Future standards at NPL from the mm-wave to THz range

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National Physical Laboratory

- The UK's national standards laboratory
- Founded in 1900
- World leading **National Measurement Institute** (NMI)
- 450+ specialists in Measurement Science
- State-of-the-art standards facilities
- The heart of the UK's National Measurement System to support business and society

Historic high GHz – THz Standards

- TDS 0.1 – 4 THz Standards: Frequency, linearity, spatial resolution:
- CW power, impedance, noise & antenna gain etc. < 110 GHz

GHz/THz Space Data Customers

- Meteorologists
- Climate change models

Prediction accuracy is linked to the quality of measurement data.

With a finite number of space instruments available, gathering all available streams is essential,

- What are the uncertainties ?
- Climate change predictions show historic temperature rises which could be measurement uncertainty.

Calibration

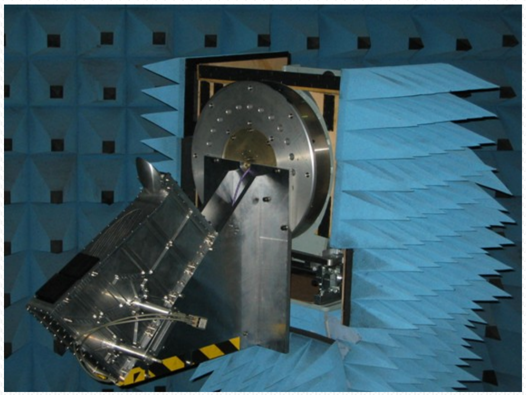
Traceability of parameters to measurement standards would underpin all measurements and tie together in-flight data in the manner we are accustomed for other parameters such as litre, kg, ampere etc….

However, **traceable** national standards are lacking above 60GHz for most parameters, and almost non existent above 110 GHz.

WHY ?

- Traceable standards are expensive to develop.

Measurement / Calibration Stages

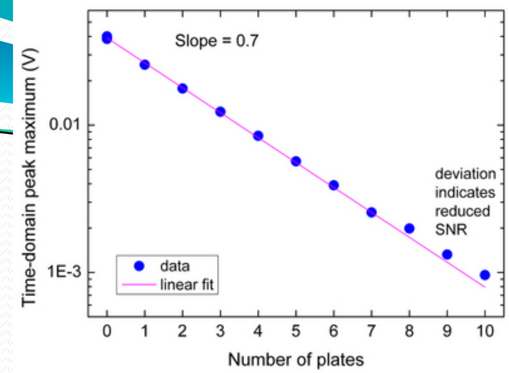


Pre-Launch Calibration
Electrical
Quasi-optics
Feed horns
Antenna Structures

Space qualification
Component redundancy

In-Flight Calibration
On-board standards
Space objects
Ground based objects

Existing THz standards



- THz measurements at NPL are mostly based on THz time-domain spectroscopy
- Fourier transform frequency resolution ~1 GHz and not very accurate at 100 GHz end
- Good for reflection/transmission material properties and spatial resolution
- Silicon etalons as linearity standards
- Silicon wafer etalons / gas cells as frequency standards

- Have yet to get funded for THz absolute power traceability but we are trying…

NPL Calibration Focus

- Space specific measurement systems for hot/cold target calibration – blackbody (not yet started)
- Power to 220+ GHz
- Attenuation to 220 GHz (not yet started)
- Antenna gain, efficiency and side-lobe measurement to 220 GHz
- Primary noise standard at frequencies > 100 GHz
- Receiver channel bandwidth and linearity calibration.

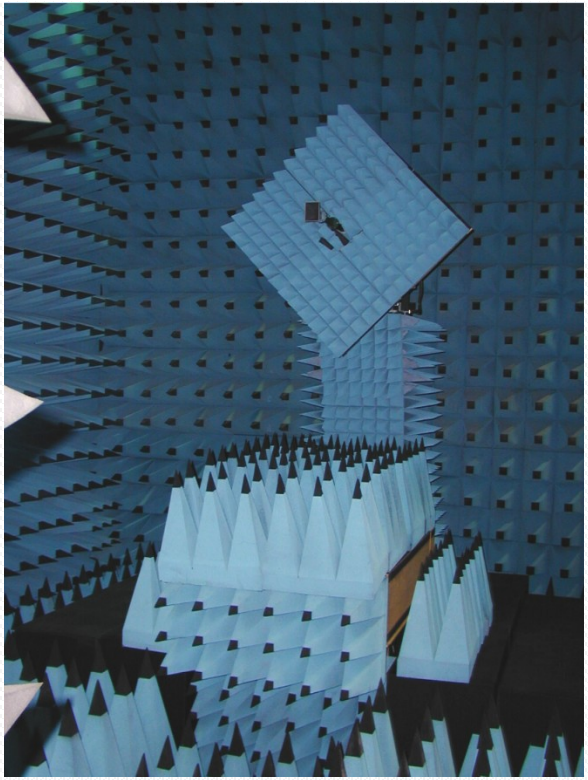
Details of these work programmes are available on the internet and NPL welcomes discussion on the content and methodologies.

Antenna Gain, Efficiency and Pattern Measurements above 110 GHz – Motivation

- Inter device data transfer – move more data
- Wireless Personal Area Networks – limited reach
- Satellite to Satellite communications: - small light antennas
- Microwave Astronomy – Resonance of atoms and molecules in the Terahertz Range
- Food imaging and process control
- Medical Replacement for X-Rays
- Anti-collision Radar
- EMC – Increased interference range

Antenna Gain, Efficiency and Pattern Measurements – Antenna Test Range

- Screened, Temperature Controlled, Anechoic Chamber
- Operates as Far-Field, Extrapolation and Spherical Range
- Operates as Spherical range from 400 MHz to 300 GHz
- **Being extended from 110 to 220 GHz**



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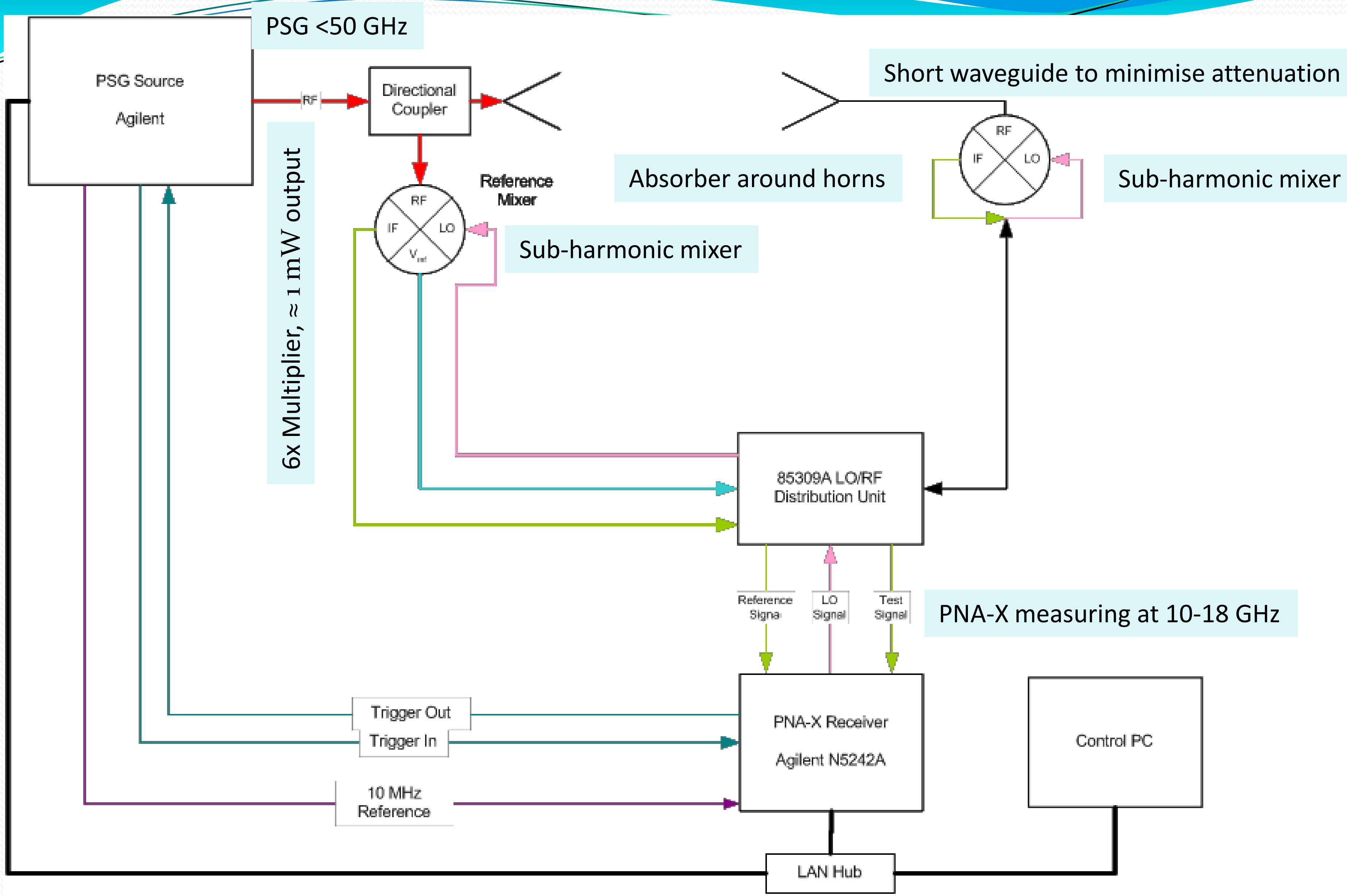
110-220 GHz antenna measurement system

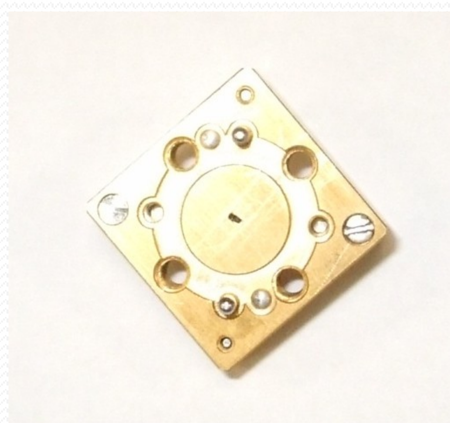


Antenna Gain, Efficiency and Pattern Measurements – Equipment 140 to 220 GHz

Multiplier Source

Mixer,
Filter and
Coupler

Isolator



- Uncertainties not known yet particularly due to effect of connections etc.

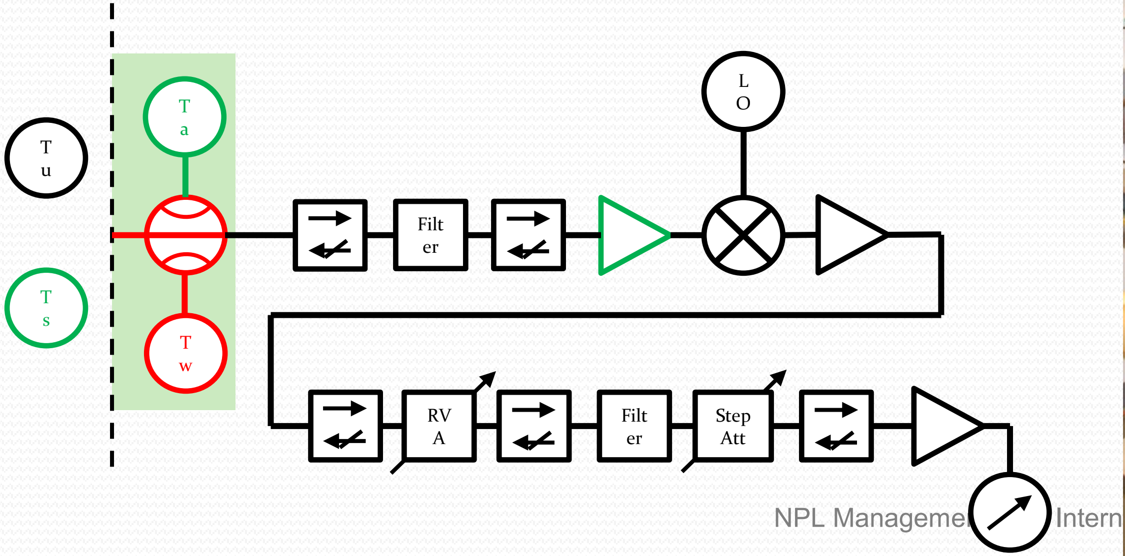
- Likely uncertainties
  - ±0.3 dB on Gain
  - ±1 dB on Pattern at -40dB

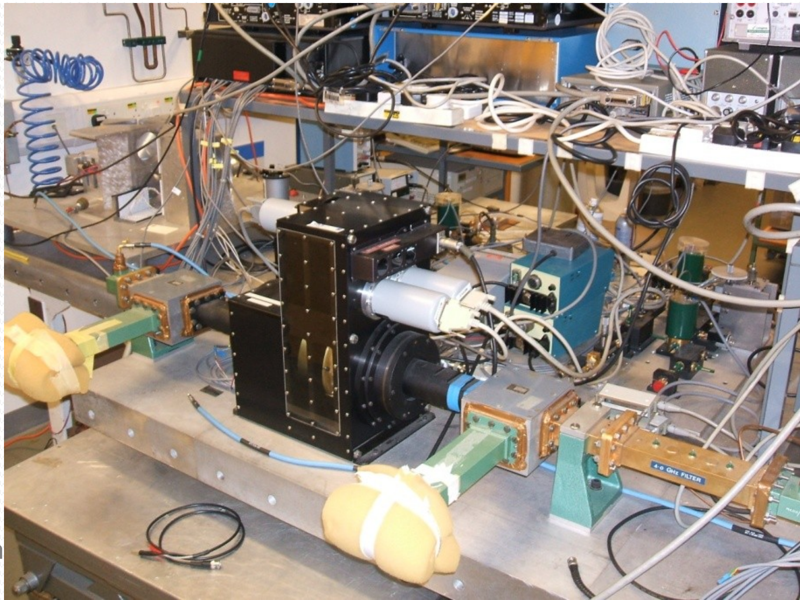
Emissivity / Blackbody / Power Measurement

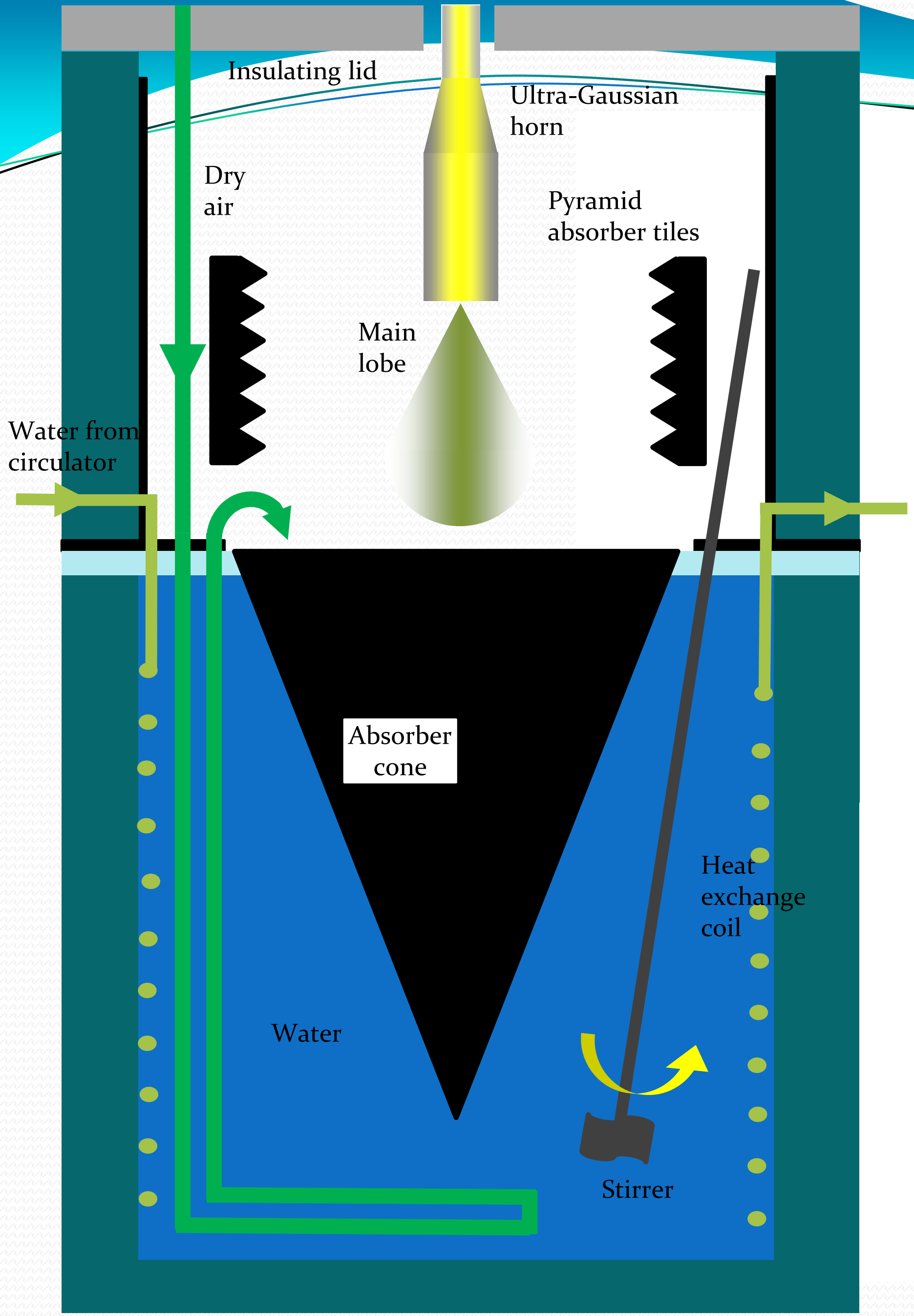
NPL have an existing radiometers that can measure the noise temperature of waveguide devices (optimized for high temperatures, noise diodes, amplifiers etc.) from MHz to 110 GHz

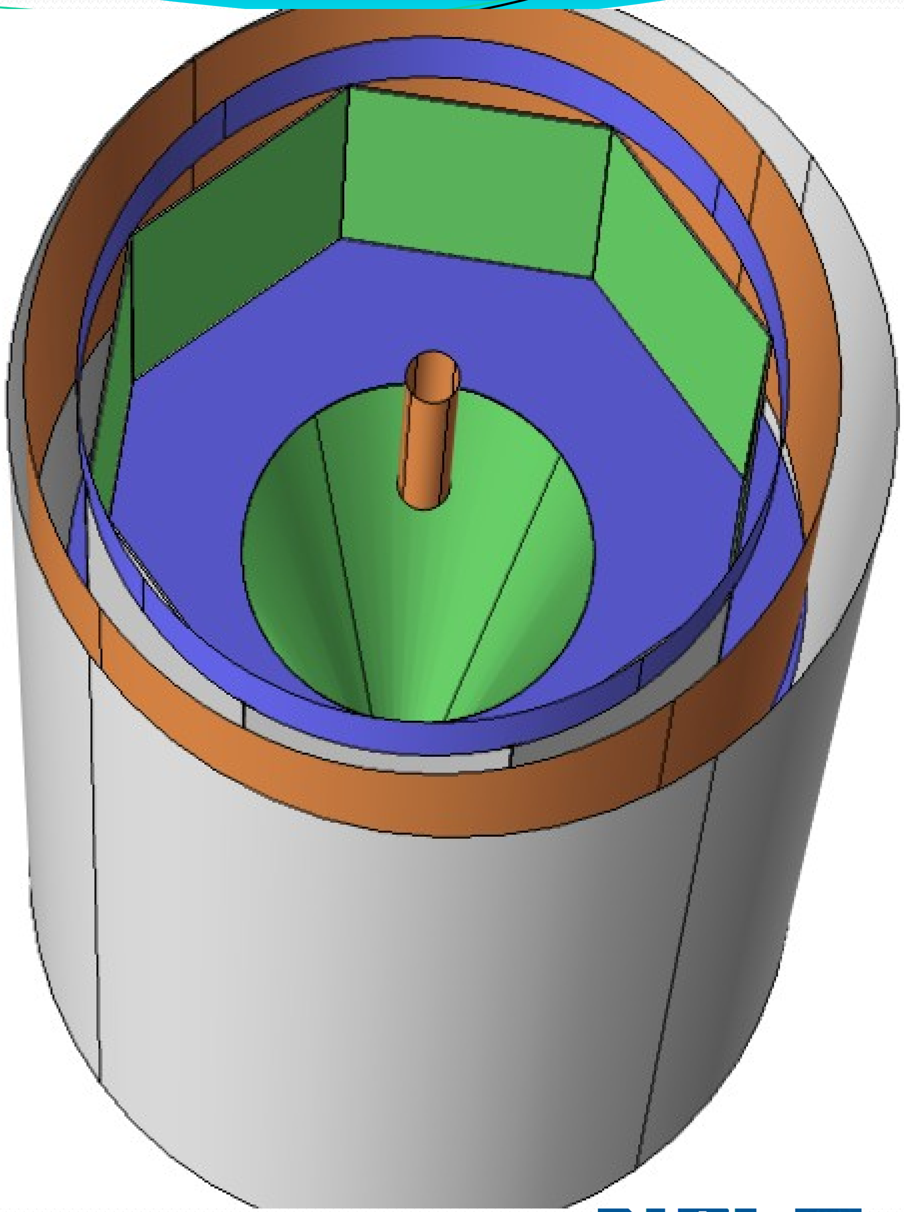
To measure emissivity of ambient or cryogenic free space loads / targets we have been modifying the 75-110 GHz system

- New waveguide working-standard at ≈60°C, waveguide switch & ambient standard
- Horn with low sidelobes
- Free-space blackbody (variable temperature)









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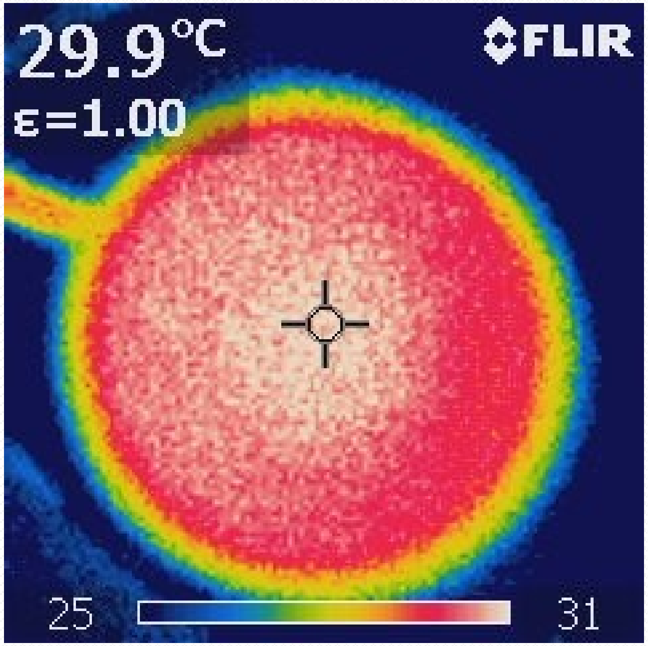
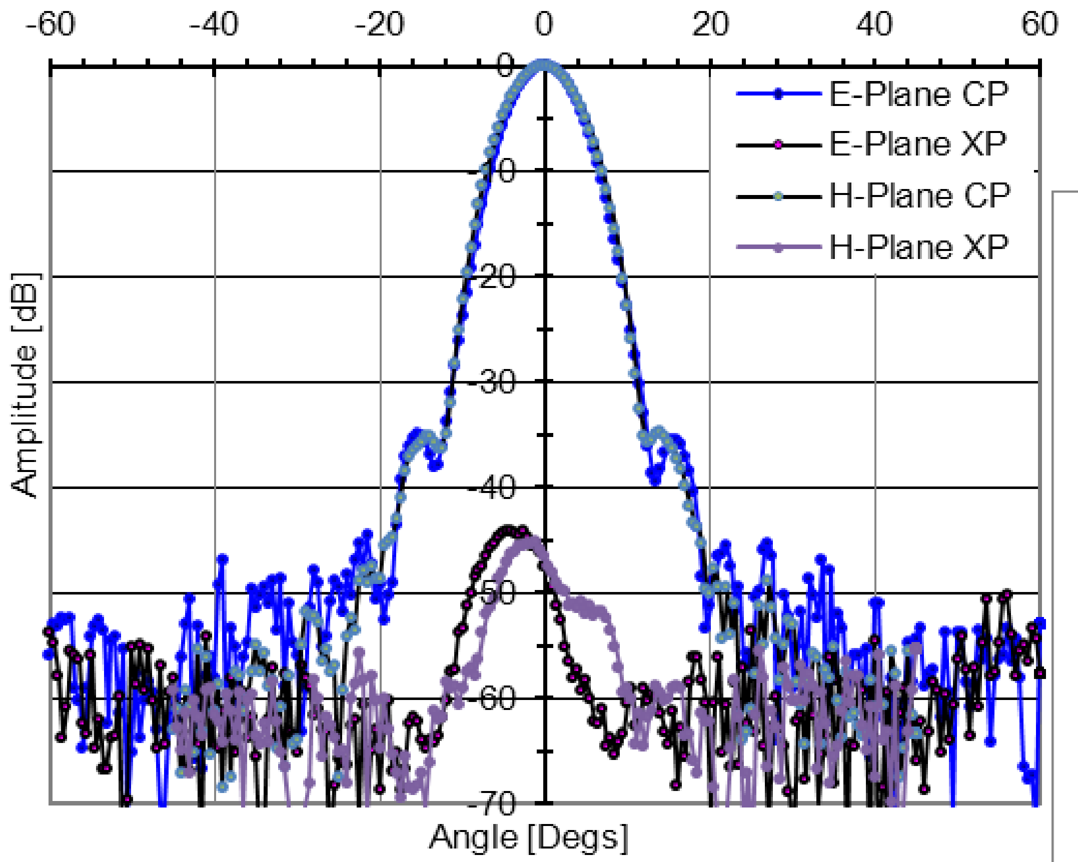
Temperature

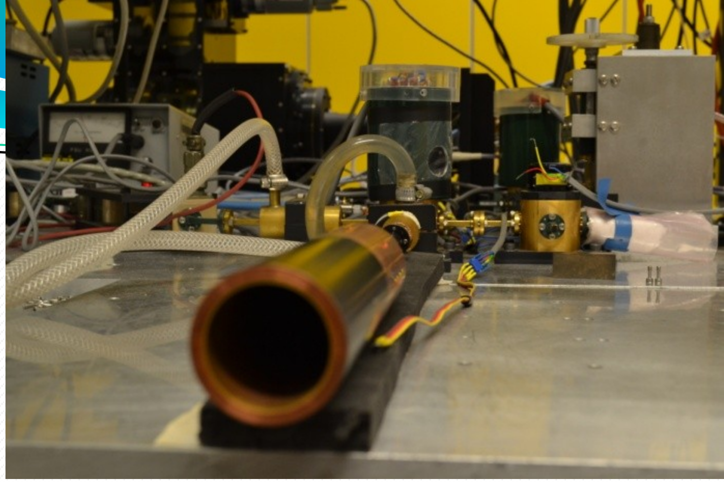
- Temperature variability from ≈ 0-40°C with very good stability
- Load temperature uniformity is measured using a combination of fixed calibrated temperature sensors and IR imaging.
- Air tube cooling outside water-bath.
- Most of cone within ~0.1K
- Achieving correct airflow and temp-controlled air buffer above cone not trivial.

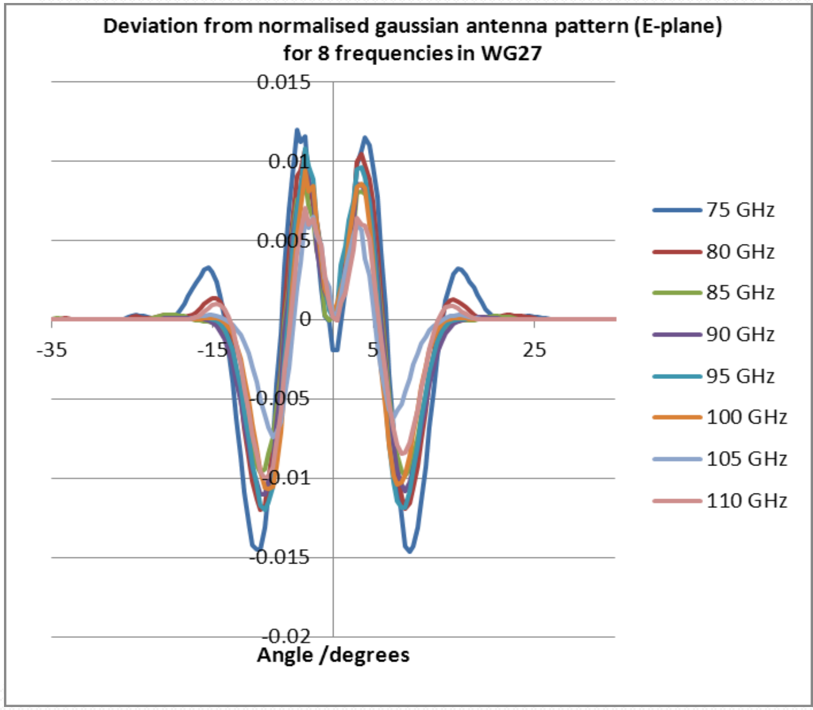


Temperature stability (old design)

Horn Measurements

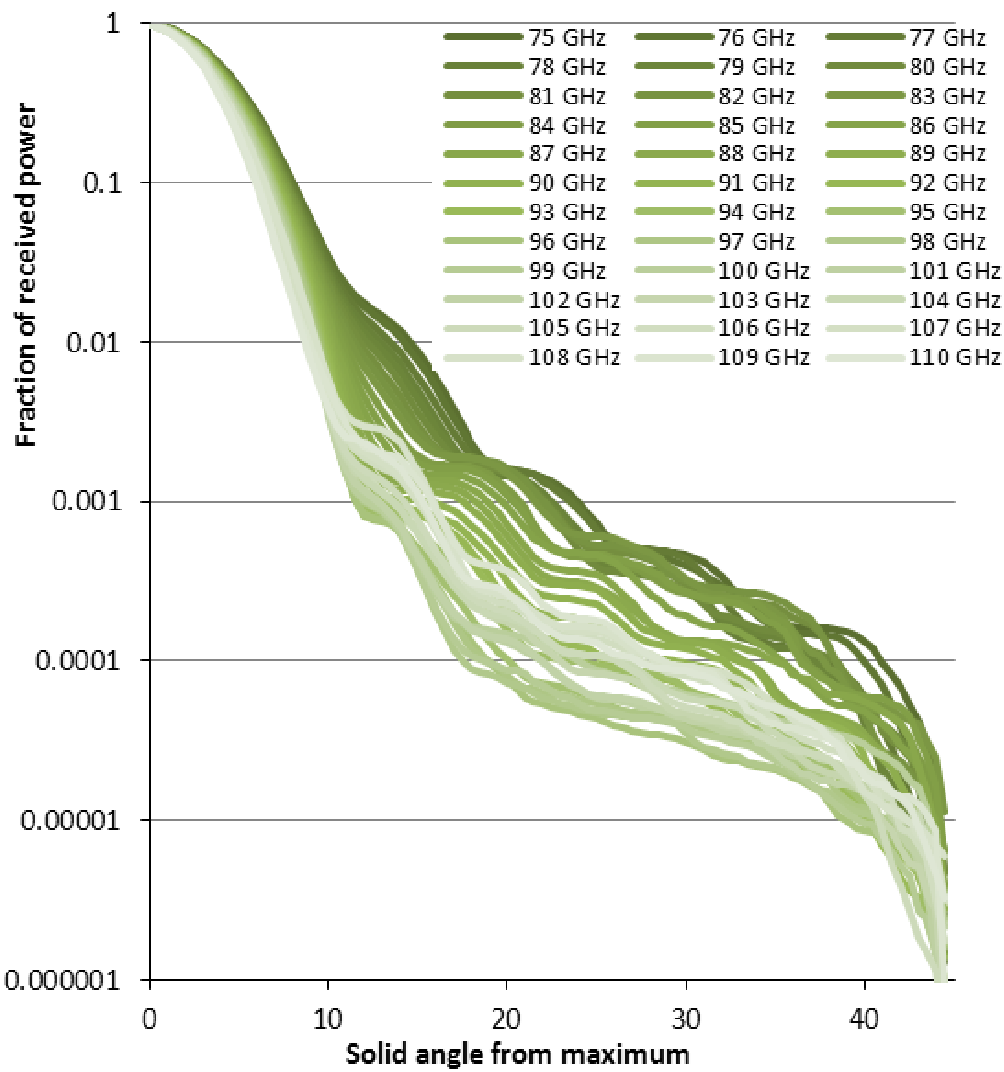


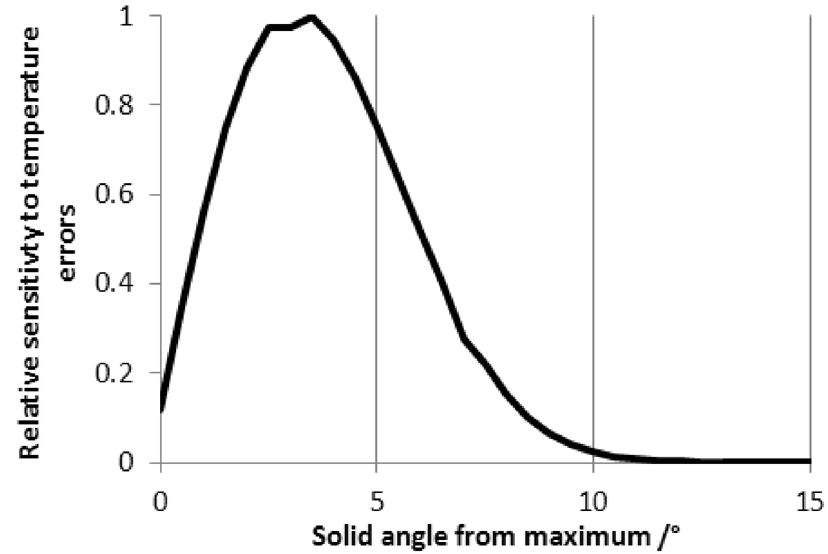




Traceable Ultra-Gaussian horn pattern measurement at 106 GHz

Fraction of antenna received power outside solid angle from maximum across waveguide band

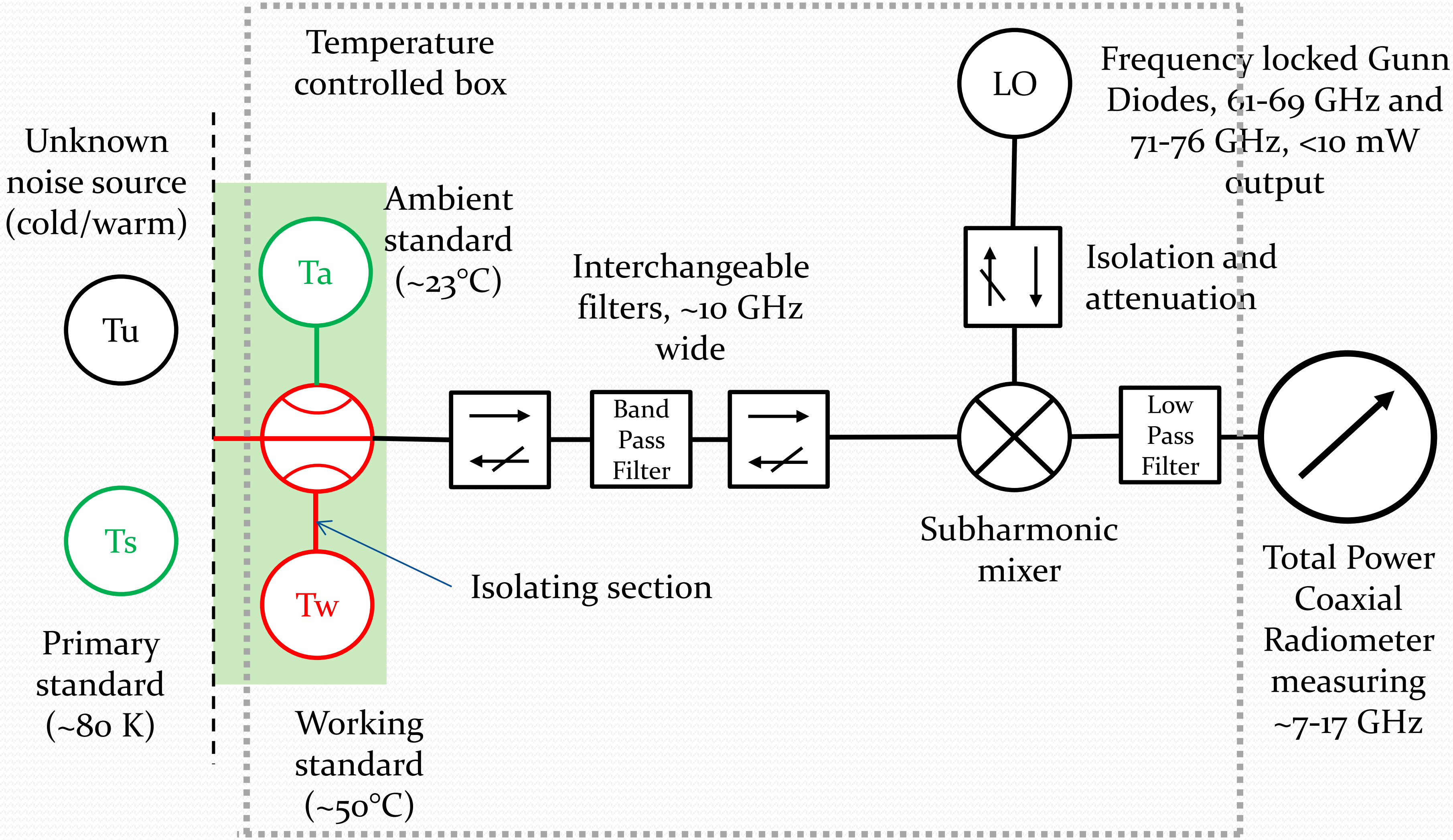




Little power is received at large angles this makes temperature control of a smaller target area much easier
So sensitivity is high at 0° but there is very little power in first degree because it is such a small area.

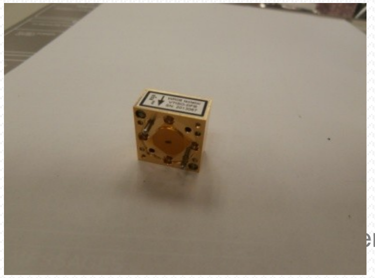
the 0° plotted point is actually the sensitivity in the 0 to 0.5° range

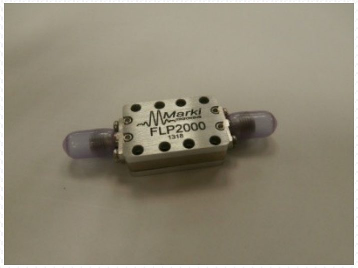
110-170 GHz Radiometer Front-End



110-170 GHz Radiometer Front-End

- Main factors determining overall uncertainties yet to be characterised. Likely to be mainly:
  - Mixer & Mismatch
- The CR18 system backend typically has uncertainties of 1.7-2.4% on Noise Temperature dominated by:
  - Primary standard
  - Mismatch
  - Working standard

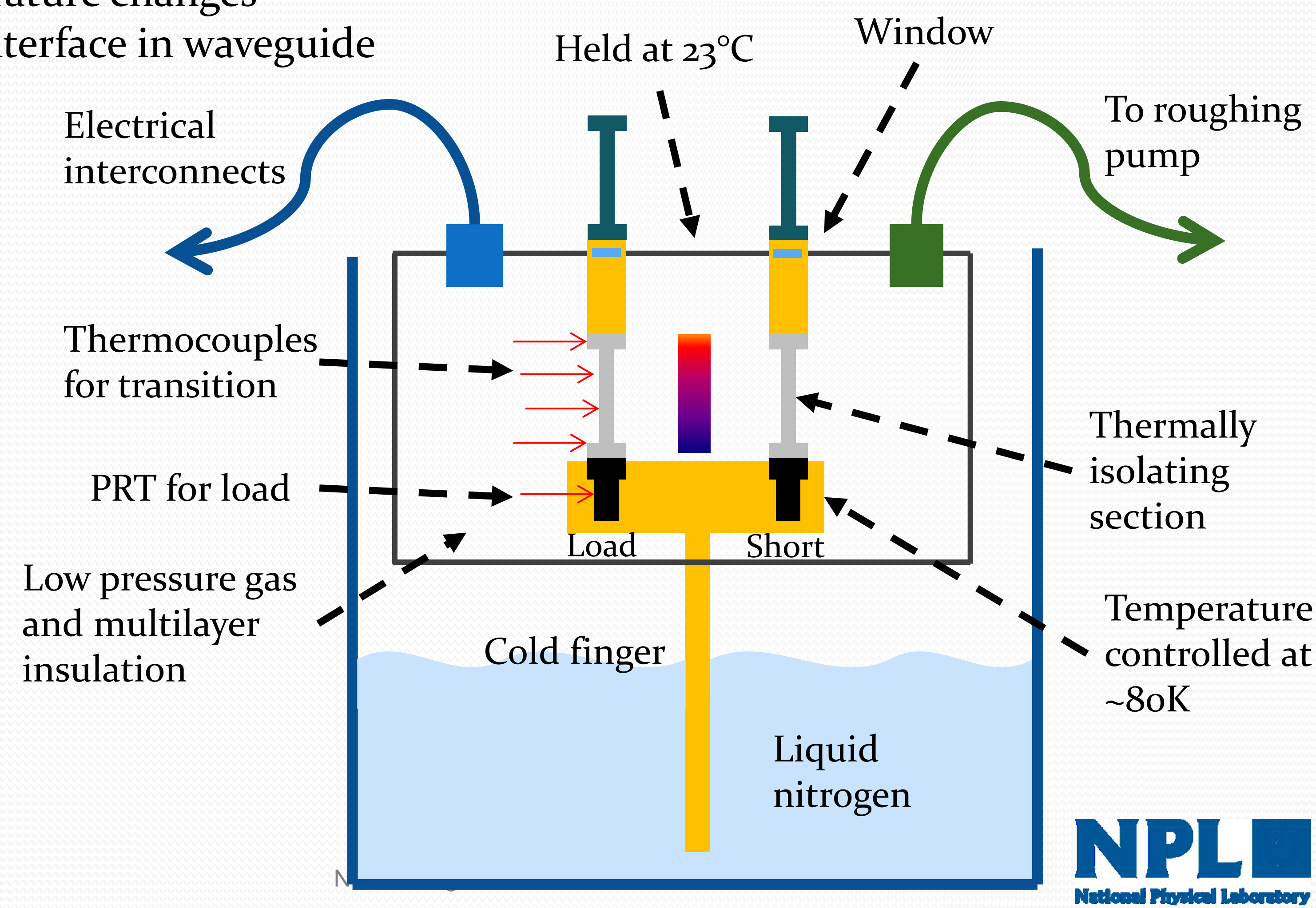




Cryogenic Primary Standard 110-170 GHz

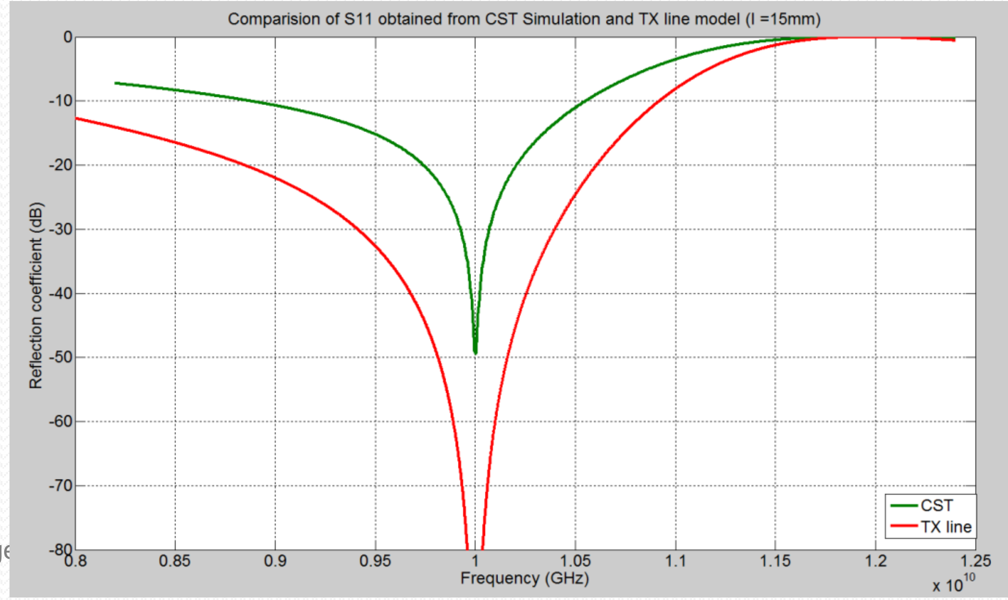
Waveguide primary standard for liquid nitrogen temperatures avoid problems with:

- Liquid nitrogen temperature variability
- Boil-off temperature changes
- Liquid-gases interface in waveguide
- Icing
- Window with temperature gradient
- Measuring attenuation of device with temperature gradient

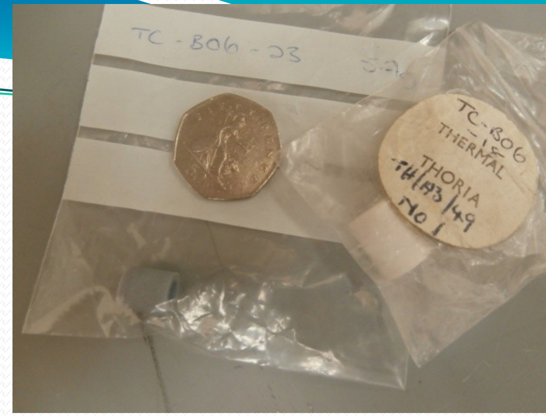


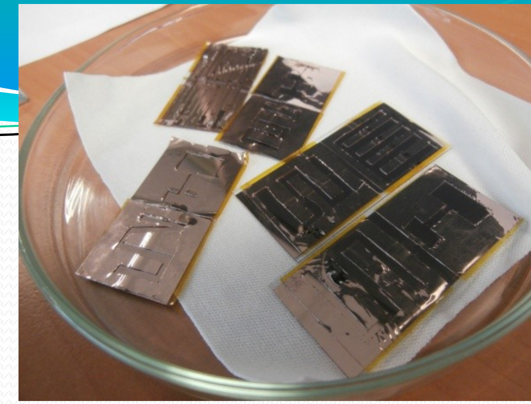
Power Standards above 110 GHz

- Preferred approach for power standard is calorimetry:
  - Compare microwave & DC heating and measure heat lost in other parts of the sensor
- There is a complete lack of commercially available waveguide power sensors above 110 GHz suitable for calorimetry
- We are working with a PhD student at Birmingham University to develop power sensors that are:
  - DC substitutable
  - Linear
  - Reasonably efficient
  - Scalable to ~300 GHz



Power





- At NPL we had another student modelling and evaporating thin metal films on dielectric
  - Copper
  - Platinum
- These are not really an ideal solution
- Ideally we would like NTC thermistor material as in the HP/Agilent/Hughes/Millitech sensors

- A calorimeter has been designed and will be built this year
- Once we have the right power sensors, uncertainties on DUT efficiency of <3% 110-170 GHz should be possible

Summary

- NPL has started a programme to extend traceability for some base parameters toward 220+ GHz.
- A focus is on space requirements for earth observation platforms
  - But standards will feed into many other applications
- Traceable standards are typically government funded to avoid market failure as development costs are high
- What are your requirements?