Detectors for mm-Waves and Terahertz (and how these might be used for EO)

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MMT Group, RAL Space

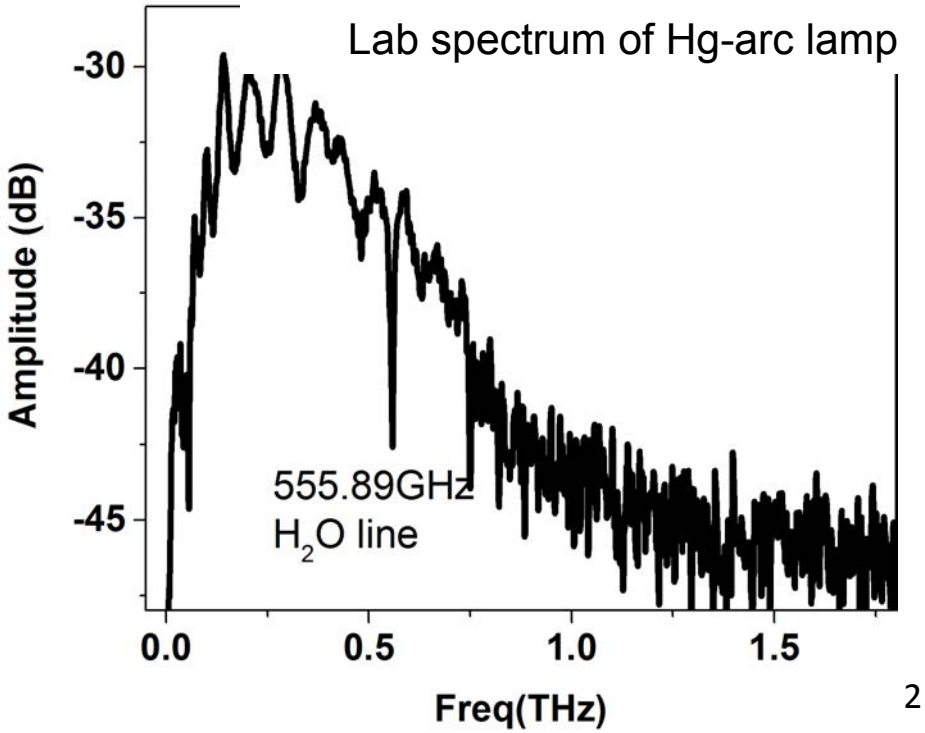
CEOI Emerging Technologies Meeting, TCH May 2017

Science & Technology Facilities Council

Introduction

- **Limit discussion to rectifying THz video / power detectors**
- **Detector dimensions << wavelength: need antennas to couple THz power to devices**
- **Spectral coverage < 50 GHz to ≈ 4 THz targeted**
- **Based on ≈ 1 µm InGaAs Schottky diodes**
- **Very fast, 300 K operation**

- **Applications**
  - **Lab spectroscopy**
  - **Imaging**
  - **Diagnostics on particle accelerators**
  - **Remote sensing radiometers, when used with low noise amplifiers**



InGaAs Detector Diodes

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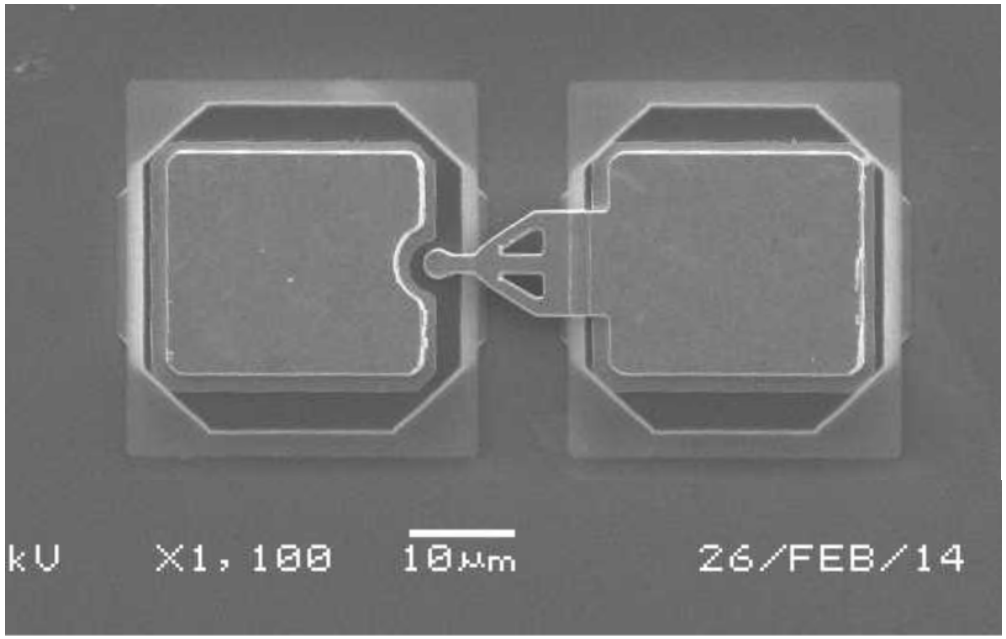
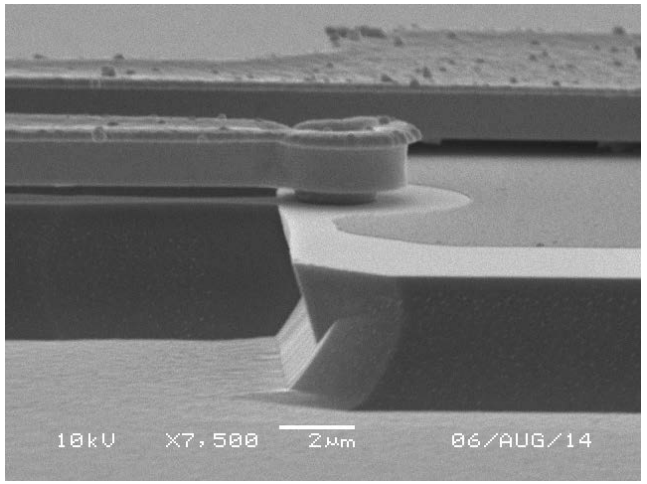
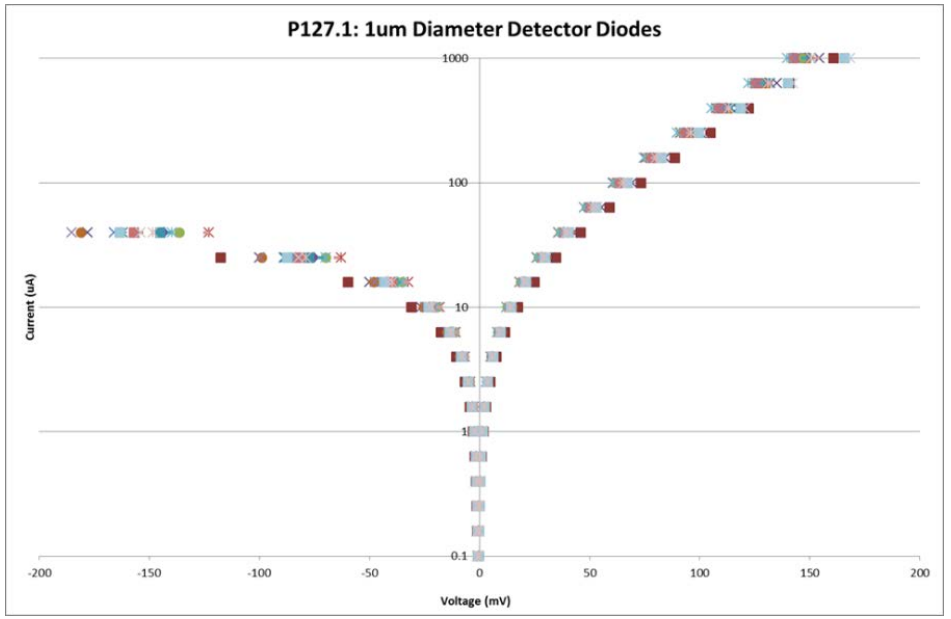




- **Development from MMT's GaAs Schottky devices for mixers and multipliers**
- **Air bridge & vertical walls: low parasitic capacitance link to ≈ 1 µm dia. anode**
- **External wafer growth**
- **In-house metals and optical lithography**
- **Dedicated equipment**
  - **Emphasis on reproducibility and yield**

Zero Bias Diode Characteristics

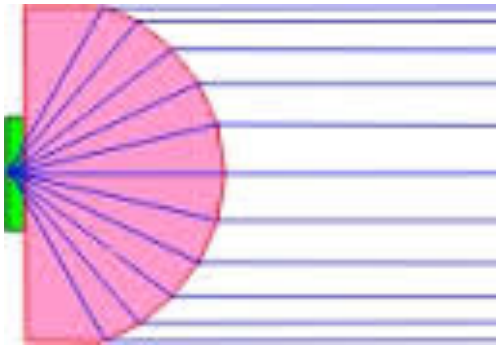
- **Asymmetric I(V) at 0 V provides detection signal**
- **No bias = no shot noise**
- **Junction resistance at 0 V ≈ kΩ**



Measured I(V) for a set of InGaAs diodes

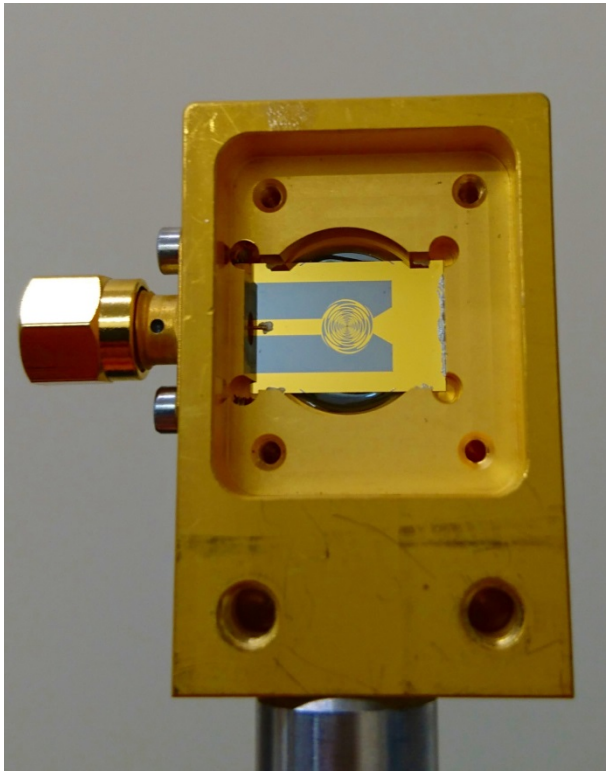
- **Diode dimensions << wavelength**
  - **Need method to couple RF power to the device**
- **Embed in waveguide or use planar antenna and lens**

Diode chip
on rear of lens

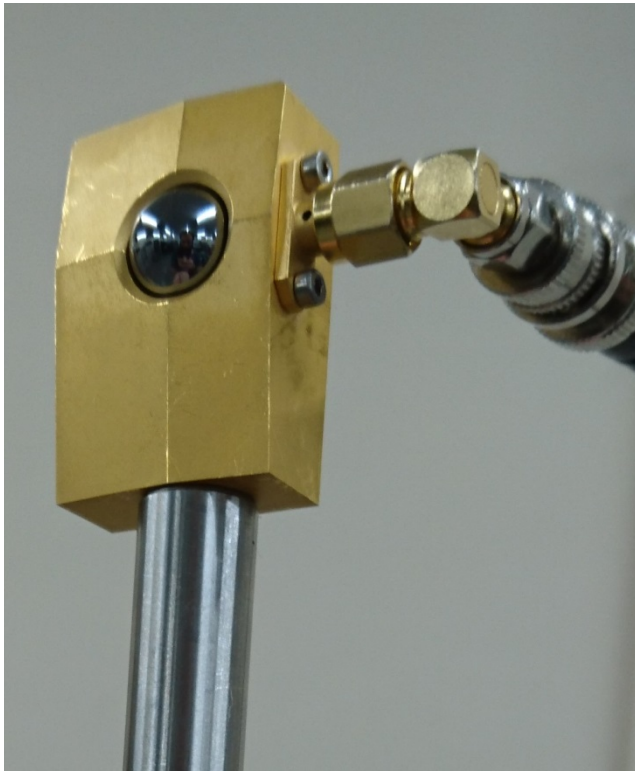


Quasi-optical detectors

Broadband sinuous antenna with diode chip in centre

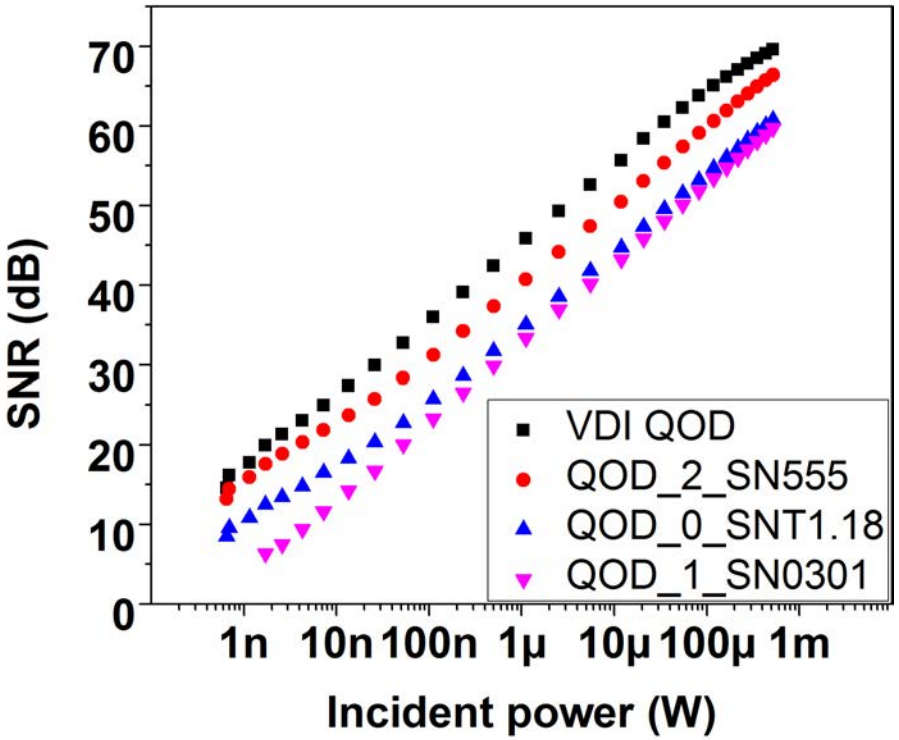


Antenna substrate on rear of lens



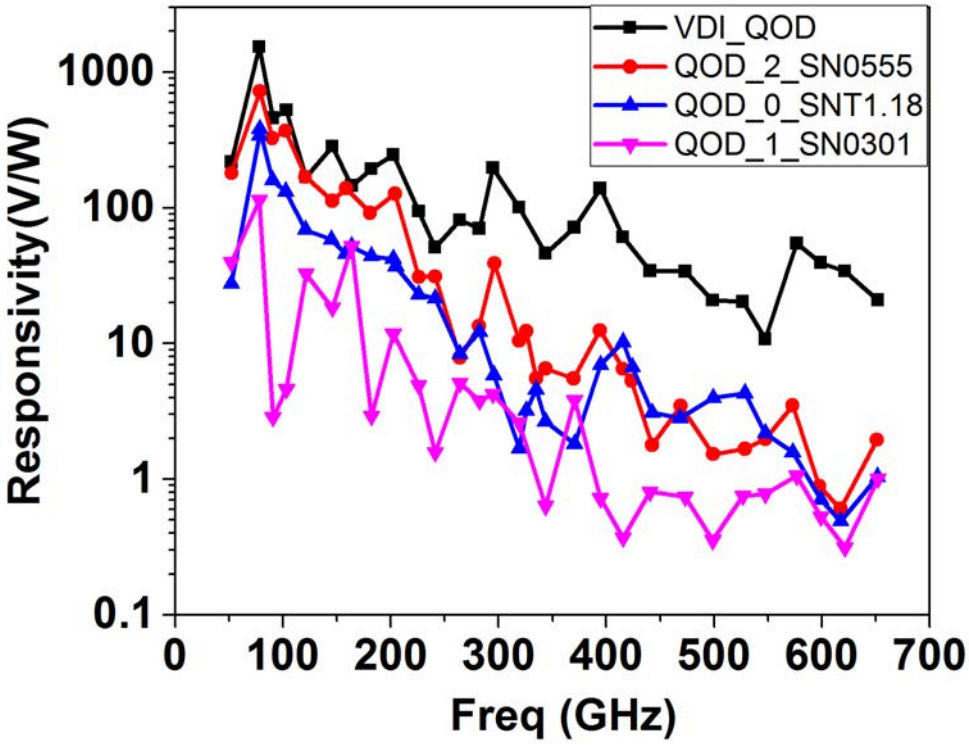
Front view. Lens is 10 mm in diameter

Performance: Linearity and Spectral

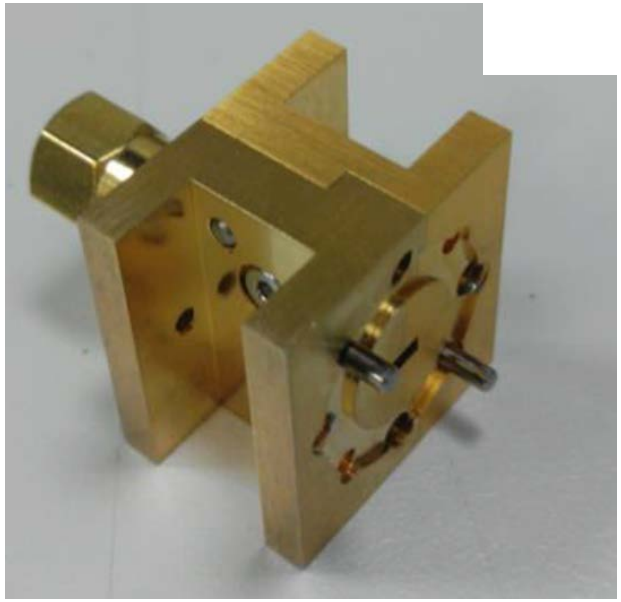


300 GHz linearity measurement

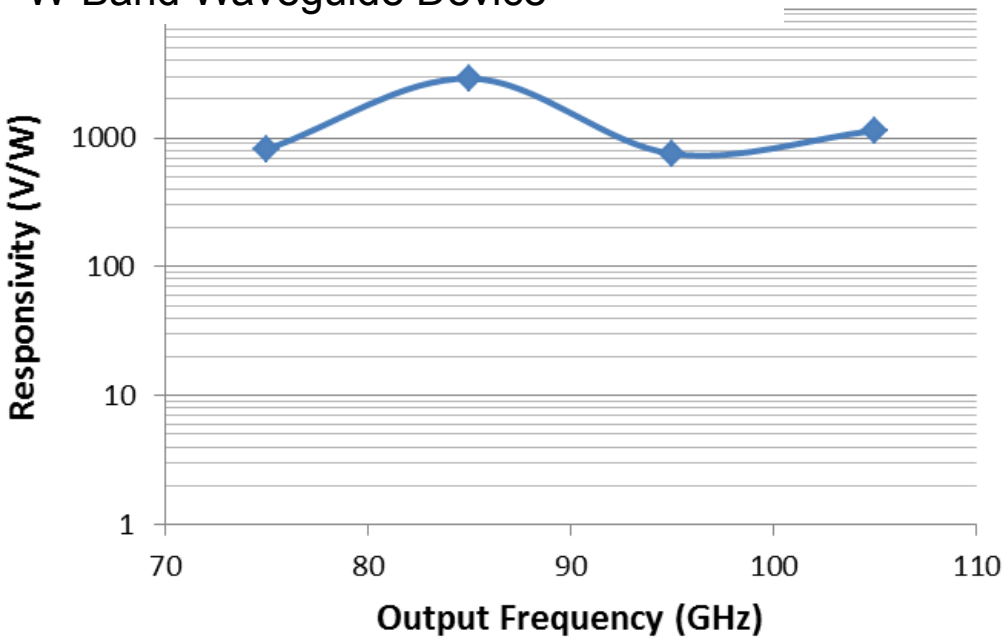
Spectral response comparison

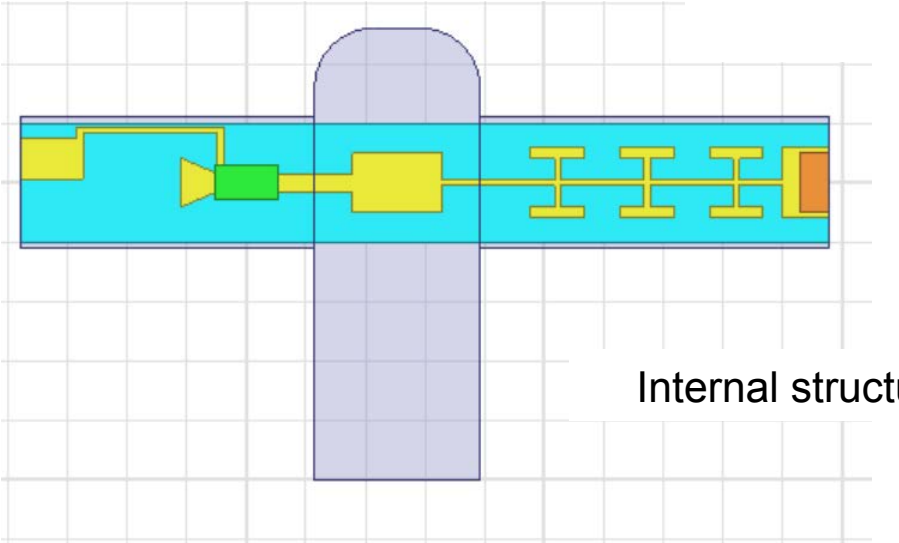


Waveguide Devices



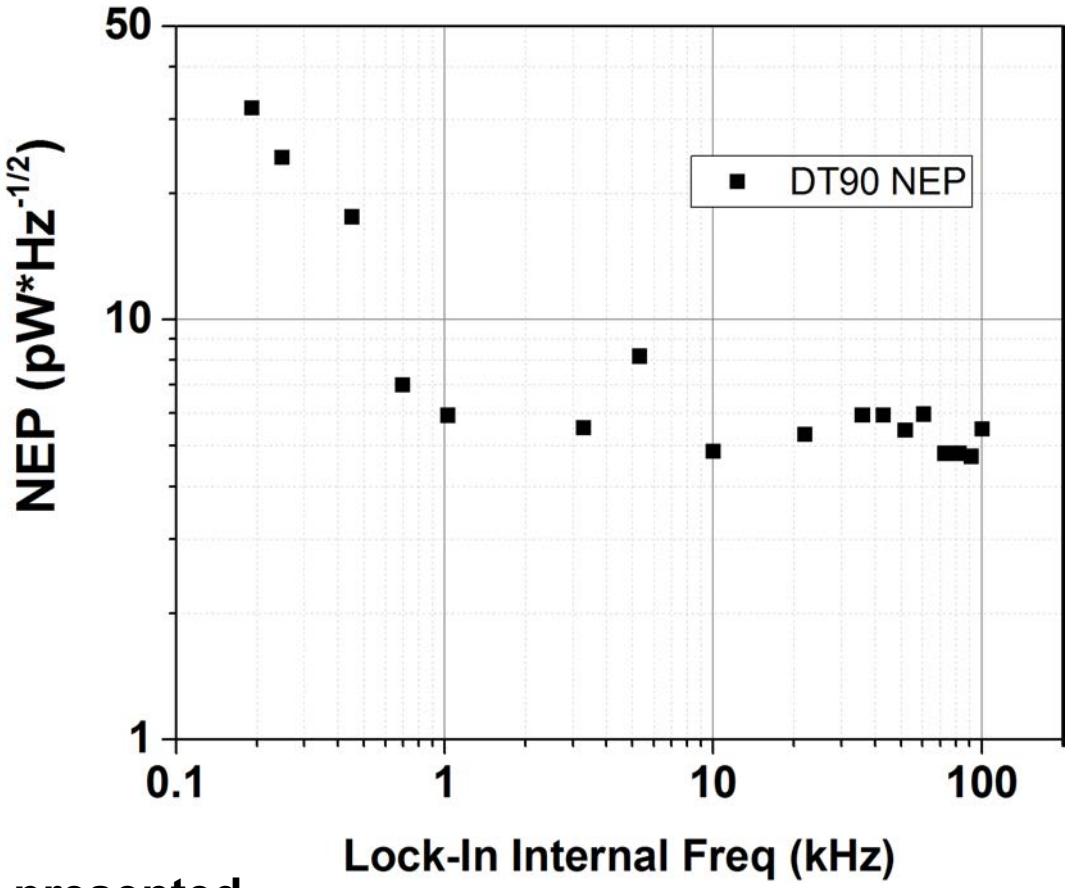
W-Band Waveguide Device





Internal structure of waveguide detector

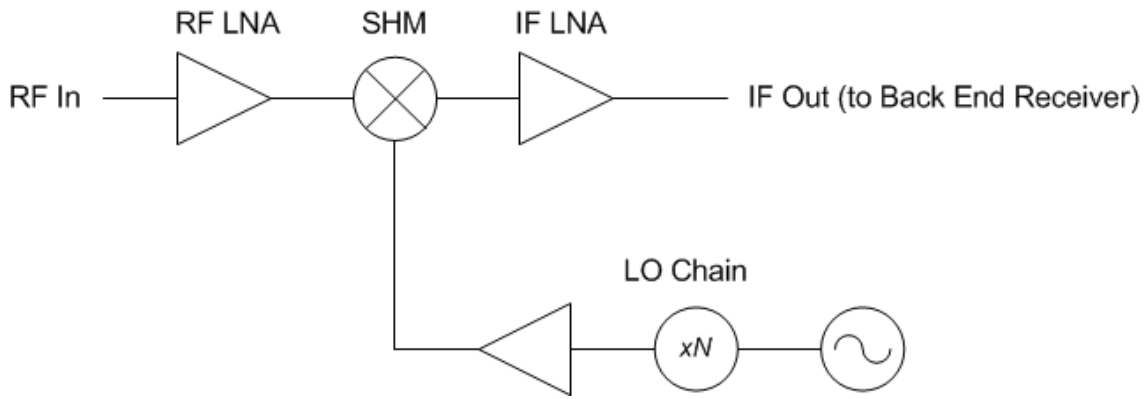
Performance: Noise



- W-band waveguide device presented
- 1/f point ≈ 500 Hz
- Noise floor of 5 pW/√Hz
  - Need NEΔT < 1 K for EO……

Application in Radiometry (1)

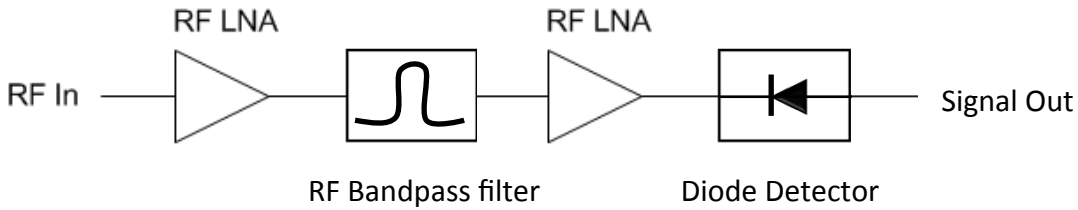
- **Typical front-end receiver → Conventional heterodyne down-converter based on Schottky & MMIC technology**



- **Complicated receiver approach, with Schottky devices in mixer and xN multiplication stages in Local Oscillator**
- **Diode detector noise of 5 pW/√Hz is not low enough to give required NEΔT, < 1 K for EO**

Application in Radiometry (2)

- **Solution: integrate detector diodes with low noise amplifiers**



- **LNA's are available to frequencies > 200 GHz**
- **Bandpass resonant cavity filters have insertion loss < 1 dB (e.g. U. Birmingham)**
- **Approach only suitable when spectral resolution of line not required**

- **Now show LNA examples taken from our work for MetOP**
  - **Used with mixers, not direct detectors, in MetOp**

MetOp Low Noise amplifiers

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- **Requirements for MetOp**
  - **Stringent receiver Noise Figure requirements:**
    - **166 GHz channels: < 5 dB**
    - **183 GHz channels: < 5 dB**
    - **229 GHz channel: < 7 dB**
    - **Gain: >20 dB**
  - **Sideband balance: gain deviation between receiver sidebands has to be < 1 dB on average**
- **RAL's LNAs widely meet and exceed those requirements**
  - **MMICs based on 50 nm mHEMT process from Fraunhofer IAF (D)**
    - **166 & 183 GHz – Common source design, 3 stages**
    - **229 GHz – Cascode design**
  - **RAL undertakes the amplifier packaging and test**
- **Extensive work performed on design and optimisation of this design together with Fraunhofer IAF (DE), RPG (DE), ESA and ADS (UK/Fr/Es)**
- **Work fully presented by Simon Rea, Proc. International Symposium on Space Terahertz Technology, Cologne, 2017**

LNA Measurement results

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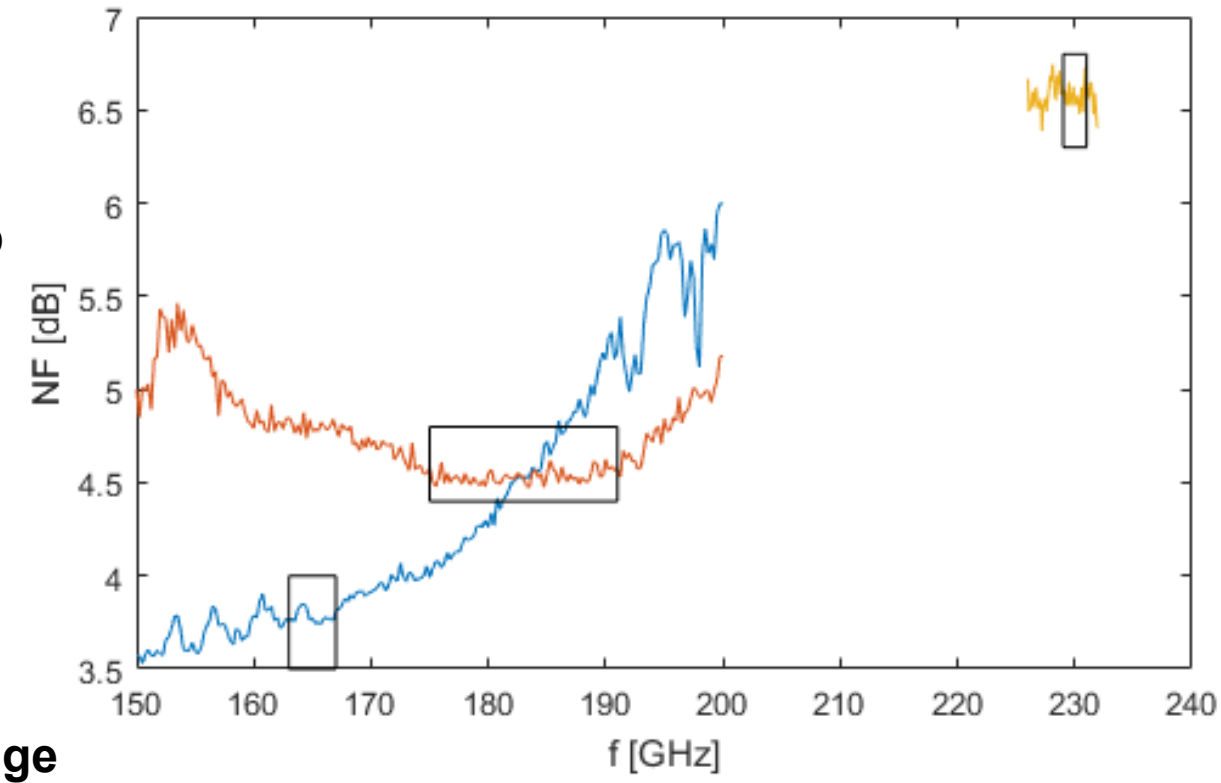
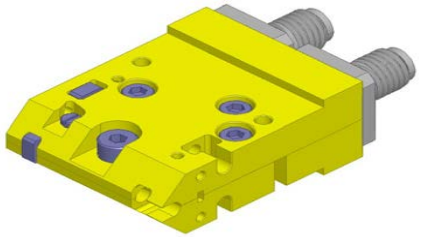
Noise figure test results

- **Blue: 166 GHz LNA**
- **Orange: 183 GHz LNA**
- **Yellow 229 GHz LNA**
- **Rectangles show MetOp bands**

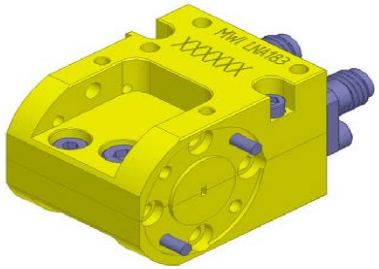


- **MetOp LNA package range**

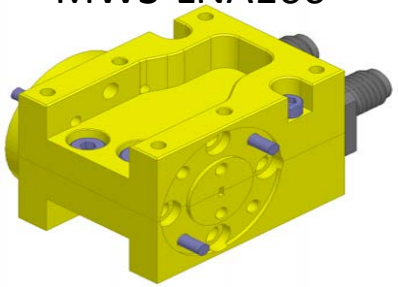
ICI-LNA183



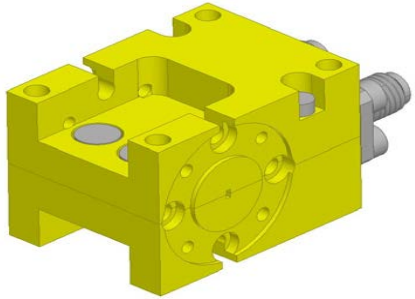
MWI-LNA183
MWI-LNA166



MWS-LNA183
MWS-LNA166



MWS-LNA229



LNAs – internal view

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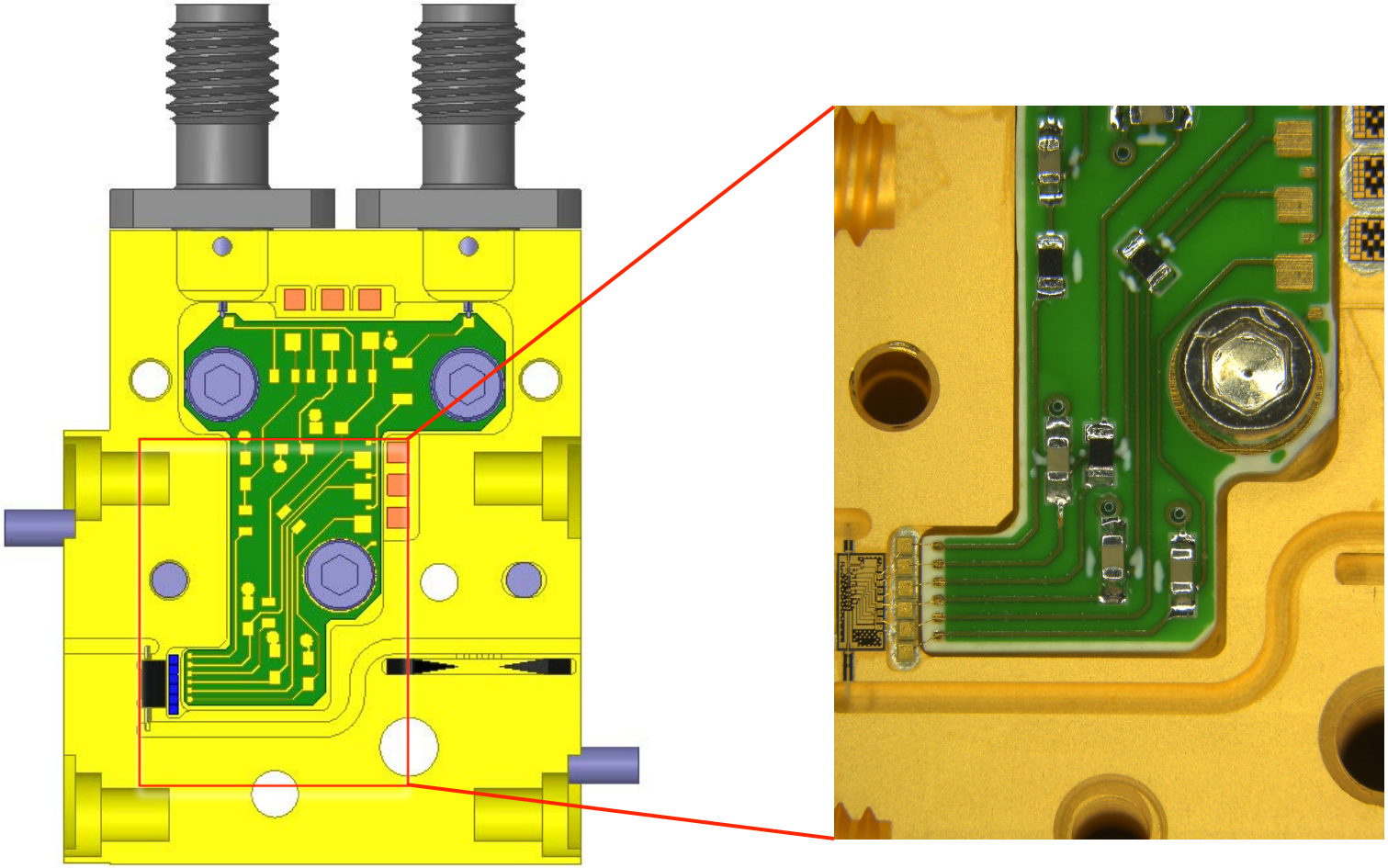
LNA Packaging by RAL

- **Quartz transitions from coplanar waveguide to hollow rectangular waveguides**
- **DC bias circuit is flexibly tuneable to optimise all 3 amplifier stages independently**
- **Waveguide equaliser to remove sideband imbalance**



Summary

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- **InGaAs diodes working in quasi optical and waveguide detectors at room temperature,**
- **Best NEP ≈ 5 pW/√Hz below ≈ 300 GHz**
- **Address response roll-off at higher frequencies with smaller devices**
- **Would need to use with low noise amplifiers for EO**
- **Summarised state-of-art Met-Op SG LNAs**

Acknowledgements

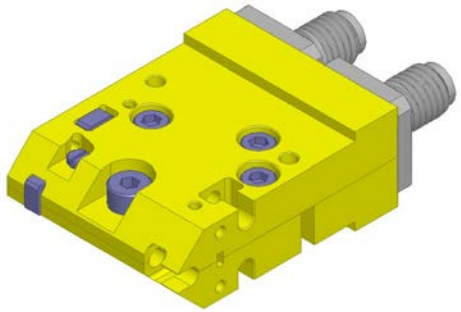
Direct detectors: STFC Centre for Instrumentation

LNA work performed in the course of MetOp-SG:

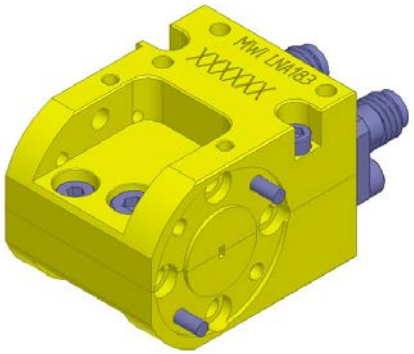
S. Rea, B. Moyna, K. Parow-Souchon, M. Henry, H. Wang, M. Oldfield, N. Brewster, P. Hunyor, R. Green, D. Smith, B. Davis, A. Obeed, D. Klugmann, M. Phillips, M. Beardsley, J. Hampton, B. Ellison, C. Howe, G. Burton, A. Marshall

Block outline

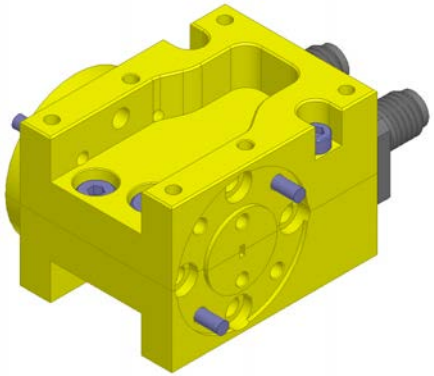
ICI-LNA183



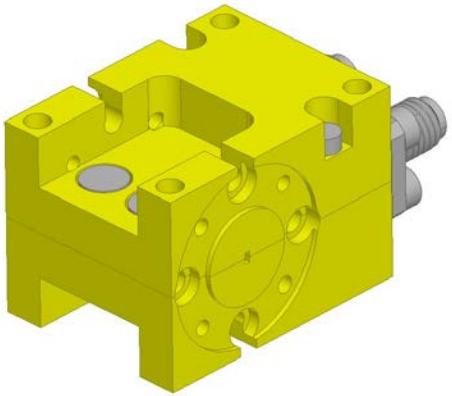
MWI-LNA183
MWI-LNA166



MWS-LNA183
MWS-LNA166



MWS-LNA229



(dimensions in mm)

Front-End Receivers for MWS & MWI (166-229 GHz)

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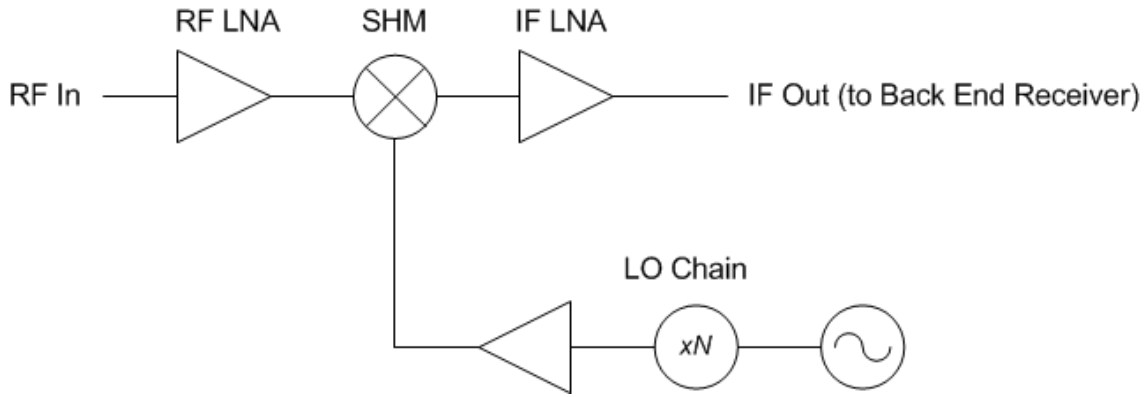
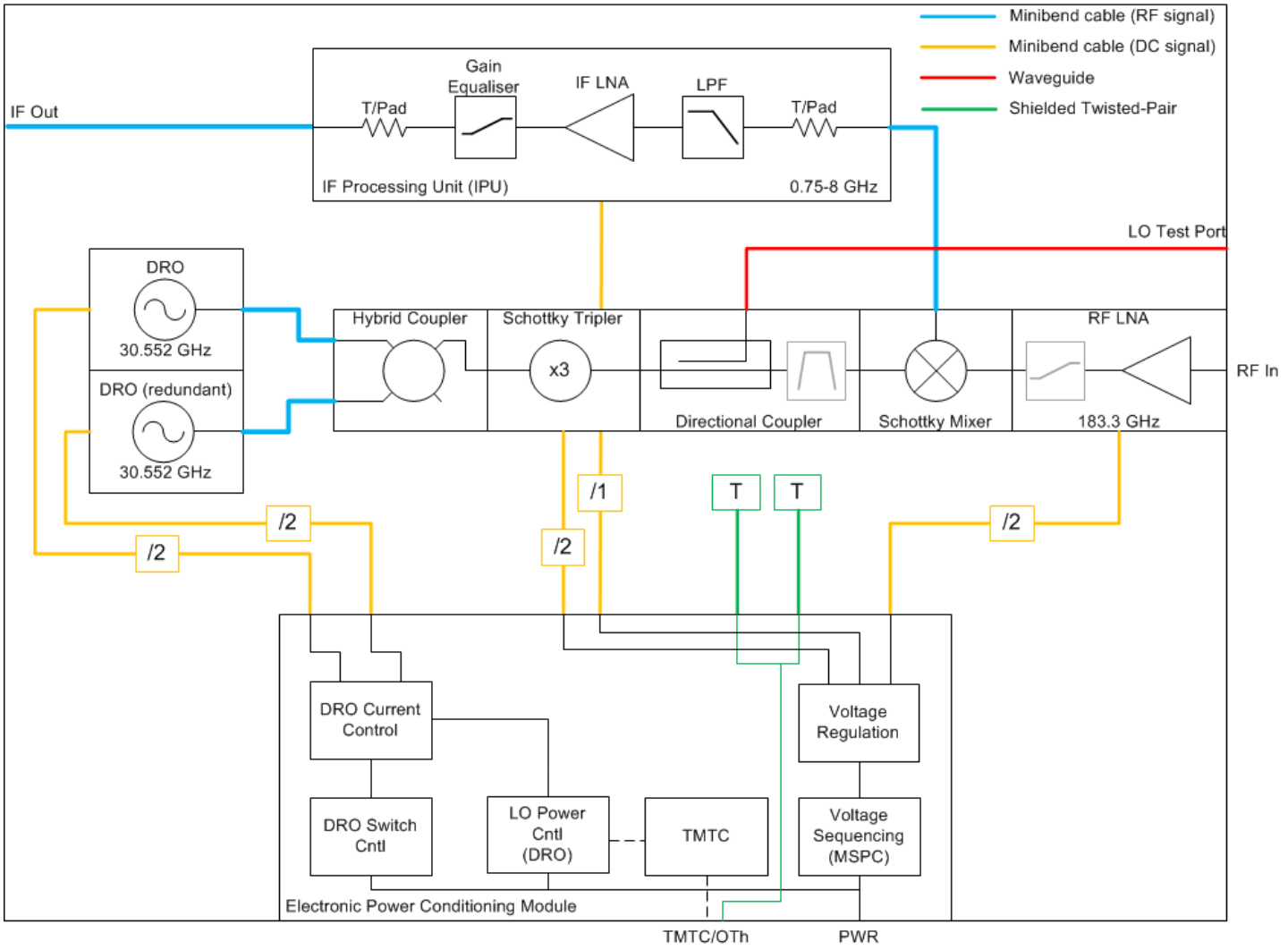
- ***Front-End Receiver → Heterodyne down-converter based on Schottky & MMIC technology***



Component / Sub-Assembly	Supplier	Internal Components
RF LNA	RAL	Fraunhofer IAF MMICs
Schottky Mixers / Multipliers	RAL or RPG	Teratech Diodes; ACST Diodes
LO Chain Power Amps / doublers	RPG	ADI-Hittite MMICs
LO Chain passive modules	RPG	
DRO	L3-Miteq	Custom: ~30 GHz, 22dBm
IF LNA	L3-Miteq	SAFS series
DC Electronics (EPC)	RAL	Various
RF Electronics (IPU)	RAL/Spur	Various

183 GHz FERX Schematic



Introduction

- MetOp Second Generation satellites in development
  - Global weather forecasting data 2020-2040
  - Two satellites (Sat-A & Sat-B)
  - Three sets of satellites, each with 7.5 year nominal lifetime
- Three passive millimetre-wave instruments being developed by European Industry
  - Microwave Sounder (MWS)
    - RAL to supply 166, 183, 229 GHz FERX
  - Microwave Imager (MWI)
    - RAL to supply 166, 183 GHz FERX
  - Ice Cloud Imager (ICI)
    - RAL to supply 183, 243, 325 GHz FERX
- Models: EQM, PFM, FM2, FM3, Flight Spare