OVERVIEW AND OUTLOOK OF SPACE SURVEILLANCE SYSTEMS AT FRAUNHOFER FHR

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Andreas Froehlich et. al

Tasks of Space Missions

Navigation

Weather

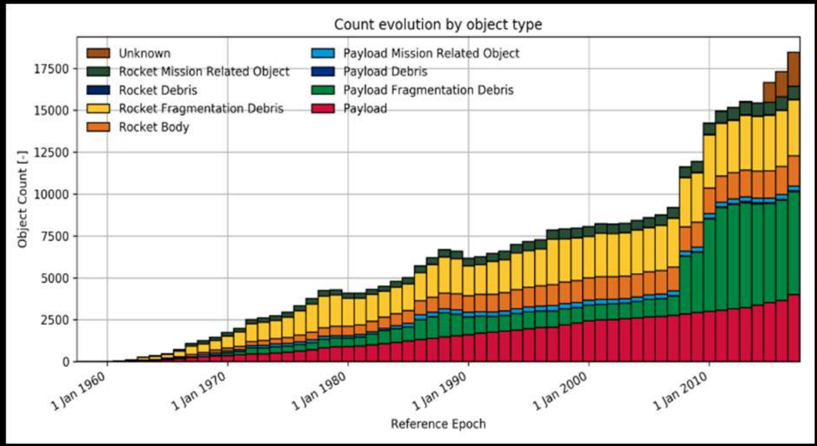
Earth Observation

Communication

Science

SPACE DEBRIS – a growing problem

- 29.000 Objects > 10 cm,
  of which ~1.400 are active satellites
  - ~ 75% of these objects are in LEO
    (Height: 200 – 2.000 km)
  - ~ 9% of these objects are in GEO
    (Height 36.000 km)
- 750.000 Objects > 1 cm
  only visible with high performance radar systems such as TIRA
- The number of space debris objects is increasing steadily



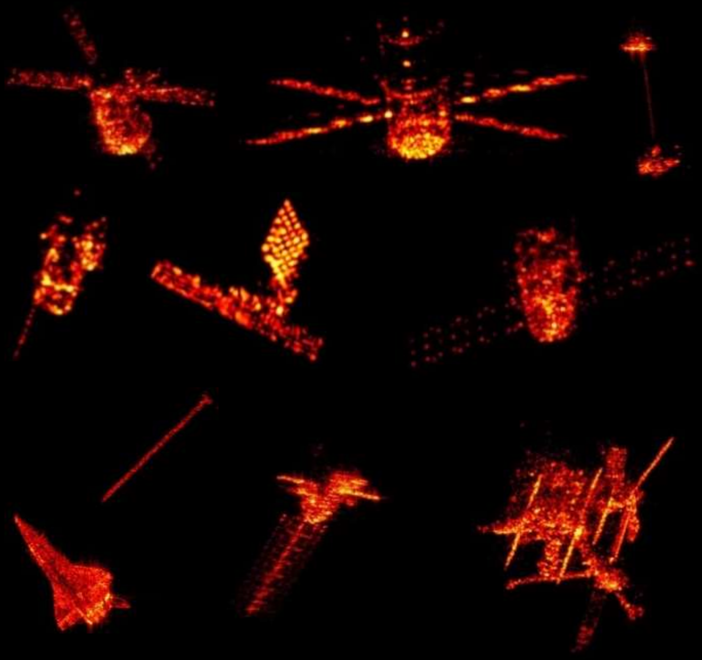
Current space debris population

- All debris are human-made
- Incidents with numerous new debris particles:
  - 2007: A Chinese rocket intentionally destroyed a Chinese weather satellite
  - 2008: A US reconnaissance satellite was destroyed with an American rocket
  - 2009: Collision between a US communications satellite and a Russian satellite
- Horror scenario: Chain reaction ("Kessler Syndrome”)

Effect of impact of a 1-centimeter aluminum ball traveling at 6,500 m/s on a solid aluminum plate with a thickness of 7.5 cm (Fraunhofer EMI)

The space observation radar TIRA

- TIRA supports all phases of space missions
  - Starts and first operation phase (LEOP)
  - Highly precise trajectory determination
  - failure analysis
  - Analysis of collision risks
  - Monitoring of operations with robots
  - Intrinsic rotation analysis
  - Supporting „Re-entry“ and „De-orbiting“ Manoeuvres

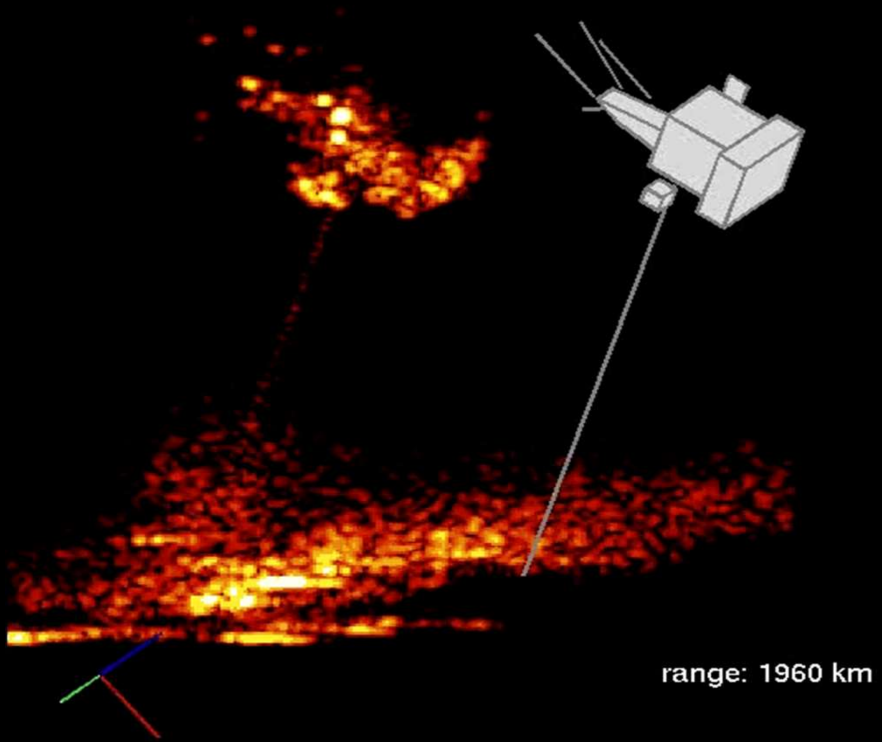


The space observation radar TIRA

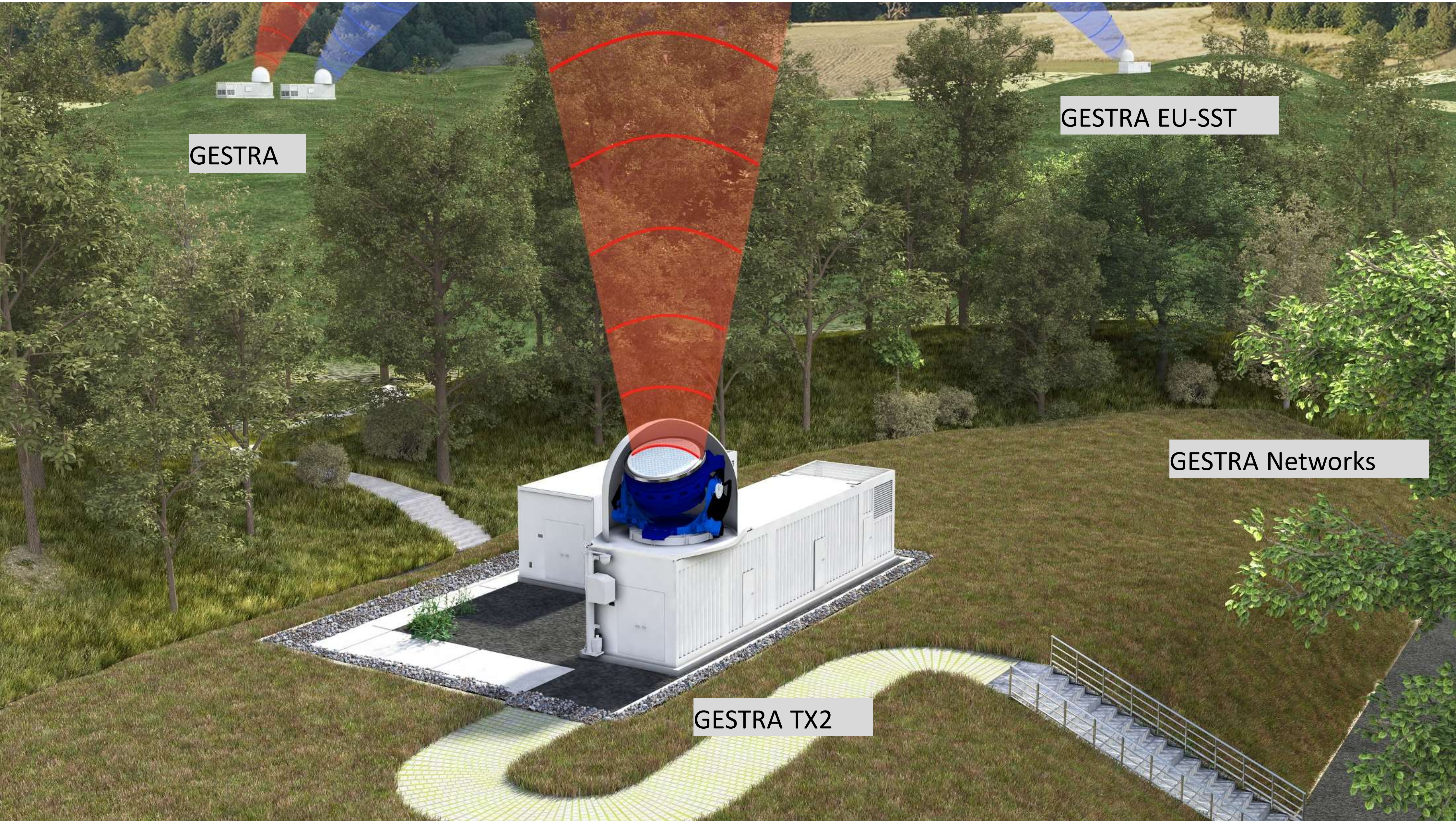
Technical data

- Target tracking and imaging radar
- Most powerful system in Europe
  - Positioning accuracy: 0.000172° - 3 mm / 1000 m
  - Diameter of reflector: 34 m (radome 47.5 m)
  - Antenna speed 24° / s (360° in 15 s)
- Target tracking radar: L-band (1.333 GHz, up to 1.5 MW transmit power), sensitivity: Detection of objects > 2 cm in 1000 km (with Effelsberg: < 1 cm)
- Target imaging radar: Ku-band (16.7 GHz, resolution better than 20 cm)

Analysis of damage and proper motion: ADEOS I



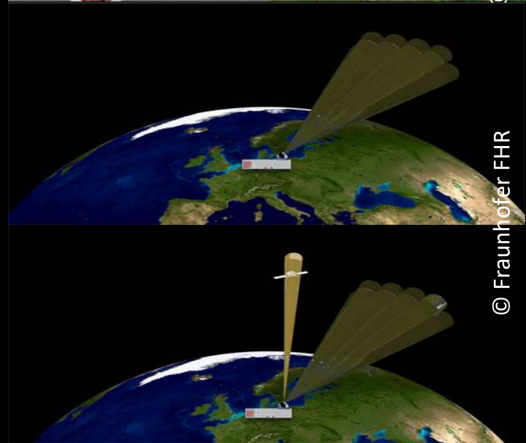
- Total failure of power supply through demolition of solar panel (24m x 3m x 0.5mm)
- Radar imaging is the only feasible damage assessment possibility!


GESTRA
GESTRA EU-SST
GESTRA Networks
GESTRA TX2

Detection and Cataloguing of Space Debris

GESTRA – German Space Surveillance Radar

- Federal government outlines necessity of establishing a national competence center for documentation and evaluation of the current situation in space
- Quasi-monostatic pulsed phased array radar in L-band (~ 1.3 GHz)
- Surveillance in orbital heights of 300-3000 km
- Electronic swiveling through HF-based modification of the wave front during transmission or digital beam forming during reception
- Numerous operating modes (surveillance volumes vs. detection capacity, track-while-scan, etc.)



Detection and Cataloguing of Space Debris

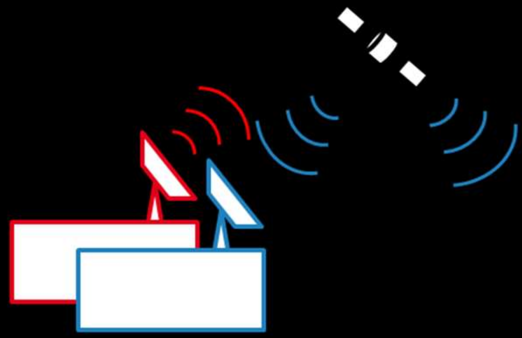
GESTRA – German Space Surveillance Radar

- GESTRA consists of:
  - 2 containers - one receiving (RX) and one transmitting (TX) unit
  - both subsystems have independent infrastructure (energy, cooling, climate control, etc.)
  - size each: 18 m x 4 m x 4 m; weight about 90 t
- each unit (RX&TX) contains:
  - a phased array antenna with 256 individual elements
  - mounted on top of a 3-D positioner

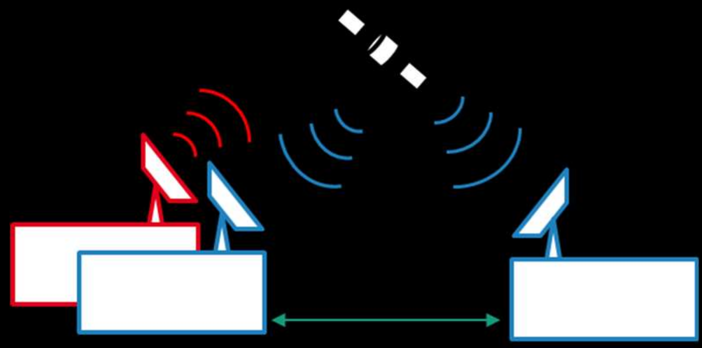
Further detection concepts and projects

GESTRA EU-SST & GESTRA networks

- the energy reflected away can be collected by a bi-static sensor configuration as implemented by EUSST (lower graph)
- alternatively, larger search volumes can be "scanned" simultaneously
- more accurate tracks can be calculated by combining multiple sensor contributions
- the sensitivity of the overall system is significantly increased by bi- or even multi-static arrangement of the sensors
- high-precision synchronization and appropriate signal processing are required for implementation



mono-static radar configuration



bi-static radar configuration

Further detection concepts and projects

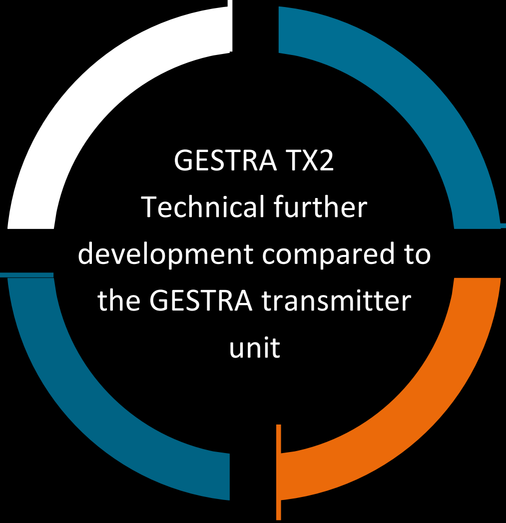
GESTRA TX2

Transmitting technology

- Development of a new transmitter module by means of the new semiconductor technology based on GaN
- Increase of the transmitting power by a factor of approx. 2

Networking

- Networked operation of TX2 together with GESTRA and EUSST (two transmitting and two receiving units)
- Time, phase and frequency synchronization
  - ➢ Performance improvement



Cooling

- Higher transmitting power requires new cooling development
  - ➢ Pulsating Heat Pipes-technology
- Project partners: Fraunhofer IPM & IWU

Signal generation

- New development of the Plank controller modules in the form of a multi-channel AWG
- Used for controlling the individual transmitter modules
  - ➢ Decentralized signal generation

Further detection concepts and projects

GESTRA network configurations

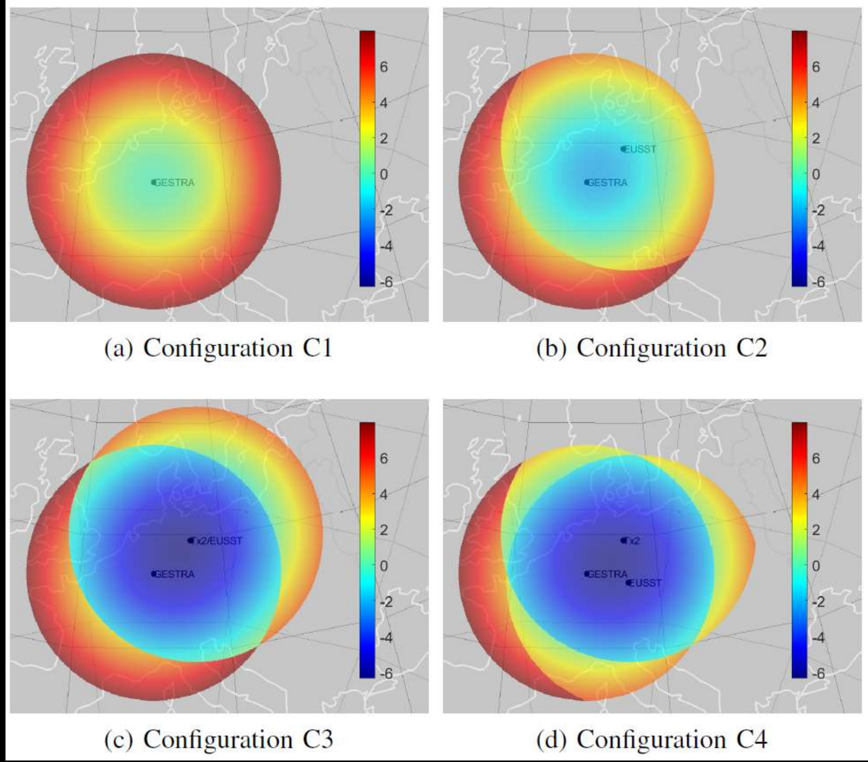
Improvement of the minimum detectable RCS in dB at 1,000 km altitude for different GESTRA network configurations.

- C1: GESTRA
- C2: GESTRA + GESTRA EUSST
- C3: GESTRA + GESTRA EUSST / GESTRA TX2
- C4: GESTRA + GESTRA EUSST + GESTRA TX2

- Attention: RCS values are normalized to the minimum detectable RCS of GESTRA (0 dB)

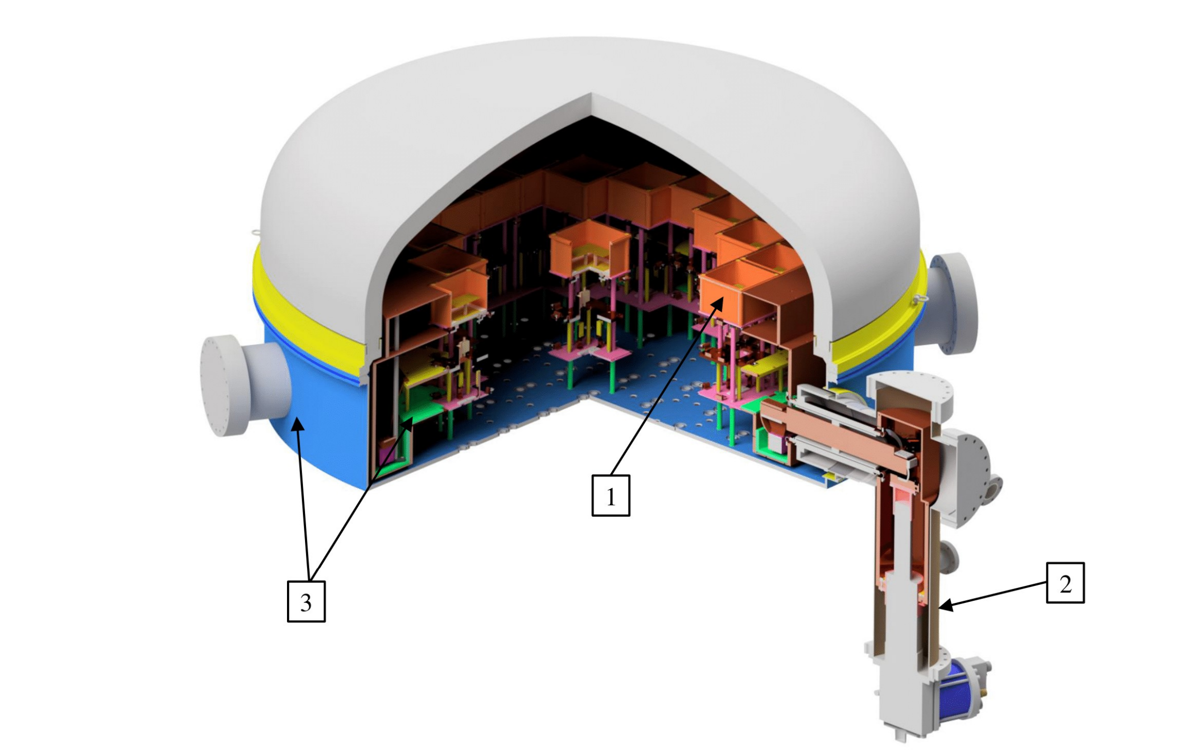
- Results:
  - C2: Detection power increases by up to 2.3 dB
  - C3/C4: Detection power increases by up to 6,3 dB

➢ **Detection of targets that are up to four times smaller**



(a) Configuration C1 (b) Configuration C2 (c) Configuration C3 (d) Configuration C4

Cryo-Cooled 37-Element Phased Array Radar Receiver



Components:

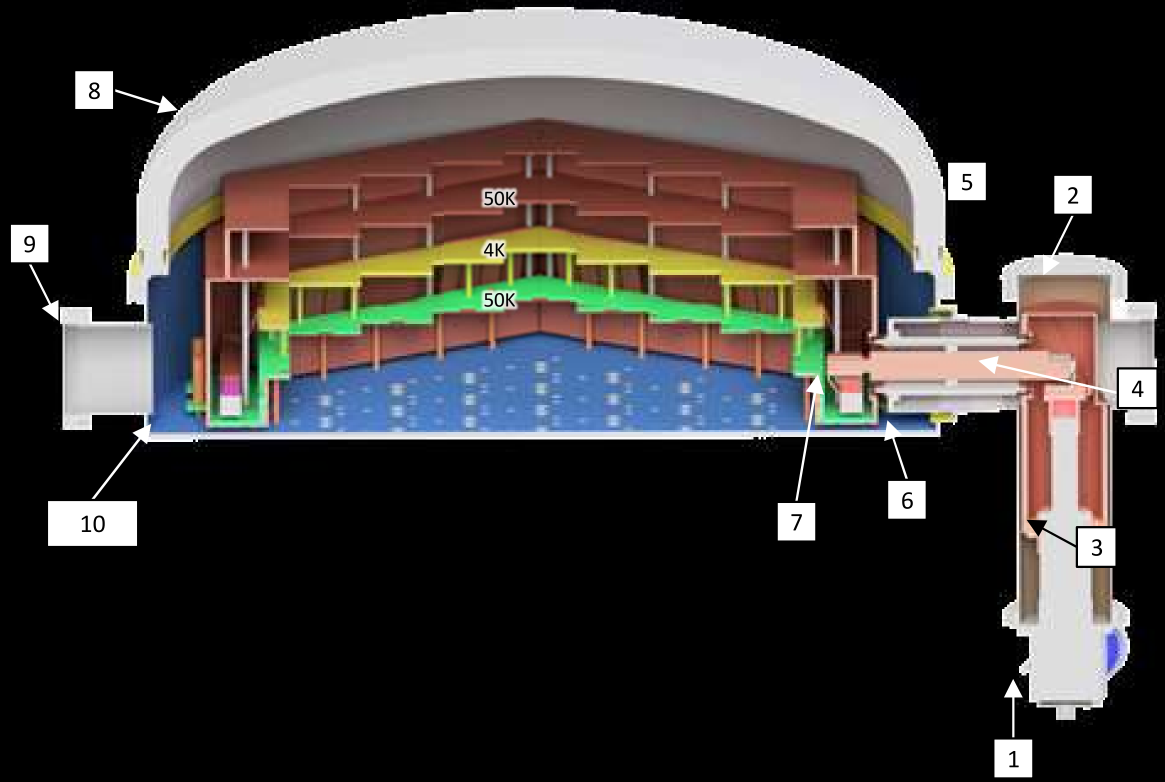
1 RF-Unit-Cell

2 2-Stage Cryocooler

3 Vacuum Vessel

Diameter 1.5 m

Cryo-Cooled 37-Element Phased Array Radar Receiver



Vaccum Vessel with Cryocooler

1 Sumitomo Cryocooler
2 Vacuum Vessel
3 50K-Stage
4 4K-Stage
5 Copper-Shield
6 Vacuum Barrier
7 Copper Rod
8 Radom
9 Vacuum Pump Interface
10 Lower Flange

Some simulation results

Maximum deformation along the Z axis was 10.45 mm
-> To reduce this value, either the thickness of the vacuum vessel can be increased or the 4 stand feet can be scaled higher

Temperature distribution in the LNA area was between 23.5 and 29.7 K
and in the antenna area between 108.4 and 134.2 K
-> Temperature differences can be reduced by increasing the cross-sectional area

- Based on the simulation results, optimizations can be made and incorporated into the hardware structure

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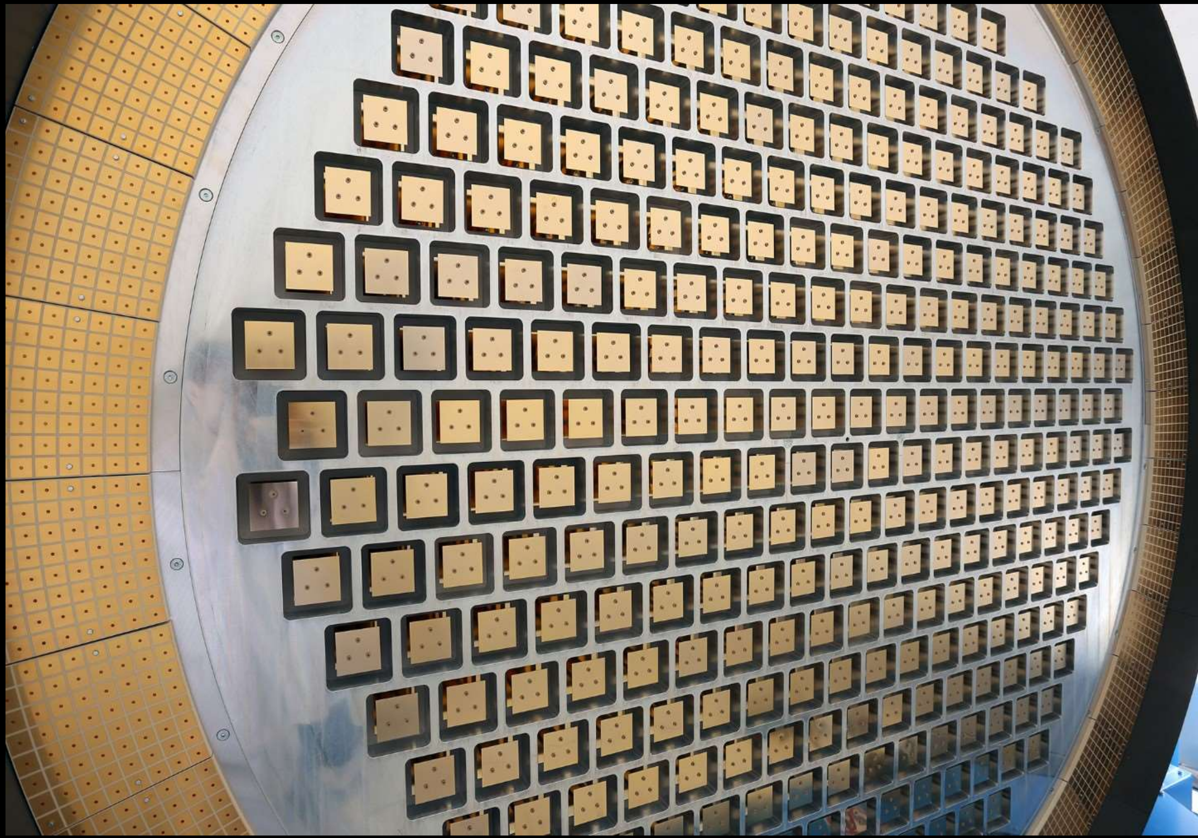
Conclusion

- Showed Space Debris is a rising problem for our infrastructures and services
- TIRA allows to support all stages of space missions
- GESTRA family a novel phased array systems for detection and catalogue space debris
- New concepts of GESTRA systems such as GESTRA Networks or cryocooled receivers improve the performance further

Thank you for your attention

Thanks to all colleagues from Fraunhofer



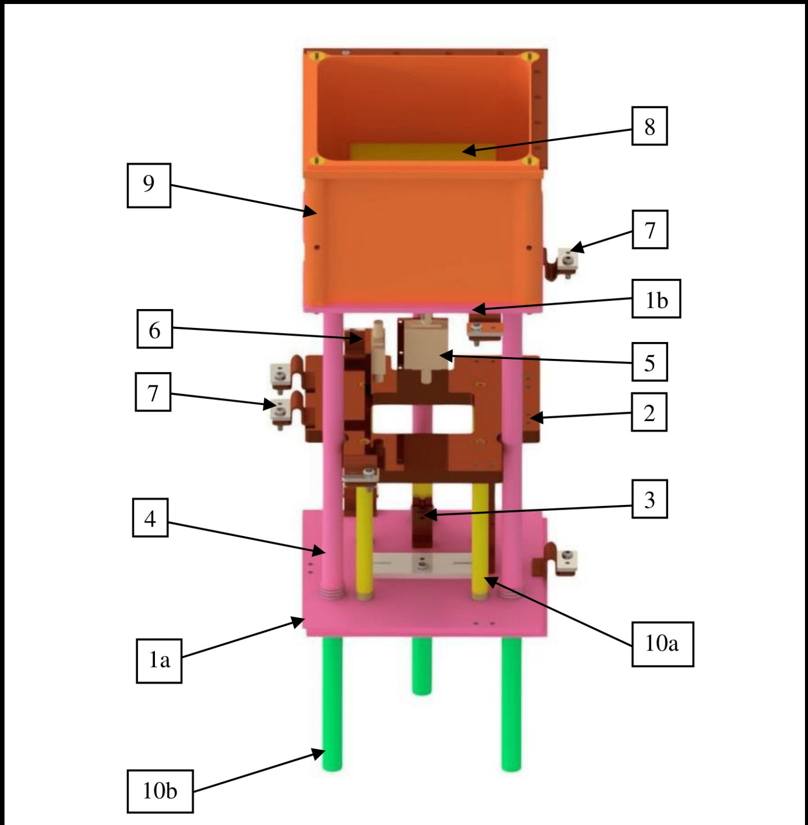
Contact:

Andreas Froehlich

andreas.froehlich@fhr.Fraunhofer.de

Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Germany

Cryo-Cooled 37-Element Phased Array Radar Receiver



RF unit cell:

1 50K-Plate

2 4K-Plate

3 Cooper Rod for RF-Cables

4 Copper Spacer

5 LNA (Low noise amplifier)

6 LNA Fixing Plate (Copper)

7 Copper Stands

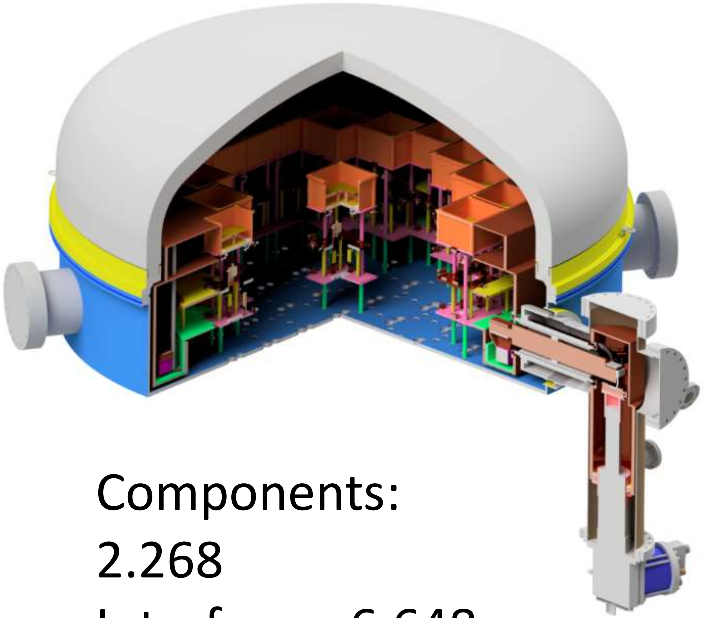
8 Patch-Antenna

9 Cavity

10 GFK-Spacer

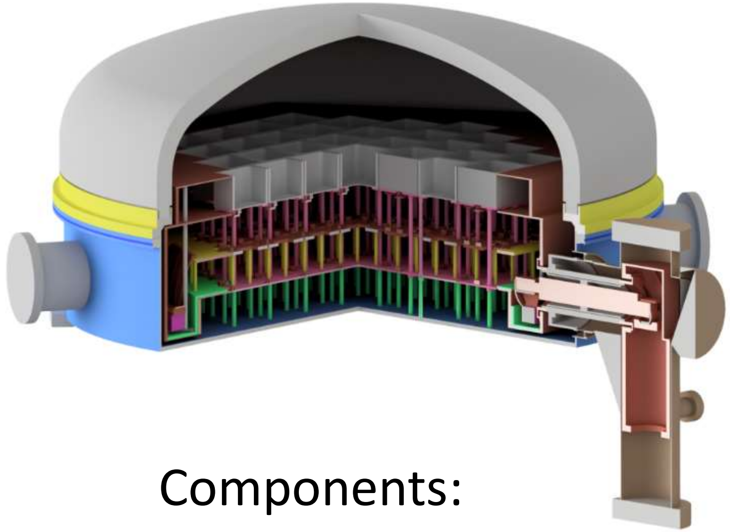
Preparing and Optimizing of 3D-Simulation Model

Full Model



Components:
2.268
Interfaces: 6.648

Simplified Model



Components:
1.467
Interfaces:
3.382

Simulation Model and Project Scheme

Thermal Model

- Heat flow of the cables

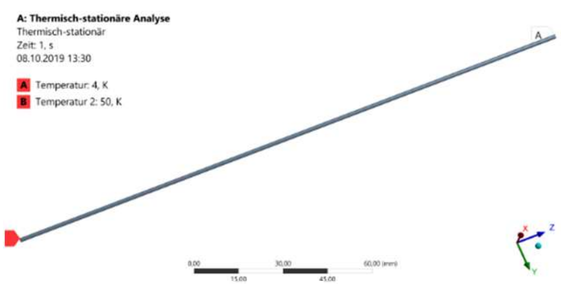
Temperature in K	heat flow in W	
	Cable 1	Cable 2
4 50 300	8,14 10,42 17,82	5,89 5,86

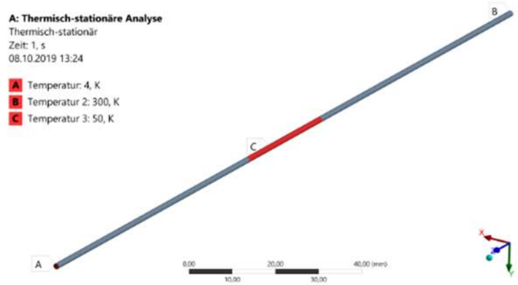
- Heat flow of the LNAs

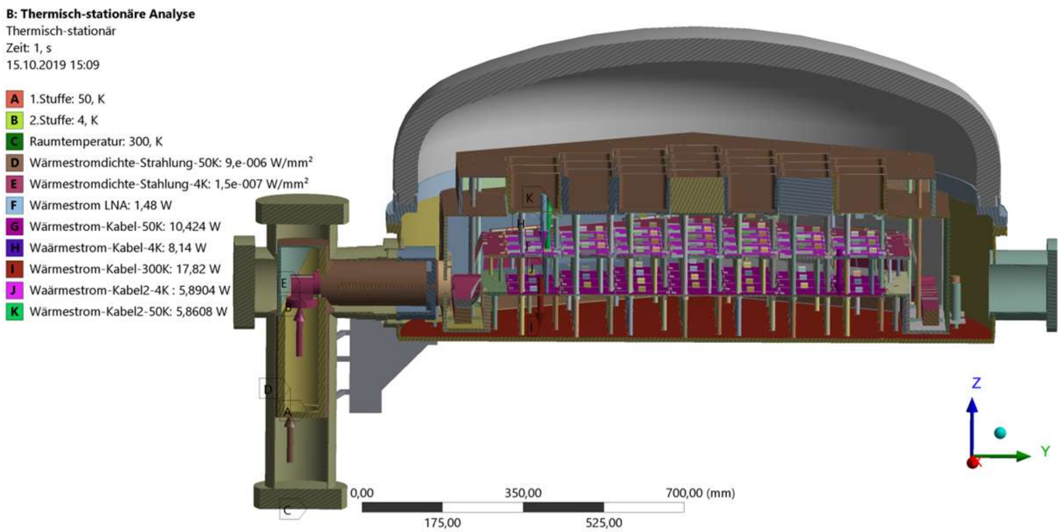
$$\dot{Q}_{Ges} = n \cdot k \cdot \dot{Q}_{LNA} = 1{,}48\ \mathrm{W}$$

- Heat transfer through thermal radiation

$$\dot{q}_{300-50\mathrm{K}} = 9\mathrm{E}-006\ \mathrm{W/mm^2}$$
$$\dot{q}_{50-} = 1{,}5\mathrm{E}-007\ \mathrm{W/mm^2}$$



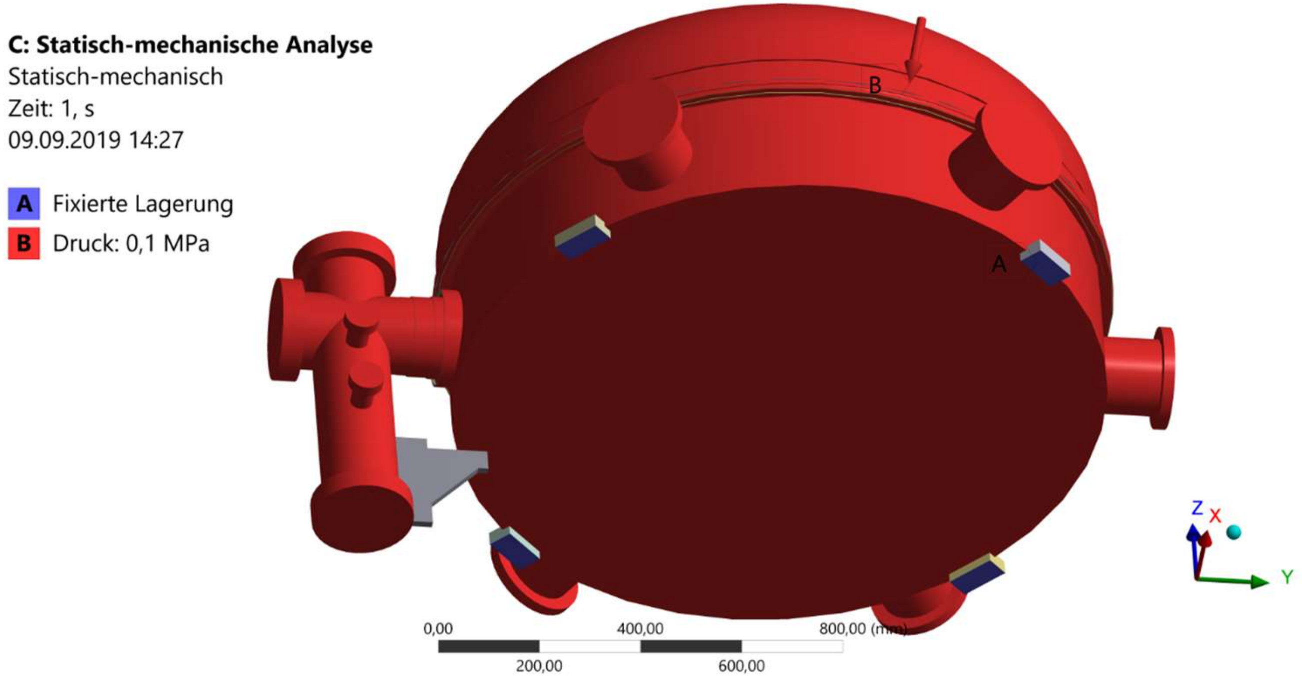




Fraunhofer FHR

Simulation Model and Project Scheme

Mechanical Model



- Fixed storage on the 4 feet of the vacuum vessel
- Atmospheric pressure in external surfaces

Simulation Model and Project Scheme

Modal Analysis

- Determination of the eigenfrequencies by the eigenvalue equation

$$(-\omega_i^2 \ [M] + [K])$$

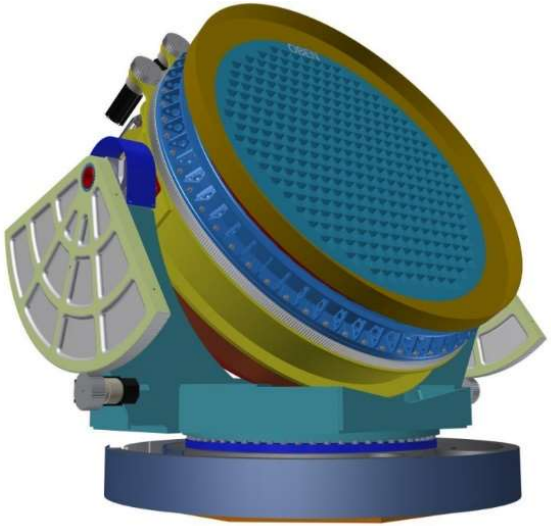
Harmonic Analysis

- Response of the system at the determined natural frequencies
- 1 Newton stimulating force

Response Spectrum

- Determination of the deformation for a given response spectrum
- At a maximum angular velocity of 5 °/s
- A maximum Angular acceleration of 5 ° / s2 results in a total acceleration of

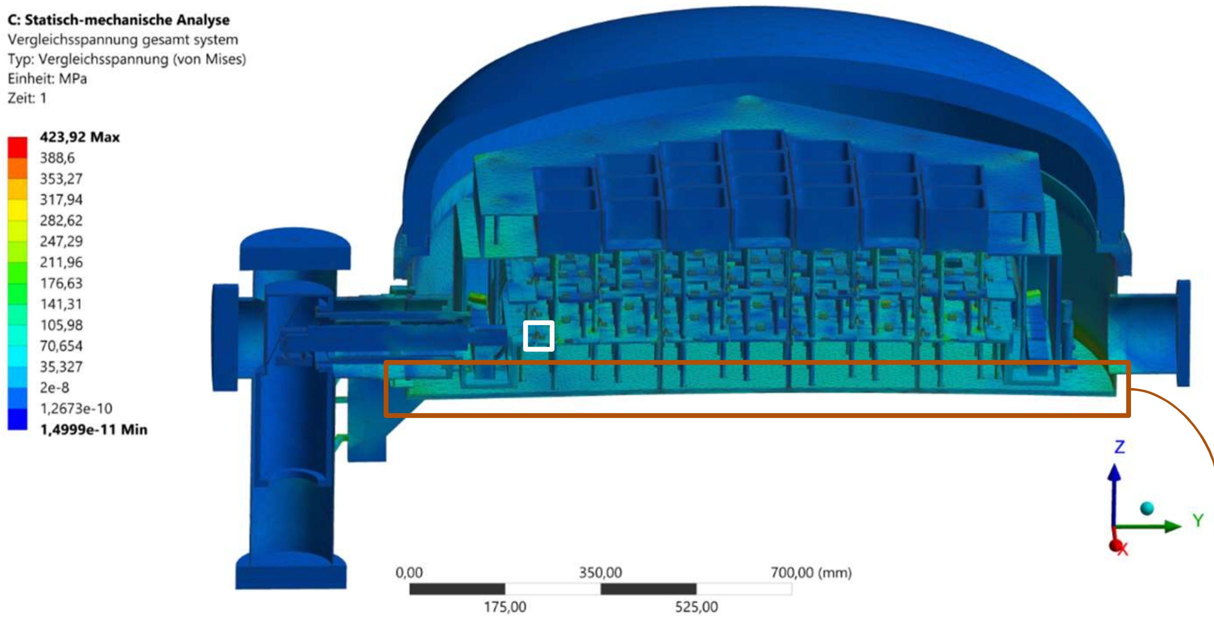
$$a_{ges} = \sqrt{a_r^2 + a^2{}_t} = 61{,}31 \frac{mm}{s^2}$$

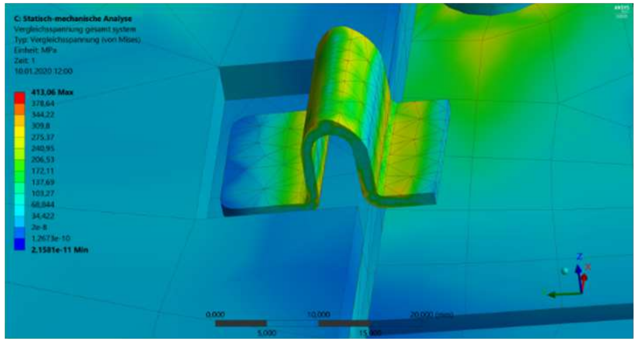


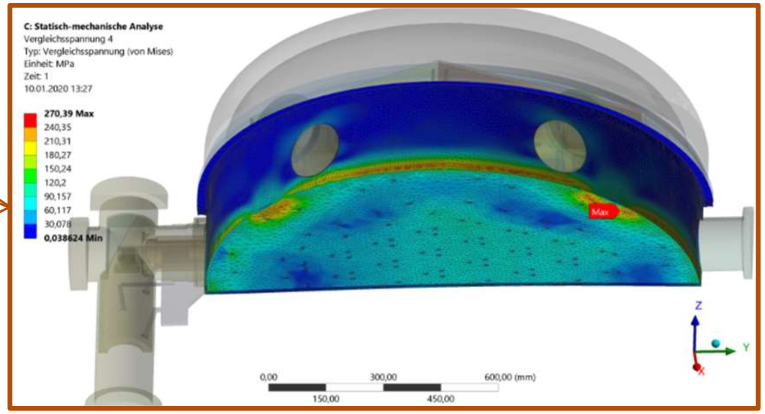
- PSD-Analysis (only Paper)
  - Determination of the deformation 3σ (99,7%)
  - $PSD = \frac{a^2{}_{ges}}{\Delta f} = 21{,}57\ mm^2 s^{-4}/Hz$

Result and Evaluation

Mechanics Model







$R_m = 1200\,MPa$ >>

Mechanical Model

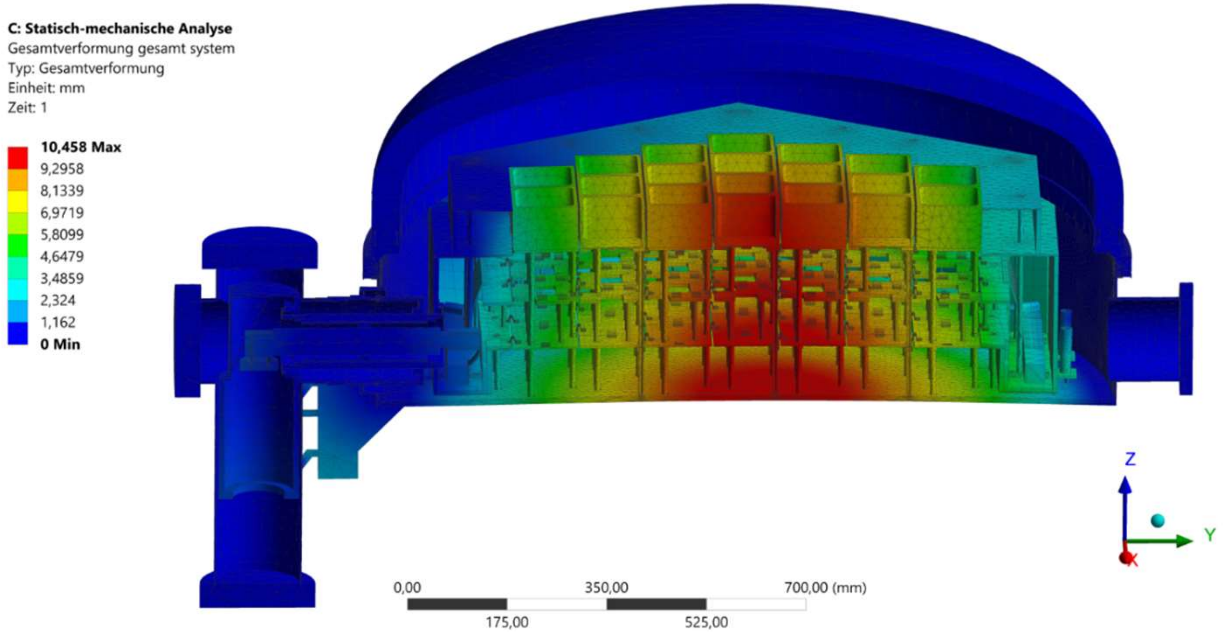
Deformation

- Maximal deformation of the
vacuum vessel because of pressure difference (upper) and shrinking
factor at 4 Kelvin

- Verification by analytical calculation

$$f = \frac{0{,}171 \cdot p \cdot r^4}{E \cdot h^3} = 15{,}2\ mm$$

- Deviation due to feet fixation on the vacuum vessel

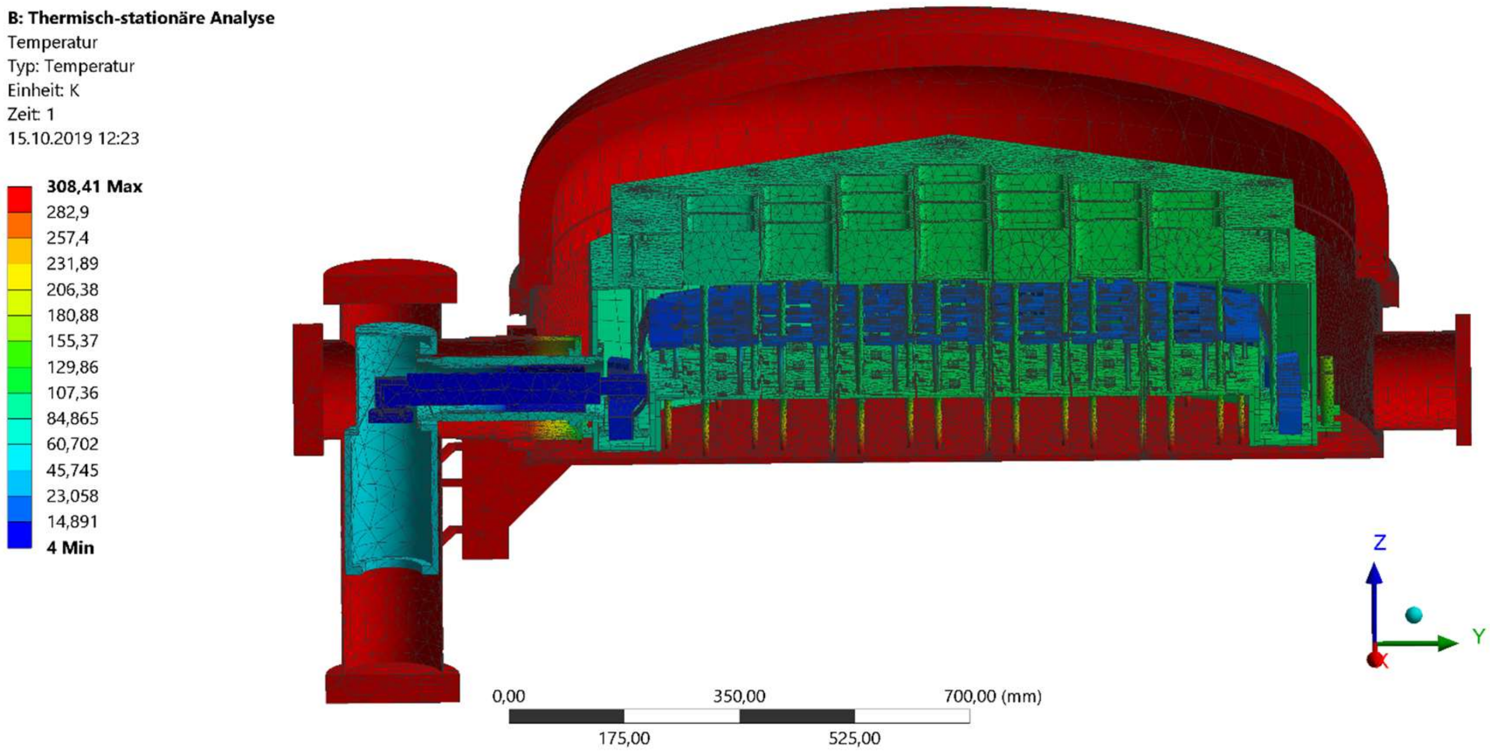


Result and Evaluation

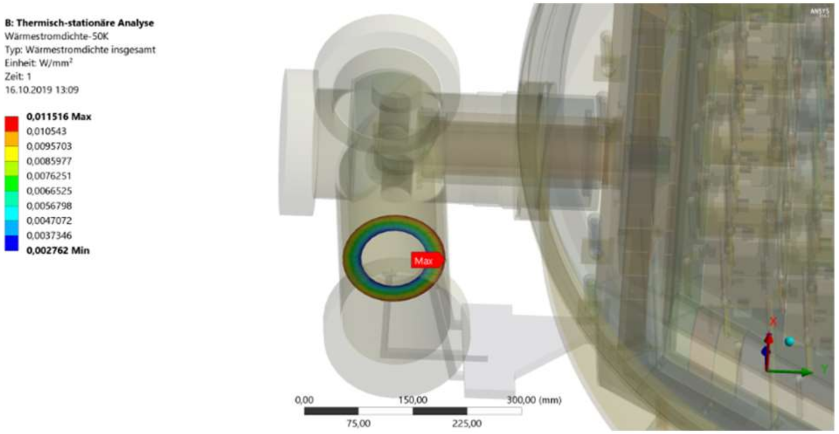
Thermal Simulation

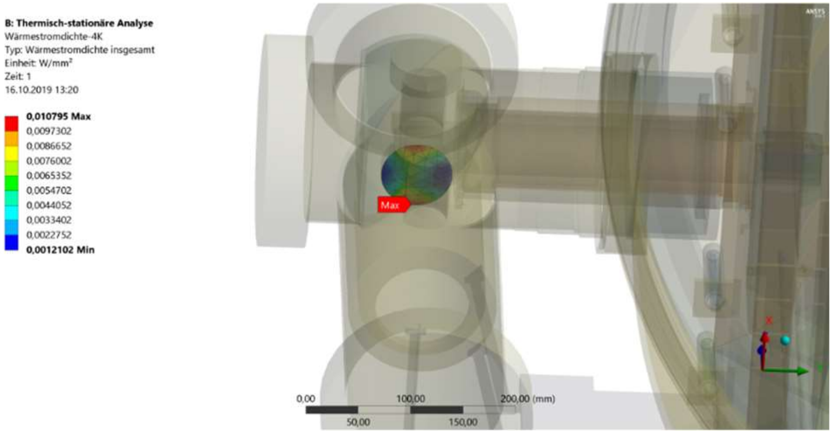
- LNA area: 23-29 K
- Antenna area: 108-134 K
- Optimization:

$$\Delta T = \frac{d \cdot \dot{Q}}{A \cdot \lambda}$$



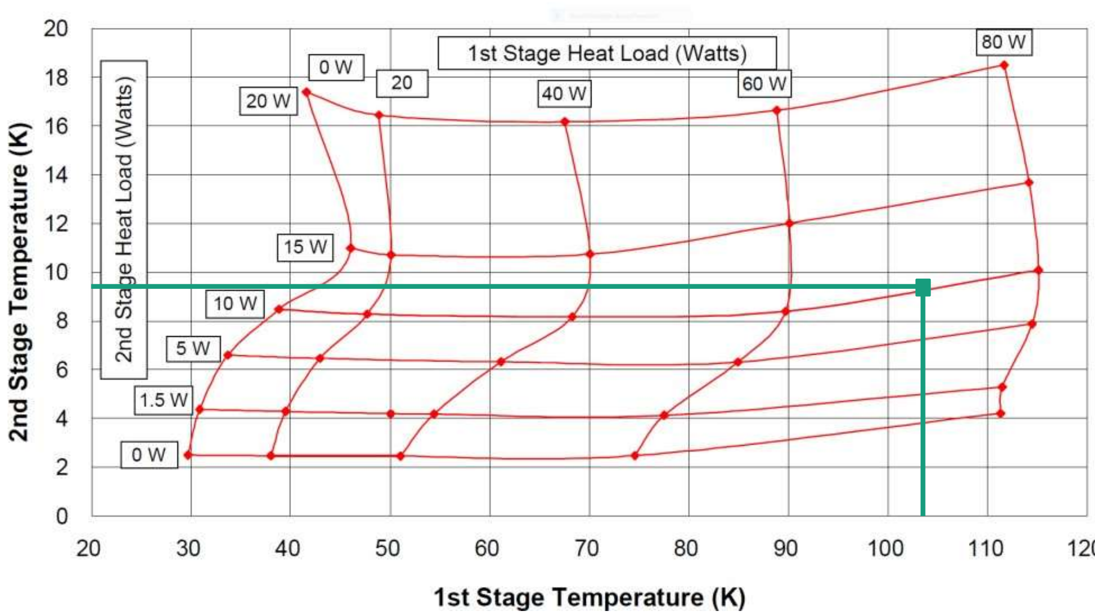
Thermal Simulation





$\dot{Q}_1 = 75{,}41\ W$ $\dot{Q}_2 = 10{,}36\ W$

RDK-415D Typical Load Map (50Hz)



$T_1 = 105\ K$ $T_2 = 9\ K$

Grafische Elemente

Kästen, Pfeile, Verbindungen und Linien (Auswahl)

! DIESE FOLIE AUS FINALER PRÄSENTATION LÖSCHEN !

- folgende Elemente können hier per Rechtsklick kopiert und an gewünschter Stelle in der neuen Präsentation per Rechtsklick wieder eingesetzt werden:

Kasten gefüllt

- Grau

Pfeile und Verbindungen

- Fraunhofer-Grün

Kasten mit Outline

- Fraunhofer-Grün
- Linienstärke je nach Größe 2, 4, 6, 8 pt
- Je größer der Kasten, desto stärker die Linie

Linien

- Fraunhofer-Grün, bis 1 pt auch Schwarz
- Linienstärke gestrichelt: 1 pt
- Linienstärke durchgezogen: 1, 2, 3, 4 und 5 pt

Farben

! DIESE FOLIE AUS FINALER PRÄSENTATION LÖSCHEN !

- folgende Farben können über die Powerpoint-Farbauswahl hier aufgenommen und damit in der neuen Präsentation angewendet werden:

- Überschriften / Fließtext / Quellenangaben / Bildunterschriften / Grafikauszeichnungen
- Grafikauszeichnungen
- Aufzählungen / Nummerierungen erster Ebene / grafische Elemente
- Grafiken
- Fonds hinter Grafiken