Millimetre Wave Technology for Earth Observation and Inter-Planetary Missions

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RAL Space

Outline

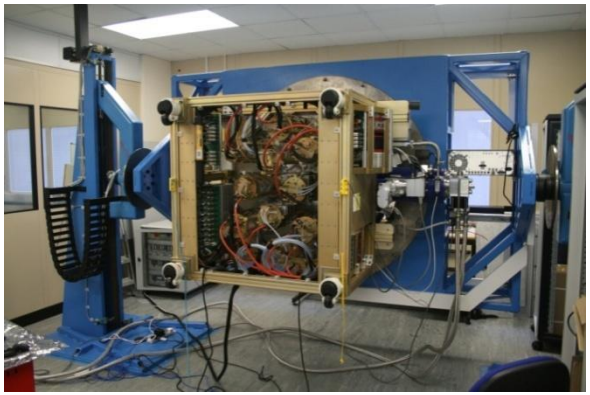
- Introduction to the Millimetre Technology (MMT) Group
  - Expertise
  - Selected Projects
- Millimetre Wave Technology Drivers
  - EO & Inter-Planetary Mission Requirements
- Selected Millimetre Wave Technologies
- MMT Support to Space Missions

MMT Group – Overview

- Develop cutting-edge technology at frequencies 100 GHz – 2.5 THz
- Primary applications: Radio Astronomy & Atmospheric Science
- ~20 full-time engineers and technicians
  - Supplemented by placement students and visiting scientists
- Expertise ranging from
  - Device fabrication (Schottky diodes & associated filters), to
  - Component design, manufacture & test, to
  - Complete instrument-level design & development

MMT Group – Selected Projects (1)

- ALMA (Atacama Large Millimetre Array)
  - Host the European Front-End Integration Centre
  - Provide several key technologies (local oscillators, photonic mixers)
- Passive & active mm-wave instruments
  - MARSCHALS, ISMAR (airborne passive radiometers)
  - 94 GHz FMCW Cloud Radar (ground-based active radar)



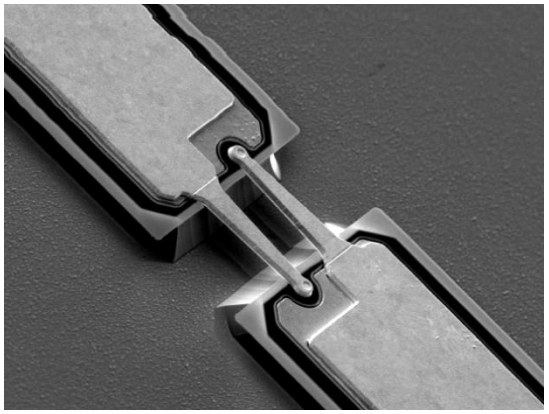
ALMA Receiver Under Test

MARSCHALS on Geophysica M55

94 GHz FMCW Cloud Radar

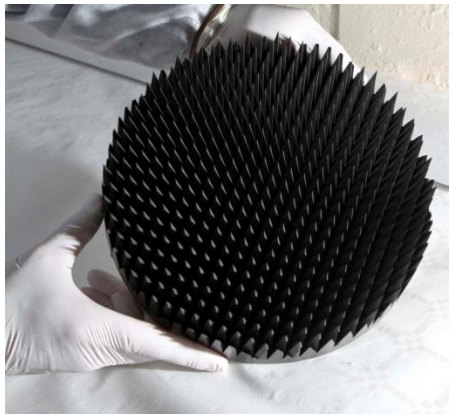
MMT Group – Selected Projects (2)

- Schottky Diode Fabrication Facility
  - Planar Schottky diodes for mixers, multipliers and detectors
  - Spin-out company: Teratech Components Ltd.
- Component Development
  - Receiver components (mixers, multipliers, detectors)
  - Optics components (feedhorns, FSS, wire grids, mirrors)
  - Calibration targets



RAL Anti-Parallel Schottky Diode Pair

Space Qualified 183 GHz Mixer (AMSU-B & HSB)



Pyramidal Calibration Target (ALMA, ISMAR)

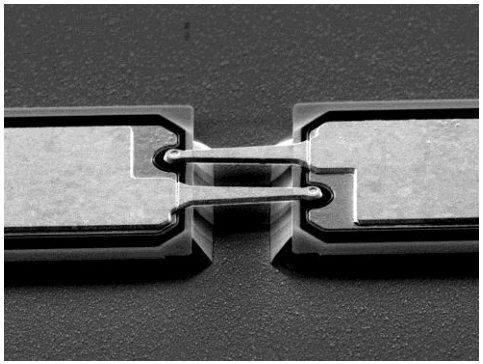
Millimetre Wave Technology Drivers

- Key Earth Observation Mission Requirements
  - Wide spectral coverage (18.7 GHz – 874 GHz) → receiver type & components
  - Multi-spectral/pixel instruments → compact receivers, component integration
  - High spectral resolution → back-end technology (e.g. digital spectrometer)
  - Cost, lifetime → operation at ambient temp. (i.e. Schottky-based)

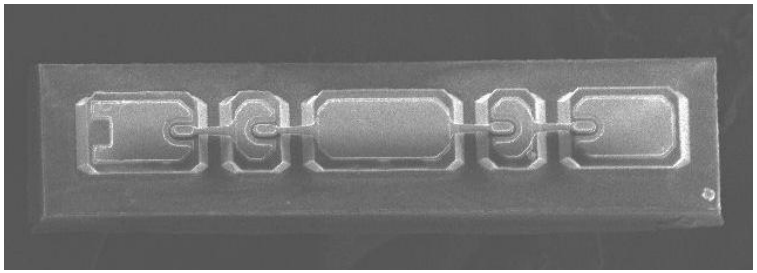
- Key Inter-planetary Mission Requirements
  - Mass and power are critical
    - → Push to higher receiver operating frequency (smaller reflector, optics)
    - → Compact receivers, component integration
    - → Operation at ambient temp. (i.e. Schottky-based)
  - Spectral resolution (atmospheric chemistry and meteorology, e.g. wind speed via Doppler shift)
    - → Back-end technology (e.g. digital spectrometer)

Technology – Schottky Diodes

- Diode fabrication and optimisation

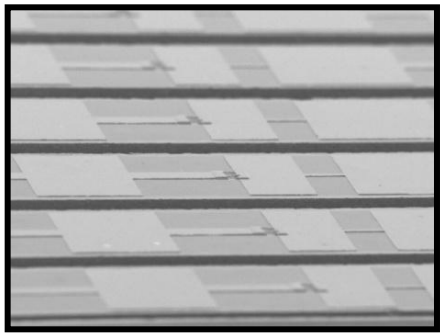


Air-bridged anti-parallel Schottky diode pair

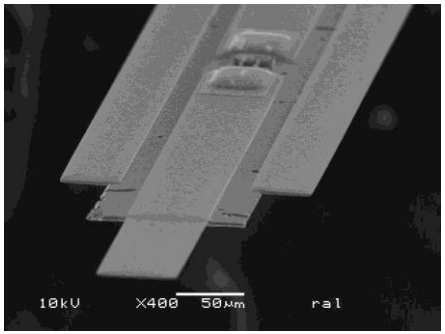


Anti-series varactor diodes for frequency doublers

- Circuit fabrication technology



Integrated circuits on GaAs



Integrated circuits on GaAs membrane

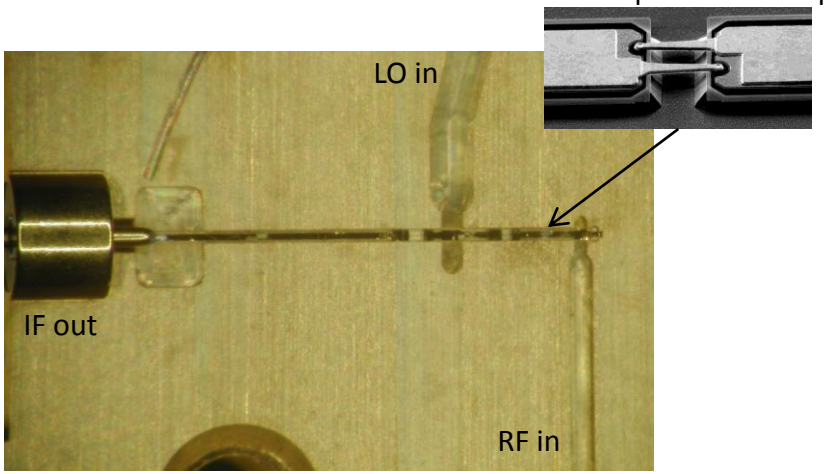
Technology – Frequency Mixers (1)

- Frequency conversion for signal down-conversion
  - Sub-harmonic mixers (common for EO)
  - Fundamental mixers (applicable to Inter-Planetary)
  - Recent developments: DSB sub-harmonic mixers from 183-664 GHz for EO missions (e.g. Post-EPS, PREMIER, ISMAR)

Performance:
Tmix=1000K
CL=6.5 dB

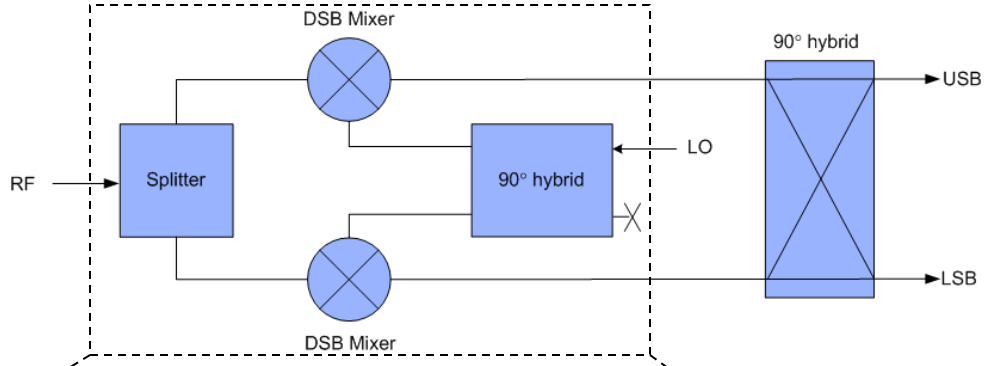
325 GHz DSB mixer

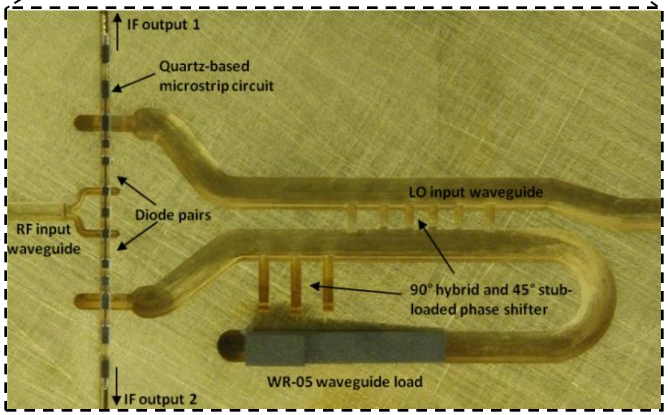
Discrete anti-parallel diode pair

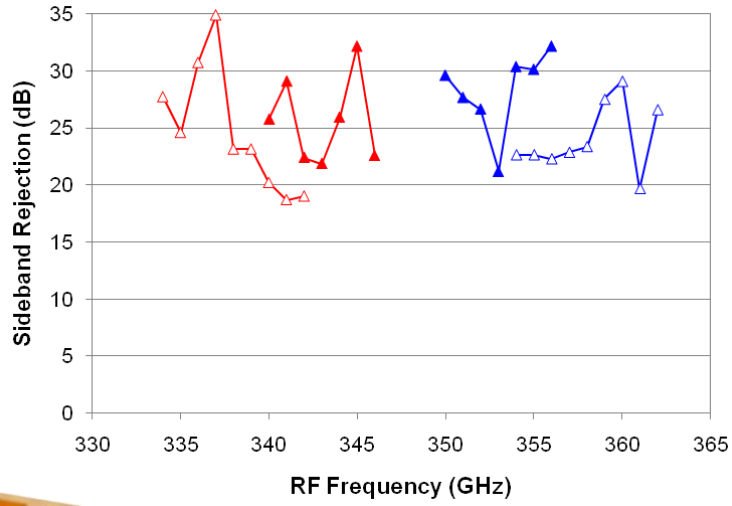


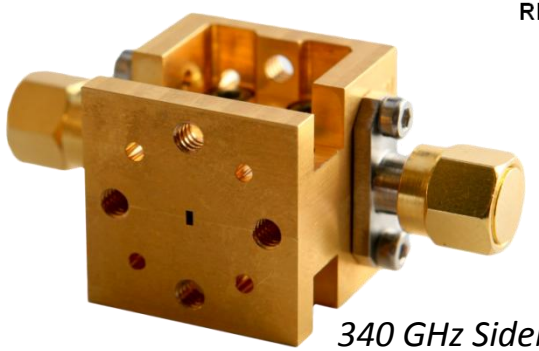
Technology – Frequency Mixers (2)

- Frequency conversion for signal down-conversion
  - Also developing sideband-separating mixers for PREMIER
    - → Incorporates 2x sub-harmonic mixers







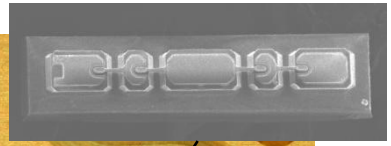


340 GHz Sideband Separating Mixer

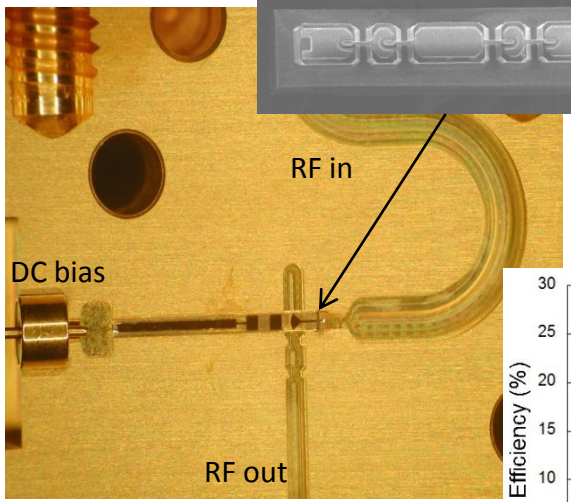
Technology – Frequency Multipliers

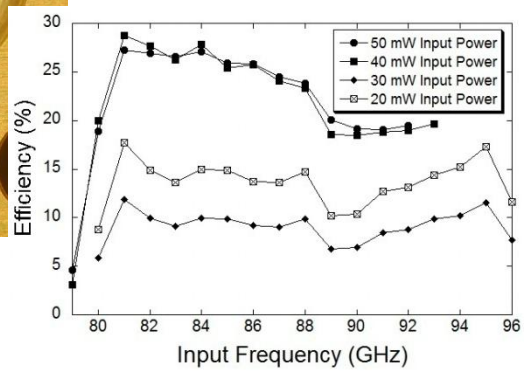
- Frequency conversion for local oscillator chains
  - High RF input power
    - → Larger diode anode size increased number of diodes per chip
    - → Thermal dissipation is critical

80-160 GHz Doubler



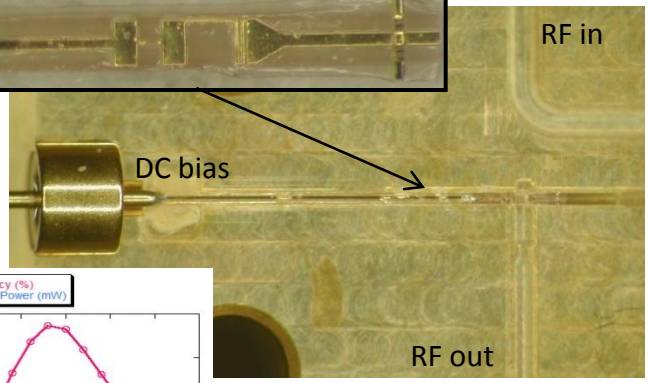
4-anode discrete diode chip

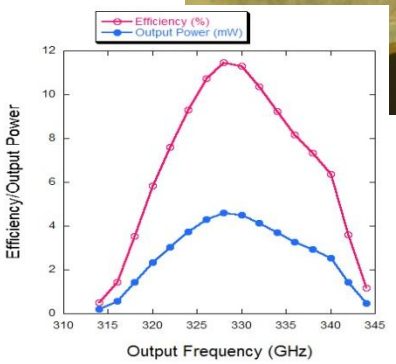




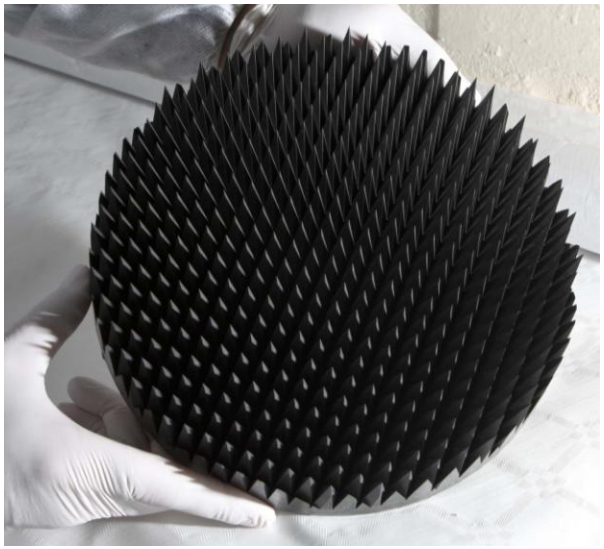
160-320 GHz Doubler

4-anode integrated diode/filter





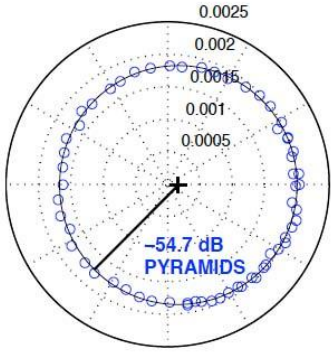
Technology – Calibration Targets



245mm diameter mg-alloy-cored calibration load for ISMAR airborne radiometer

- Metal-cored black body calibration loads for radiometer calibration:
  - Ground-based (ALMA)
  - Airborne (MARSCHALS, ISMAR)
  - Space
  - Lightweight aluminium or magnesium alloy core
  - Wide temperature range 77-370k

- Wideband performance
  - Typically better than 50dB return loss from 100GHz to at least 700GHz
  - Can be optimised for other frequency ranges



Return Loss of ALMA prototype load at 600GHz

Technology – Spectrometers

- For millimetre-wave spectroscopy
  - Wide spectral coverage
  - High spectral resolution
  - Compact and power efficient

Prototype Digital FFT Spectrometer

- High Speed ADC (3Gs/s)
- SpaceWire data bus
- FPGA with custom DSP
- Instantaneous bandwidth: 1 GHz
- Spectral resolution: 1 MHz
- Additional funding secured for further development

STAR-Dundee

ASTRIUM
AN EADS COMPANY

MMT Support to Space Missions (1)

- Post-EPS (Post-EUMETSAT Polar System)
  - European platform for Operational Meteorology from ~2018
  - 2 millimetre wave imagers proposed (MWI, ICI)
  - RAL currently supporting Phase A/B1 industrial studies
  - Developing receiver concepts from 18.7 GHz – 664 GHz
  - Participating in ESA technology development programmes

- PREMIER (candidate Earth Explorer 7 mission)
  - To study the chemical composition of the atmosphere (UTLS) at IR & MMW
  - Currently supporting critical technology development for STEAM-R (CEOI national funding)
  - 340 GHz sideband separating mixer

MMT Support to Space Missions (2)

- FengYun 4 (China)
  - Meteorological platform from GEO
  - Millimetre/Sub-millimetre Sounder (MSS): 118-424 GHz
  - Potential feasibility study – receiver hardware

- JUICE (Jupiter Icy Moon Explorer)
  - Was Europa Jupiter System Mission – Laplace
  - Development of ORTIS payload concept (ORbiter Terahertz Infra-red Sounder)
  - 3 THz radiometer with digital spectrometer back-end
  - Simultaneous observation of key molecular species present Jupiter upper atmosphere (H_2O and CH_4)
  - Brightness temperature mapping of Ganymede

Thank-You!

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