Superconducting system-on-chip filterbank spectrometers for hyperspectral microwave atmospheric sounding

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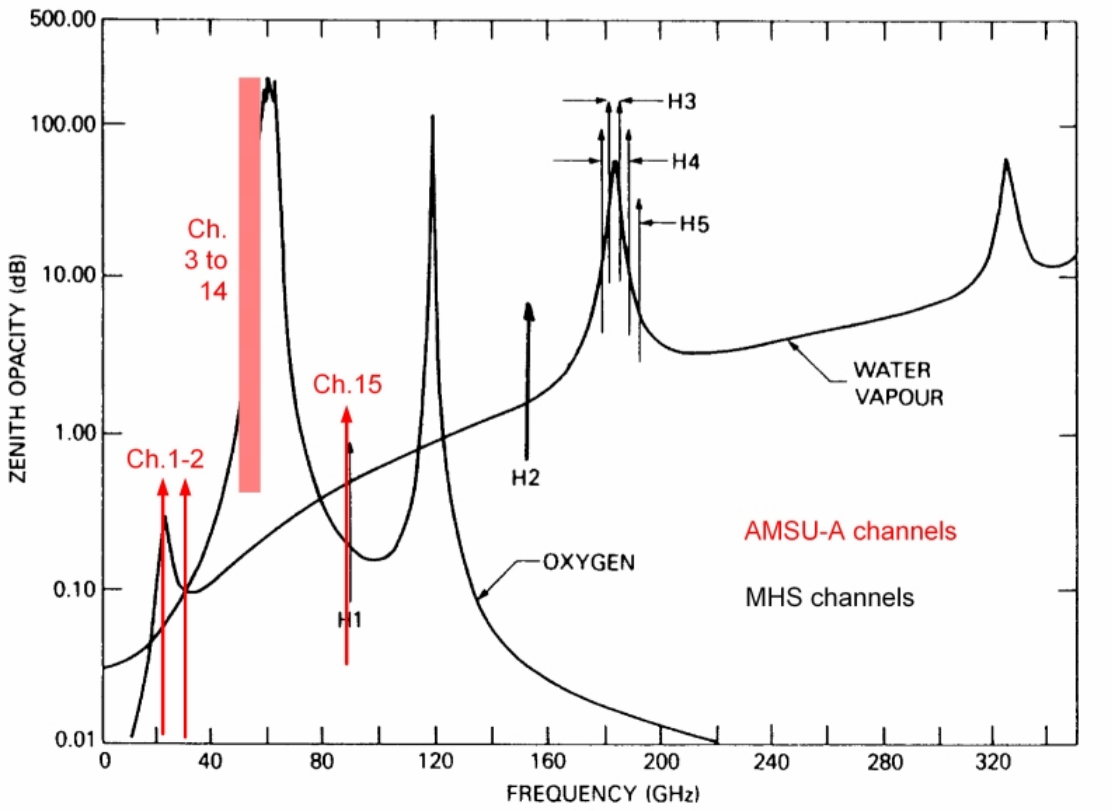
Microwave atmospheric sounding

- Instruments measure total power in narrow spectral channels in range 20-250GHz.



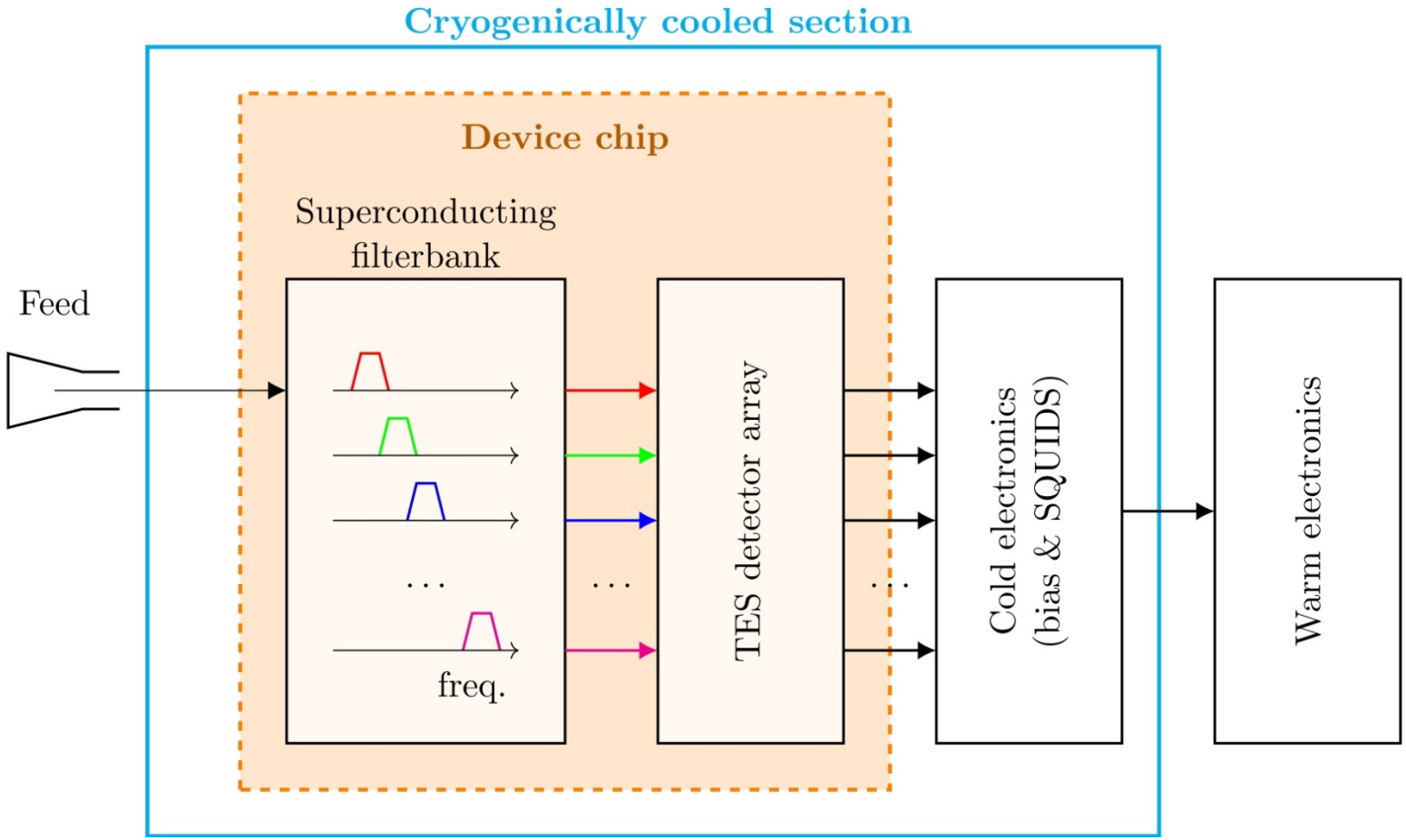
- O_2 line complex at 60GHz used for temperature sounding.
- H_2O line at 183GHz used for humidity sounding.

AMSU-A and MHS channels as taken from www.eumetsat.int

Enhancing sounder capability

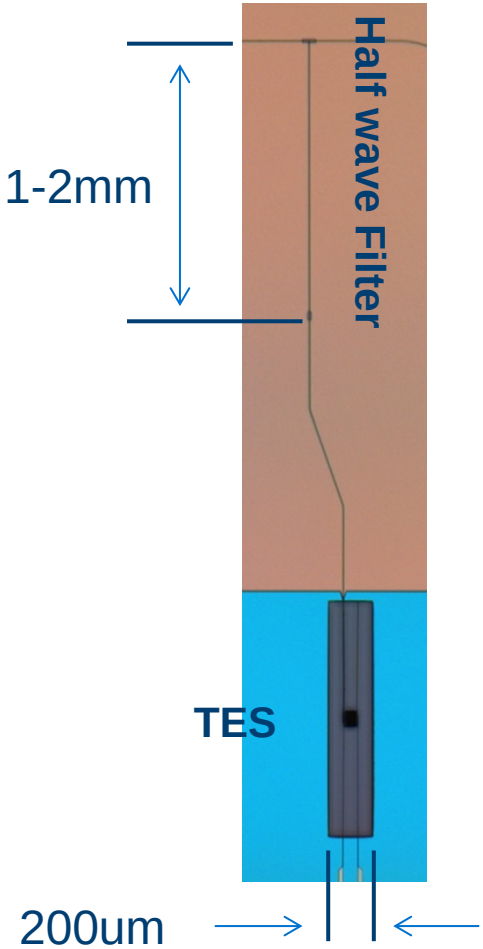
- The cloud-penetrating capabilities of microwave sounders make them important inputs for numerical weather prediction.
- Challenges for improving performance:
  - **'Hyperspectral' capability** – delivering large numbers (hundreds) of narrower bandwidth (R > 500) channels.
  - **Improving/maintaining radiometric sensitivity** on moving to hyperspectral operation.
- Superconducting system-on-chip filterbank spectrometers are a way of meeting this challenge… (**and others, such as ice cloud studies**)

Superconducting on-chip filterbank spectrometers



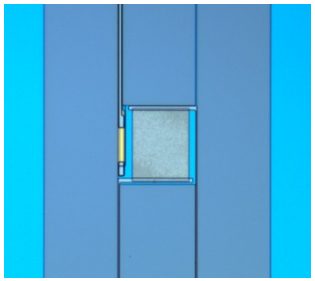
Advantages: Physically small channels

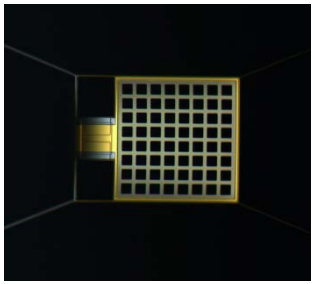
- Operate at signal frequency, so distributed filters are mm sized for frequencies above 60 GHz!
- Slow-wave effects on superconducting lines further reduce this dimension.
- Ohmic losses negligible, so dimensions can be reduced without degrading performance (e.g. filter bandwidth, efficiency).
- **Can fit large number of channels on small chip area – enables hyperspectral instrument.**

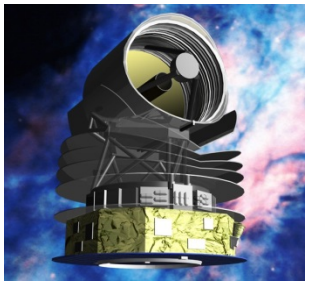


Advantages: Transition Edge Sensors (TESs)

- Superconducting power detector.
- **Extremely sensitive**: NEP < 10^{-16} W/Hz$^{0.5}$ for operation at 350mK.
- **Wideband, high-efficiency, coupling** to transmission line circuits up to 1THz. Ideal for this application.
- **Tuneable operating temperature**: NEP scales only as T.
- **Favourable operating characteristics**: linearity, high dynamic range and insensitivity to changes in background loading.
- **Significant operational experience with mature multiplexing technology**. For smaller channel counts (<50), a multiplexer would not be necessary.

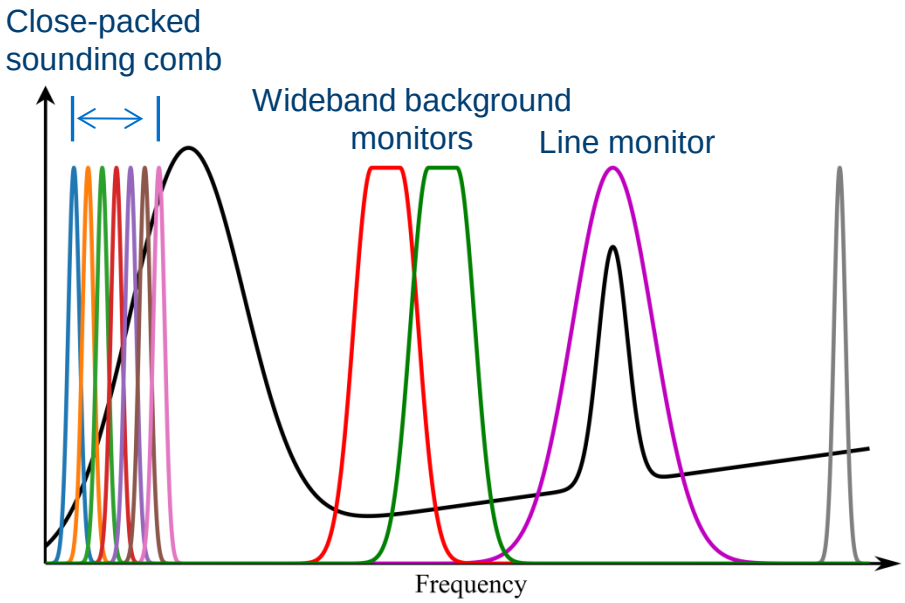






Advantages: Operational

- **Wide instantaneous observing bandwidth** (limited by feed(s))
- **Control over channel placement and shape,** so can optimize scientific return for given number of detectors.



- Eliminates mechanical interfaces between components – improves ruggedness.
- Chips straightforward to reproduce.

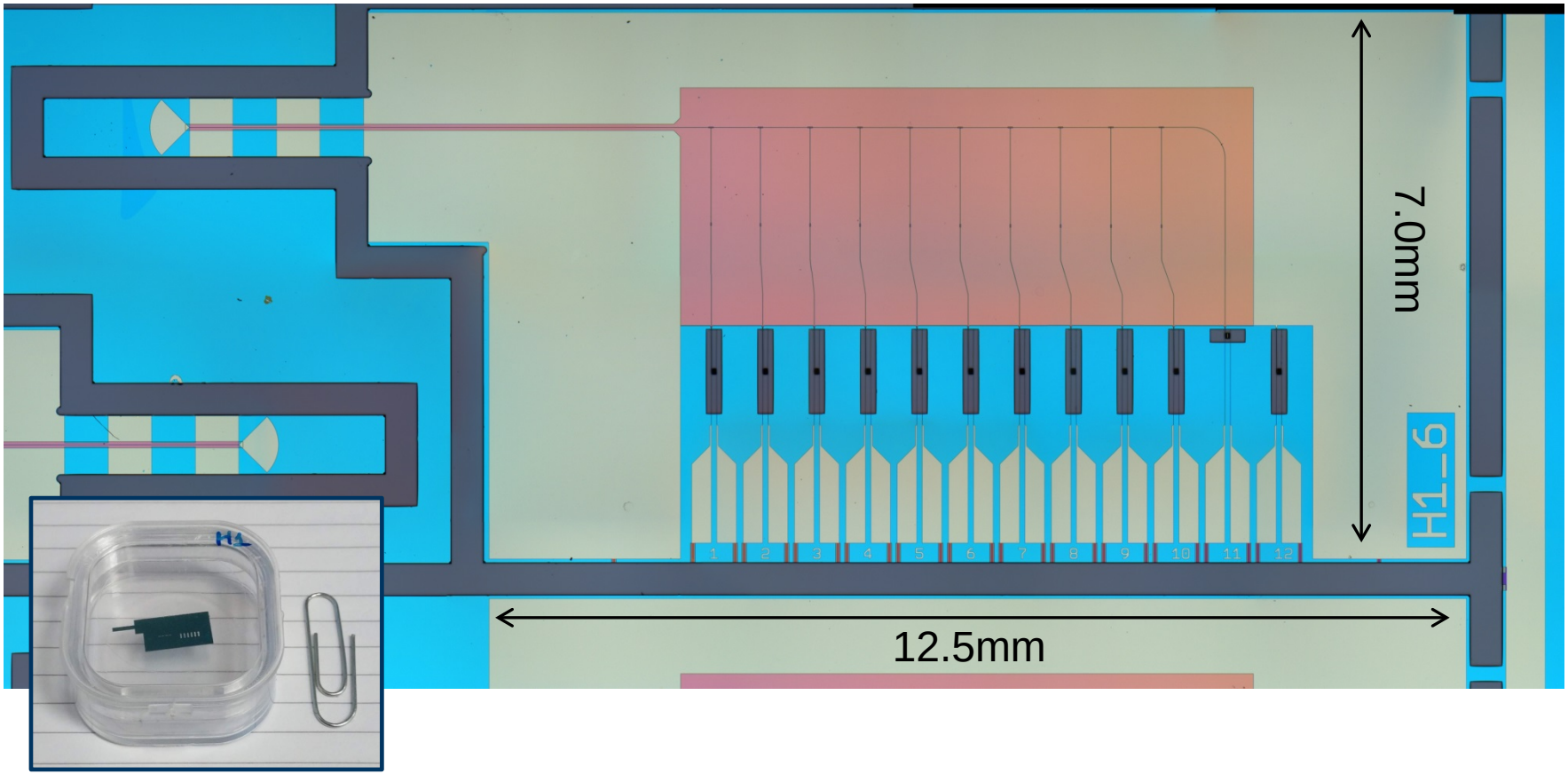
The HYMAS project

- Stands for **HY**perspectral **M**icrowave **A**tmospheric **S**ounder.
- CEOI funded pathfinder project to examine technology.
- Set of devices fabricated to demonstrate key technologies for temperature sounding on the 60GHz O_2 line.
- Retrieval studies to model instrument performance.

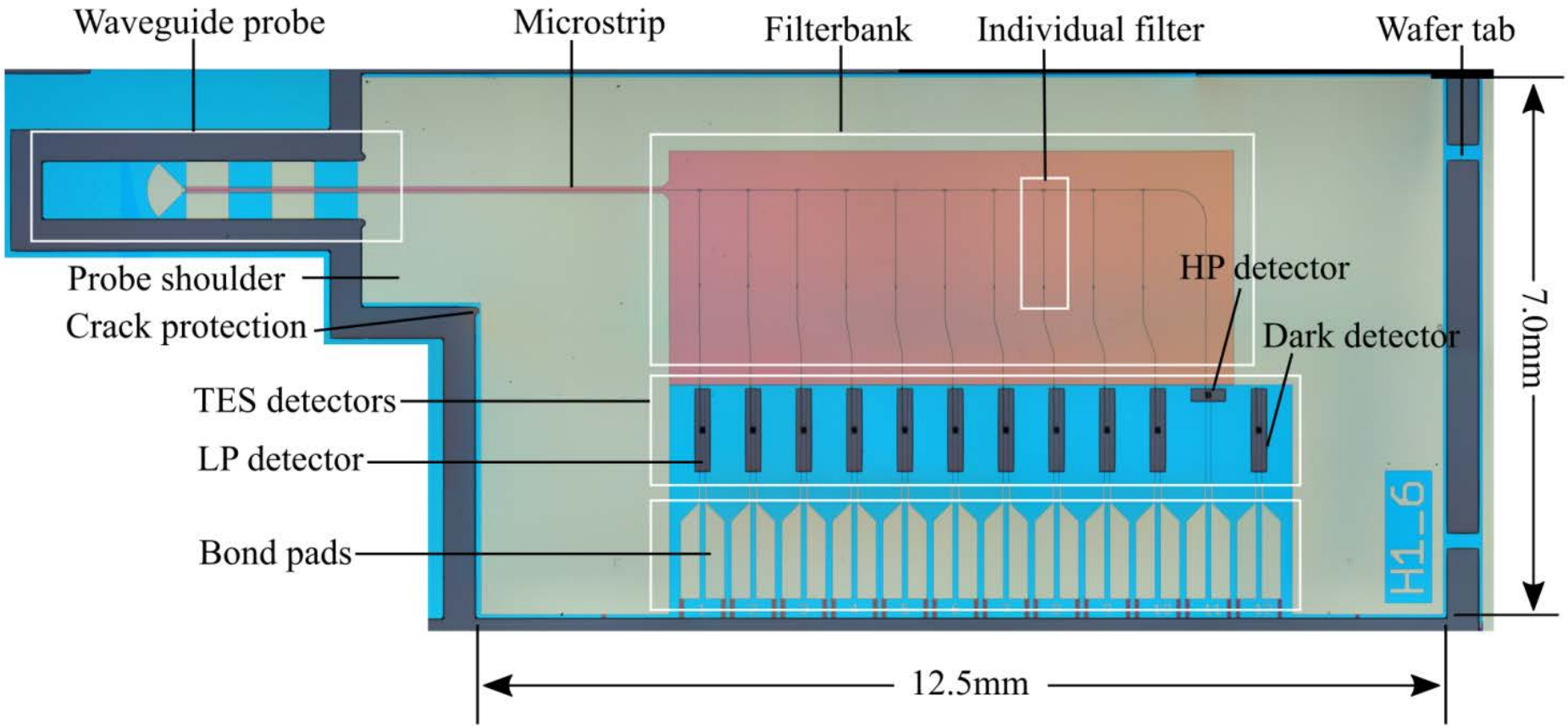
Demonstrator chip targets:

Parameter	Target
Operating temperature	350mK
Channels per chip	10
Operating frequency range	45-65 GHz
Spectral resolution ($\Delta\nu/\nu$)	300-1000
Feed	WR15
Detector dark NEP	11 aW/Hz$^{0.5}$
Detector power handling	1.4 pW
Detector response time	0.4ms

Demonstrator chips

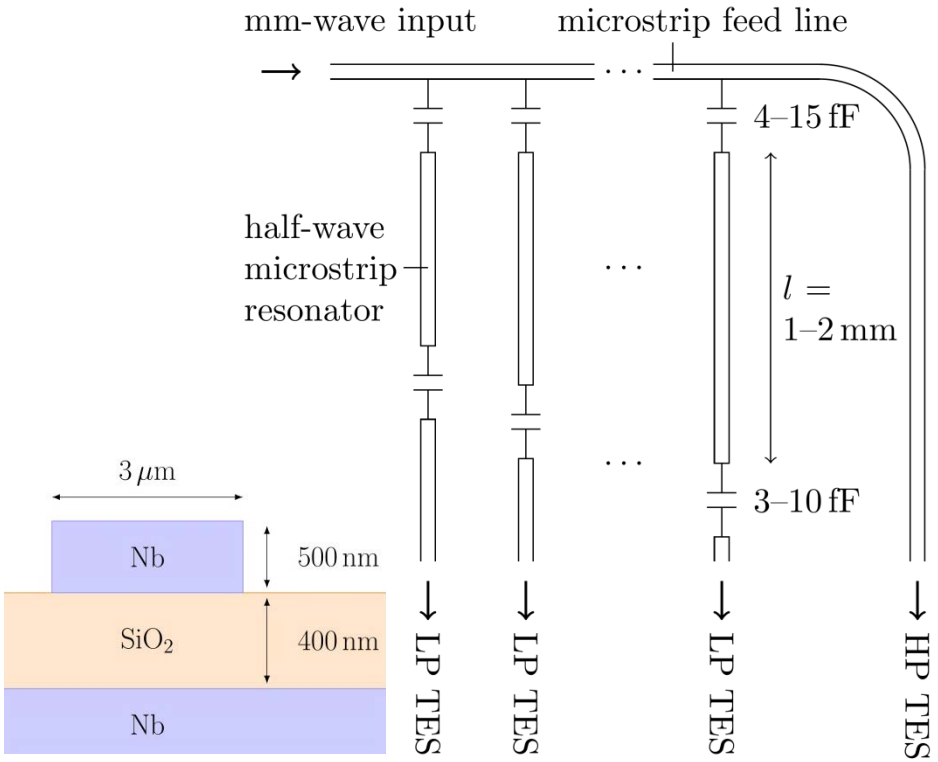


Demonstrator chips

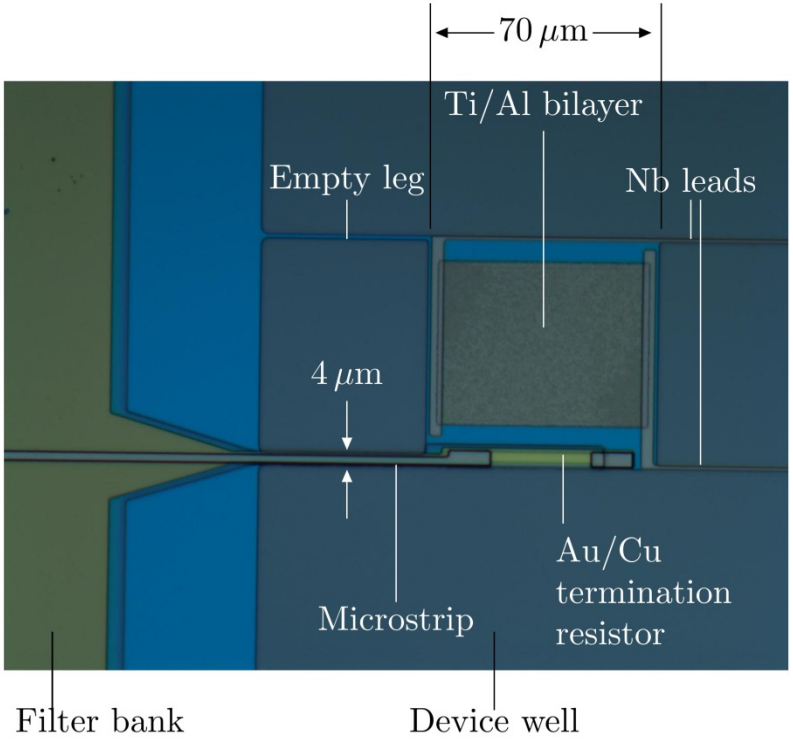


Technology

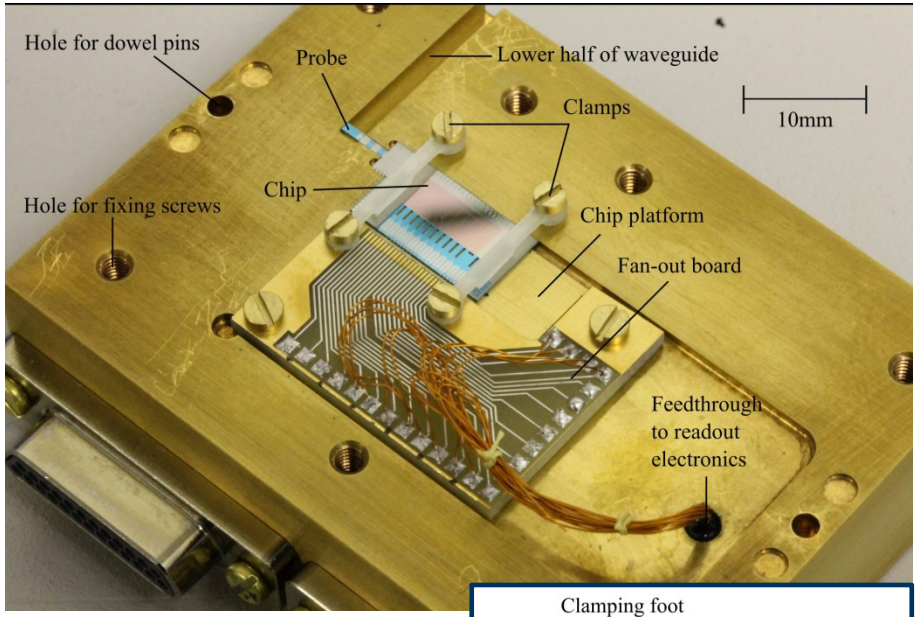
Superconducting microstrip filter bank

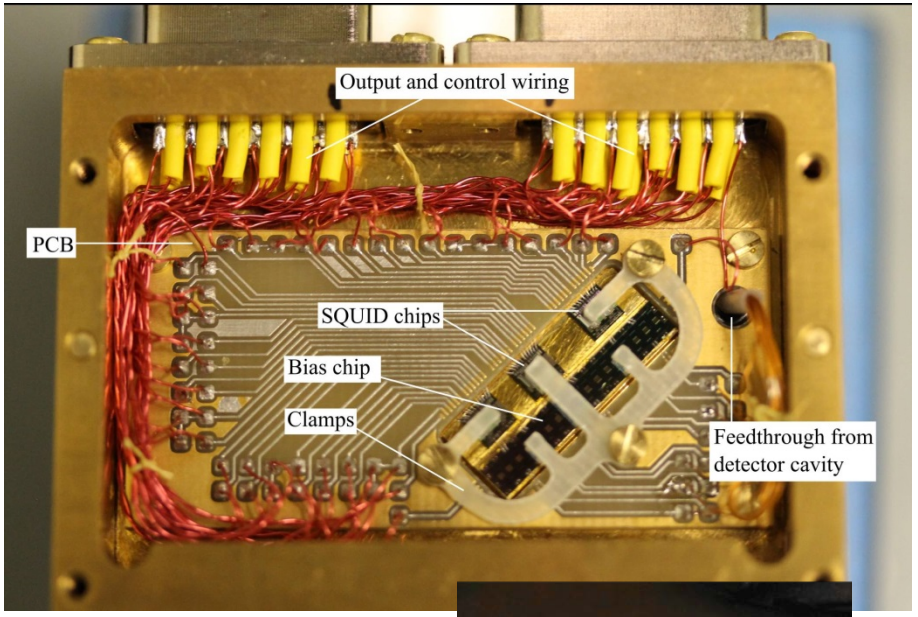


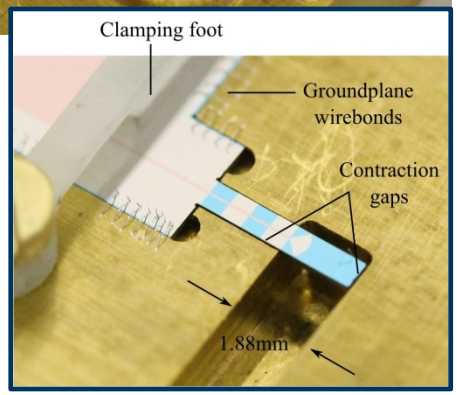
MS coupled Ti/Al TES



Detector packaging

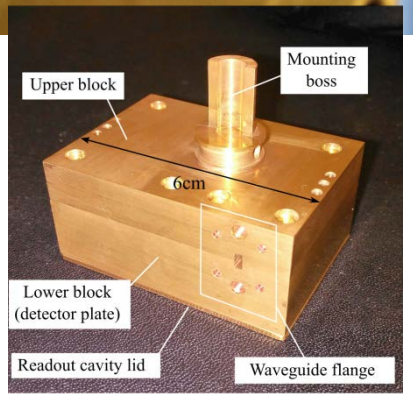




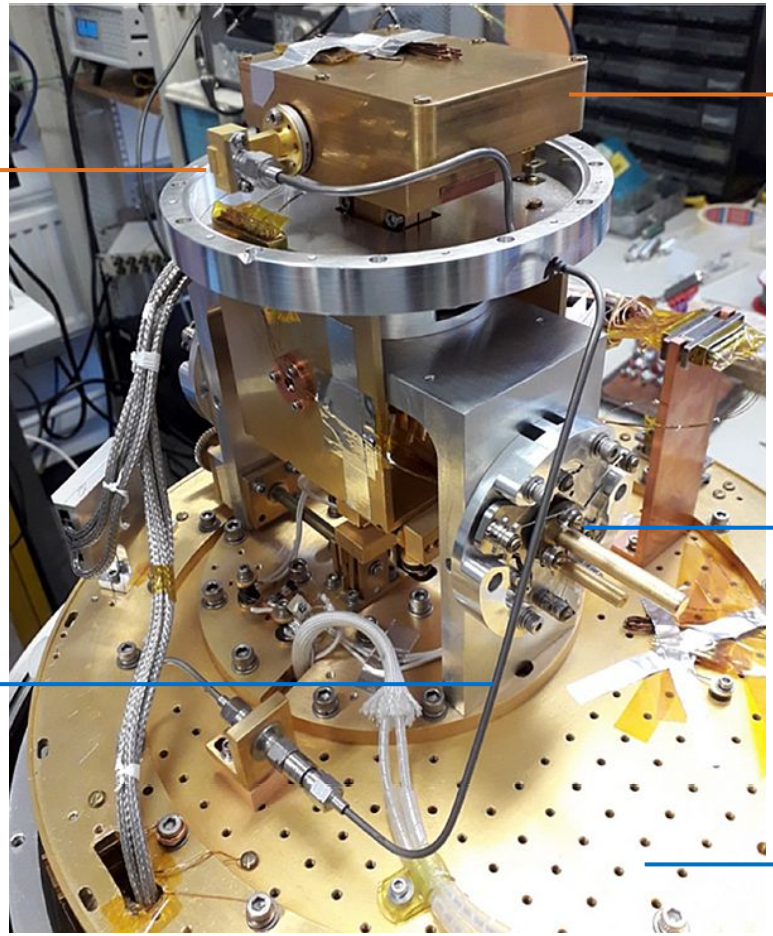


Close up of radial probe in waveguide (1.88mm wide)

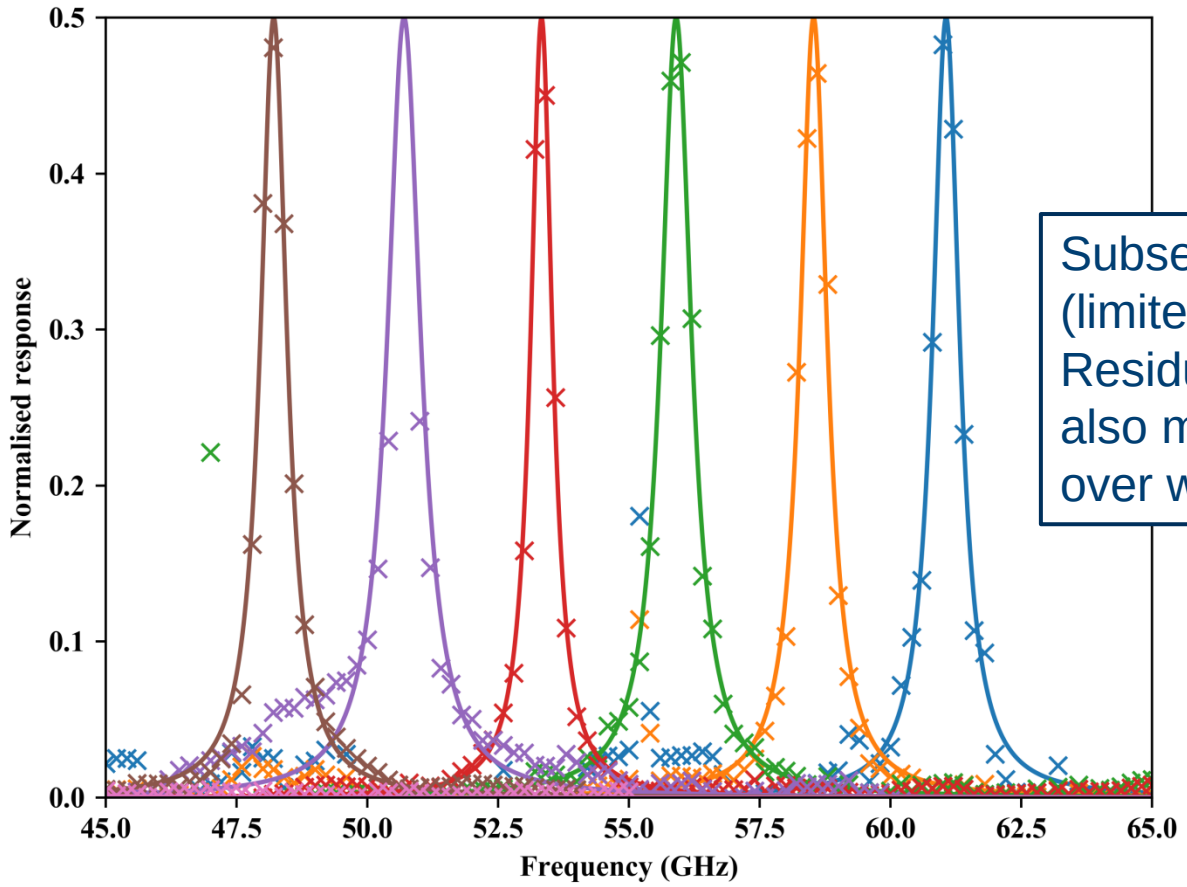
Assembled block (long edge 6cm)



Experimental characterisation

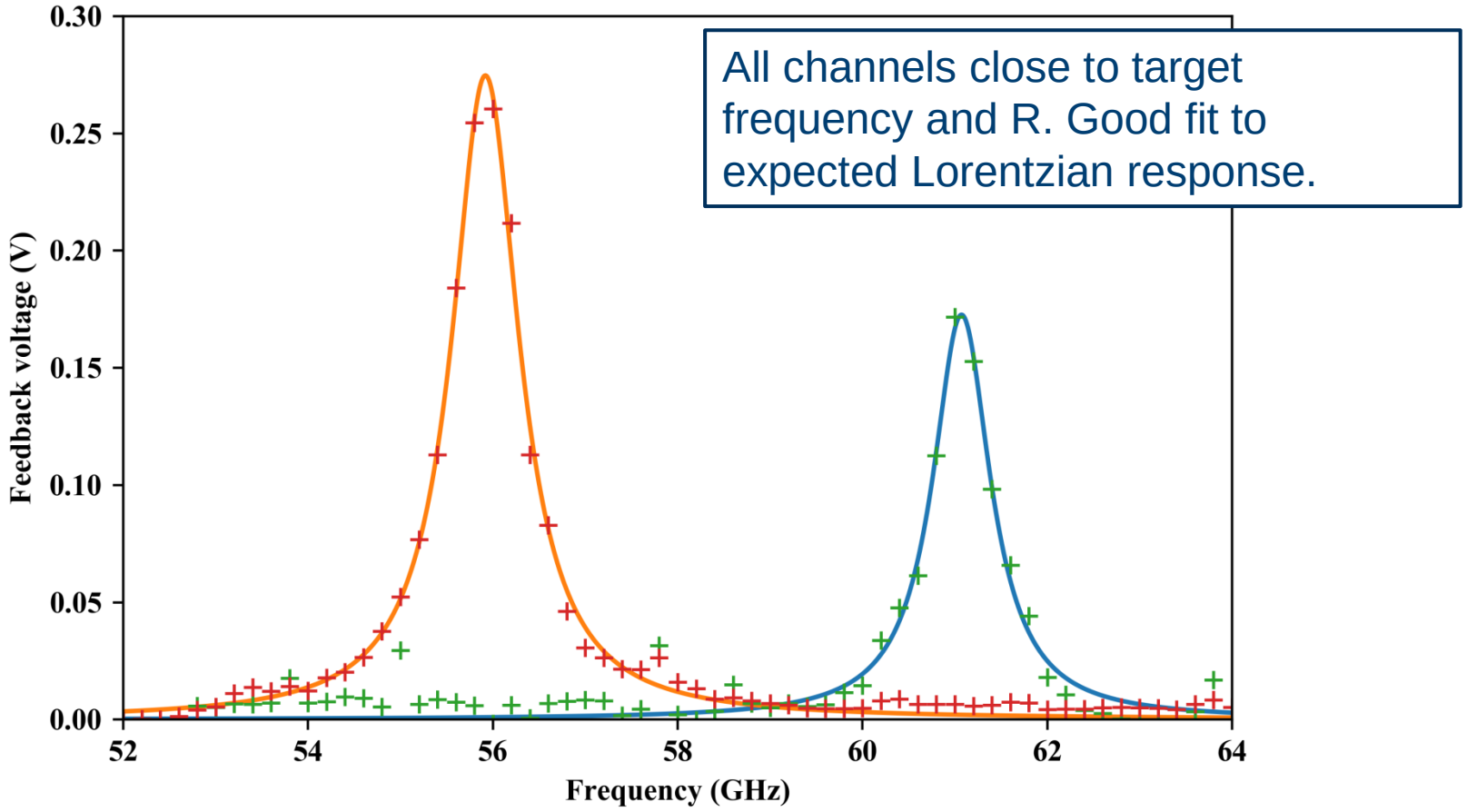


Measured channel shapes



Subset of channels (limited by wiring). Residual power detector also measures power over whole bandwidth.

Measured channel shapes (more detail)



HYMAS-X (HYMAS eXtended)

- Follow on project underway, with the following strands…

HF Devices

- Demonstrate operation at 183GHz.
- Ultra wideband feed study.
- Compactification.

Enhanced LF Devices

- Improved 60GHz design.
- Higher R filters with increased efficiency.
- Improved detectors.
- Operational aids (calibrators).

Instrument planning

- Development of demonstrator concept.
- Cooling chains for HAP and LEO deployment.

Conclusions

- Superconducting on-chip spectrometers are a promising technology for hyperspectral microwave sounders (and potentially ice cloud studies).
- See Dongre (doi: 10.1117/12.2500516) for analysis of potential scientific performance.
- Thank you to CEOI for funding this work.

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