# Hyperspectral Microwave Sounder: Preliminary Test Results

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# Hyperspectral Microwave Sounder: An Introduction

- Space-borne heterodyne microwave **'Hyper-Spectral Imaging'** is a new and emerging Earth observation remote sensing technique that provides improved atmospheric retrievals though detailed spectral profiling of key molecular species.
- Hyper-Spectral mean **'many channels'** and at microwave frequencies it means hundreds of detection channels spread across a wide signal range.
- Currently, operational radiometers for example AMSU A/B and those under development for example MetOp SG provide information over a **limited number of channels**, say ~20 channels, the maximum. This restriction is imposed by the previously **poor spectral resolution offered by space-borne back-end spectrometers**.
- ESA's recent study on HYMS shows that an enhancement of spectral resolution will substantially improve weather forecasts and Numerical Weather Prediction.
- Interested in the sampling across two well known molecular species in particular i.e., $O_2$ and $H_2O$ (~60 GHz and 183 GHz).
- **Advanced technical development and timely demonstration of this technique is essential if UK is to champion 'HYMS instrument' eventual deployment in space.**

# Hyperspectral Microwave Sounder: Objectives

- Build and demonstrate a Novel HYper-Spectral Microwave Laboratory Demonstration system that possess **high radiometric sensitivity** and **exquisite spectral resolution.**
- The system will target the most important line, **$O_2$ spectral signature with centre frequency around 60 GHz**.
- This requires development of an **innovative Rx system architecture**, **critical component selection , especially in the areas of low noise amplifier technology, and the use of new ultra-high-speed digital backend data processing**.
- The output will be a novel and highly advanced UK generated spectroscopy system that will be the precursor to a new wave of microwave remote sounders.

# Observational Requirements and Technological Challenges

| Spectral Band | Frequency Range (GHz) | Channel Bandwidth (MHz) | | Polarisation | | Radiometric Sensitivity NEΔT (K) | | Frequency Stability (MHz) | | Priority |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Goal | Minimum | Goal | Minimum | Goal | Min | Goal | Min | |
| $O_2$ @ 60GHz | 50-57.3 | 3 | 10 | QH & QV | QH or QV | 0.4 | 0.5 | ±1 | ±5 | 1 |
| | 63.3-67.9 | 3 | 10 | QH & QV | QH or QV | 0.4 | 0.5 | ±1 | ±5 | 1 |
| $H_2O$ @183GHz | 175 -191 | 40 | 400 | QH & QV | QH or QV | 0.4 | 0.4 | ±25 | ±25 | 2 |

**Requirements, NEDT<0.4K, Spectral resolution: 10 MHz minimum, 3 MHz (goal)**
**Radiometric noise temperature increases with decrease in spectral resolution bandwidth.**

Need to sample the spectral intensity within a narrow BW and this will require a **reduction in system noise if the same radiometric precision is to be maintained w.r.t. current available systems.**
The sensitivity requirement is **four-fold higher compared to the best predicted performance of Met-OP SG instruments** for a similar spectral resolution in the 60 GHz band.

# Observational Requirements and Technological Challenges

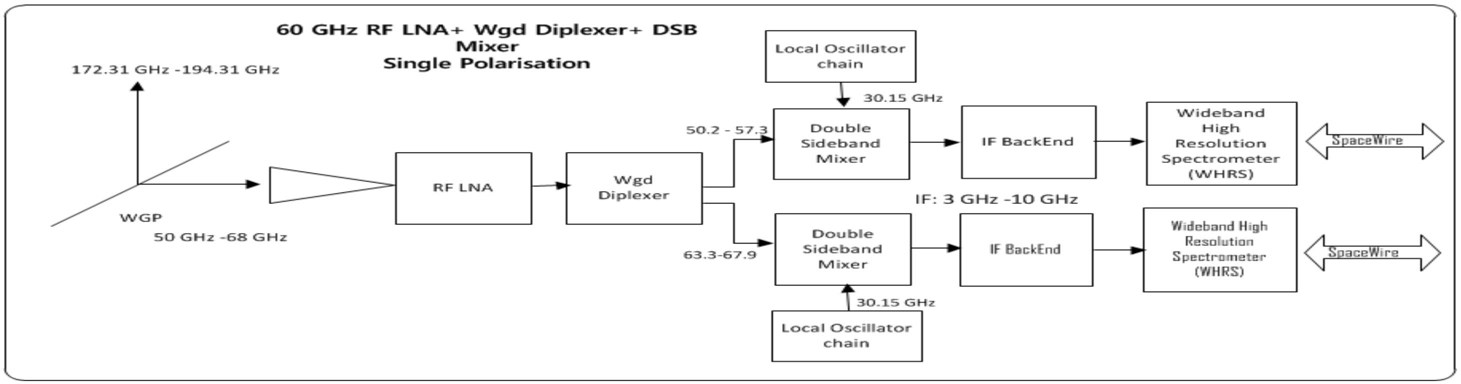
- Achieving required specification consequently needs critical hardware elements to be developed and demonstrated:
    1. Ultra-low noise (NF<2.5 dB) and high gain (50 dB) amplifier
    2. Ultra-high speed, ultra-wideband (~8 GHz) and high resolution (3 MHz) backend digital signal processing system

- Within Europe, Fraunhofer IAF are the only supplier of LNA devices operating within the required BW (50-68 GHz) and with required gain of >25 dB for a single chip and NF <2.5 dB. IAF has agreed to supply 50 GHz LNA chips for this proposed program.

- Careful selection of IF components is needed to minimise the Rx noise contribution and to ensure adequate gain stability

# HYPER SPECTRAL MICROWAVE NDER:
# 60 GHz RADIOMETER SYSTEM CONFIGURATION

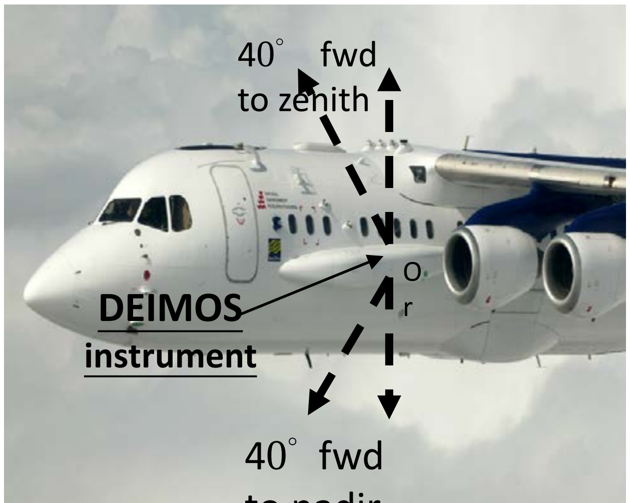
## *60 GHz RF LNA+ WGD Diplexer+ DSB SHM+ 2SSB*




## Salient Features:

- Waveguide Polariser (WGP) splits the incoming signal to two frequency bands: 60 GHz and 183 GHz.
- RF LNA is the first element in the 60 GHz Rx chain. Due to the high gain RF LNA, the noise contributions from the subsequent elements in the chain is significantly reduced, which is the key for achieving high spectral resolution performance.
- Wgd Diplexer is used for separating the two sidebands with an **image band rejection ~40 dB**.
- Gain compensation circuitry is needed to achieve the required gain and thermal stability.
- DSB Sub Harmonic Mixers are used in this option rather than a Sub Harmonic Image Rejection Mixer to increase the side band rejection to 40 dB.
- Slightly complex architecture due to separate LO required for pumping the DSB mixers in the USB and LSB Rx chains.

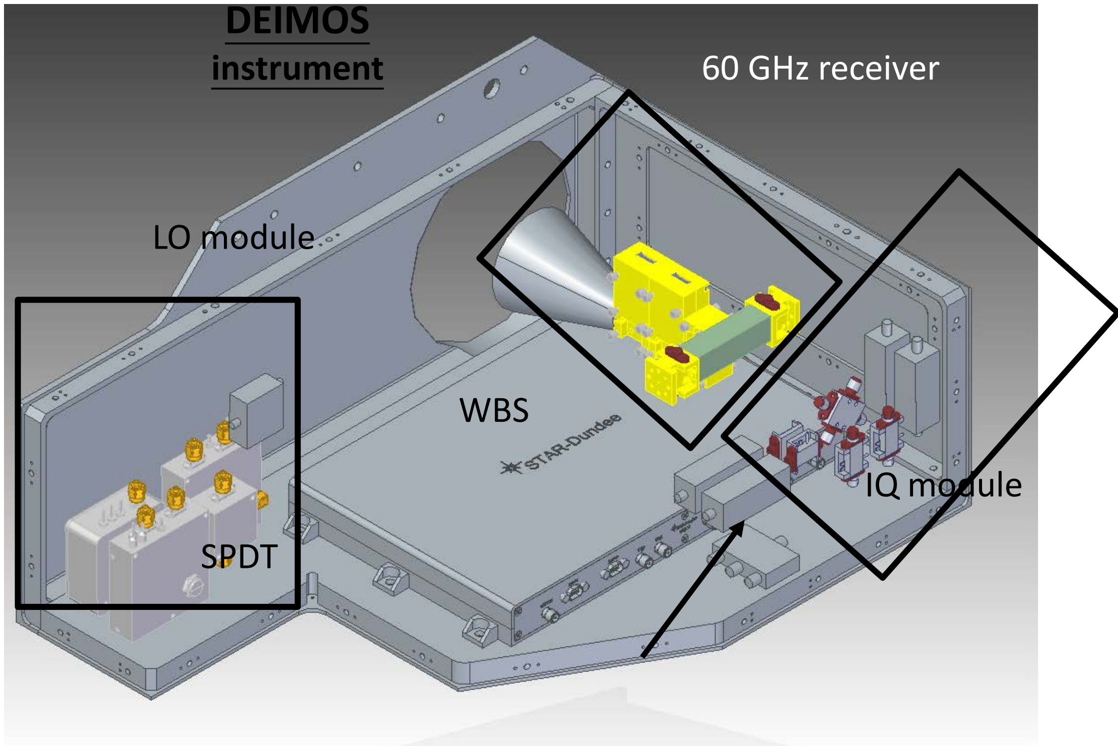
# HYPER SPECTRAL MICROWAVE SOUNDER: Airborne Demonstration for the proof of concept demonstration




*Facility for Airborne Atmospheric Measurements (FAAM) BAE-146.*

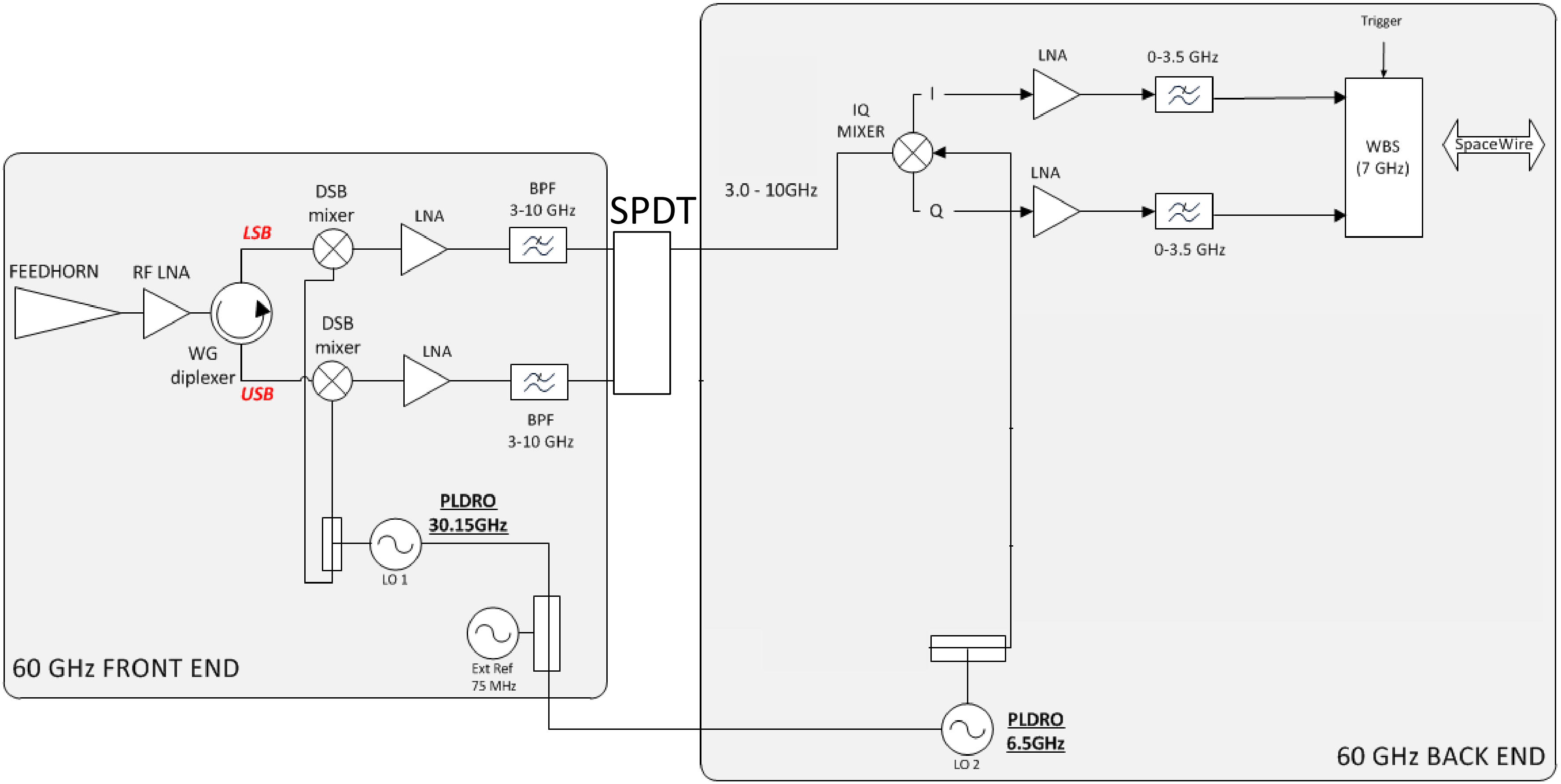
*View a range of zenith angles, as well as the more usual nadir angles.*

*Half Power Beamwidth (HPBW) : 5º to 10º.*



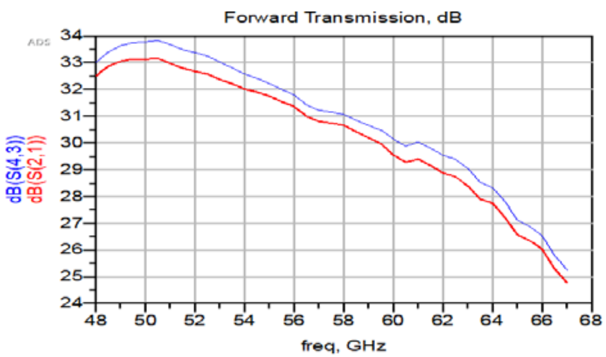

- IF chains need closer integration to the spectrometer
- IF IQ outputs are arranged closer to the spectrometer IQ inputs

# HYMS Detailed Schematic

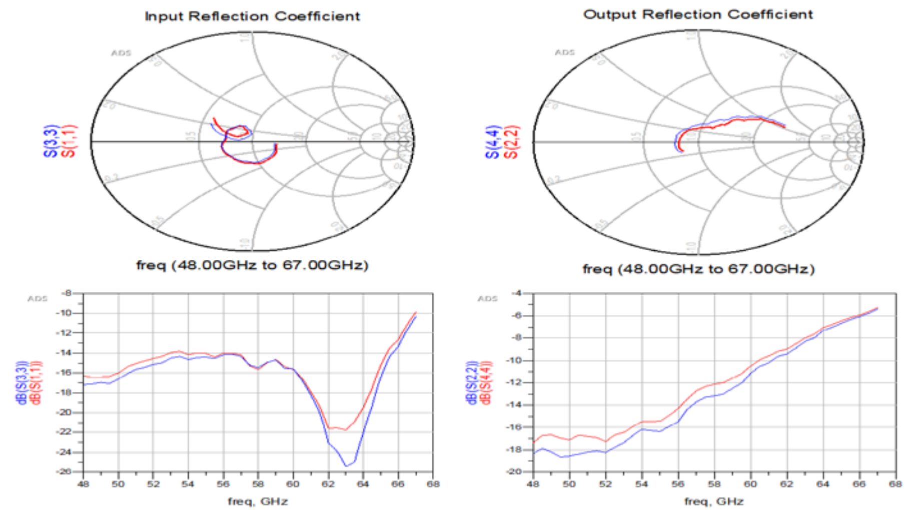


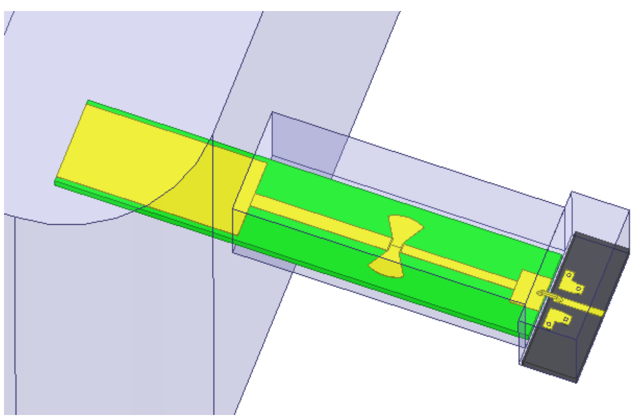
JCR SYSTEMS Met Office STAR-Dundee RAL Space

# HYMS Critical Component Design - Low Noise Amplifier

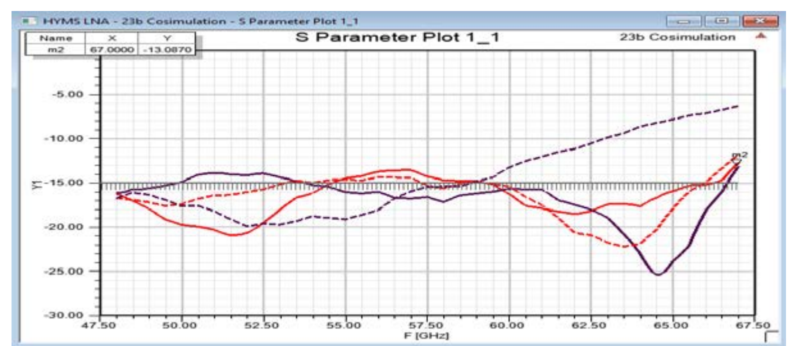



Gain of a single chip is rolling off over the required BW. An Equaliser has been designed to provide negative shape to compensate MMIC gain.



A transition has been designed to improve high frequency match (e.g. transform to 80 Ohm) for a wider frequency match

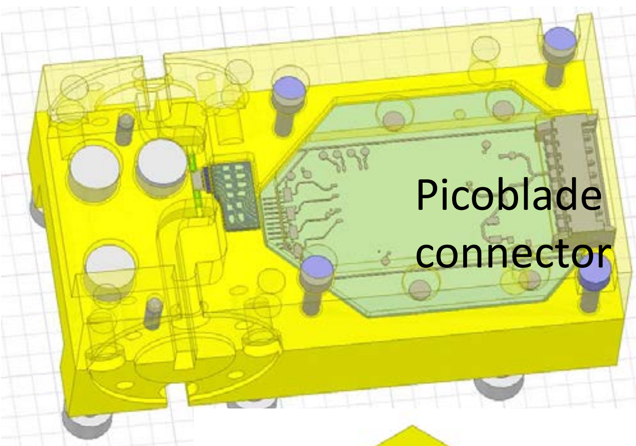



**S11: red, S22: black, dashed: MMIC, solid: MMIC+ transition**

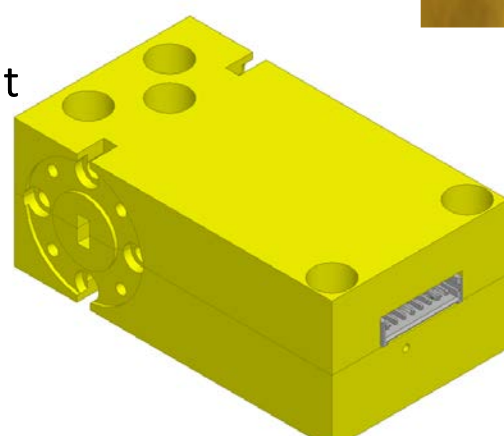
# Low Noise Amplifier Mechanical Configuration

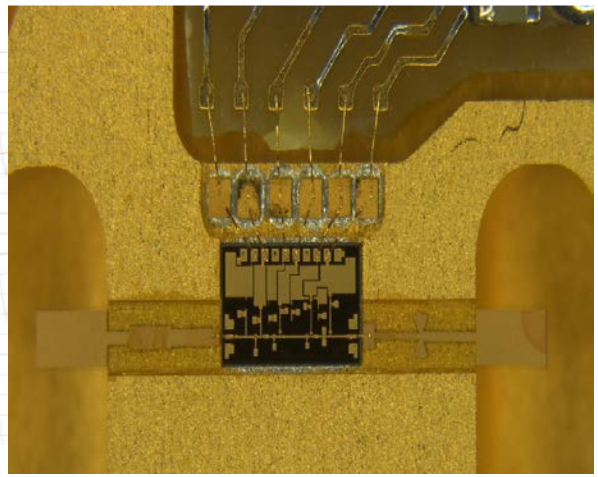
**It is critical to be able to control the bias applied to the LNA to achieve good noise performance.**

Input

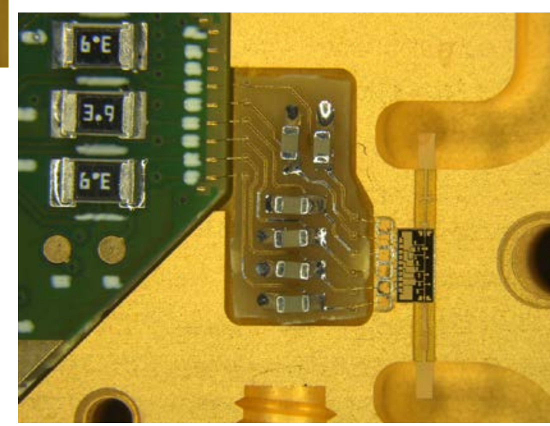



Output



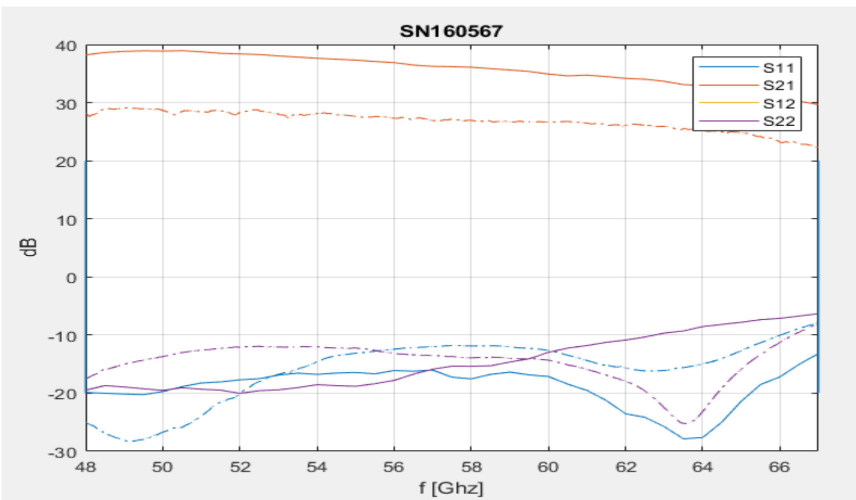


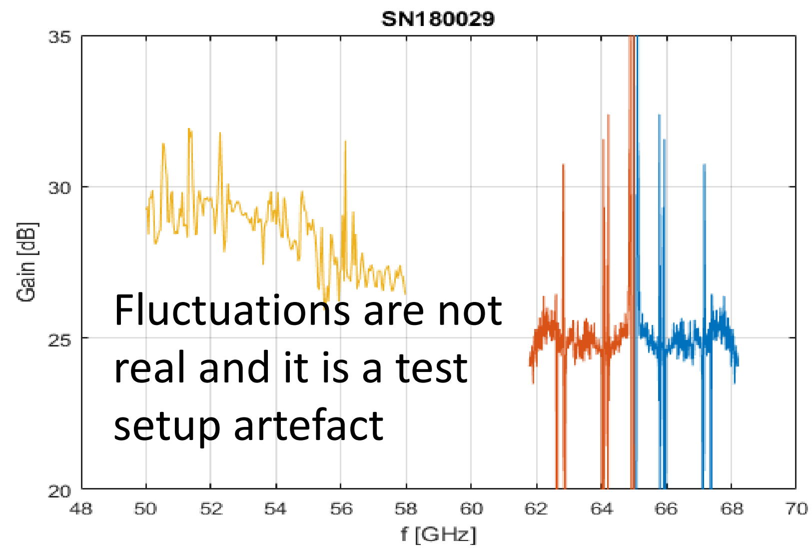
Assembly
Photographs



# Low Noise Amplifier Preliminary Test Results

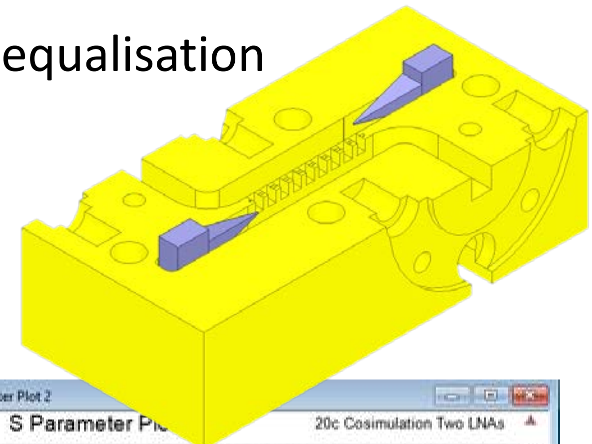
**Gain better than 25 dB measured over the whole BW of 50 GHz to 68 GHz.**

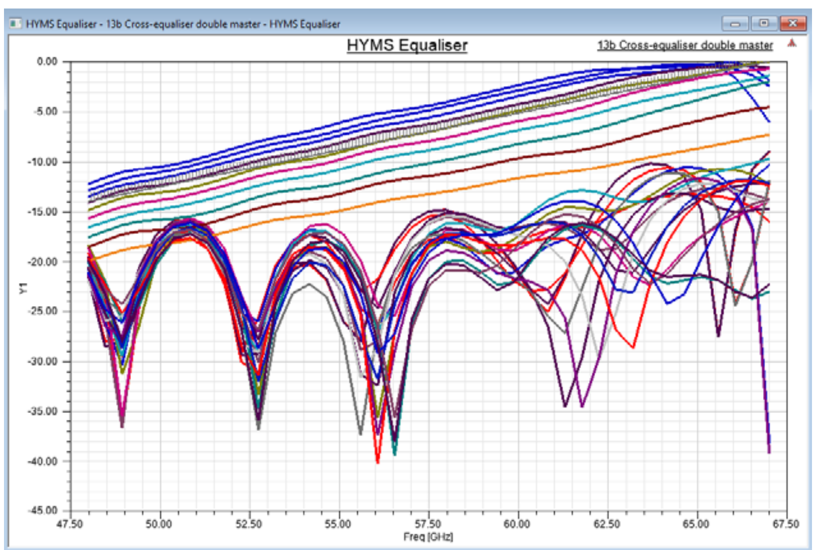


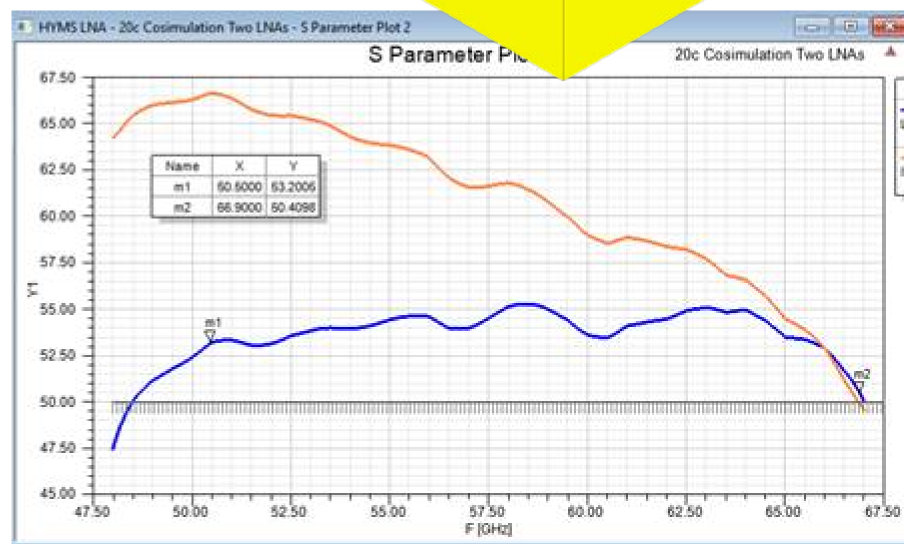
# HYMS Critical Component Design – Equaliser Design

- Cross-coupled hybrid, providing lossy (well-matched) equalisation
- Tuneable by shorting irises with bond wires
- Meets required linear S21 slope





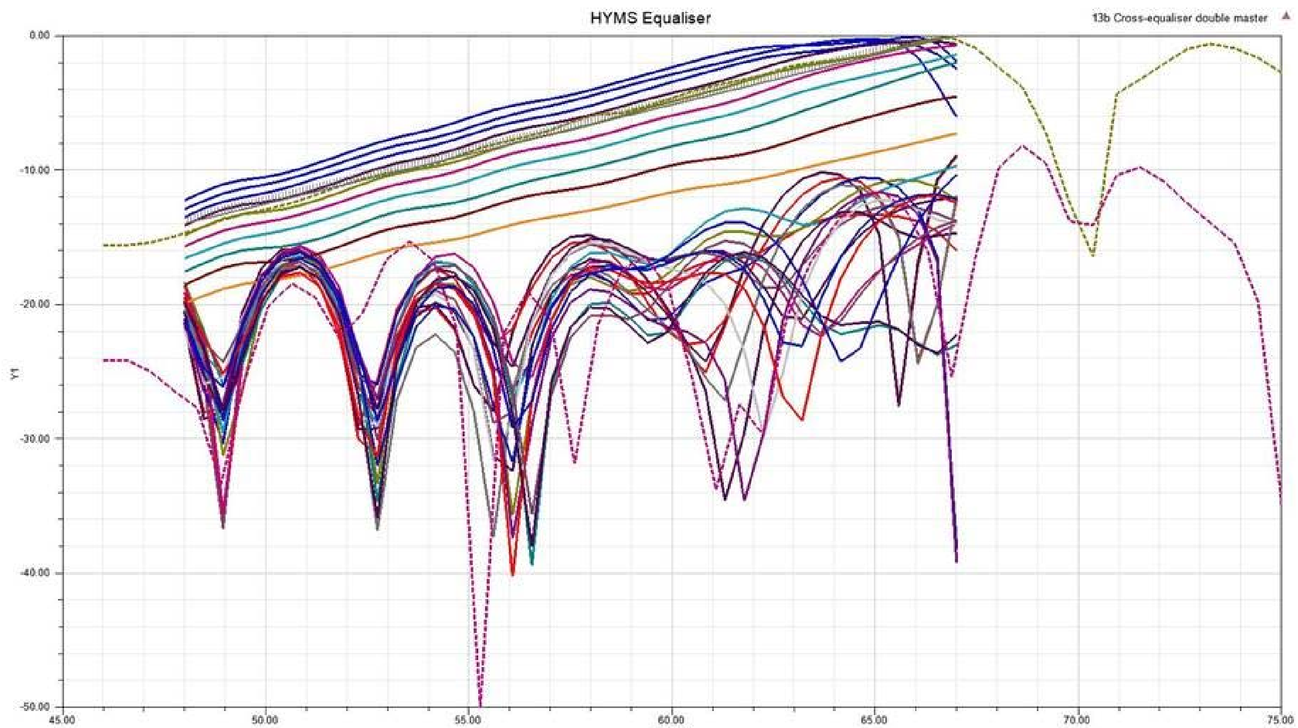

Equaliser S21 and match against required equalisation slope (limit line)



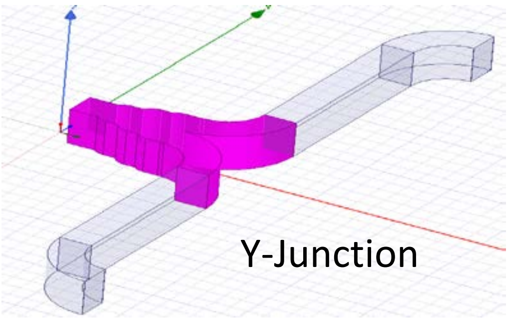

Preliminary simulated S21 of two LNAs with and without equaliser

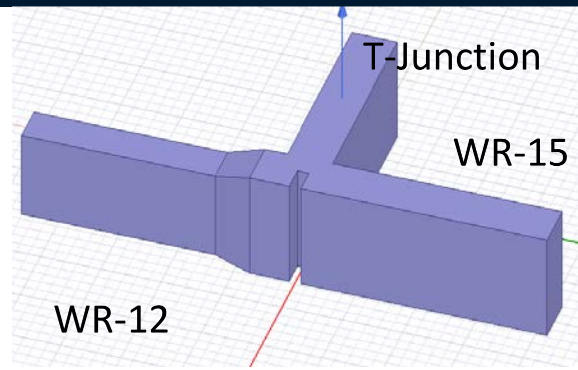
# HYMS Critical Component Design – Equaliser Measured

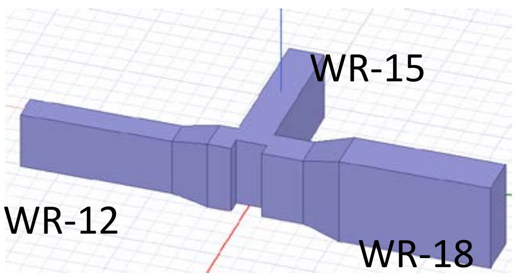
- The equaliser was measured at it's nominal positon (14 dB slope) and matches very accurately with the prediction.
  - It can now be tuned for inclusion in the full module, depending on LNA module performance

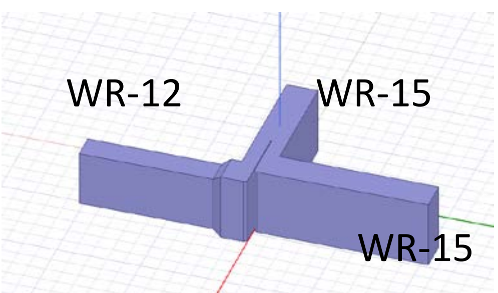


# HYMS Critical Component Design - Diplexer

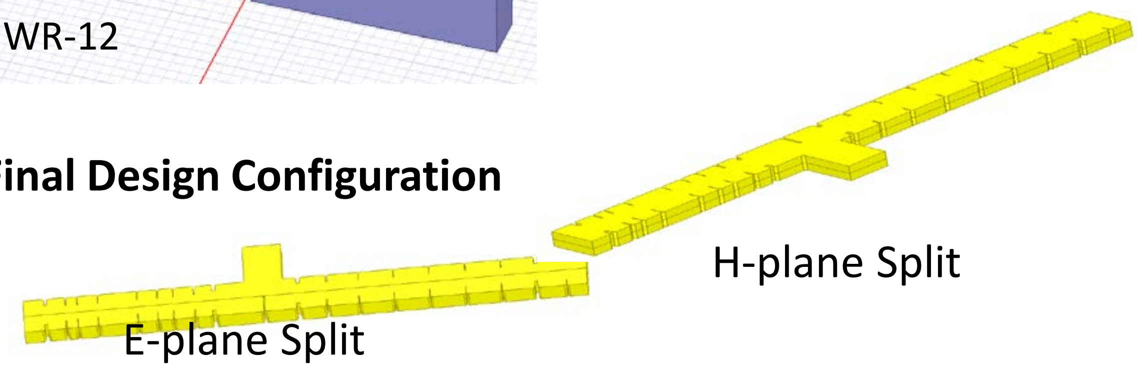


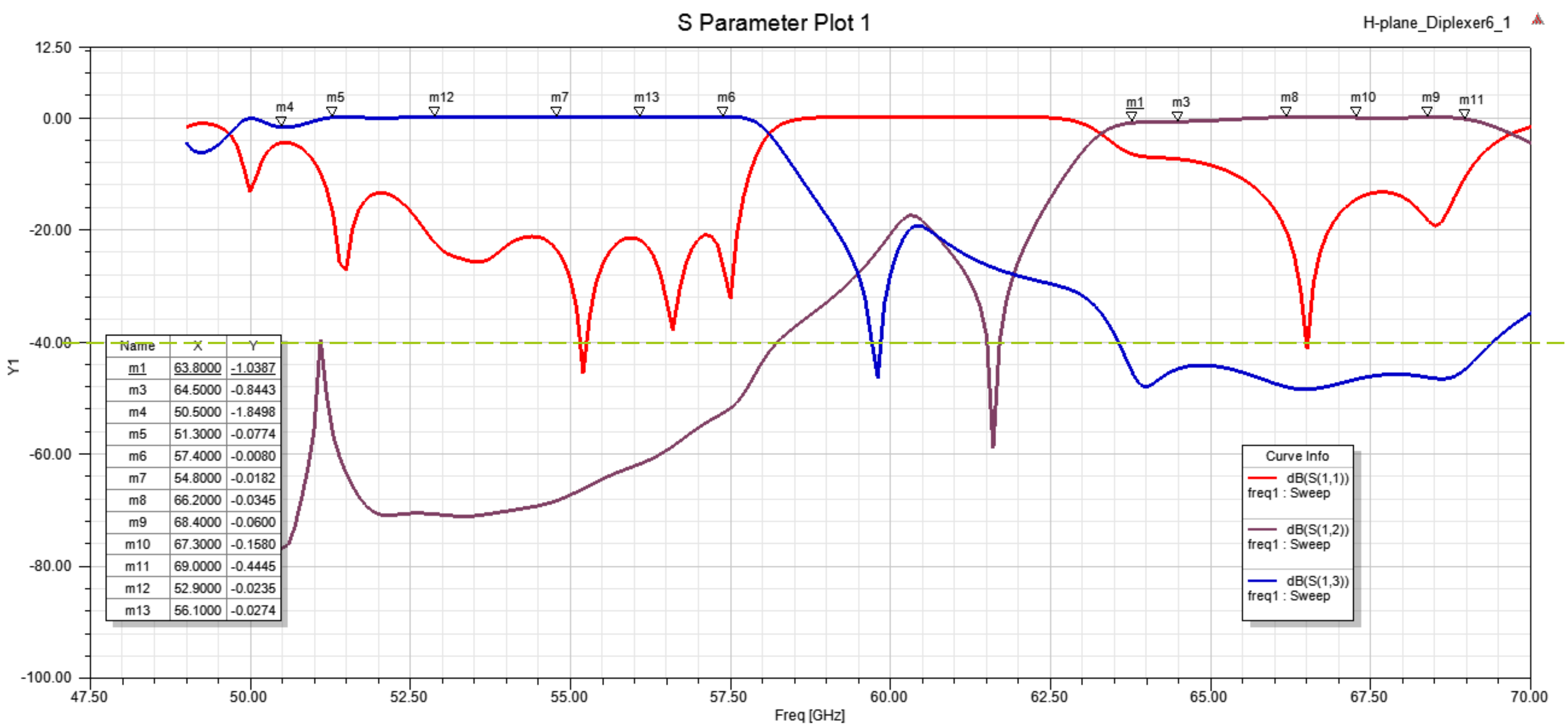




**Final Design Configuration**




- T junction with a chamfer provides the 3 dB power split into the two waveguide branches
- 9 section filter in both branches for achieving very low loss in the pass bands
- E-plane split design to reduce insertion losses

# Diplexer Predicted Performance

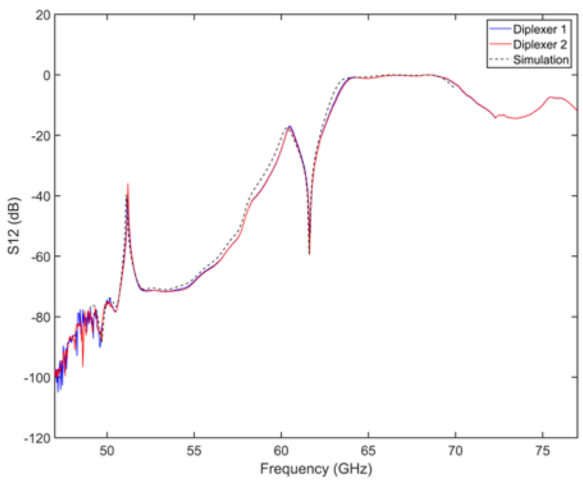


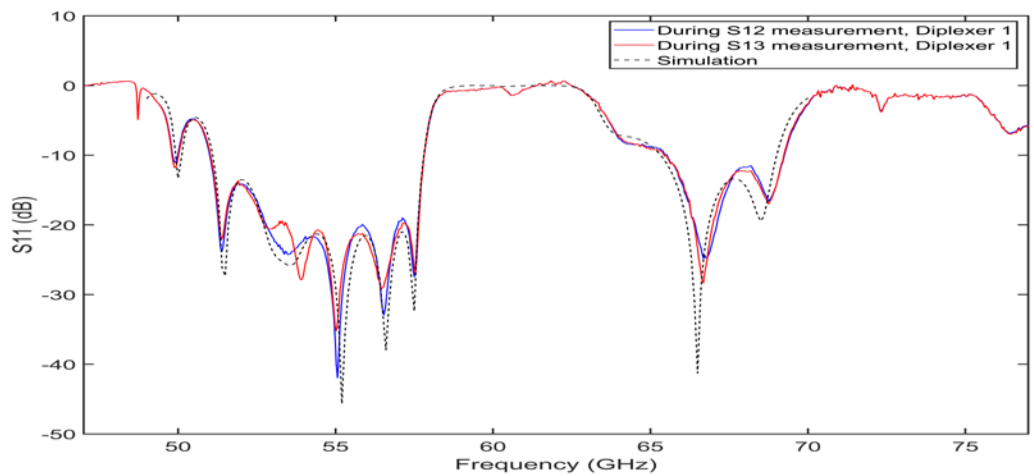

Worst insertion loss is -1.03 dB at the edge of the USB @63.8 GHz.

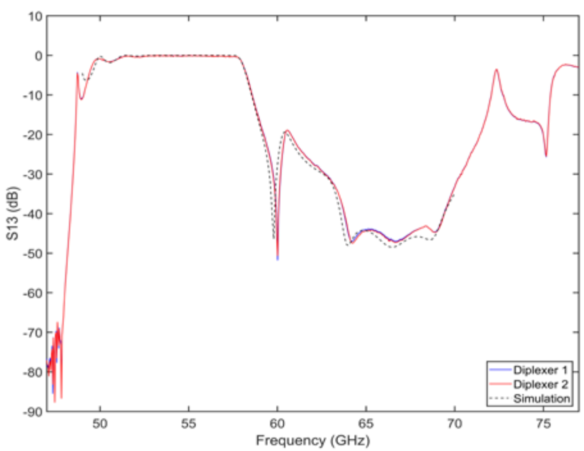
Over 95% of the bandwidth the insertion loss is less than 0.1 dB.

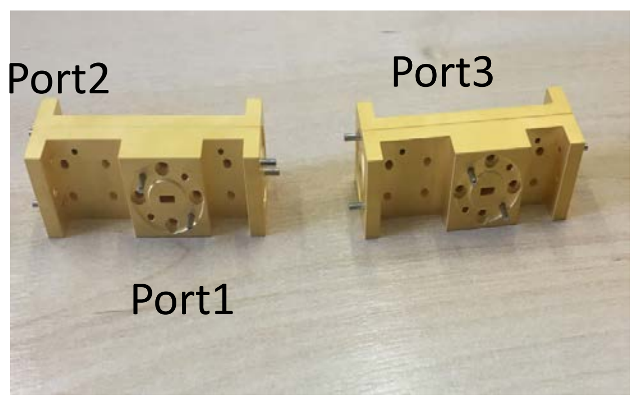
40 dB Side band rejection requirement is met.

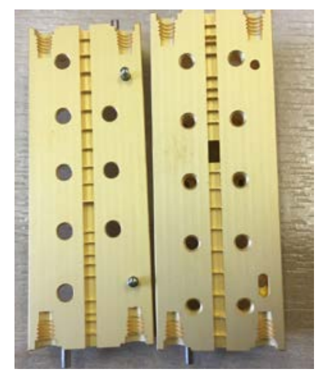
# Diplexer Measured Performance



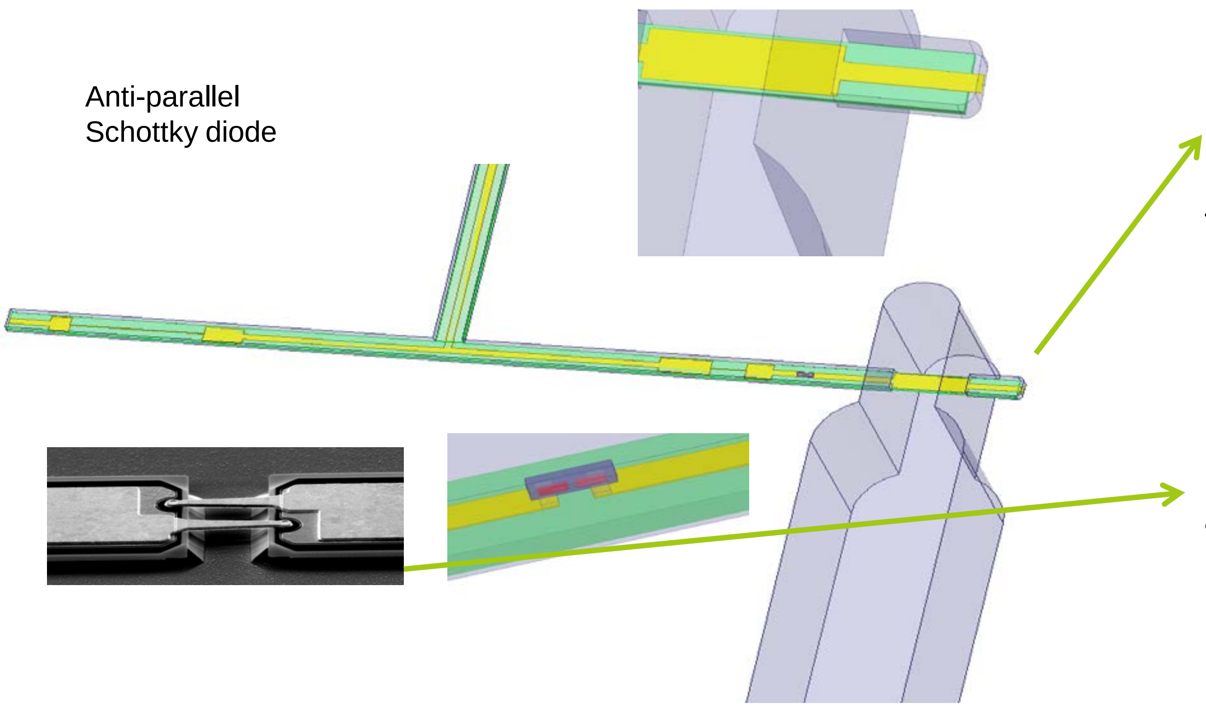



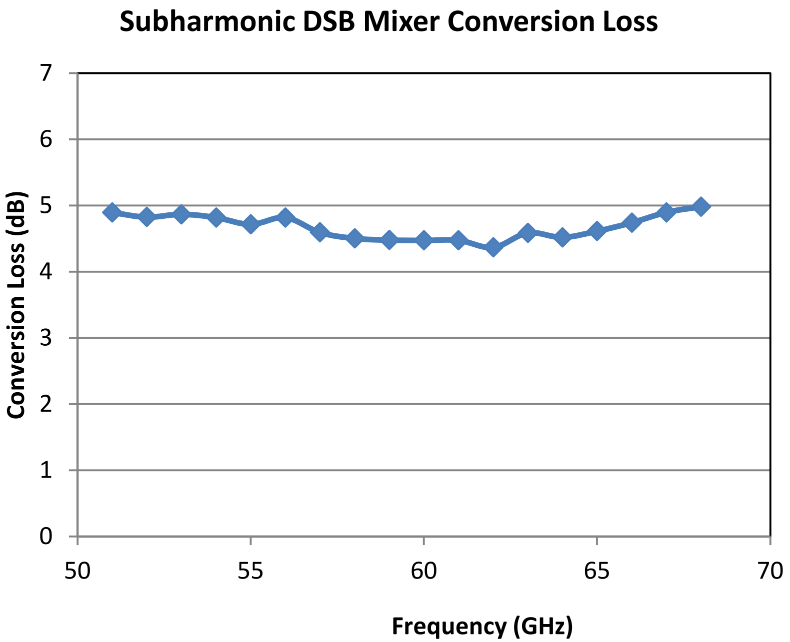



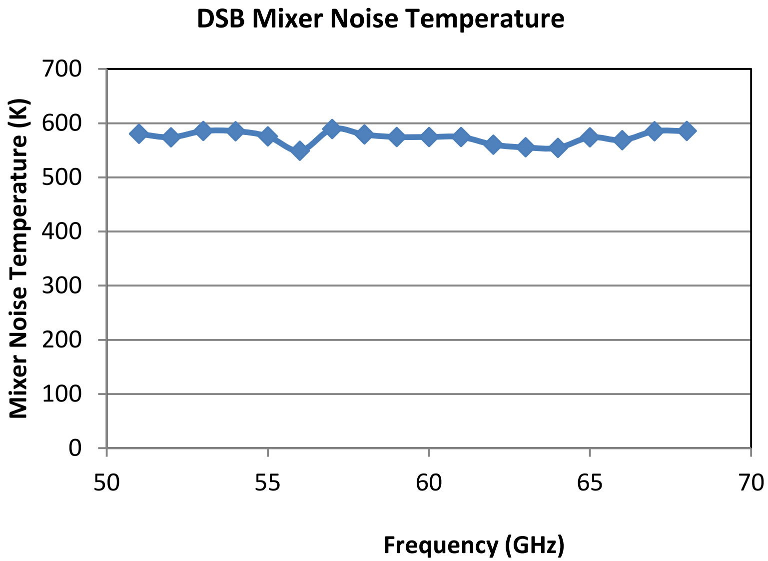
# HYMS Critical Component Design
# Double Sideband Mixer



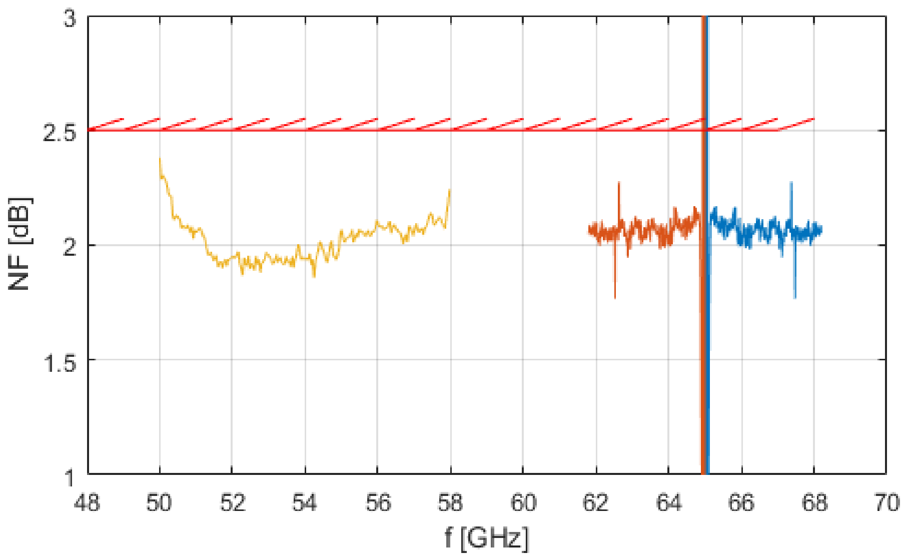

The final design configuration of the subharmonic DSB mixer in HFSS.
Beamlead is sandwiched between the two split blocks to provide grounding to the diode.
RAL anti-parallel Schottky diode is used as the active component in the design for generating mixer products (below).

# HYMS Critical Component Design
# Double Sideband Mixer Predicted Performances



# Hyperspectral Microwave Sounder Preliminary Receiver Measurements




Y-factor measurements were performed using available commercial mixers.
Noise figure requirement is 2.5 dB (target) and 2.2 dB (goal)
Slight fluctuation are due to the picking up of the GSM signals at 0.8, 0.9 and 2.1 GHz

# Conclusions

- A baseline design to meet the instrument and observational requirement of a HYMS instrument was selected after a detailed trade-off study.
- Critical components were designed and manufactured which includes low noise amplifier , diplexer and double sideband subharmonic mixer. Preliminary measured results of these components agrees well with predictions.
- Wide band High Resolution Spectrometer of 8 GHz BW and 3 MHz spectral resolution is currently getting fabricated at STAR Dundee.
- Preliminary noise figure measurements on the LNA gives promising results and meet the critical NEDT requirements.