ECIT | The Institute of Electronics, Communications and Information Technology

Queen's University Belfast

# 183 GHz Frequency Selective Surface (FSS)

## CEOI Technology Conference

21 – 22nd April 2015
Abingdon, Oxfordshire

**Raymond Dickie**

Project supported by the EU Programme for Peace and Reconciliation
Invest Northern Ireland
Department for Employment and Learning

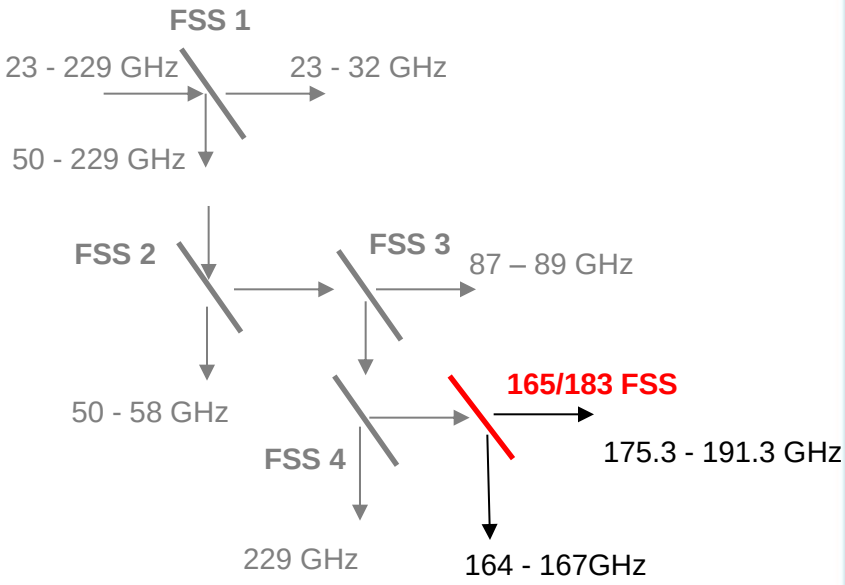
# Outline

- Application Area
- FSS Modelling
- FSS Specification
- Design Concept
- Tolerance Analysis
- FSS Manufacture
- TEST 140 – 200 GHz
- Conclusions

# ECIT | FSS Application Area: MWS Radiometer

- MWS radiometer provides measurements of temperature and humidity profiles and total liquid water columns
- Proposed change to the extension to the MetOp-SG layout to reduce insertion losses
  - 165 / 183 GHz FSS Introduced

| Channel name | Frequency (GHz) | Utilisation |
|---|---|---|
| MWS-1 | 23.8 | Water-vapour column |
| MWS-2 | 31.4 | Window, water-vapour column |
| MWS-3 | 50.3 | Quasi-window, surface emissivity |
| MWS-4 | 52.8 | Temperature profile |
| MWS-5 | 53.246±0.08 | Temperature profile |
| MWS-6 | 53.596±0.115 | Temperature profile |
| MWS-7 | 53.948±0.081 | Temperature profile |
| MWS-8 | 54.4 | Temperature profile |
| MWS-9 | 54.94 | Temperature profile |
| MWS-10 | 55.5 | Temperature profile |
| MWS-11 | 57.290344 | Temperature profile |
| MWS-12 | 57.290344±0.217 | Temperature profile |
| MWS-13 | 57.290344 ±0.3222±0.048 | Temperature profile |
| MWS-14 | 57.290344±0.3222±0.022 | Temperature profile |
| MWS-15 | 57.290344±0.3222±0.010 | Temperature profile |
| MWS-16 | 57.290344±0.3222±0.0045 | Temperature profile |
| MWS-17 | 89 | Window |
| MWS-18 | 165.5±0.725 | Quasi-window, water-vapour profile |
| MWS-19 | 183.311±7.0 | Water-vapour profile, precipitation |
| MWS-20 | 183.311±4.5 | Water-vapour profile |
| MWS-21 | 183.311±3.0 | Water-vapour profile |
| MWS-22 | 183.311±1.8 | Water-vapour profile |
| MWS-23 | 183.311±1.0 | Water-vapour profile |
| MWS-24 | 229 | Quasi-window water-vapour profile |



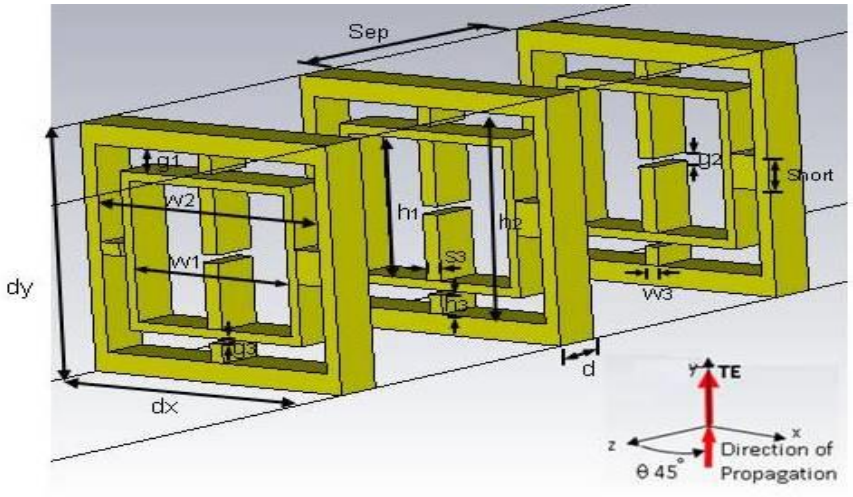
# FSS Specification

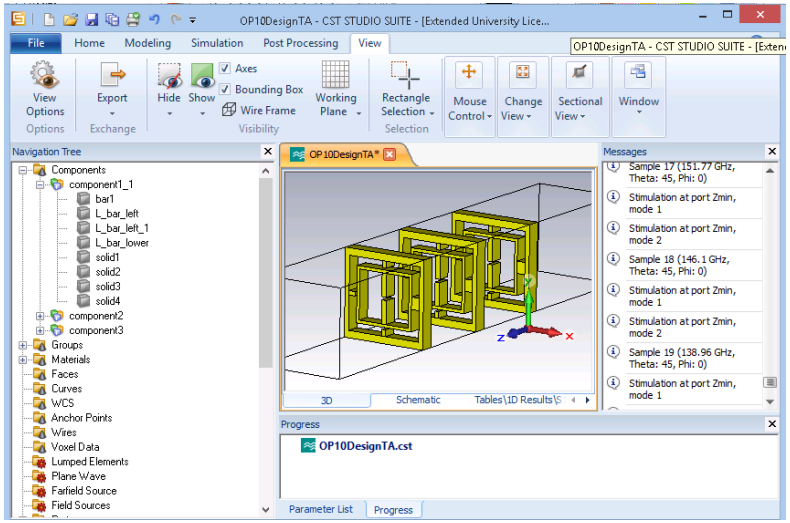
- Insertion loss is to be < 0.5 dB in both the 165 GHz and 183 GHz Bands
- The filter is orientated at an angle of 45° to the optical axis, making the instrument more compact

| Parameter | Requirement |
|---|---|
| Transmission Band / Loss Target | 175.3 – 191.3 GHz / < 0.5 dB |
| Reflection Band / Loss Target | 164 - 167 GHz / < 0.5 dB |
| Incident Angle / Polarization | 45° / TE |
| Physical diameter / Optical diameter | 100 mm / 80 mm |

# FSS Modelling

- **Numerical modelling by CST Microwave Studio**
- **FSS illumination by a TE 45° plane wave, S21, S11 calculated**

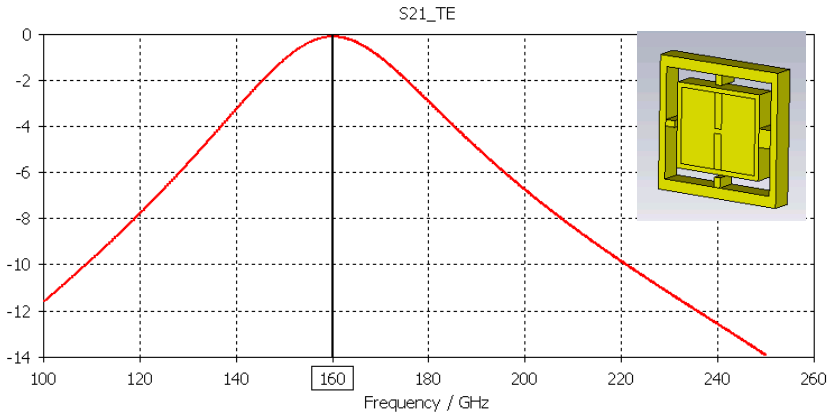


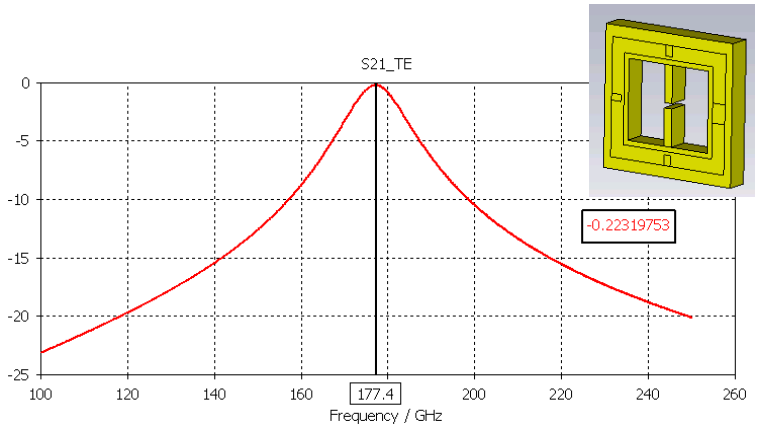

Layout of the final three layer FSS design. (Electric field directions for TE polarisation shown in the lower right)

# Design Concept

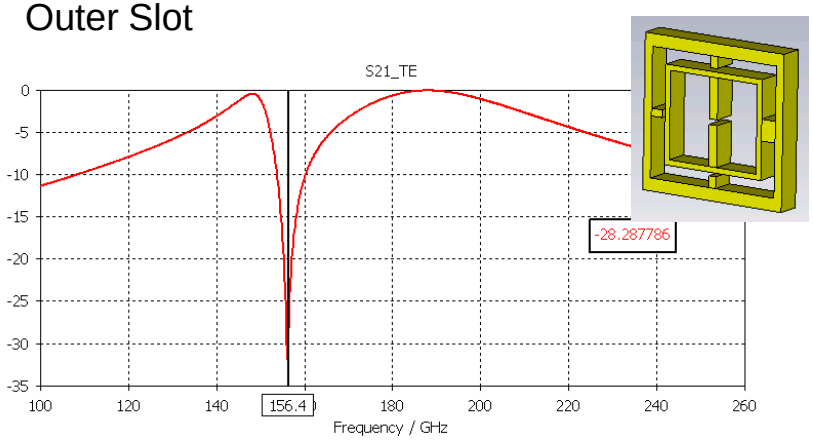
- Nested resonant slots resonating at 160 and 174.4 GHz
- Combined to give a anti-resonance in the 164 – 167 GHz stopband
- Multilayers to improve performance, wide passband 175.3 – 191.3 GHz



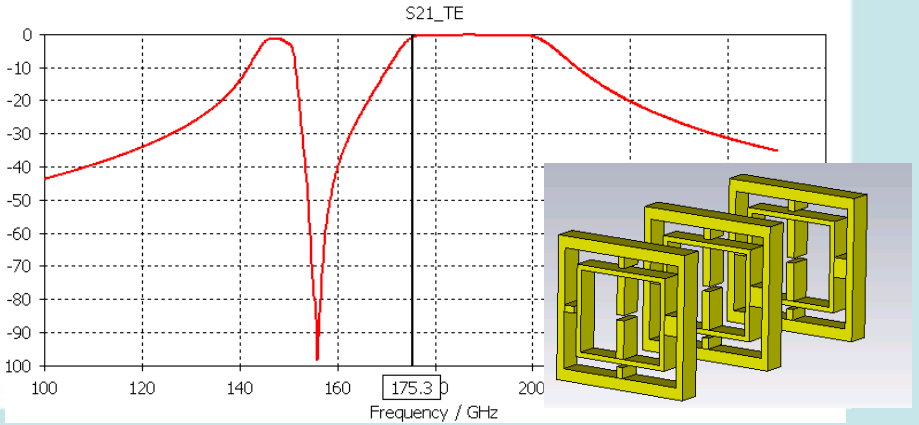

Outer Slot




Inner Slot




Outer and Inner Slots

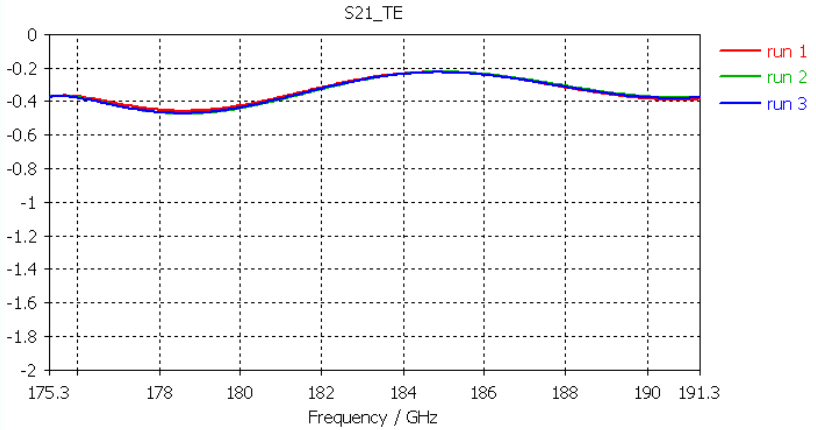



Three layers

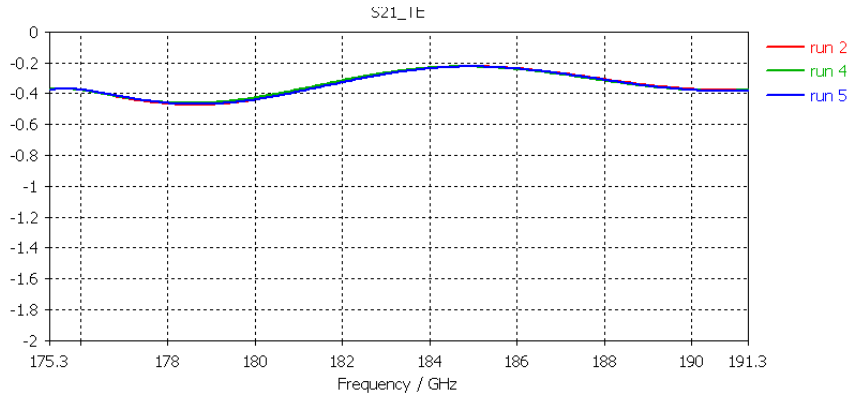
# Tolerance Analysis (1)

**175.3 - 191.3 GHz Passband**

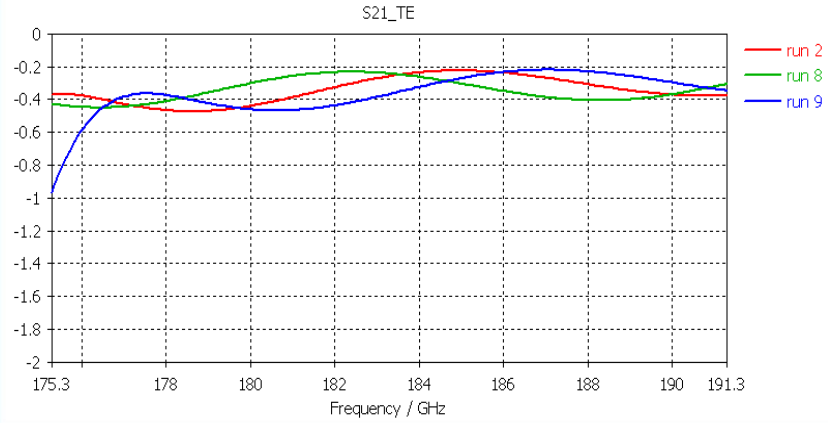
**Good tolerance on the periodicity, sensitive to tolerance on the slot width, but manufacture tolerance better in this region**



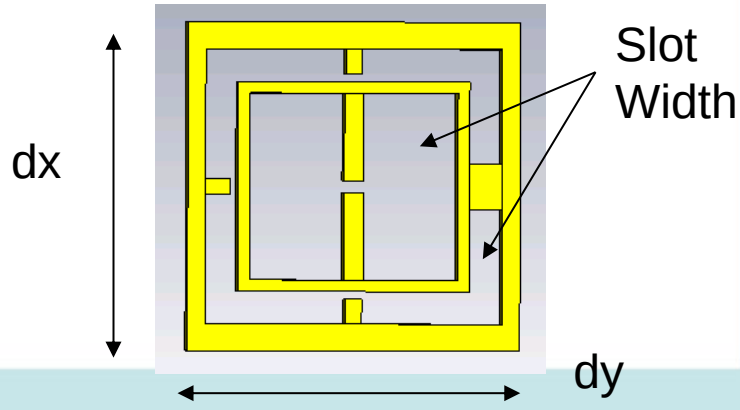

**Periodicity dy +/- 2um**




**Periodicity dx +/- 2 um**



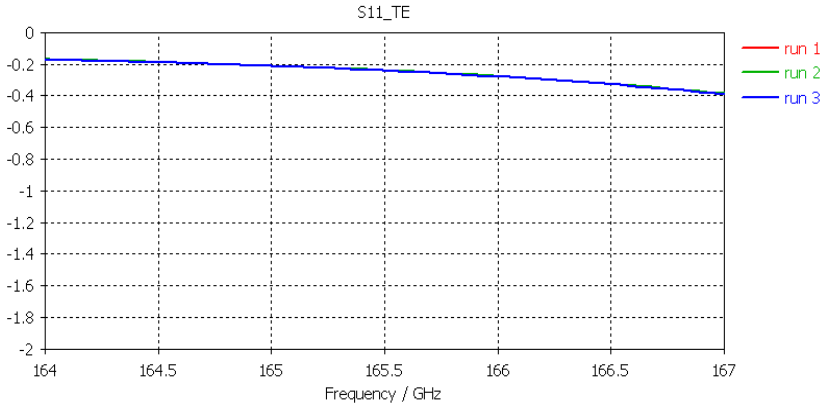

**Slot Width +/- 1um (run 8 -1, run 9 +1)**



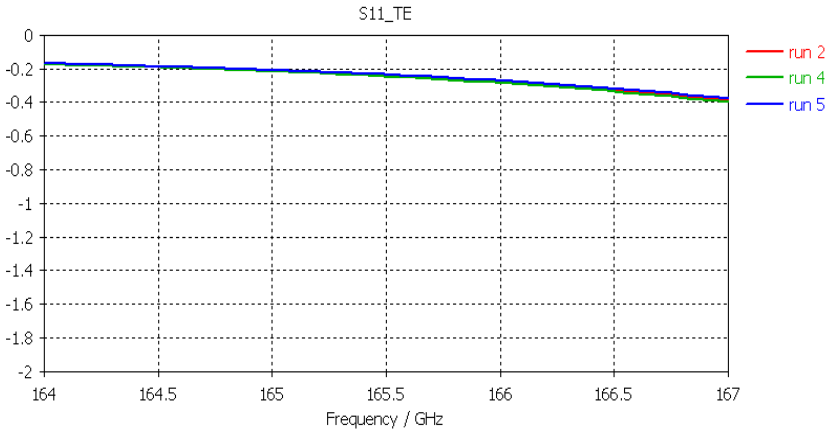
# Tolerance Analysis (2)

**164 – 167 GHz Reflection Band**

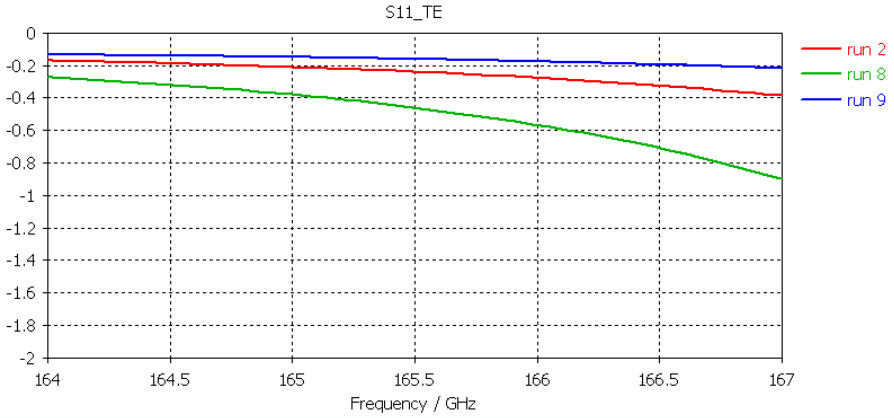
**Good tolerance on the periodicity, sensitive to tolerance on the slot width. Improved manufacturing tolerance on slot width.**



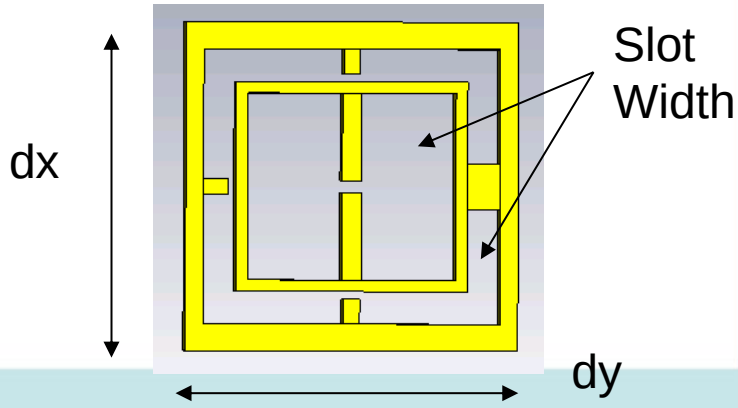

**Periodicity dy +/- 2um**




**Periodicity dx +/- 2 um**



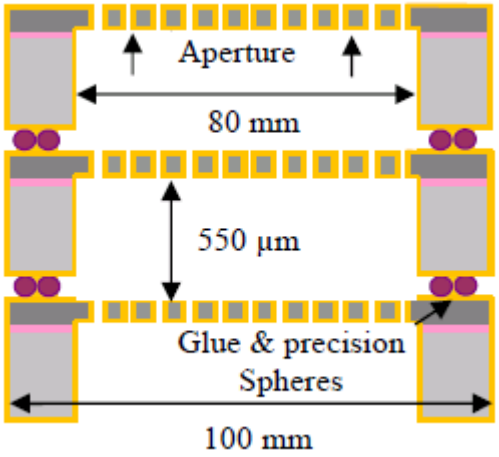

**Slot Width +/- 1um (run 8 -1, run 9 +1)**



# FSS Structure

- Schematic of the three layer FSS cross-section, 100 µm thick freestanding aperture

- Silicon on Insulator Substrate (SOI)
  - FSS core, handle, oxide thickness and diameter definable
  - Mirror like surface finish due to polishing of SOI
  - High silicon mechanical strength (6800 MPa) to support 100 µm perforated surface



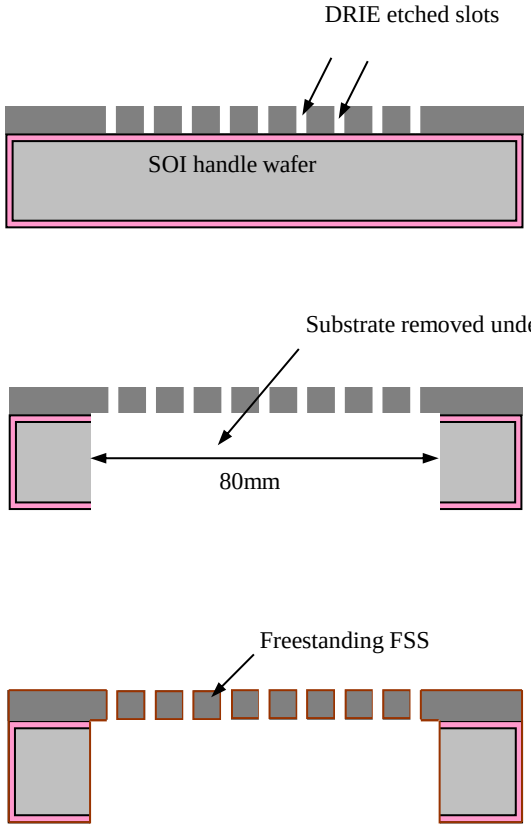
# Manufacturing Steps

**Main fabrication steps**

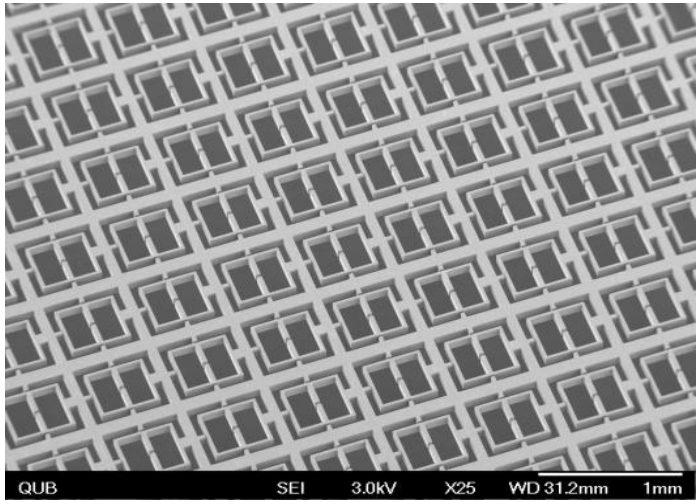
1. 100 μm SOI wafer has slot array etched by DRIE (etch rate 3.5 μm/min)

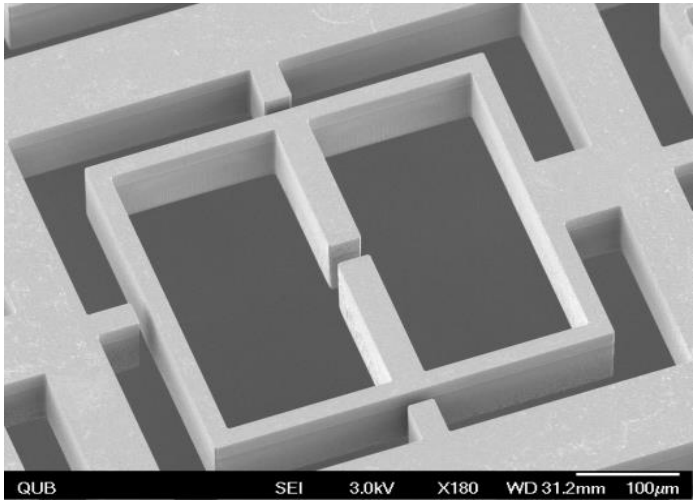
2. The 100 mm diameter 320 μm thick substrate is also DRIE etched (etch rate 8 μm/min)

3. The array is sputter coated with 0.25μm copper seed layer and 1μm electrodeposited copper or silver



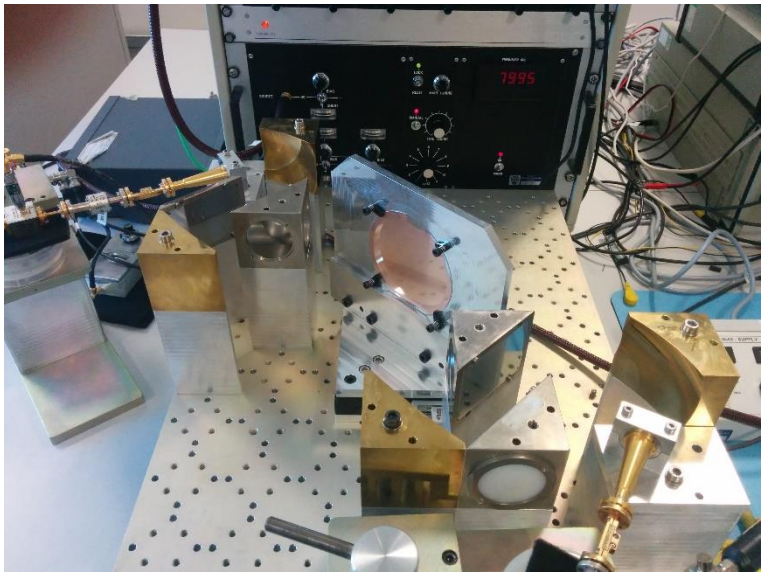
# SEM Images of the FSS Slots



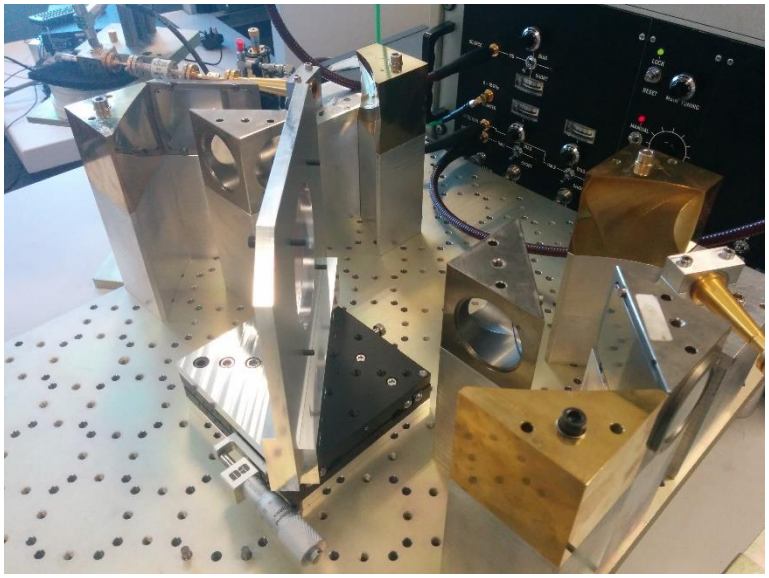



# TEST 140 – 200 GHz

- Abmm VNA
- TK QO Test Bench



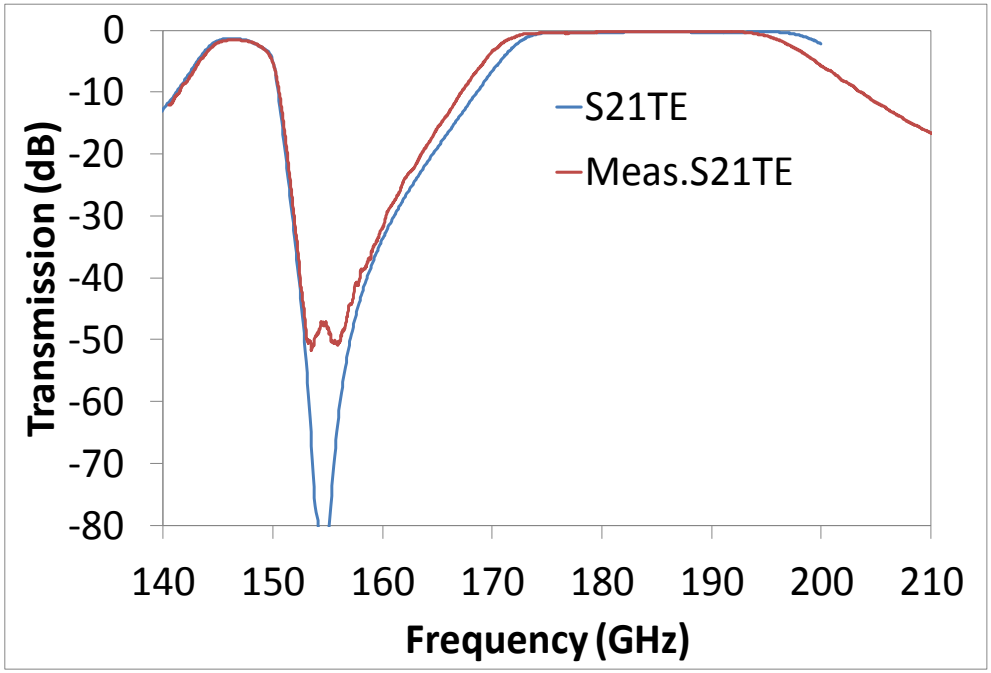
Reflection Setup

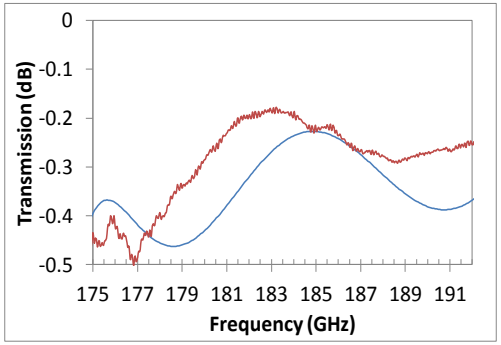


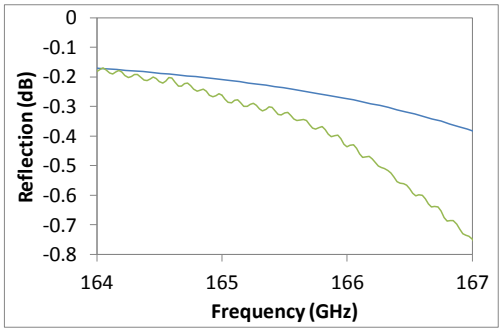
Transmission Setup

# ECIT | S21, S11 Spectral Measurements

- Spectral transmission and reflection measurements were made with the ABmm VNA in conjunction with a quasi-optical test bench
  - measured passband loss is between 0.2 dB and 0.5 dB
  - measured reflection band losses are between 0.2 dB and 0.75 dB



# Conclusions

- ✓A new low loss FSS has been designed, manufactured and tested
- ✓RF measurements show good agreement with the electromagnetic design
- ✓The FSS has been optimised for operation in the MWS instrument

| **Parameter** | **Requirement** | **Max / Min Measured Loss** | **Average Measured Loss** |
|---|---|---|---|
| Transmission Insertion Loss | 175.3 – 191.3 GHz Target: < 0.5 dB | -0.5 dB / -0.18 dB | -0.29 |
| Reflection Insertion Loss | 164 - 167 GHz Target: <0.5 dB | -0.75 dB / -0.16 dB | -0.38 |