Feasibility Study on Integrated Multi-Pixel Heterodyne Receiver Chip and Module working at 220 GHz

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OUTLINE

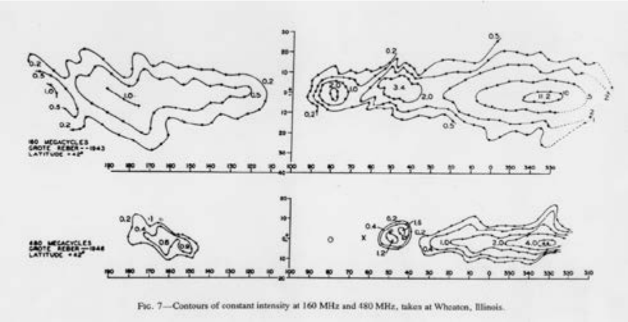
- Motivation
- Current technologies and challenges for constructing a large format (~100 pixels) sub-THz heterodyne receiver
- Our approaches and current status
- Conclusions

Trace of Radio Telescopes

Short wavelength

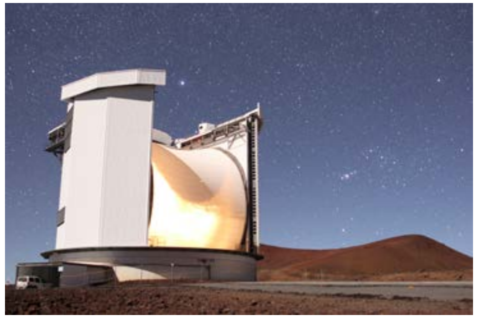
Large Aperture

Grote Reber, 1937, 160MHz



Milkyway @160 and 480 MHz

Nobeyama, Japan, 45m, 1982, mm wave

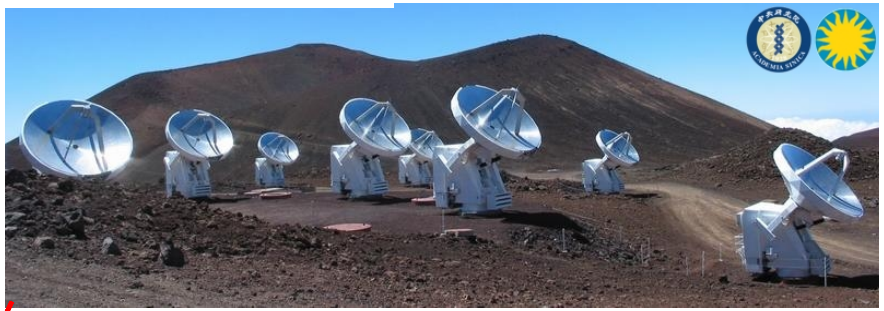


JCMT, Hawaii, 15m, 1987, submm wavelength

Arecibo, 305m, 1963, 6m-3cm

VLA/EVLA, Socorro, 1982, 25m x 27

High resolution



SMA, Hawaii, 2003, 6mx8, baseline ~500m

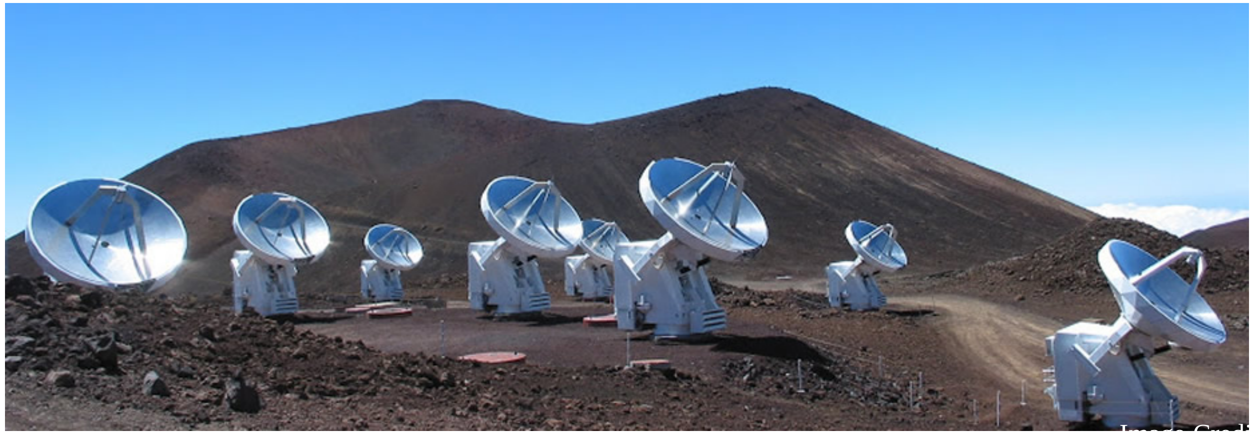
FAST, China, 500m, 1m-6cm, 2016

SKA, radio, 100m x few hundred, 2023

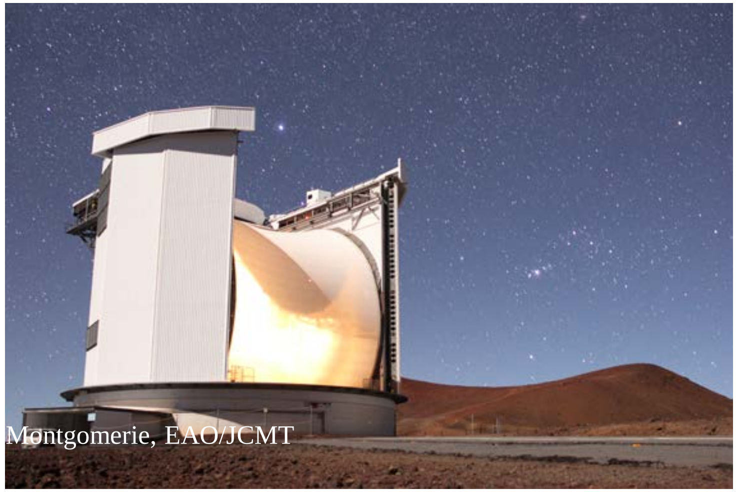
ALMA, Chili, 2013, 12m(50)+ACA, baseline ~20km

sub-THz Heterodyne Receiver (ASIAA involved)

SMA (6m x8, Mauna Kea, Hawaii)



JCMT (15m, Mauna Kea, Hawaii)



ALMA (12m x50, Atacama, Chile)

GLT (12m, Greenland)

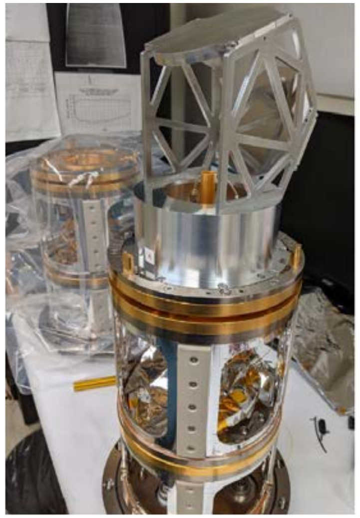
ASIAA Clean Room Facility

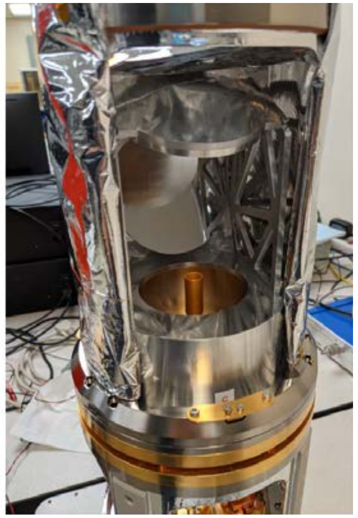
Photo-lithography process (class 100)
minimum dimension ~ 1μm

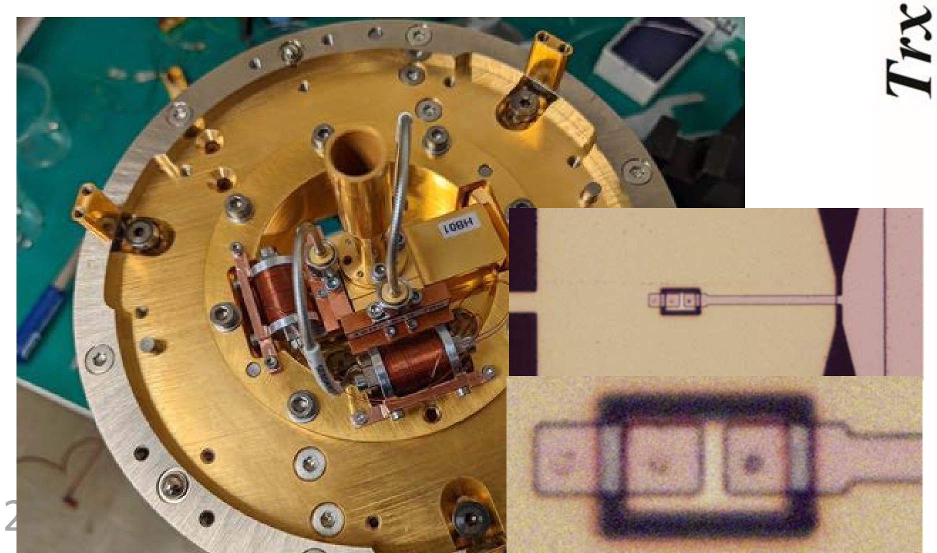
Thin film process
(class 1000)
Nb, Al, SIO2, Au, Ti, Cr
Deposition and etching

Quantum noise ($h\nu/K_B$) limit detection

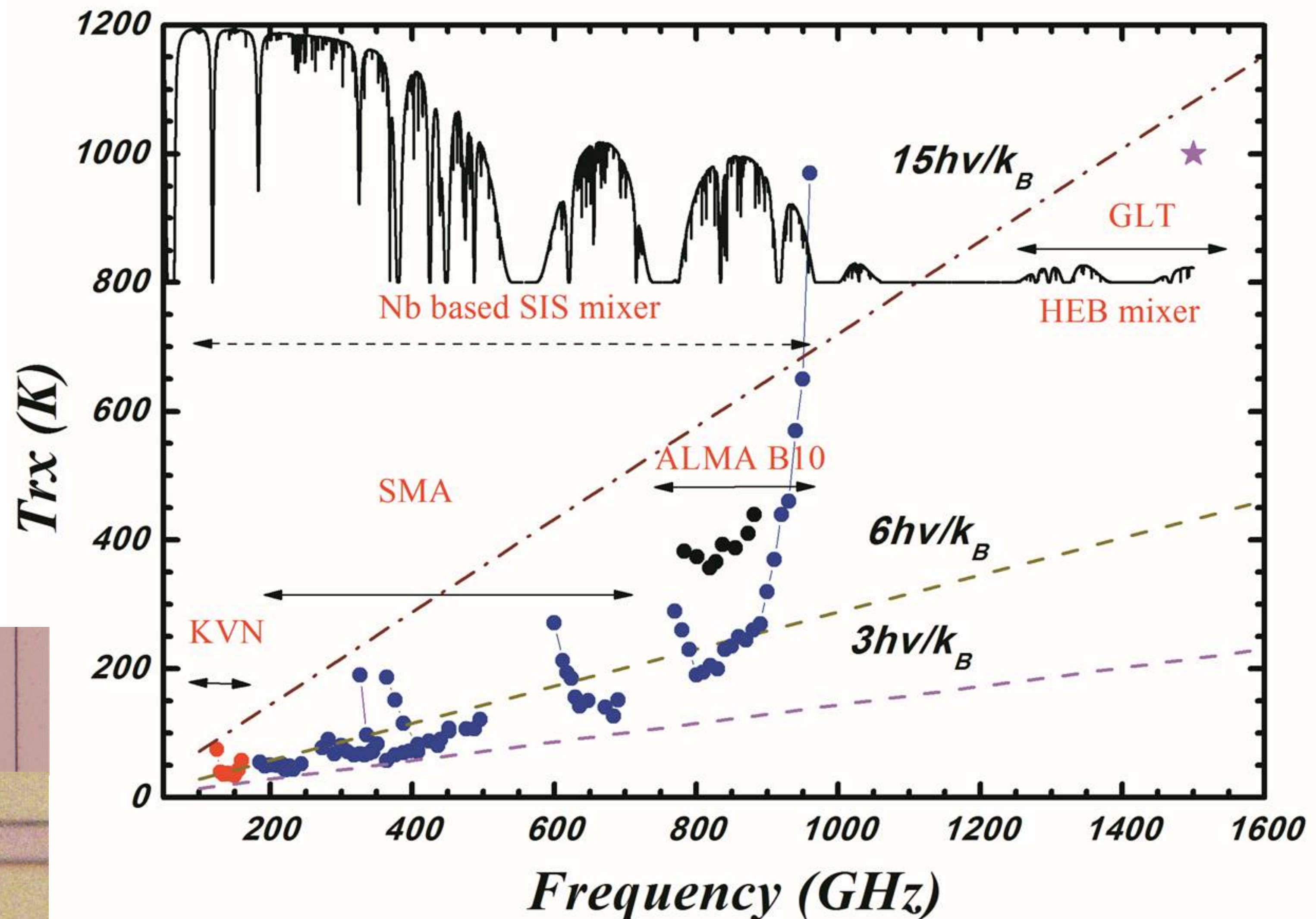
wSMA high band receiver (345 GHz)



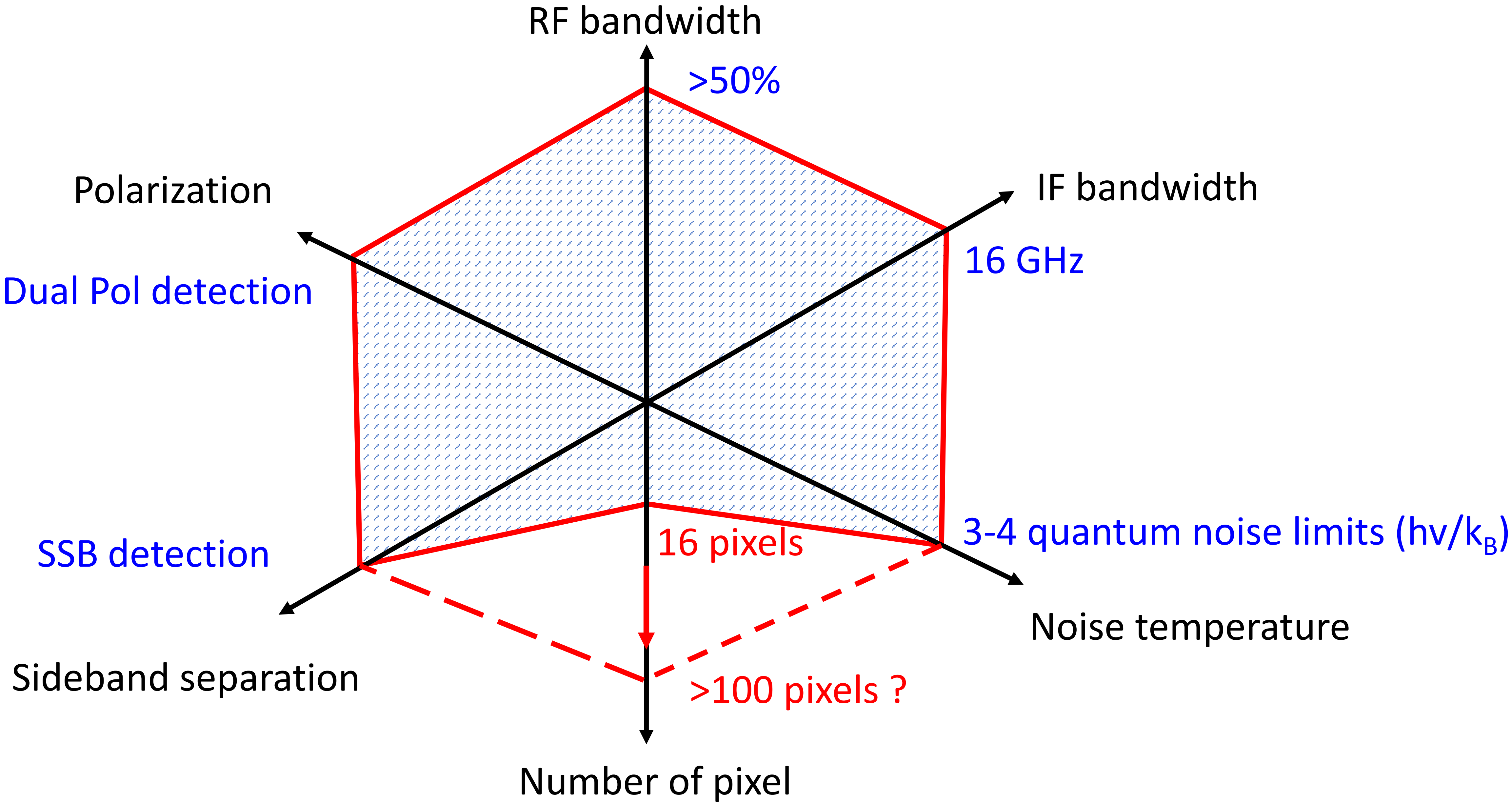




Receiver noise temperature = 3-6 $h\nu/K_B$



Radio Heterodyne Receiver



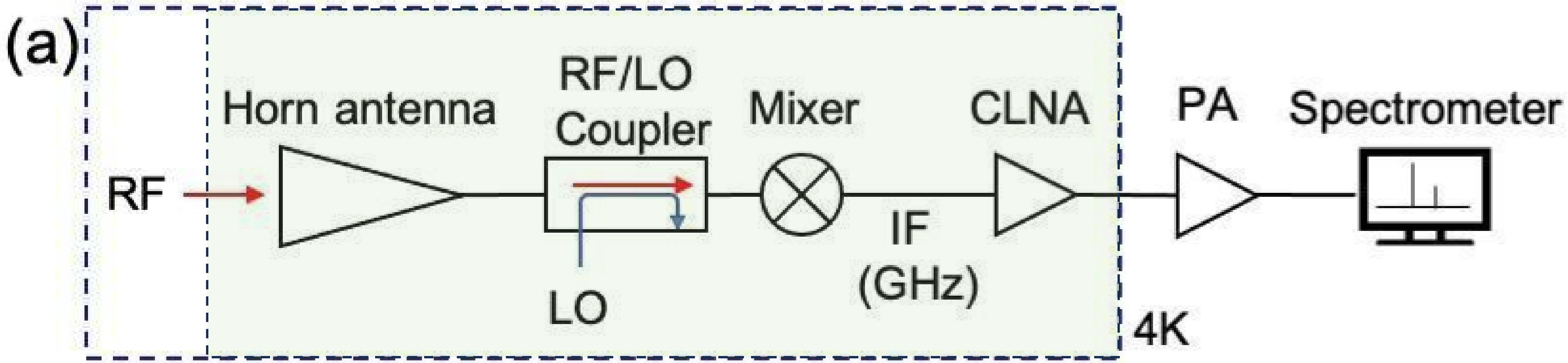
Why multi-pixel sub-THz heterodyne receiver?

- sub-THz telescope is very expensive, non-linear increase with the aperture size (10 to 500 M$)
- Multi-pixel receiver increases the mapping speed for sky survey
- Heterodyne receiver can get spectrum lines as well as total power information from astronomical sources, more information than that from bolometric detector

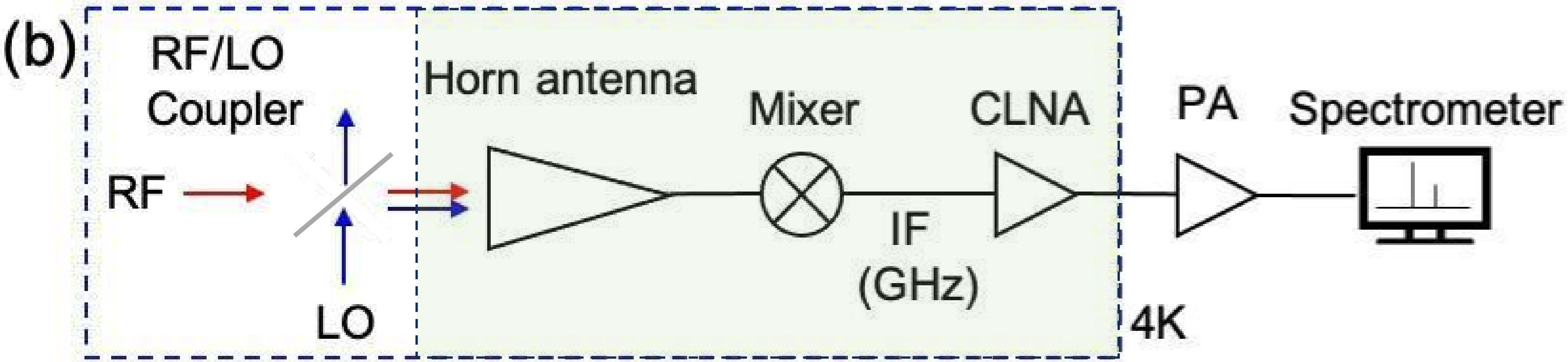
Two Schemes of sub-THz Heterodyne Receiver

(Semiconductor amplifier is too noisy, Frequency down-conversion technique is used)

RF/LO Waveguide coupling (low frequency)

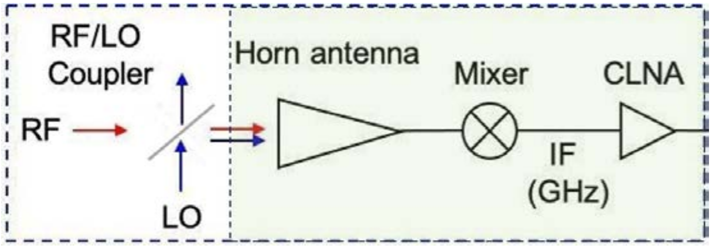


RF/LO beam splitter coupling (high frequency)

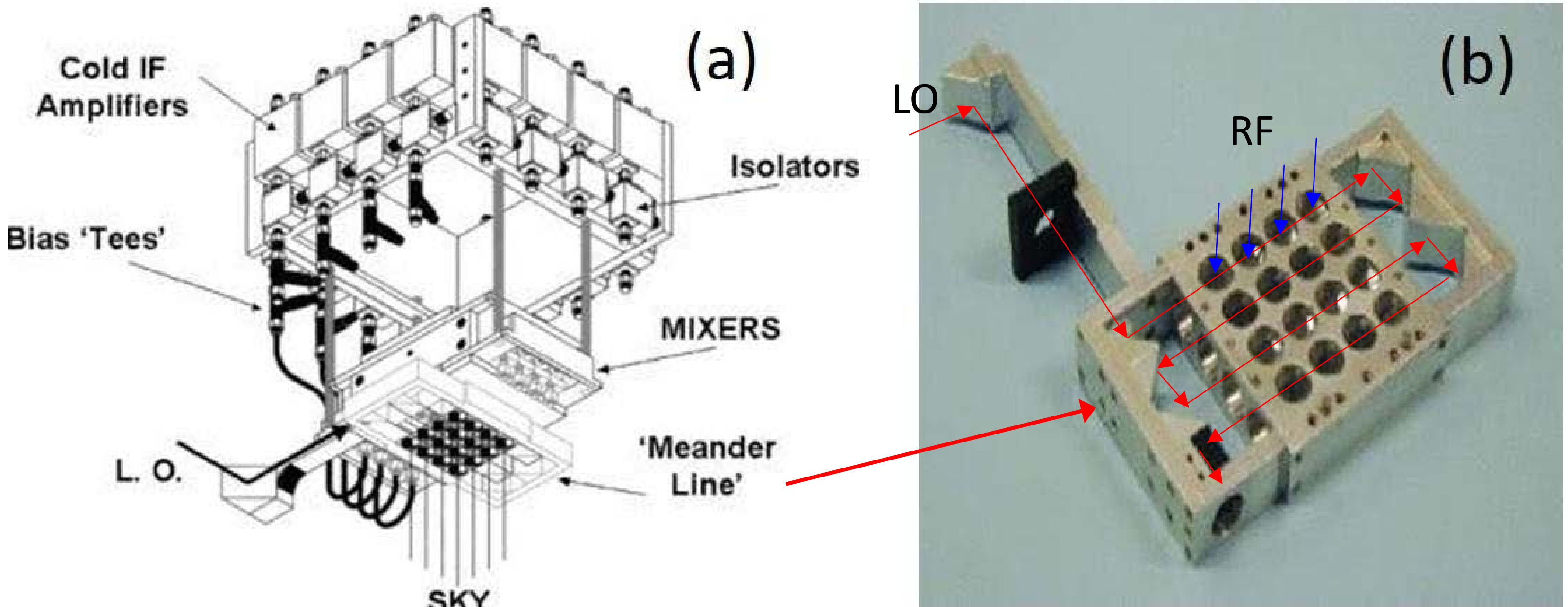


16-pixel Receiver – HARP (JCMT)

*J. V. Buckle et al. Monthly Notices of the Royal Astronomical Society, **399**, Issue 2, 1026-1043, October 2009,*



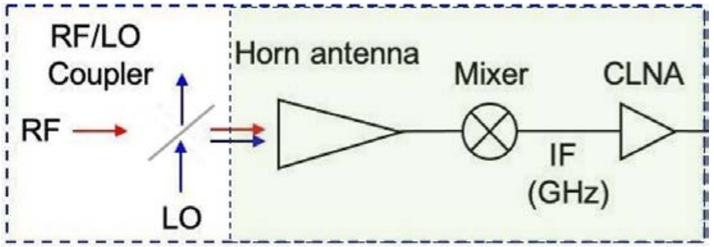
- Working at 345 GHz (DSB)
- 4x4 SIS mixer module
- Quasi-optical RF/LO coupling (beam splitter): Series beam splitter for RF/LO (95%/5%) coupling (Meander Line) with beam splitter

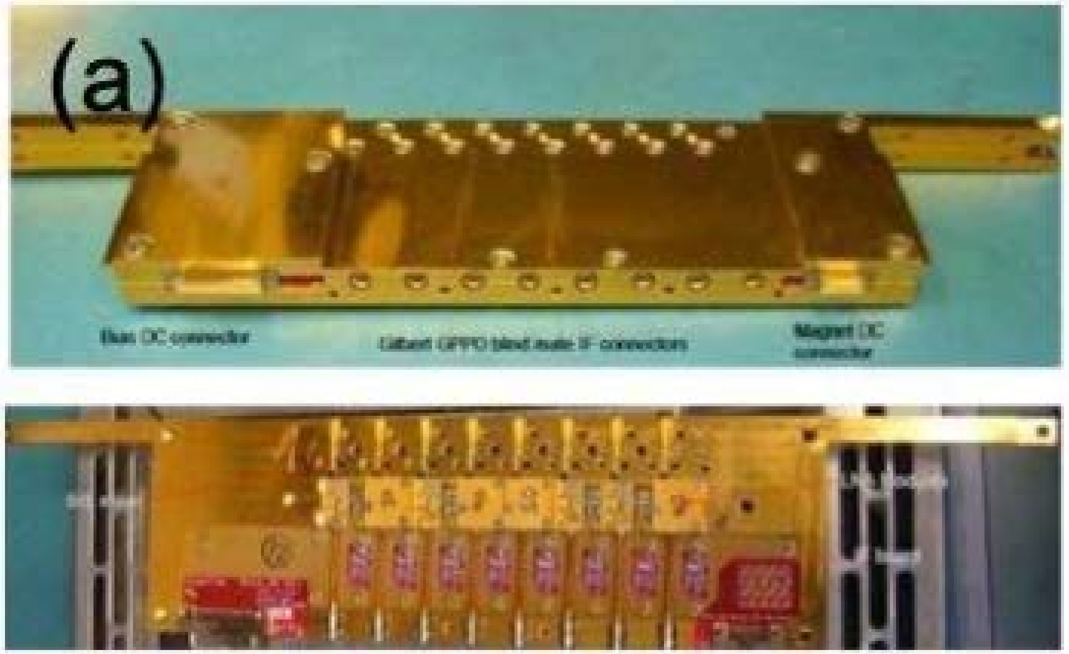


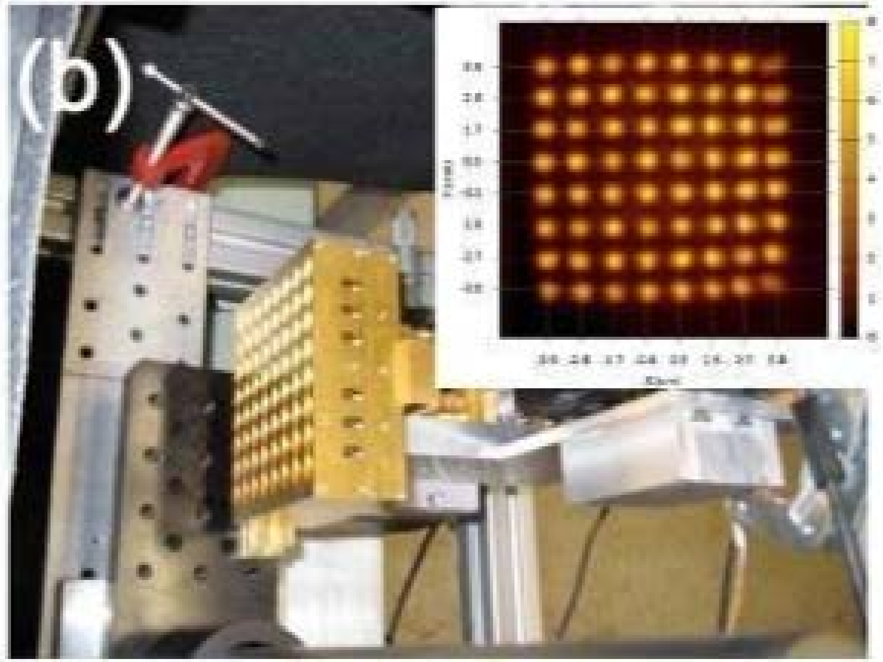
64-pixel Receiver – SuperCam

C. Groppi et al. Proceedings of the 20th International Symposium on Space Terahertz Technology, Charlottesville, p.90-96, 20-22 April 2009

- Working at 350 GHz (DSB)
- 8-pixel module using traditional receiver scheme
- Each module integrating SIS mixer and CLNA
- 8x8 LO source module
- Quasi-optical RF/LO coupling (beam splitter)

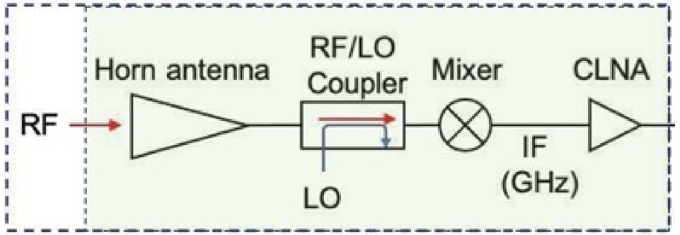




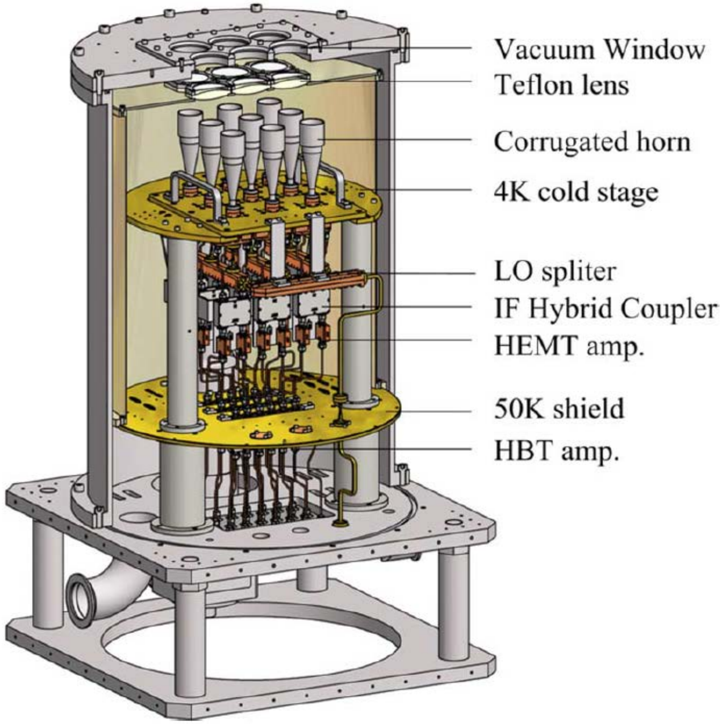


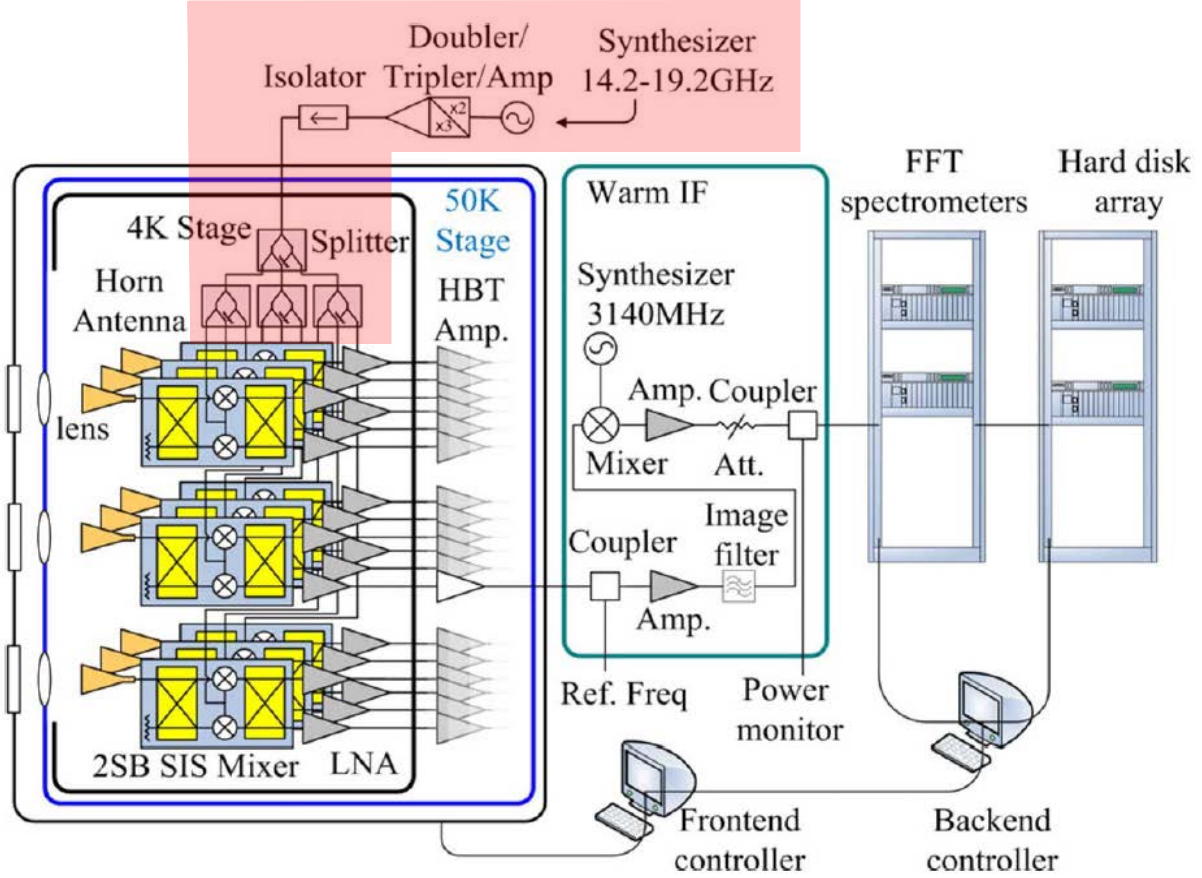
9-pixel Receiver – Delingha Telescope, PMO

WL Shan et al, IEEE TRANS. THz SCI. AND TECH., VOL. 2, NO. 6, NOVEMBER 2012



- Working at 85-115 GHz (SSB)
- 3x3 SIS mixer module
- Waveguide RF/LO coupler – split LO to 9 pixel before coupler

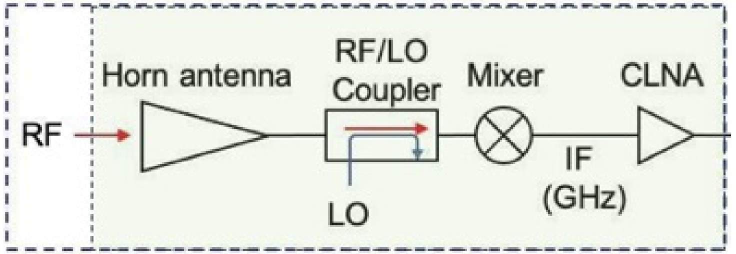


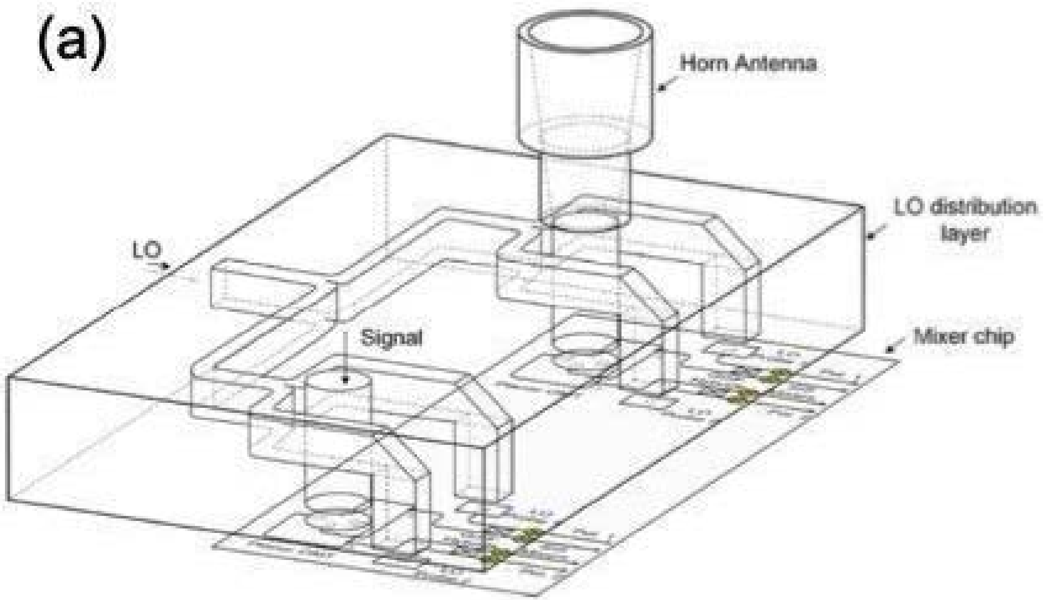


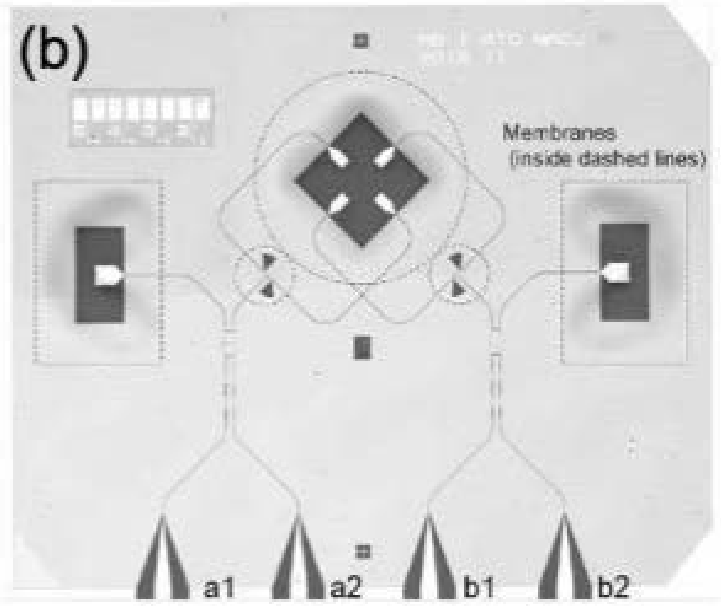
Two-Pixel Integrated Receiver Chip

*Shan et al. SPIE, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy IX, **10708**, 125-139 (2018)*

- Working at 140 GHz
- Si membrane technology using SOI technology
- Integrating RF(LO) probe, power combiner, quadrature coupler (RF/LO coupler), SIS mixer, and IF output circuit
- Waveguide-type LO distribution scheme







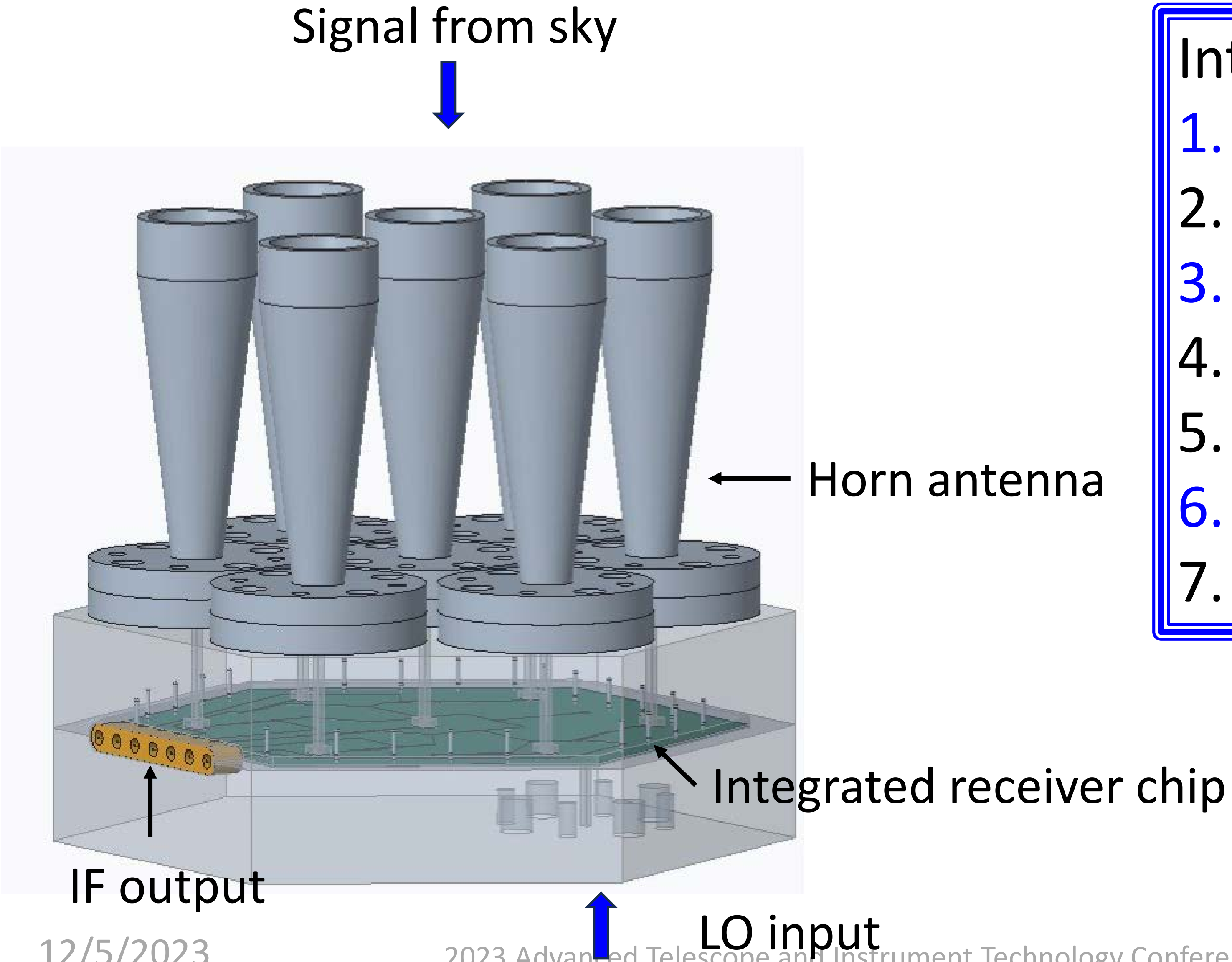
Challenges of constructing a large format heterodyne receiver

- Local oscillator (LO) distribution
- RF/LO coupling
- Magnetic field tuning of SIS mixer
- System integration and wiring (IF, DC bias, CLNA)

Our approach – 5-Year project (2023)

- Multi-pixel receiver module: 7-pixel unit in hexagonal configuration
- Planarized components: LO distributor, RF/LO directional coupler, …
- Integrated multipixel heterodyne receiver chip
- Permanent magnet for individual SIS mixer magnetic field tuning
- Integrated IF output port

Multi-pixel receiver module (7-pixel unit) @ 220 GHz

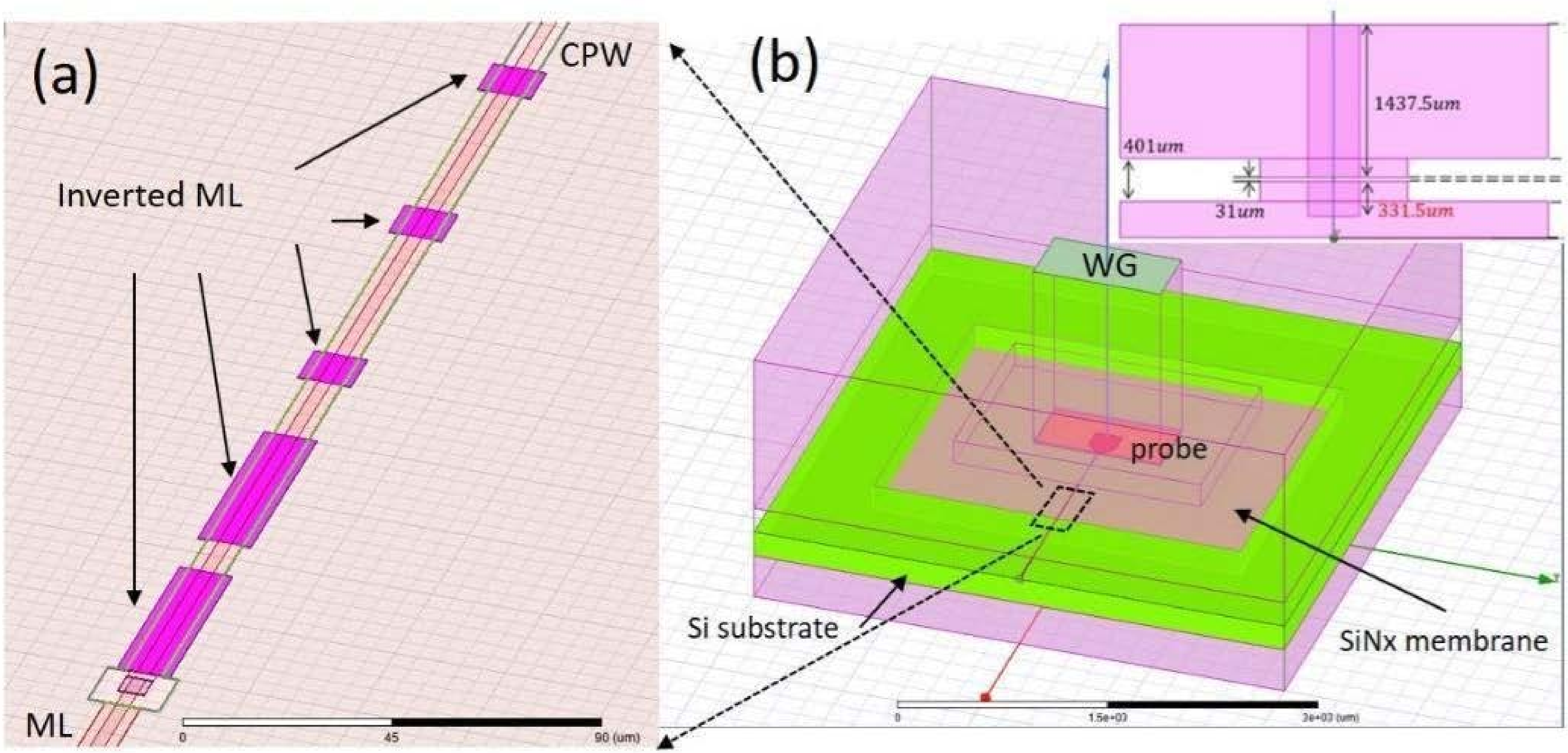


Integrated receiver chip

1. RF(LO) Probe (WG-CPW-MTL)
2. Planar LO distributor
3. LO/RF directional coupler
4. SIS mixer
5. RF/LO matching circuit
6. Magnetic field tuning
7. IF signal output circuit

RF (LO) Probe (from WG to CPW/MTL)

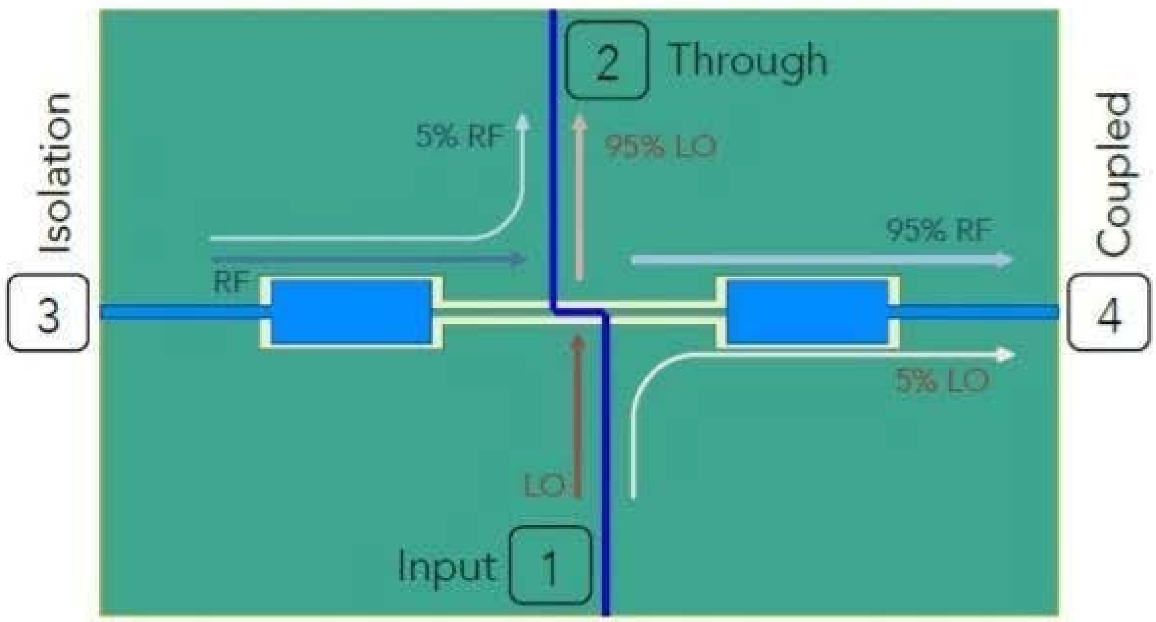
Probe on 1um SiNx Membrane in Waveguide

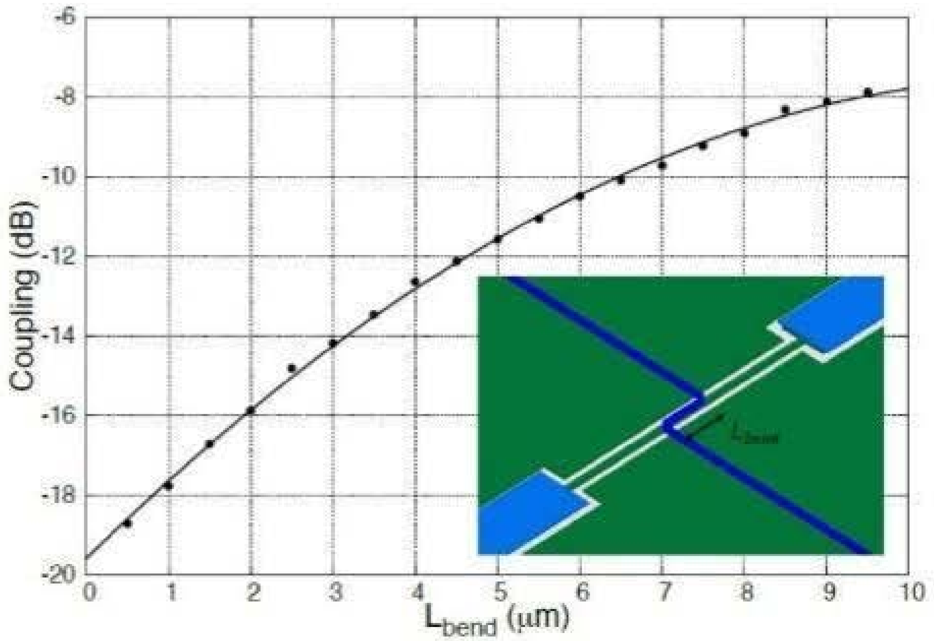


Planar RF/LO Directional Coupler

B. -K. Tan and G. Yassin, IEEE Transactions on Terahertz Science and Technology, vol. 7, no. 6, pp. 664-668, Nov. 2017

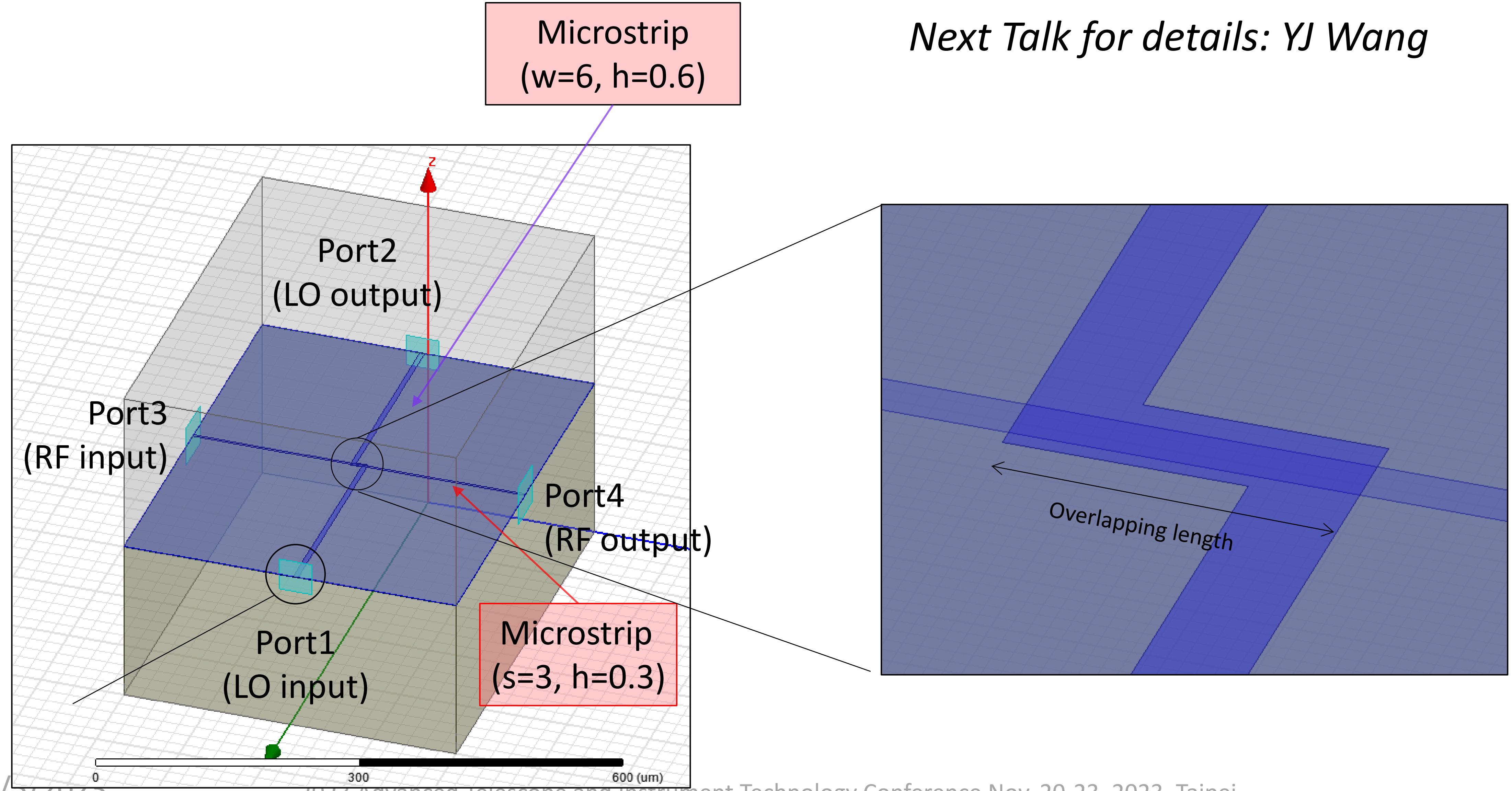
- Overlapped Microstrip transmission line (MTL)/Coplanar waveguide (CPW)
- Design for 650 GHz band
- Scaled model at microwave verified



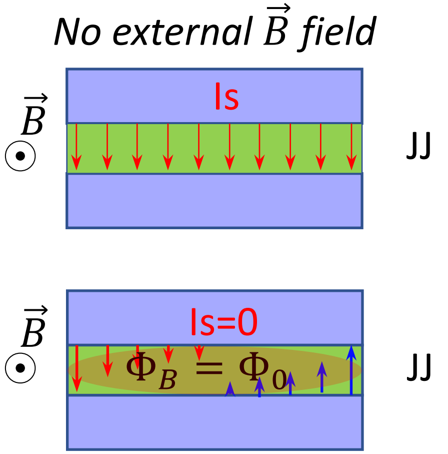


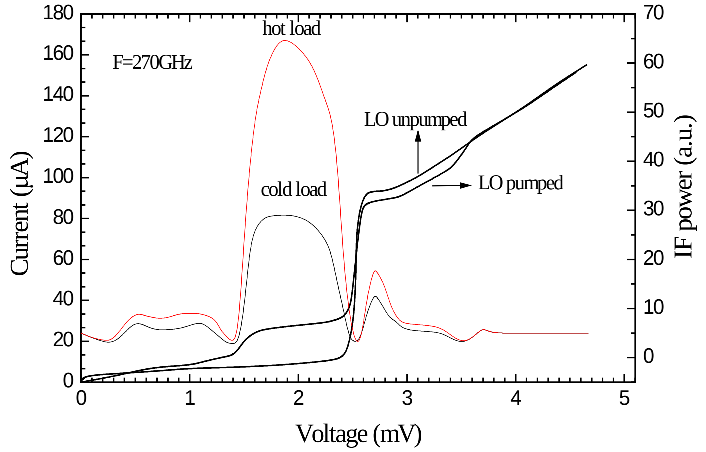
Overlapped MTL Planar RF/LO Directional Coupler

Next Talk for details: YJ Wang



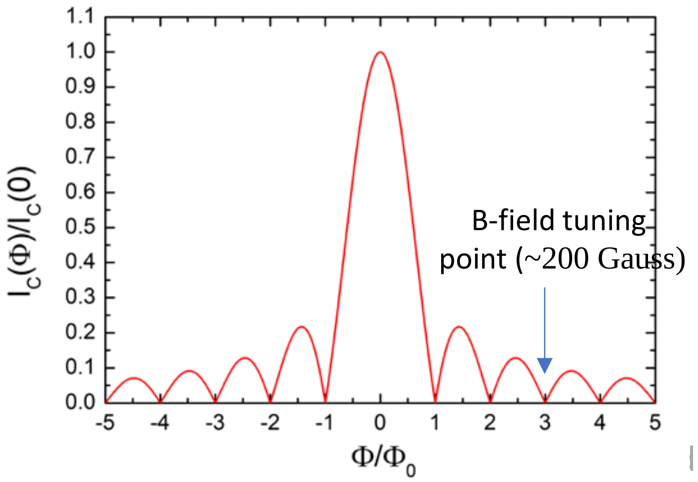
Permanent magnet for SIS mixer tuning

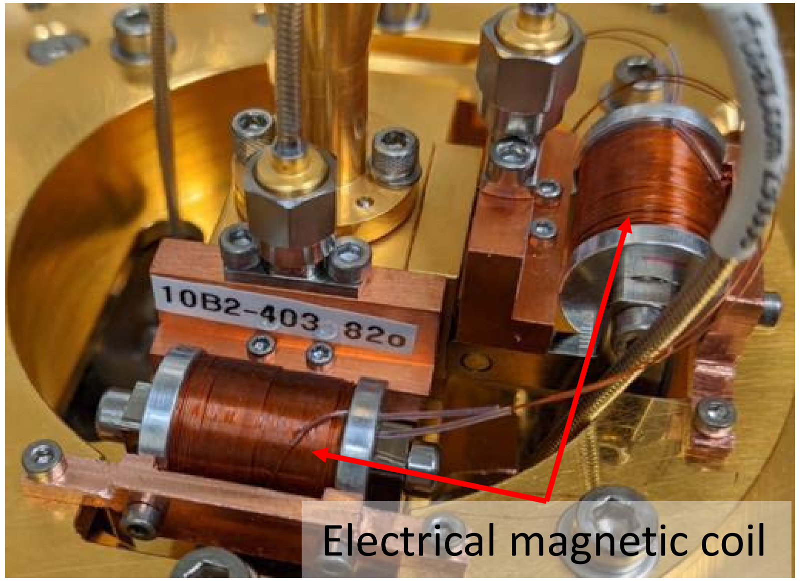


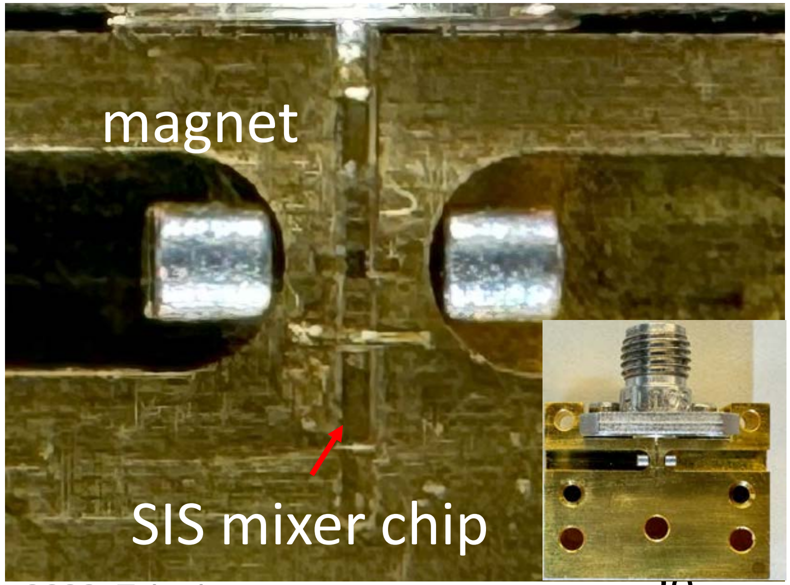


- Typically, electrical magnetic coil used to generate magnetic field
- Using permanent magnet
- However, difficult to be implemented in integrated multi-pixel receiver module because of relative orientation of SIS junction and magnetic field

$$I_c = I_c(0)\left|\frac{\sin(x)}{x}\right|, x = \frac{\pi\Phi}{\pi\Phi_0}$$



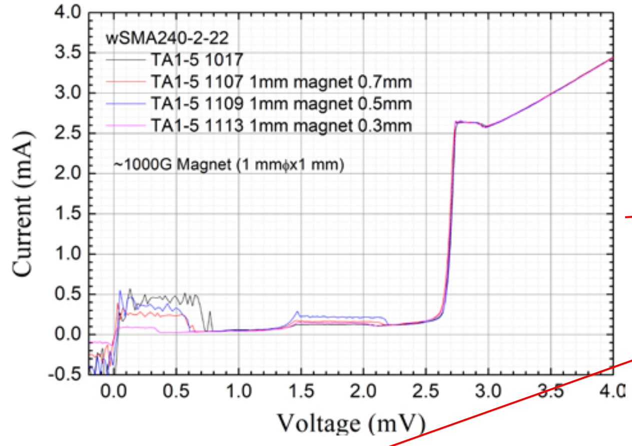


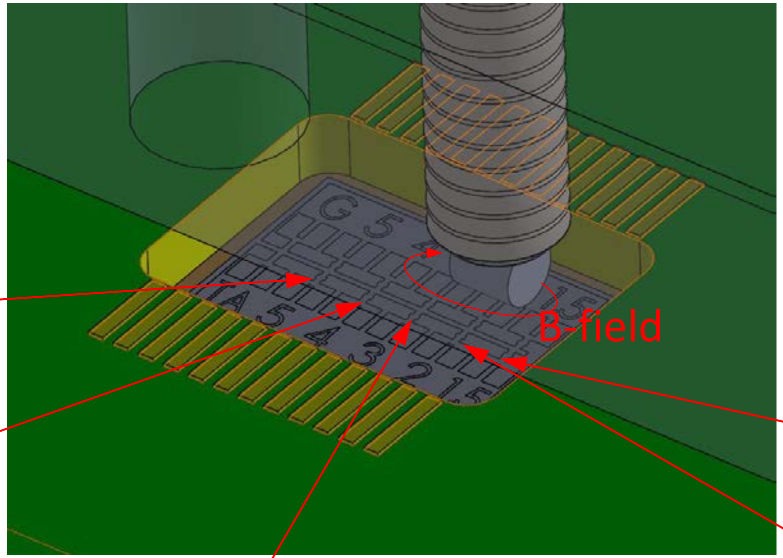


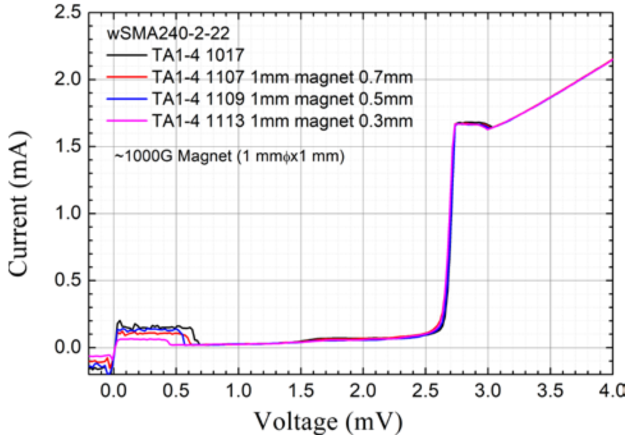
Preliminary results

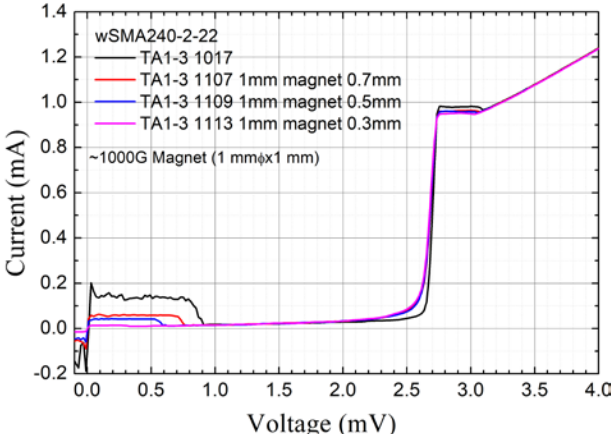
I-V curves of SIS junction with a permanent magnet at different distances

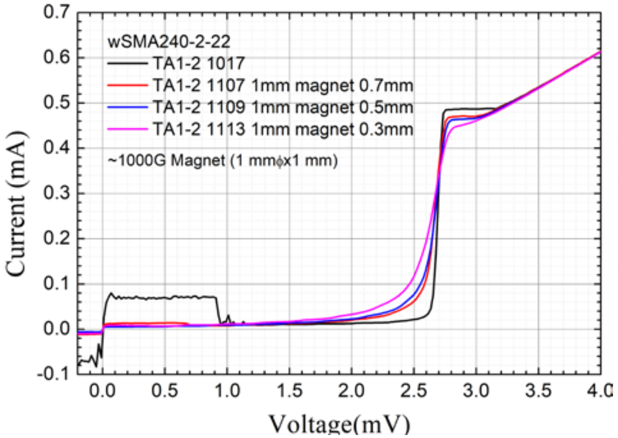
- Magnet is on the top of 1.5um and 2 um Junction
- Distance of magnet is 0.7, 0.5, 0.3 mm
- 1 mmϕ x 1 mm magnetic field is strong enough at distance of 0.7 mm (maybe strong already)

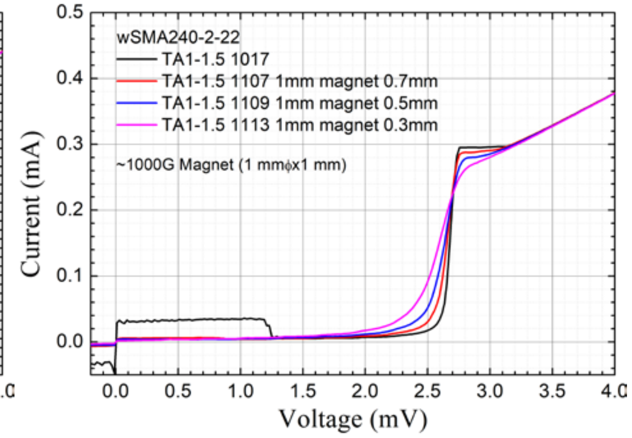






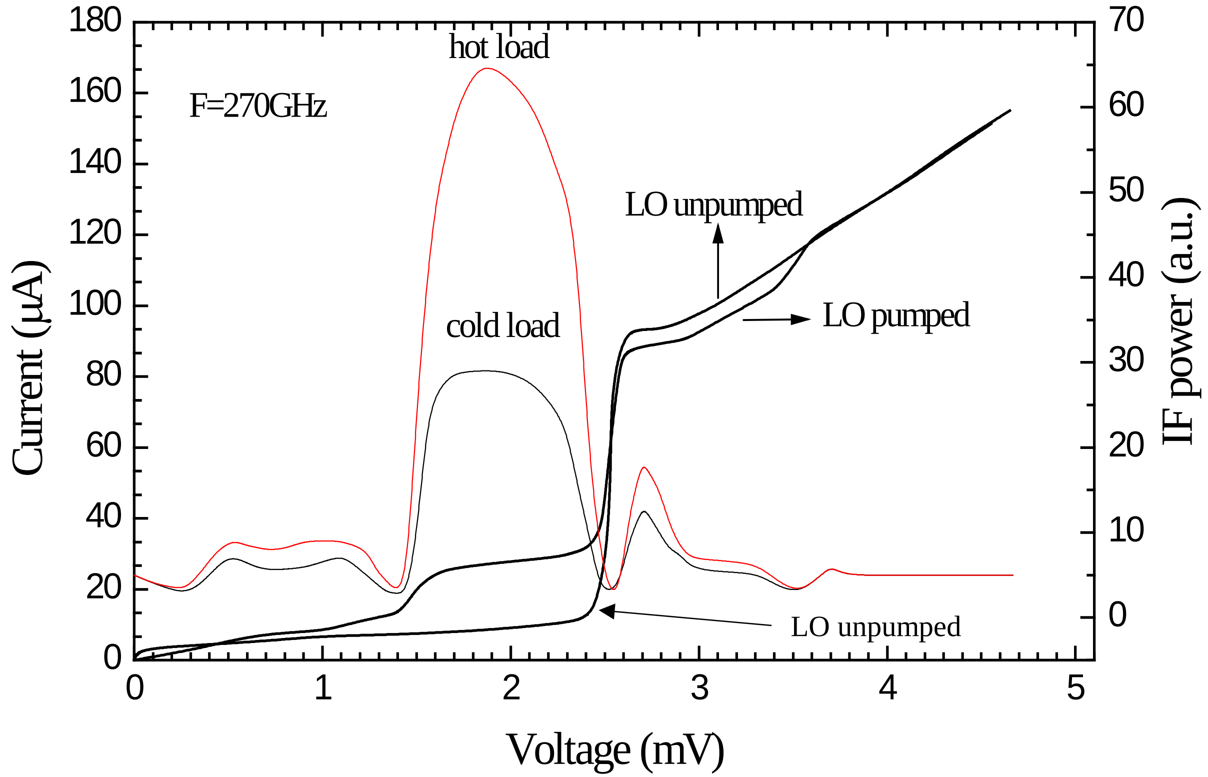




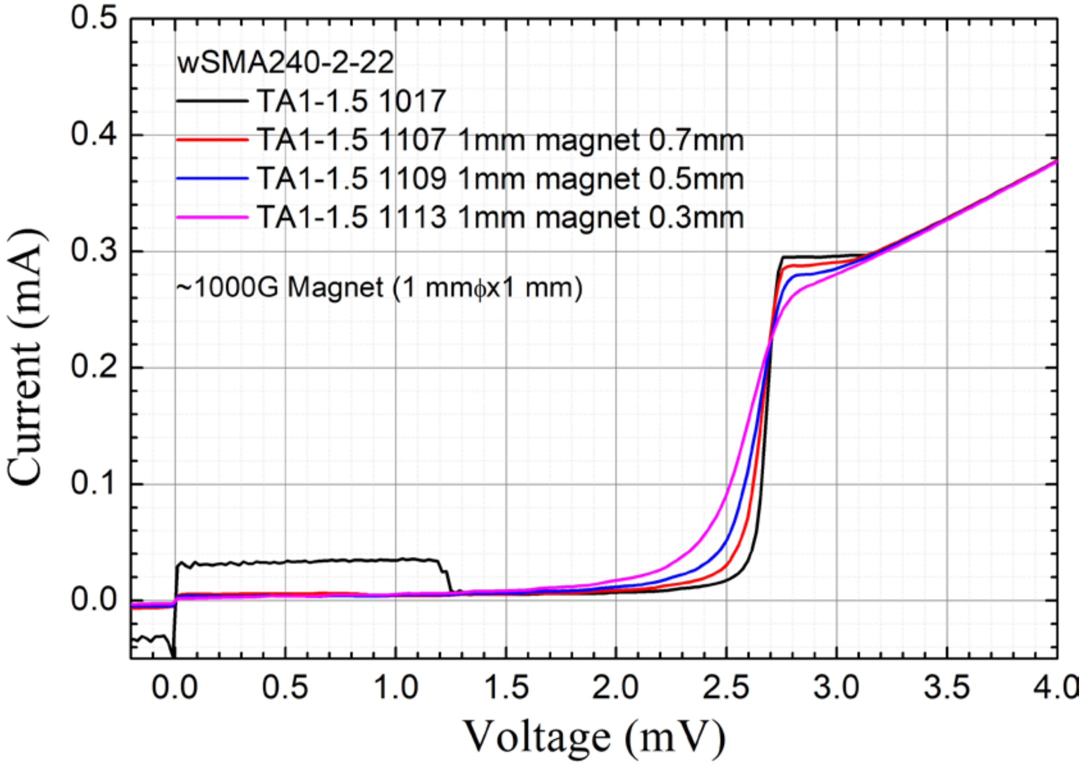


Feasibility of magnetic field tuning

Magnetic coiled (in-situ adjustable) (coil and external control line)



Permanent magnet (pre-adjusted) (no external control line)



IF output cabling

- Miniaturized connectors are necessary (<3 mmϕ)
- G3PO connector for dense cabling
- CLNA with G3PO connector is available

Cable with G3PO

LNF-LNC4_16SB
4-16 GHz, Male G3PO

Conclusions

- Large format multi-pixel sub-THz heterodyne receiver is essential for future large aperture single dish telescopes (50m class)
- Planarization of sub-THz receiver components is key for constructing large format multi-pixel sub-THz heterodyne receivers
- A compact 7-pixel sub-THz receiver module working at 220 GHz with a integrated receiver chip was proposed (5-year project)
- A planar LO/RF coupler was designed. Scaled model is fabricated and under test.
- Magnetic field tuning can be solved by using a permanent magnet with a proper distance from SIS junction
- Still a long way to go