Cryocooler development, use in RF applications

Thales Cryogenics, Eindhoven
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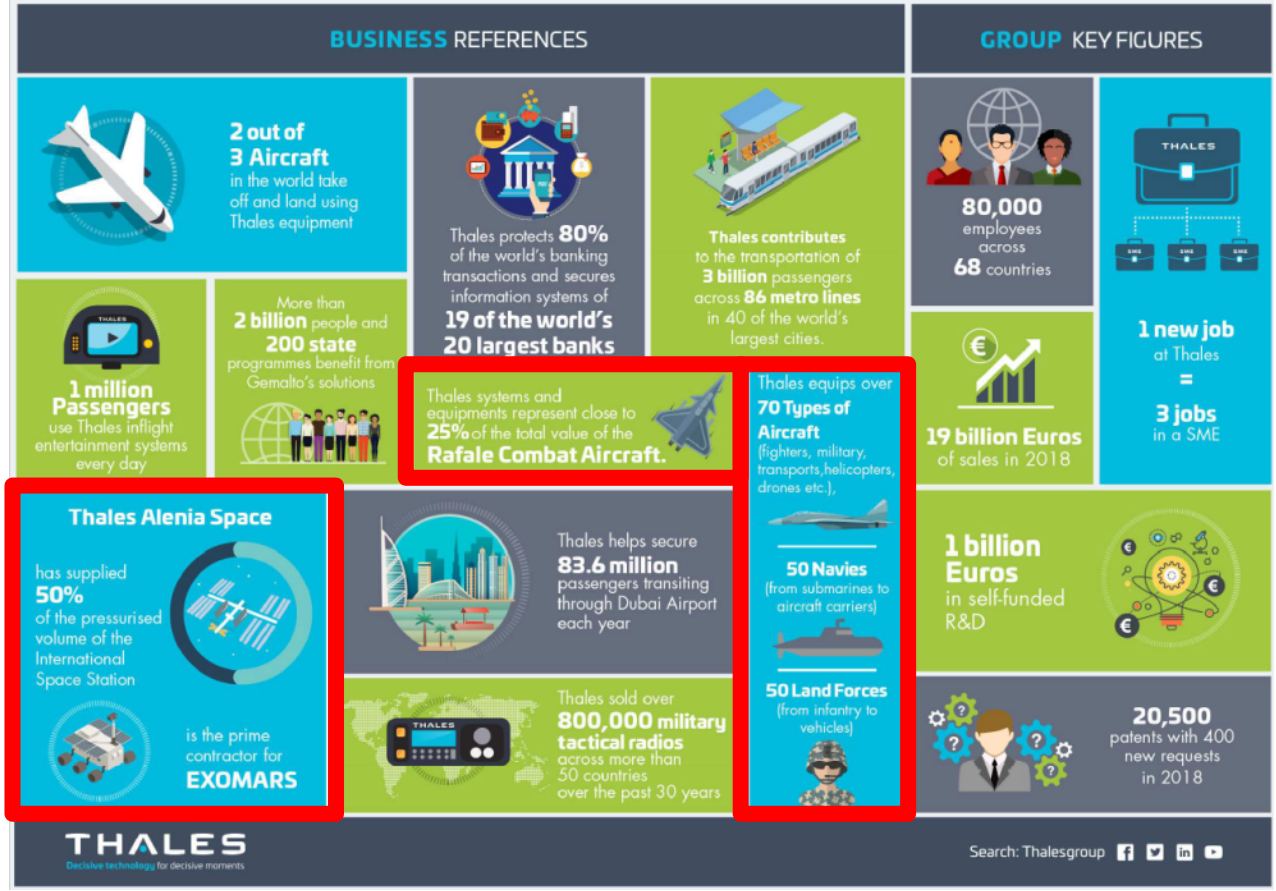
2019-05-15

Thales group at a glance



Using cryogenics today

Thales Cryogenics profile

Thales Cryogenics

Defence 75% | Civil 25%

Customer segmentation

Revenues

30 Million Euros

R&D efforts

20% of Revenues

Head count

210 FTE

R&D population

20%

Production population

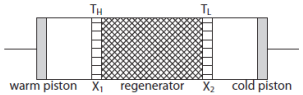
40%

Deliver best in class cryogenic coolers or systems for various applications (Defense, Space, Civil) that will exceed customer expectations in terms of performance and life.

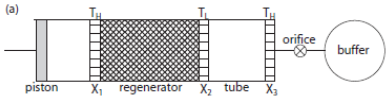
Focus on used technologies

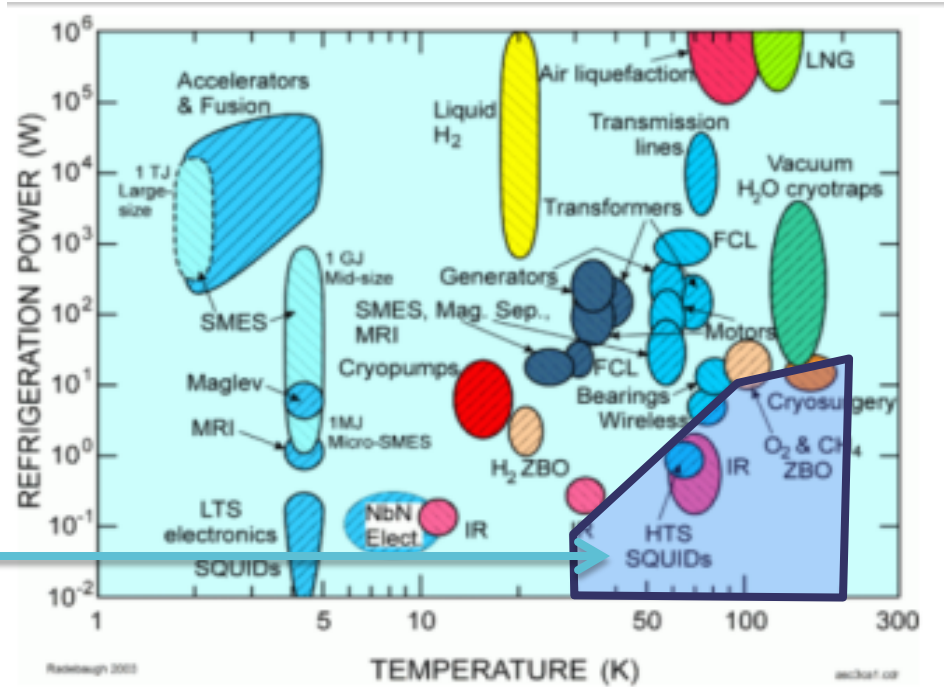
Focus of Thales Cryogenics

- Compact systems
  - Input power < 500 W
  - Temperature range 30 .. 150K
- Used cooling principles:
  - Stirling Cycle



  - Pulse Tube cycle

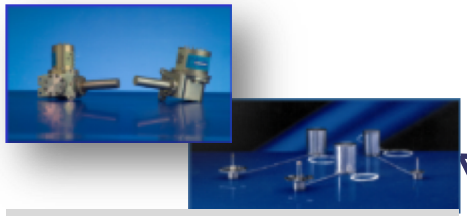




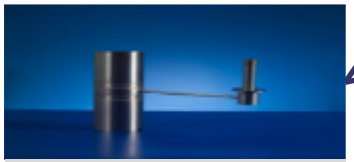
PRODUCT DESIGN REQUIREMENTS: Compact, Closed Cycle, No Maintenance, High Availability

Overview of Thales Cryogenics Product Line Perimeter

Type of coolers



Contact seal coolers



"Flexure" coolers

Pulse Tube coolers

Market requirements

Defense Markets (Stirling coolers)

Compact, robust & Efficient
New (IR-) detectors

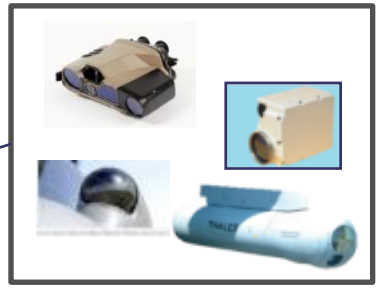
Commercial Markets (Stirling & Pulse tube)

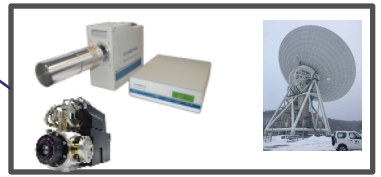
Extreme reliability &
Cost effective solutions

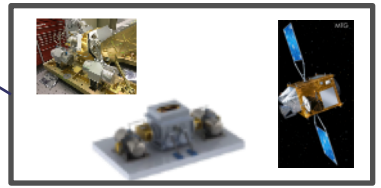
Space Markets (Pulse tube coolers)

Extreme reliability
High efficiency
"No" vibrations
Reduction of (development) costs

Typical applications



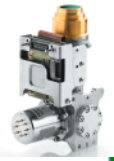




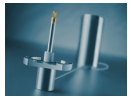
THALES

Our markets and examples of applications

IR today still the biggest identified market for compact Cryocoolers



- IR-detectors
  - Military
  - Civil applications

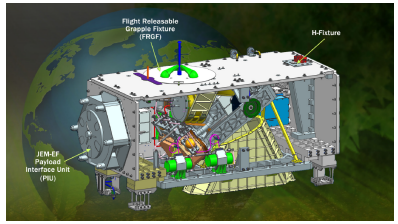


- New technologies requiring cooling 30 .. 150K
- Medical systems

- Superconductive systems (non RF)
  - SQUID / SQIF's
  - Superconductive bearings
- Superconductive devices RF devices
  - Low Noise Amplifiers (RF domain)
  - Superconductive filters (RF domain)

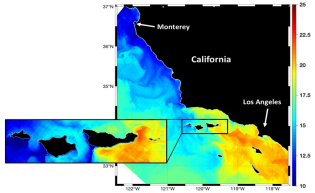
Markets

- Space

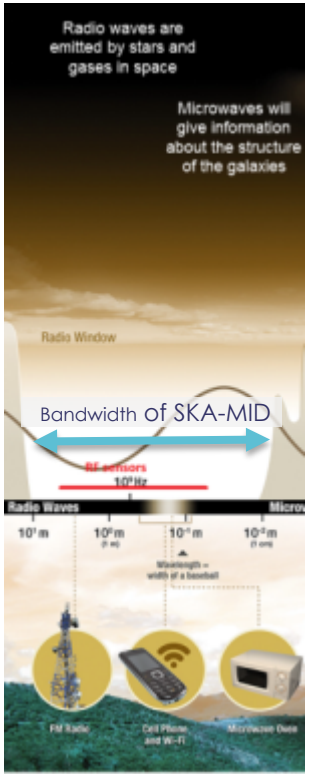


- Germanium sensors

- Zero boil-off



SKA-MID Dishes (artist impressions)



All about sensitivity:

- Large number of dishes
- Large spread of dishes to filter local disturbances
- Uniform performance of the dishes required
- High sensitivity receivers
- Low noise electronics
- Huge amount of data handling

Cryogenic cooling required
4 K // 20 K // > 50 K

SKA-Mid challenges

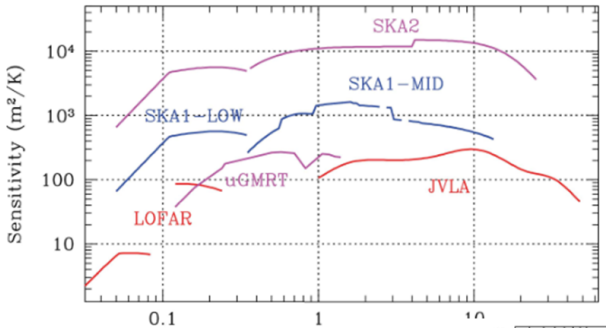
SKA mid:

- Measurement at different bands (500 MHz .. 13 GHz)
- Different instruments for different bands
- Higher frequency bands need receiver electronics cooled to cryogenic temperatures

Today's system:

- Using GM cryocooler cooling electronics to temperatures below 20K
  - Complex / large system
  - High input power
  - Yearly maintenance

- Advantages:
  - Known technologies
  - High cooling power available below 20K



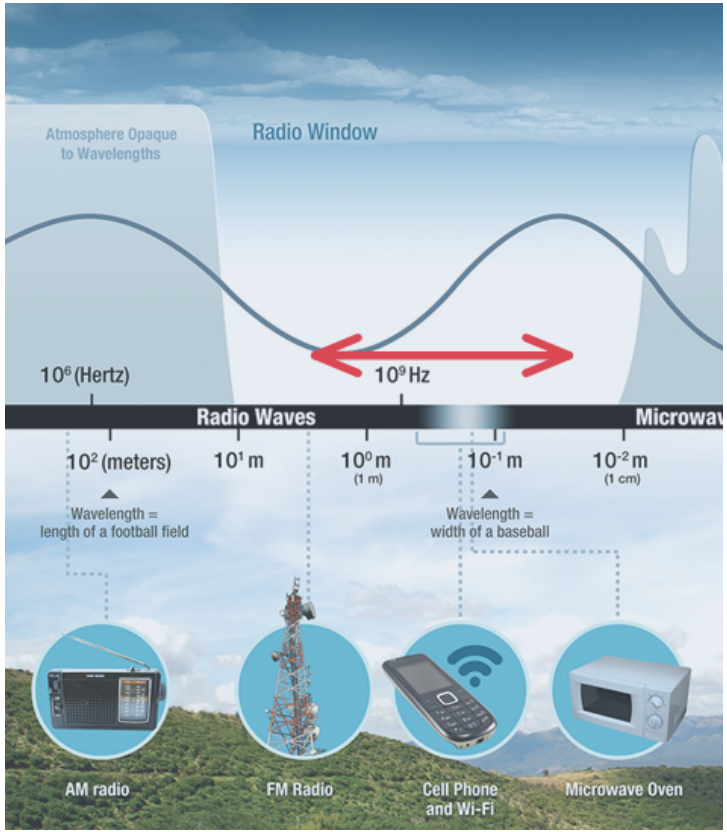
Radio Frequency Interference challenge

SKA will be created in today a low RFI environment.

However, there will interference from:

- Potential future RFI sources
- Communication from satellites and planes

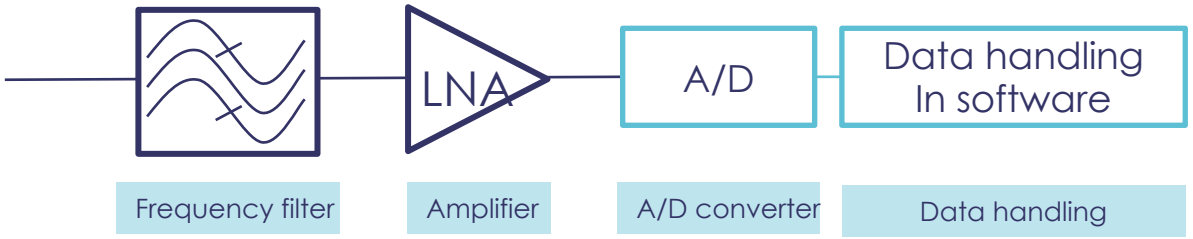
High efficient filtering could be required in the future



Background information: Filter & LNA or only LNA

There are (at least) two options for the filtering:

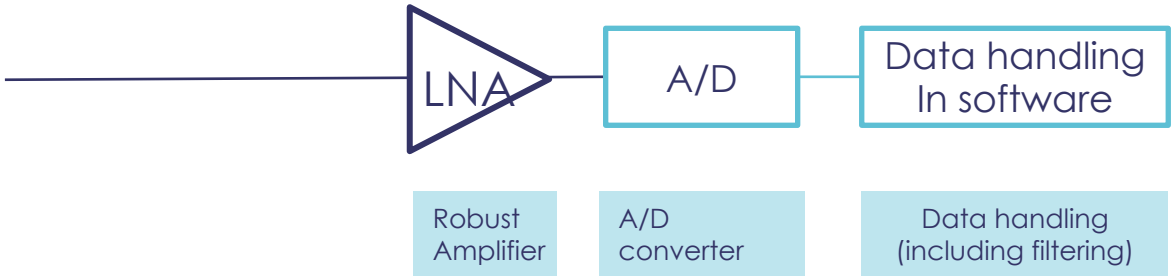
> "RFI elimination": Use of superconductive filter before the LNA.



Advantages:
- Lower load on components after filter

Disadvantages:
- Use of HTS filter
- Not flexible wrt filtering characteristics

> "Classical method": Use of a robust LNA with (digital) filtering after the LNA output



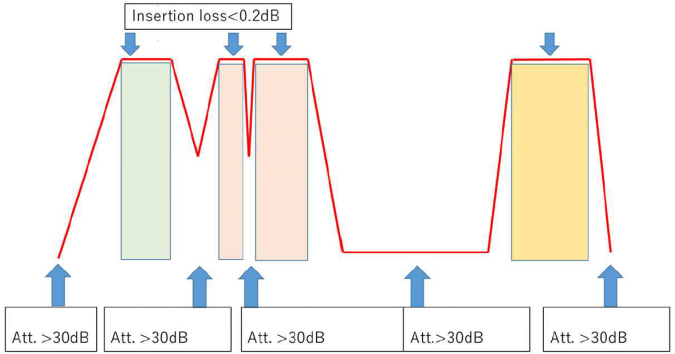
Advantages:
- No HTS filter required

Disadvantages:
- Higher load on LNA etc.
- Flexible filtering (software)

Thales involvement in RF - projects

Since 2015 Thales has been in contact for cooling RF filters and LNA's operating at temperatures around 77K

- Cooling of HTS filters:
  - » For secure communication
  - » For elimination of Radio Frequency Interference signals
- Cooling of HTS narrow band oscillators
- Cooling of LNA's

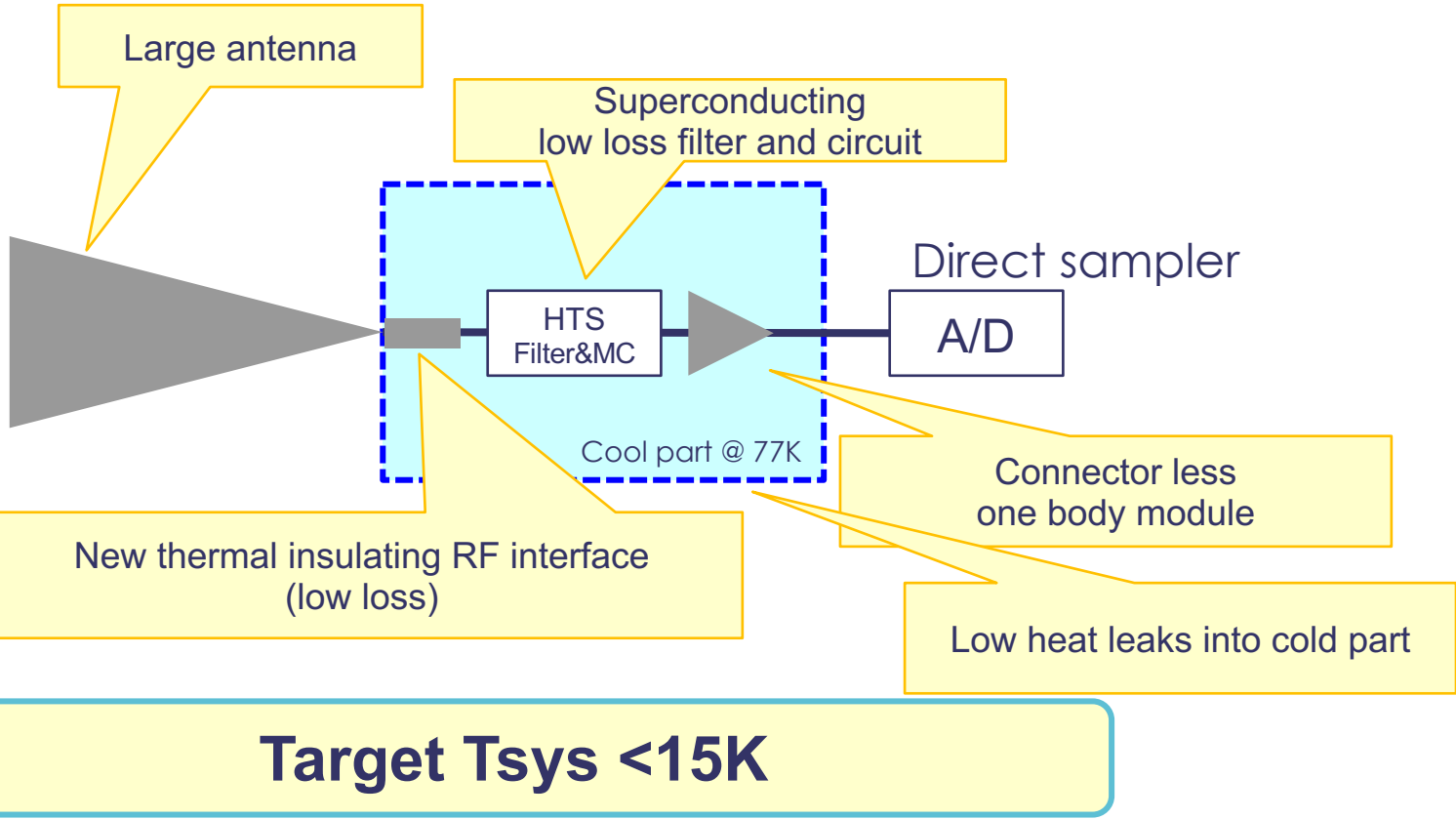


For these markets 2 kinds of zero maintenance compact Stirling cooler are under qualification:

- One 2W @ 77K | 2 kg cooler
- One 10W @ 77K / 2W @ 40K | 6 kg cooler

Possible system design

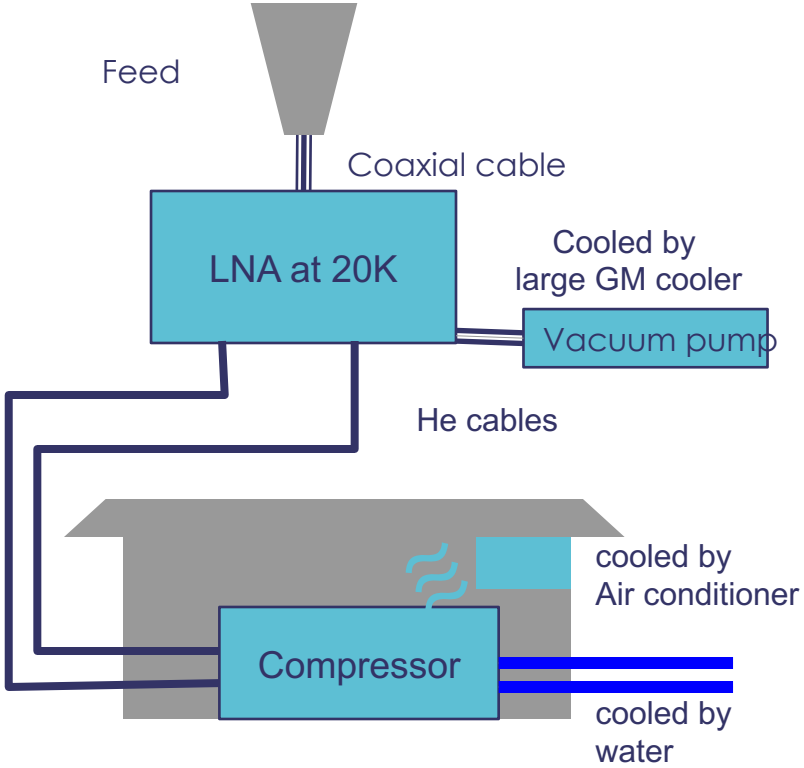
Low signal with Strong RFI



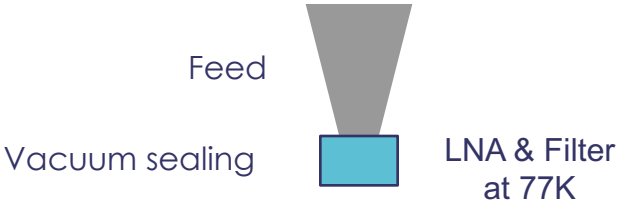
Target Tsys <15K

Configuration of Cryo-receiver

Conventional Cryo-receiver



Compact Cryo-receiver



Cooled by small Stirling cooler
(incl. compressor)

- Simple configuration
- Lower cost
- Lower maintenance
- Higher reliability
- Lower energy consumption
- Wide temperature range

System test in Radio Telescope (Mizusawa and Ishigaki Japan)

Actual cryo-receiver (at 20K)

Tsys=96K @1.4GHz

Tsys=85K @1.6GHz

Improvement of sensitivity
-25% to -40%

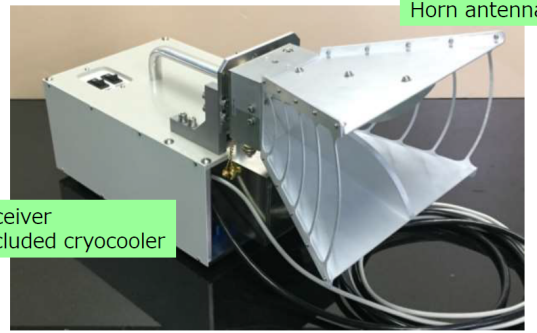
Toshiba's cryo-receiver (at 77K)

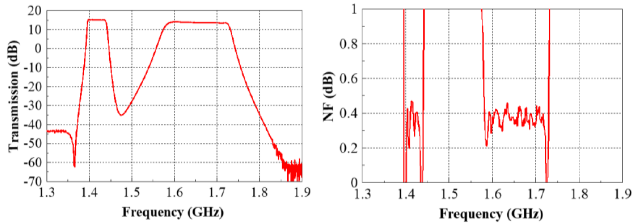
Tsys=56K @1.4GHz band

Tsys=65K @1.6GHz band

New RF receivers have been installed Febr 2019 (incl HTS filters) which allowed continuous operation (eliminating RFI)

Demonstration unit for RFI tests

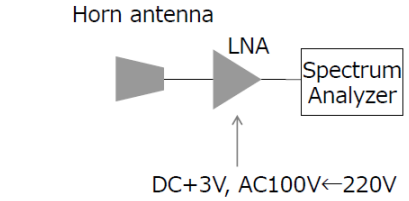


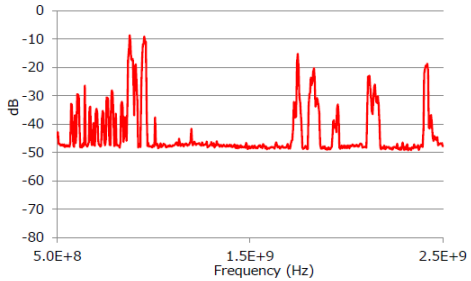


LNA Gain: about 15dB
Receiver noise temperature: 24K

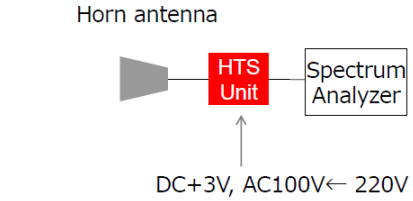
Measurement of RFI test using Horn Antenna

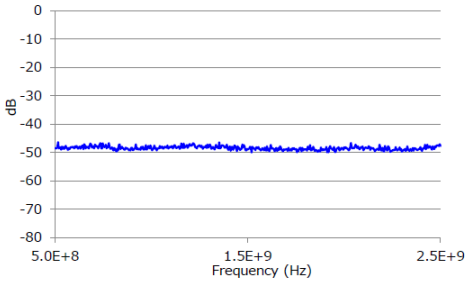
Without filter





With superconducting filter



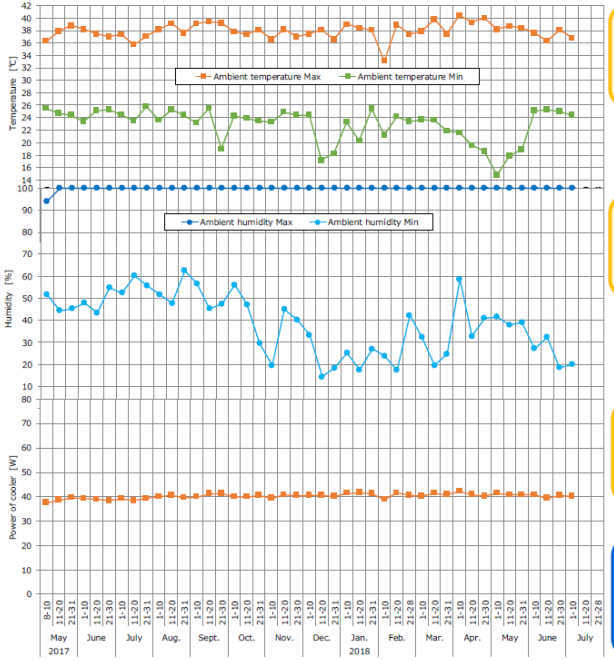


Work performed by Toshiba, sponsored by NJAO and Ministry of Internal Affairs and Communications Japan

Field tests of Receiver units in Thailand

Cryogenic Unit
6 LNA modules
12 IO interfaces
80W cryocooler

Field test of the Cryogenic Receiver



It is high temperature in Thailand

It is high humidity in Thailand

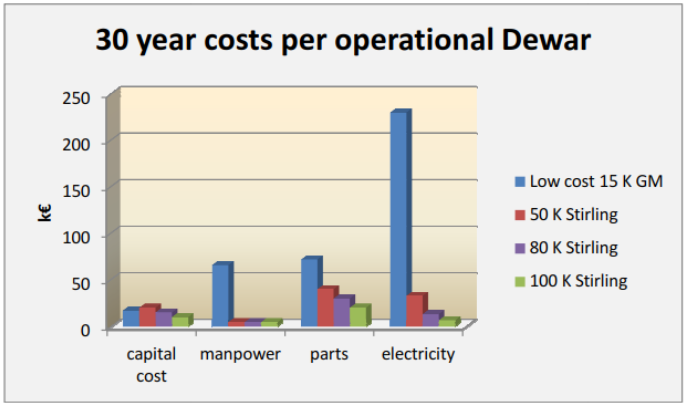
Power consumption < 42 W
Half power operation

Continuous operation over 1 year
(Zero maintenance and no stop)

Tests started May 2017 and systems are still running perfectly.

Required innovations steps for SKA-MID

- **Optimize cooler performance < 50K**
- **Development of Wide band LNA's > 40K**
- **Decide on use of full HTS circuit's (incl filtering)**
- **Optimize thermal design**
  - High vacuum dewar
  - Low thermal heat leaks
- **Low RF insertion losses:**
  - Low insertion loss RF interfaces



Conclusions

SKA-MID could benefit from insertion of new technologies

- HTS; Filters, LNA's, and matching circuits design
- Low loss RF connections
- Zero maintenance Cryocoolers
- High vacuum technology dewars

Over the past years Thales has been working with several international customers in the Astronomy (RF-)market segment at R&D level and gained more insight in this market segment.

Future R&D will be required in an international setting in order to be able to mitigate high operational costs for SKA-Mid.

ASTRON and Thales Cryogenics could play an important role in SKA-Mid