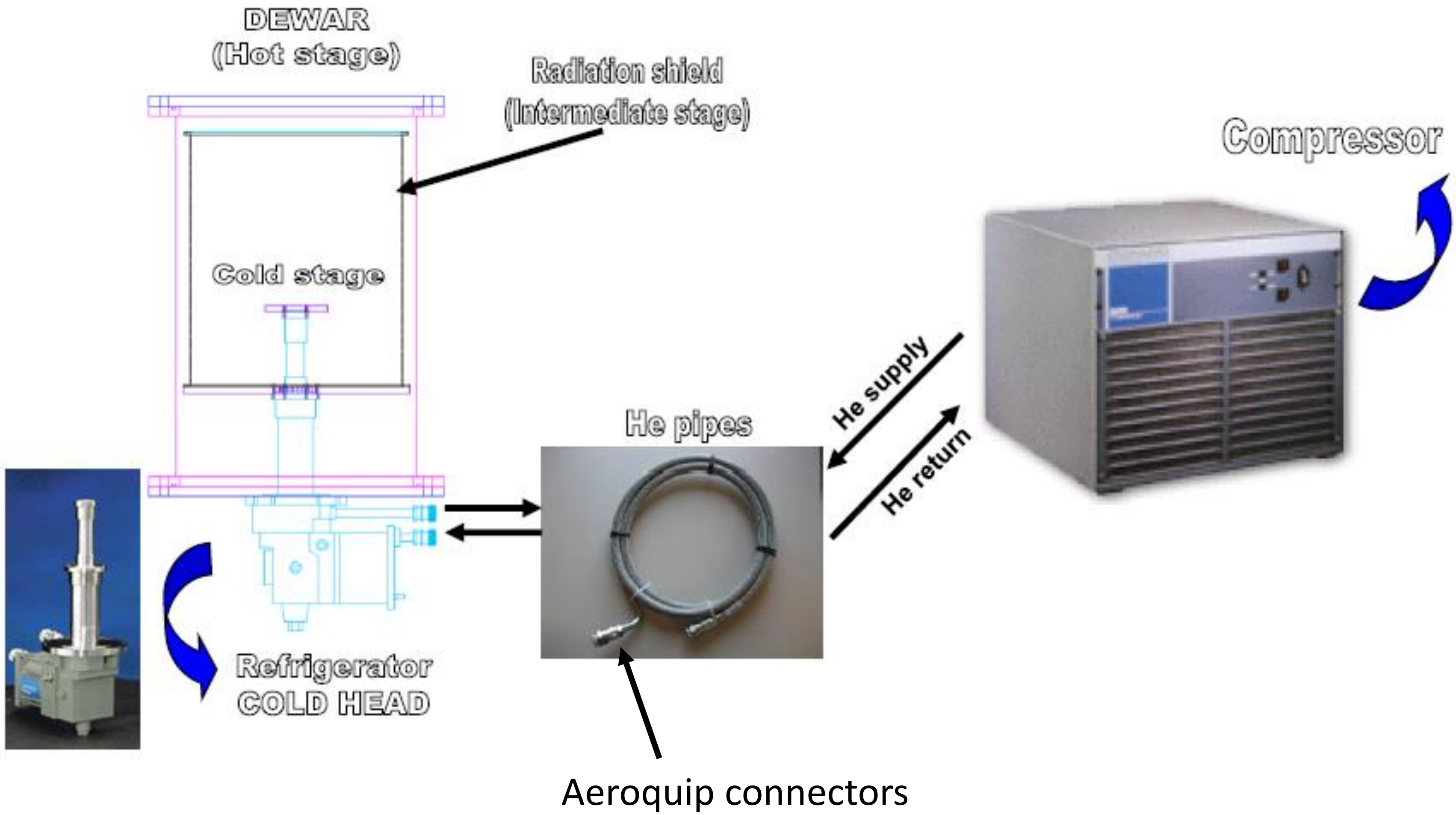
An overview of the Cryogenic system

- Basic cryogenic system consists of a helium compressor, interconnecting high-pressure hoses, cold head / refrigerator, vacuum Dewar and related interconnecting cables
- The compressor compresses the helium gas, extracts the additional heat by compression (heat exchanger) and raises the operating pressure of the helium supply to the refrigerator
- 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

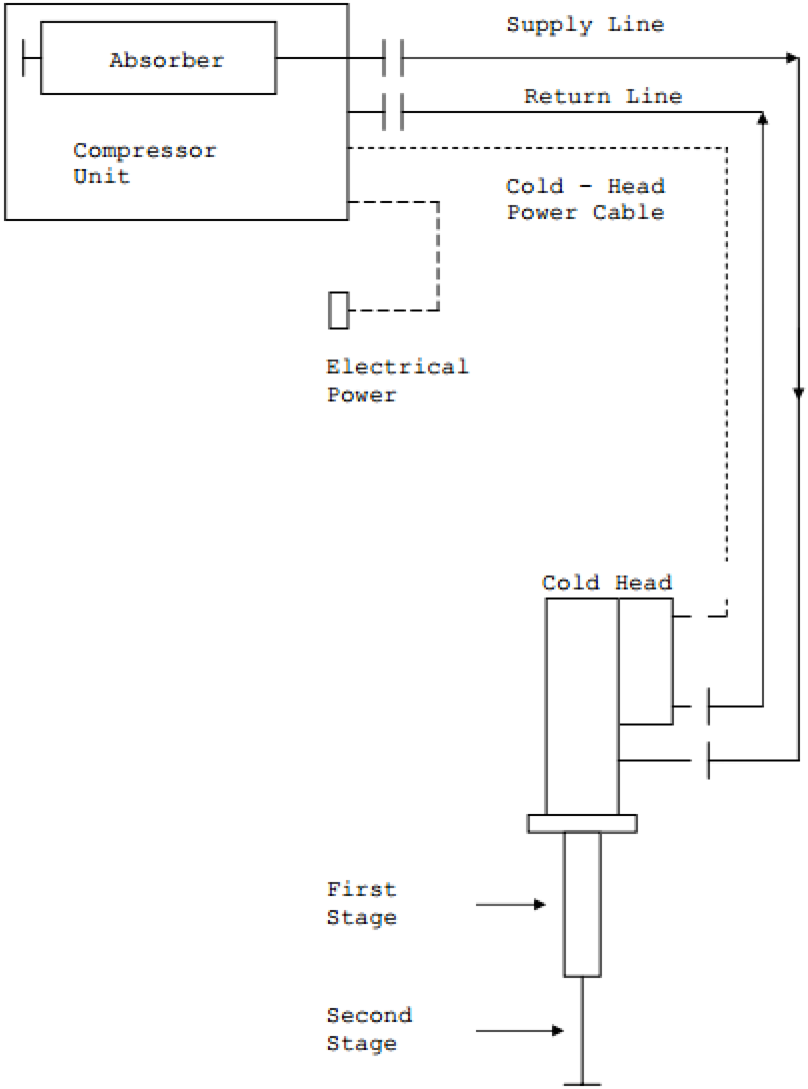
An overview of the Cryogenic system

- The cold head extracts the heat from the Dewar cooling the inner parts of the Dewar to 20 Kelvin
- The standard VLBI Dewar contains the X- and S-band LNA's
- Helium is circulated through the Dewar via cylindrical displacers
- The helium returns to the compressor (low pressure or return side) through lines of the same type as the high-pressure side

Cryogenic System scheme



Cryogenic System scheme



- E.g. Model CTI Brooks 8200:
  - Static pressure 245-250 psig (1690-1725 kPa) within 16 to 38 °C)
  - Nominal operating pressure: 270-290 psig (1860-2000kPa)

Helium compressor

- E.g. Model
  CTI Brooks 8200 (™) used in Wettzell for the 20 m radio telescope:
  - Air cooled
  - Static pressure 245-250 psig (1690-1725 kPa) within 16 °C to 38 °C
  - Nominal operating pressure: 270-290 psig (1860 kPa to 2000 kPa)

Helium compressor

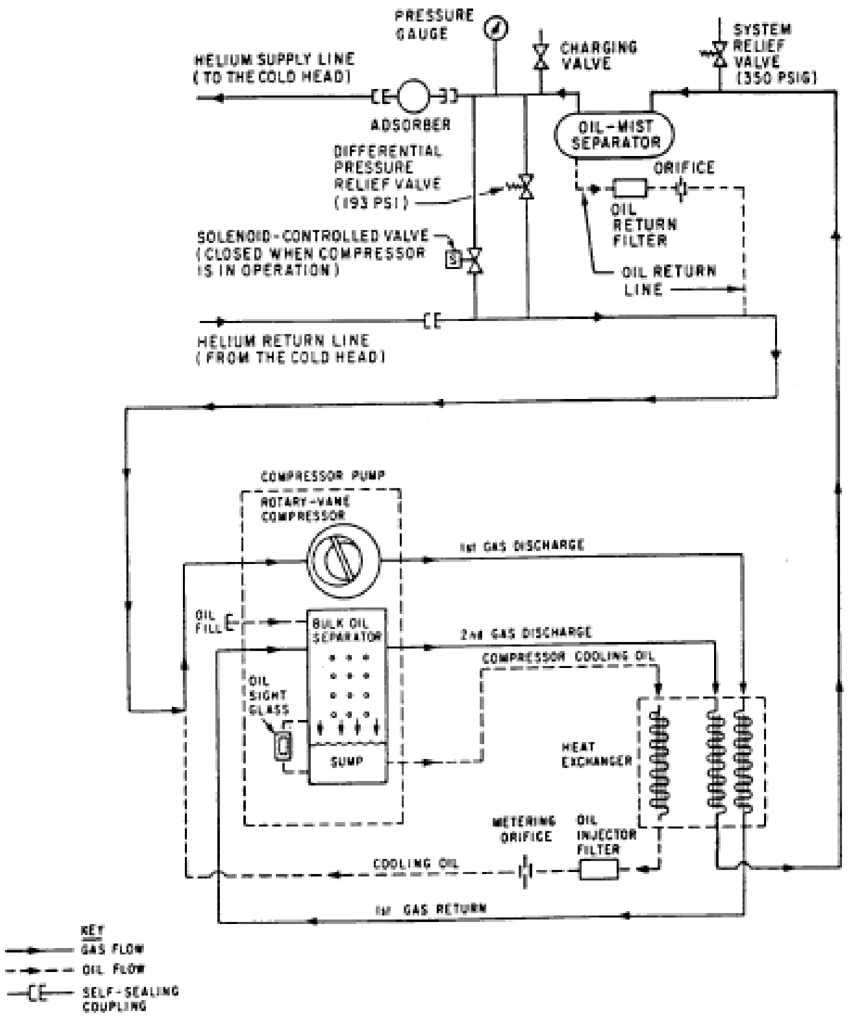
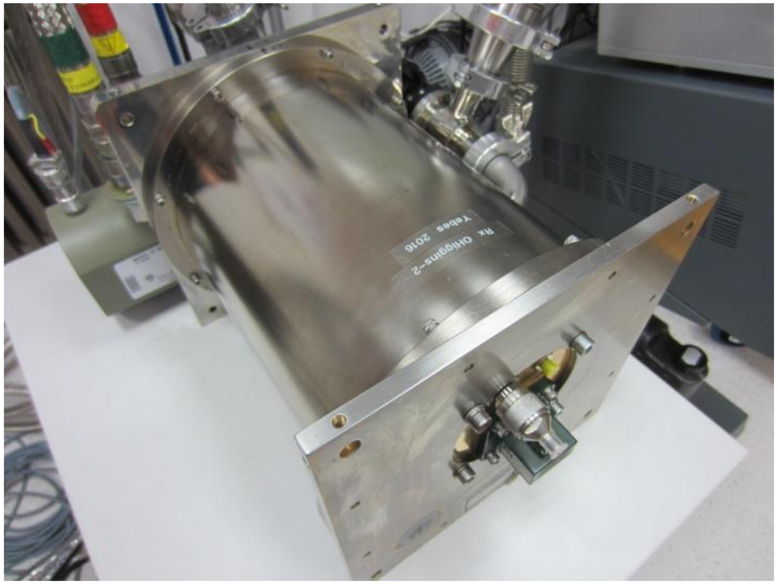


Figure 6-5: Flow Diagram of the 8200 (Air-Cooled) Compressor

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

Cryocooler and Dewar

- In order to reach cryogenic temperatures, a vacuum chamber (DEWAR) containing the receiver is evacuated to a very high vacuum, and a closed cycle refrigerator is used to remove the heat
- Types of cryostats:
  - Closed cycle: Using cold heads (He gas, 77K and 20K)
  - Open cycle: (Liquid N: 77K, liquid He: 4K)
  - Hybrid: „cold head“ + liquid He filling: 0.35 K with He-3



Cryocooler cold head

- Cold head
- Gifford McMahon (GM) coolers:
- Widely used for cryocooling the first LNA stages
- Temperatur reached < 20K

Cryocooler selection

- 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

$$Wtot = Wcond + Wrad + Wgas + Wdiss$$

Cryocooler selection

Thermal load due to conduction

- $W_{cond} = \frac{A}{l} * \lambda * (T_2 - T_1)$
- 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 with low thermal conductivity, small cross section and long. (e.g. stainless steel)

Cryocooler selection

Thermal load due to radiation

- $W_{rad} = Fe * FF * \sigma * A_1 * (T_2^4 - T_1^4)$
- Fe : Emissity factor
- FF: Configuration factor (depends on geometry)
- σ: Boltzman constant
- T_2: Hot stage temperature
- T_1: Cold stage temperature
- A_1: Area of inner surface
- A_2: Area of outer surface
- $\varepsilon_1, \varepsilon_1$: emissivity of the surfaces

Cryostat performance

Most important considerations of the performance of the refrigerator:

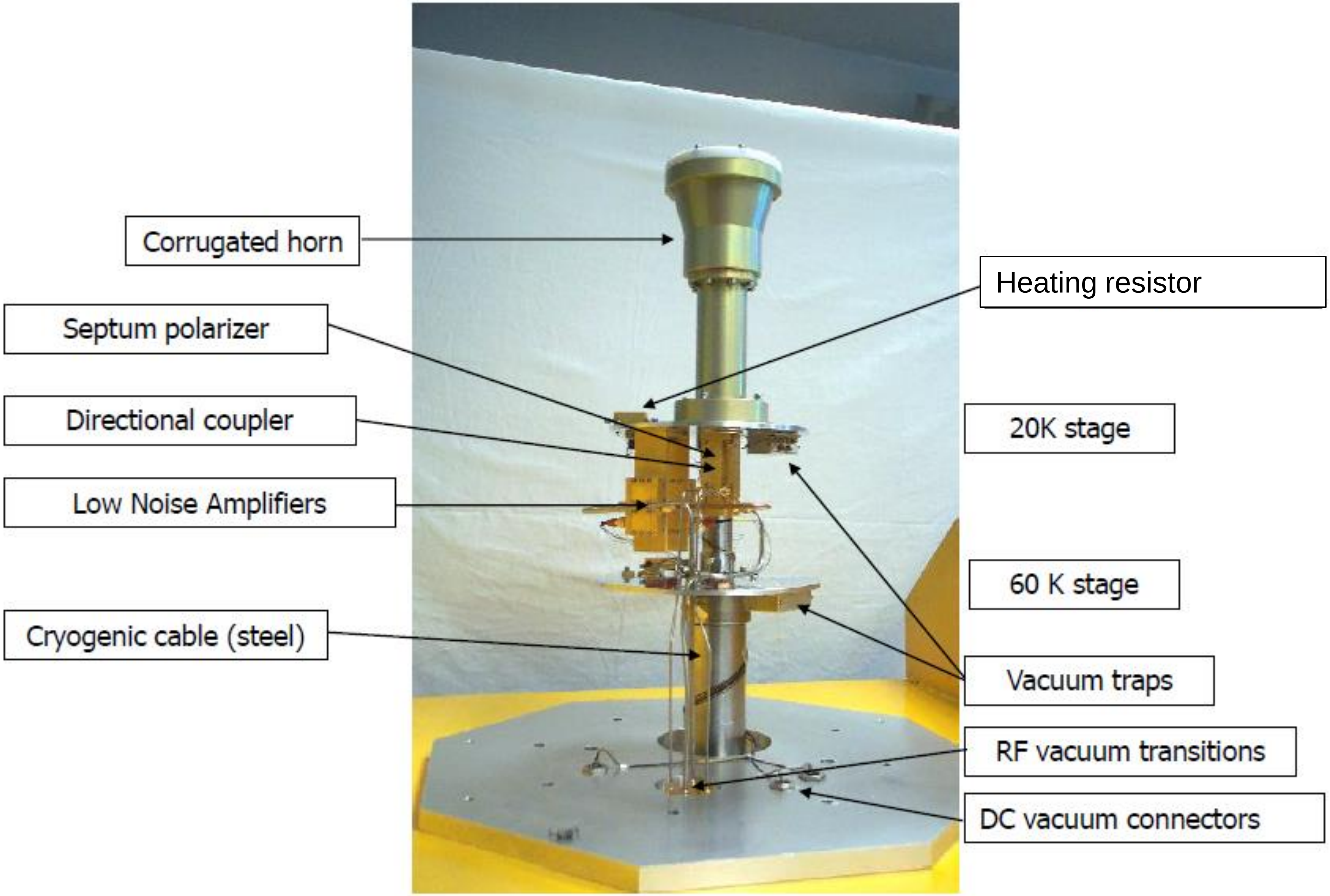
- Temperature reached and maintained
- Degree of vacuum achieved
- Maintainability
- Refrigerator selection, choice of materials for the vacuum chamber walls and internal components, fabrication techniques, cleaning procedures and evacuation procedures are important considerations affecting **reliability**

Dewar scheme

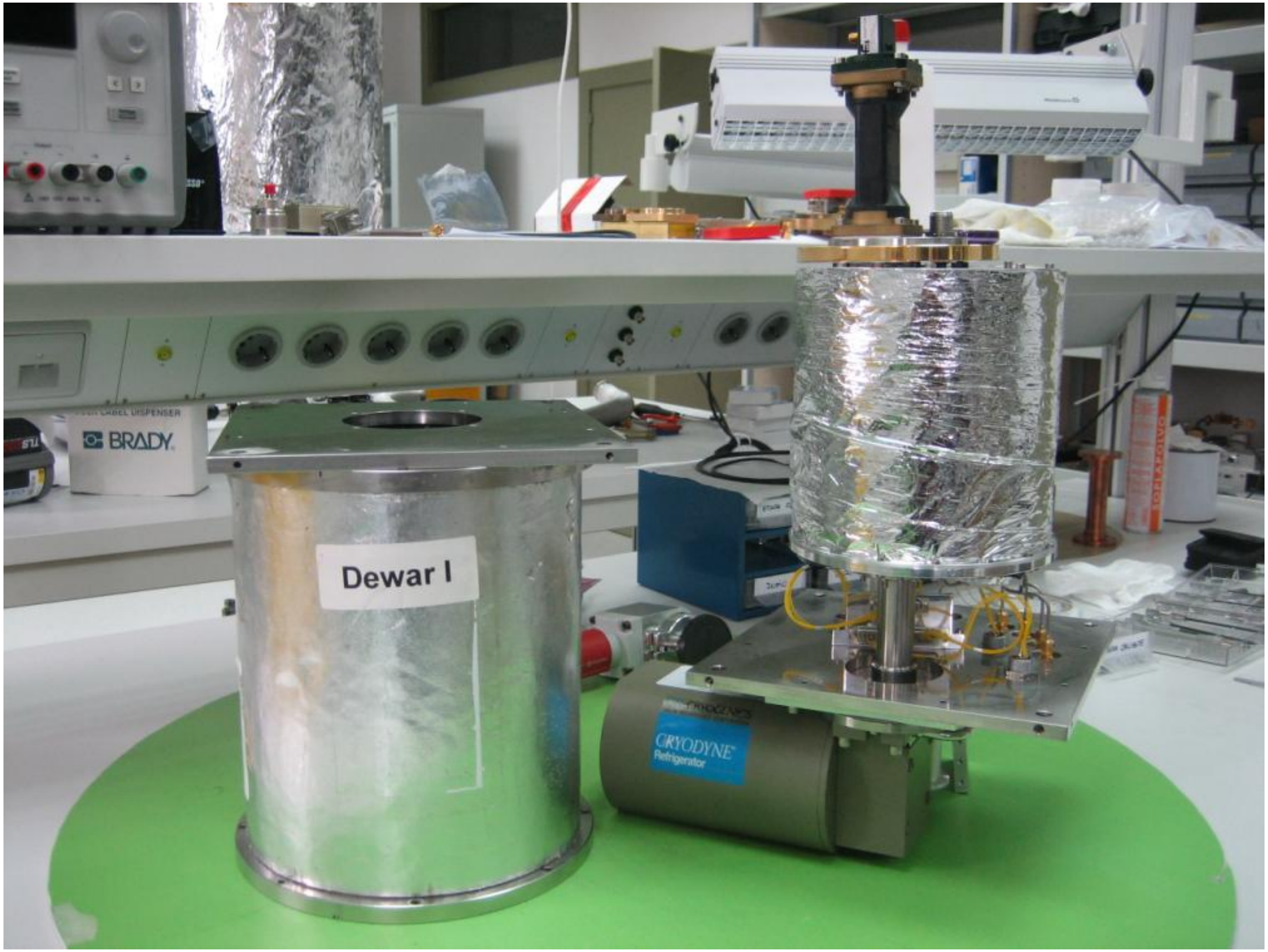
Different elements inside the Dewar:

- ✓ Vacuum window
- ✓ Thermal transition
- ✓ IR filter (blocking thermal radiation from outside)
- ✓ LNA (Low noise amplifier, e.g. for S-Band and X-Band)
- ✓ Directional coupler (for input matching S11)
- ✓ Polarizer
- ✓ Feed horn / Corrugated horn / Waveguides / Hybrids
- ✓ Cables (DC and RF)
- ✓ Housekeeping elements (heaters, vacuum traps, temperature sensors)

Example of internal parts of a Dewar



Example of 20 m Wettzell S-/X-band Dewar



Why receiver noise temperatures are important?

- Each radio source emits power, which is quantified by the unit of measure Flux Unit (FU) and is described as detected rise in system noise power
- Measured in units of Jansky $[10^{-26} \frac{Watt}{m^2 \times Hz}]$
- **System temperature** (**Tsys)** is expressed in **Kelvin (K)**
- Important for VLBI operation as indication that all is fine
- Important for analysis (see e.g. gain calibration)

Noise diodes and the receiver system

- **Noise diodes** provide the standard by which the received flux of an astronomical radio source is compared
- This calibrated noise power from the **Noise diode** is added to the system’s overall detectable power to allow measurement by substitution of the Antenna and receiver noise to provide the accurate measurement and calibration of system temperatures
- This is what is generally called noise calibration (caltsys procedure in the NASA Field System)

Noise diodes and the receiver system

- Methods to inject noise to the receiver:
  - Radiated using another feed in the antenna optics
  - Directional coupler: preferred method (just after the feed, before the LNA. Problem: This has losses and increases T_{rx}

- Two methods for switching the noise diode:
  - Continuously with 80 Hz
  - Switched on and off (e.g. system temperature measurement by the NASA Field System)

Techniques used to measure receiver noise temperature

- There are many methods for measuring receiver noise temperatures. The following technique is both practical and accurate. This is generally called Y factor method.
- This measurement will use a cold sky (a sky with as few noise sources as possible) and an absorber (such as Eccosorb ®).
- The sky will provide the cold reference ~3K while the absorber acts as a hot termination of ~290K.

Techniques used to measure receiver noise temperature

The procedure for calibrating the receiver is as follows:

- Point the receiver feed straight up at the sky (zenith angle) or use an aluminum reflector about 1 meter square at a 45 degree angle to reflect noise from the cold sky into the feed.
- The angle should be adjusted to give the lowest possible power output from the receiver IF).

Cold-sky-ambient aperture load noise measurement system

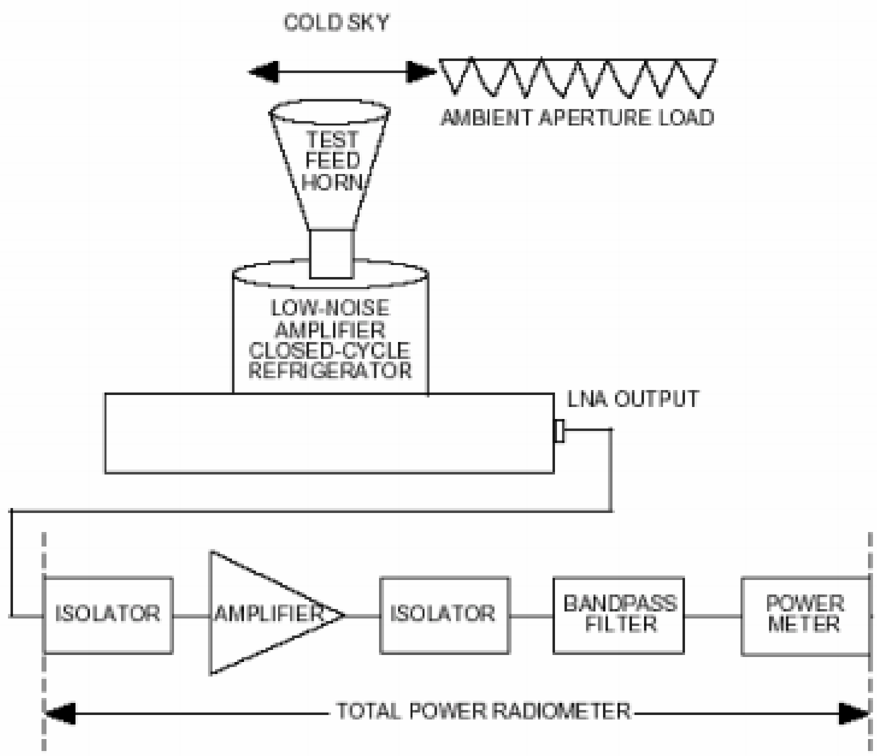


Figure 1. Cold-sky-ambient aperture load noise measurement system.

Steps: Cold-sky-ambient aperture load noise measurement system

1. $Y\ (dBm) = P_{hot}\ (dBm) - P_{cold}\ (dBm)$

2. $Y = 10^{(\frac{Y}{10})}$

3. $T_{rx}(K) = \frac{(Th - Y * Tc)}{Y - 1}$

- Where T_{rx} is the receiver noise temperature
- Tc is the temperature in Kelvin of the cold sky, about 10 Kelvin for a clear sky and about 20 Kelvin for an overcast sky

Would you like to read more about it?

An excellent discussion of Noise Temperature Measurements may be found in the

IPN Progress Report 42-154. Authored by C. T. Stelzried, R. C. Clauss and S. M Petty

Link:

https://ipnpr.jpl.nasa.gov/progress_report/42-154/154G.pdf

The importance of Cryogenics in receiver systems

- Noise contributed by internal noise of the Low Noise - Amplifier (LNA) can be greatly reduced by cooling the LNA to an low physical temperatures.
- Thermal-Electric cooling can obtain 230 K.
- To make real gains in performance the use of cryogenic Gifford McMahon cryocooler cycle will lower the operational temperature of the LNA to 20K.
- The overall effect of the cryogenic cooling is a >10 fold improvement in system temperature and thus system sensitivity.

Sources of Cryogenic parts

Examples of cryogenic suppliers:

- http://www.trilliumus.com/cryogenics.html
- This Company is a supplier of CTI cryocoolers and compressors.

- http://www.shicryogenics.com
- This Company is a supplier of cryogenic equipment (e.g. Sumitomo cold head and compressors)

Basic maintenance, repair and replacement of Cryogenic parts Refrigerator 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, grease where necessary. You need some experience! When opening the cold head from cylinder there may lead dust be freed up!

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 Refrigerator 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.

Refrigerator 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.

Refrigerator 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.

Resulting benefits from this presentation

From this presentation you should have a better understanding of the following:

- ✓ Noise temperature and it’s relevance to the VLBI receiving system
- ✓ Procedures for calibration of the noise diodes
- ✓ Procedures for the calibration of the receiver
- ✓ The use of cryogenics in the receiver system
- ✓ Procedures for replacing the refrigerator
- ✓ Procedures for purging the pressurizing the refrigerator

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 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

Very important:

- Never break a vacuum isolation of a cold system
- Always store a Dewar under vacuum condition

- Vacuum valve of the Dewar should never be touched unless the vacuum pump is connected
- Start up the vacuum pump before opening the valve
- If the vacuum is lost by accident connect the vacuum pump as soon as possible and pump the Dewar until the temperature is above 293 Kelvin
- Do not disturb the installation more than necessary
- Repeated disconnection and re-connection of gas may lead to gas loss and possible contamination

Thanks for your Attention!

Questions?

Please email to: **christian.ploetz@bkg.bund.de**