

Idea of Waveguide-Diplexer-based Quad-band Sideband Separation (4SB) Receivers for ALMA 2040: Configuration and Technical Challenge

Yuh-Jing Hwang

Academia Sinica Institute of Astronomy and Astrophysics

Taipei, Taiwan

2026-07-16



*East-Asia ALMA Community Workshop - ALMA2040 Sci. & Tech. Perspectives,
July 15- 17, 2026, Mitaka, Japan*

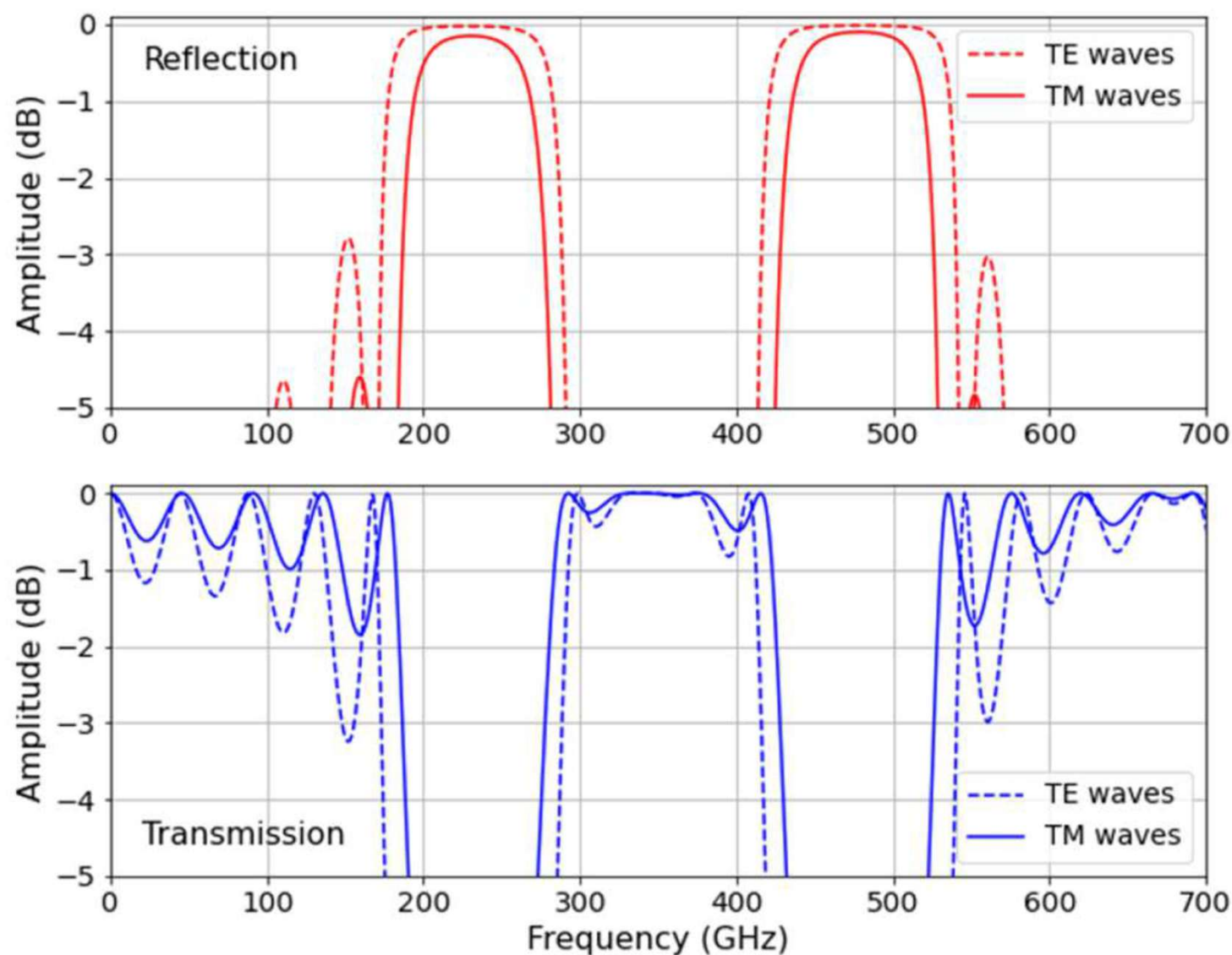


Introduction

- Broadband heterodyne receivers – to simplify and speed up the observations
- 1980s - 1990s: NMA, SMA, double-sideband (DSB) receiver, RF band $< 40\%$, IF bandwidth $\sim 2\text{GHz}$, dual single-polarization receiver simultaneously observed by wire-grid polarizer.
- 2000s: ALMA receivers, RF band $< 40\%$, dual polarization by waveguide OMT, sideband separation (2SB) by waveguide quadrature hybrid, IF bandwidth $\sim 4\text{GHz}$ per polarization per sideband.
- 2010s: KVN receivers, dichroic quasi-optical diplexer to observe different frequency bands with certain frequency separation, originally for phase transfer: to calibrate high-frequency-band phase data by low-frequency-band data.
- 2020s: ALMA WSU receivers, dual-pol, 2SB receiver with IF bandwidth ~ 12 to 16GHz , $> 52\%$ fractional RF bandwidth is feasible (ex: Band-2, $67 - 116\text{GHz}$)
- 2030s: aiming for ALMA2040: **512 GHz instantaneous bandwidth (signal from sky)**

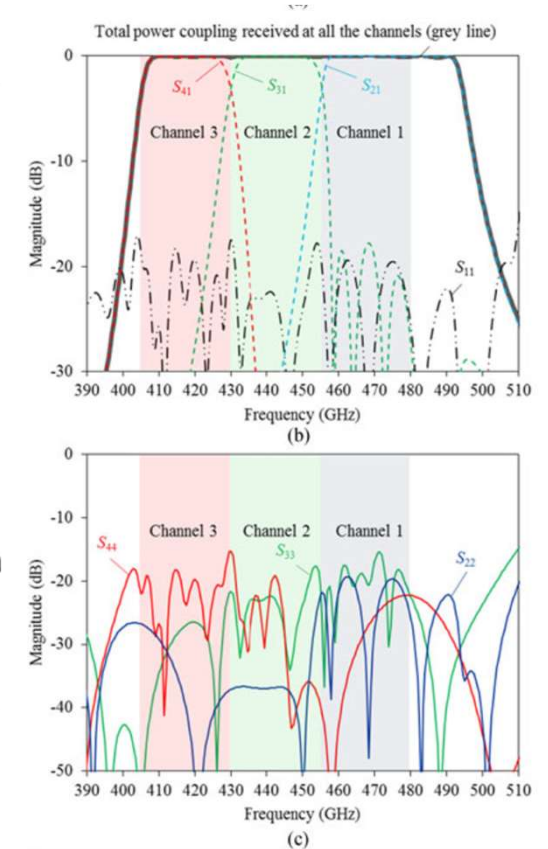
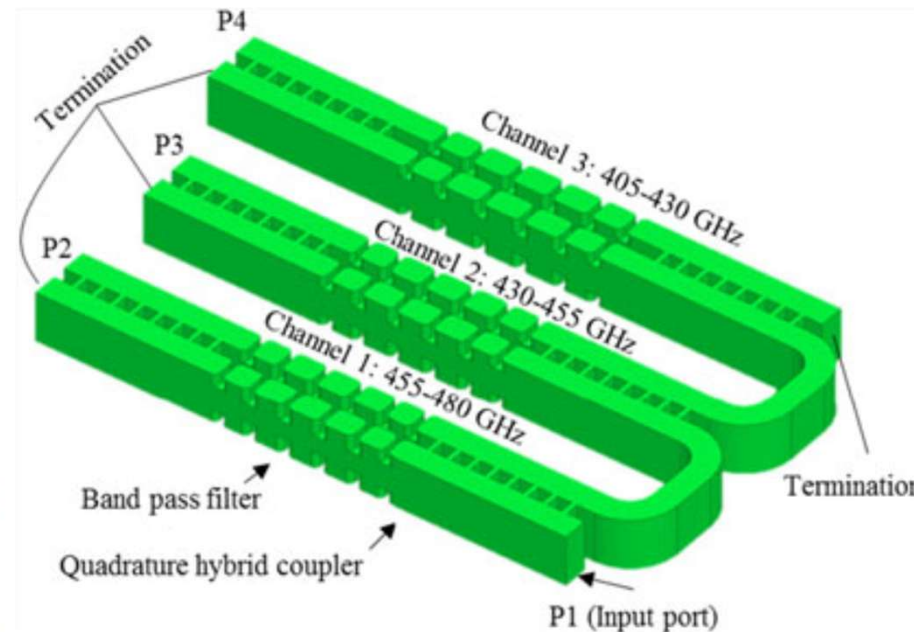
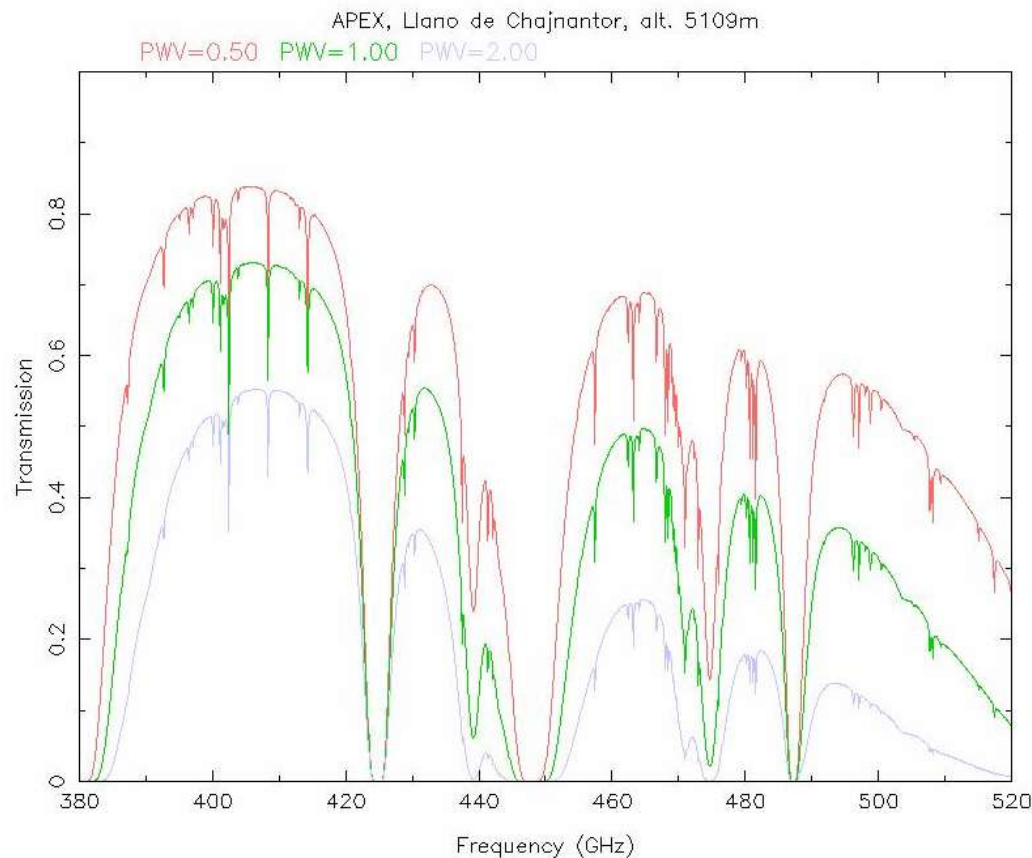
SMA2040: Panchromatic Heterodyne Receiver System

- Idea from C.-Y. Edward Tong (CfA) for long-term future of SMA.
- Optical multiplexing by Dichroic filters, or quasi-optical filters composed by low-loss dielectric stacks.
- Inconsistency on the TE/ TM mode passband, either transmission or transmission, leads to **~20-GHz frequency gap**.
- C.-Y. Edward Tong, G. Keating, and R. Blundell, “Roadmap to a Panchromatic Heterodyne Receiver System Stretching from 85 to 700 GHz,” *50th Intl. Conf. Infrared, Millimeter, and THz Waves (IRMMW-THz 2025)*, Espoo, Finland, Aug. 17 – 22, 2025.
- 85 – 700 GHz = 615GHz, excluded 116 – 125 GHz, 370 – 380 GHz, 518 – 602 GHz oxygen absorption bands = (615 – 103) GHz = 512GHz available.



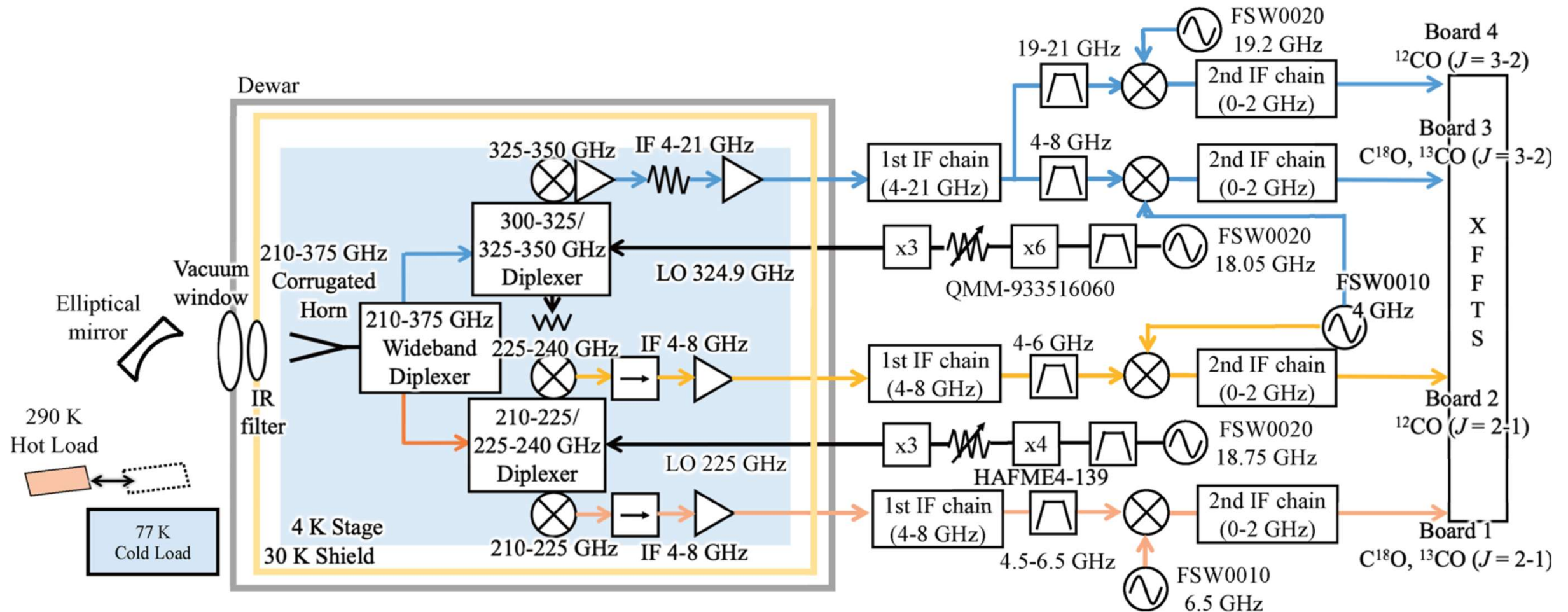
W/G Multiplexer based Receiver for Band-8

- Take the advantage of the fragmental atmospheric windows within 380 – 500 GHz, there are strong absorptions at 425GHz, 446 GHz, and 487GHz.
- In the conceptual design, the RF window is divided into three 25-GHz-BW channels by W/G multiplexer : Channel-1: 455–480 GHz, Channel-2: 430–455 GHz, and Channel-3: 405–430 GHz.
- T. Kojima, A. Gonzalez, S. Asayama, and Y. Uzawa, “Design and development of a hybrid-coupled waveguide multiplexer for a multiband receiver,” *IEEE Trans. THz Sci. Tech.*, vol. 7, no. 1, pp. 10 – 19, Jan. 2017.



W/G Multiplexer-based Receiver: example (II)

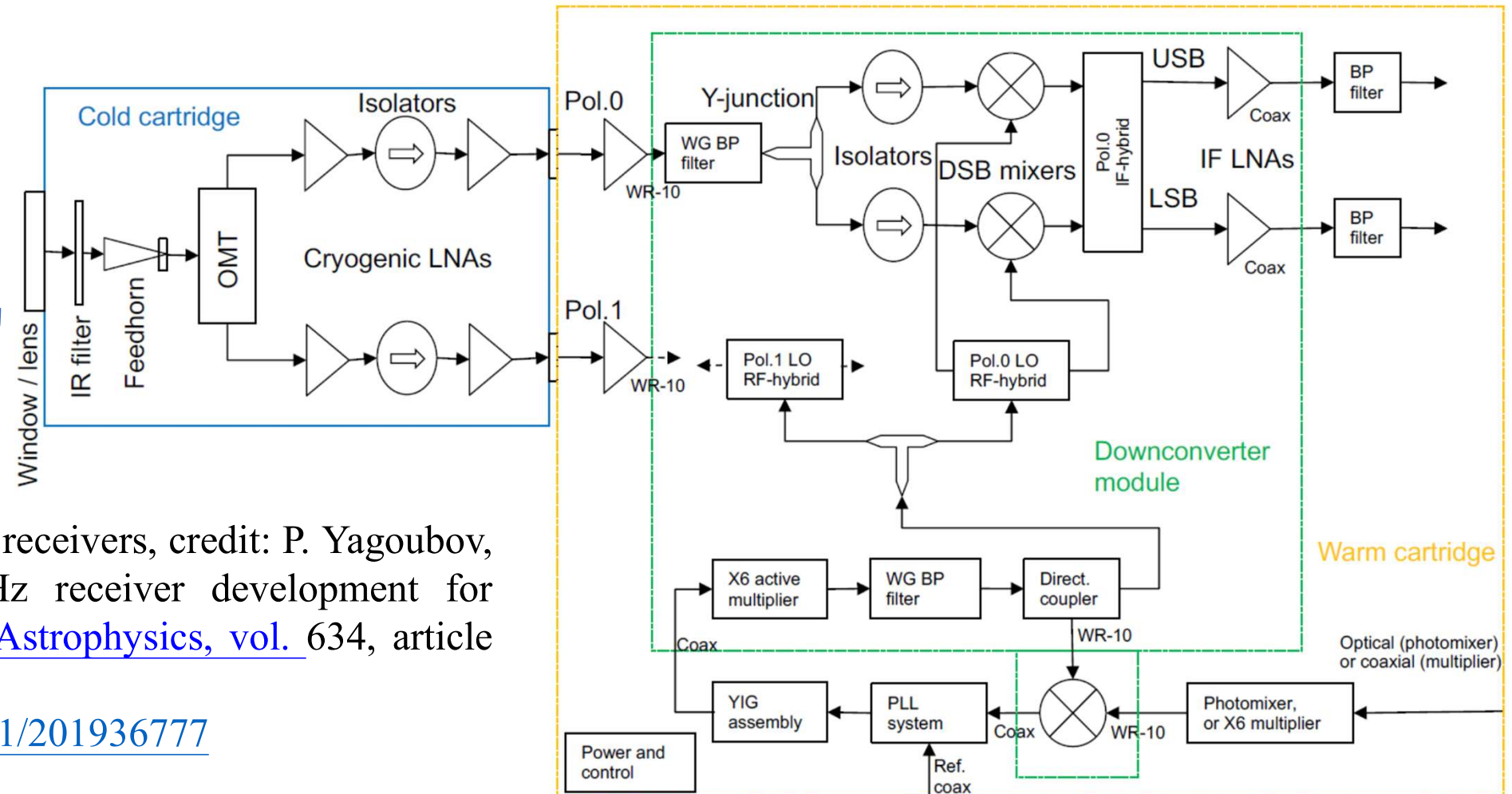
- S. Masui, Y. Yamasaki, H. Ogawa, et. Al, “Development of a new wideband heterodyne receiver system for the Osaka 1.85m mm-submm telescope: receiver development and the first light of simultaneous observations in 230 GHz and 345 GHz bands with an SIS-mixer with 4–21 GHz IF output,” *PASJ* (2021), 73(4): 1100 - 1115.



ALMA 2030 WSU Band-Combining

- Example: production-type Band-2 receivers, actually cover both the original band-2 (67 – 90GHz) and band-3 (84 – 116GHz) RF signal frequency range.
- **Dual-polarization, sideband separation (2SB) scheme:** four 4-18 GHz IF channels to cover two RF passband with 8-GHz frequency separation $((f_{LO} - 18) - (f_{LO} - 4))\text{GHz}$ and $((f_{LO} + 4) - (f_{LO} + 18))\text{GHz}$.

Broadband feedhorn,
broadband OMT to
cover 67 -116 GHz;
broadband LO
quadrature hybrid for
79 – 104GHz

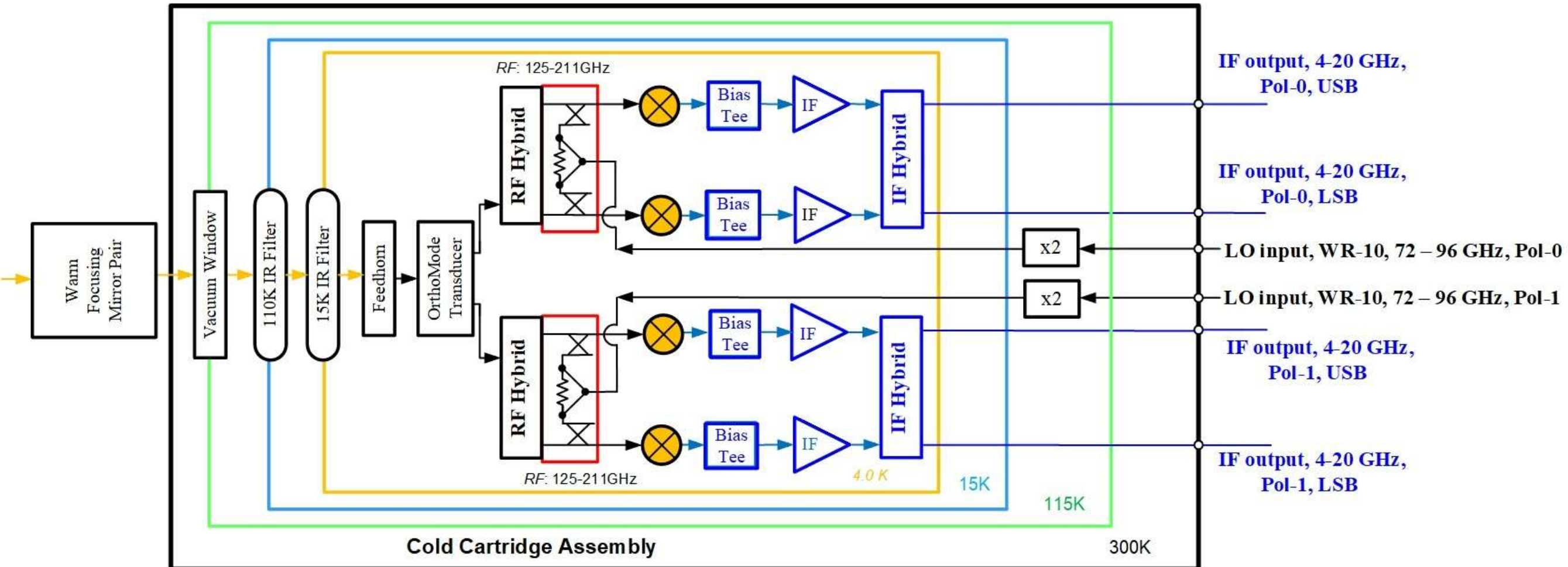


Block diagram of ALMA Band 2 receivers, credit: P. Yagoubov, et. Al. “Wideband 67–116 GHz receiver development for ALMA Band 2,” [Astronomy & Astrophysics](#), vol. 634, article no. A46, Feb. 2020.

<https://doi.org/10.1051/0004-6361/201936777>

ALMA2030 WSU Band-4+5 Receiver

- Baseline design currently under developing in ASIAA
- **Dual-polarization, sideband separation (2SB) scheme.**
- In any instance, the RF frequency range $((f_{LO} - 20) - (f_{LO} - 4))\text{GHz}$ and $((f_{LO} + 4) - (f_{LO} + 20))\text{GHz}$

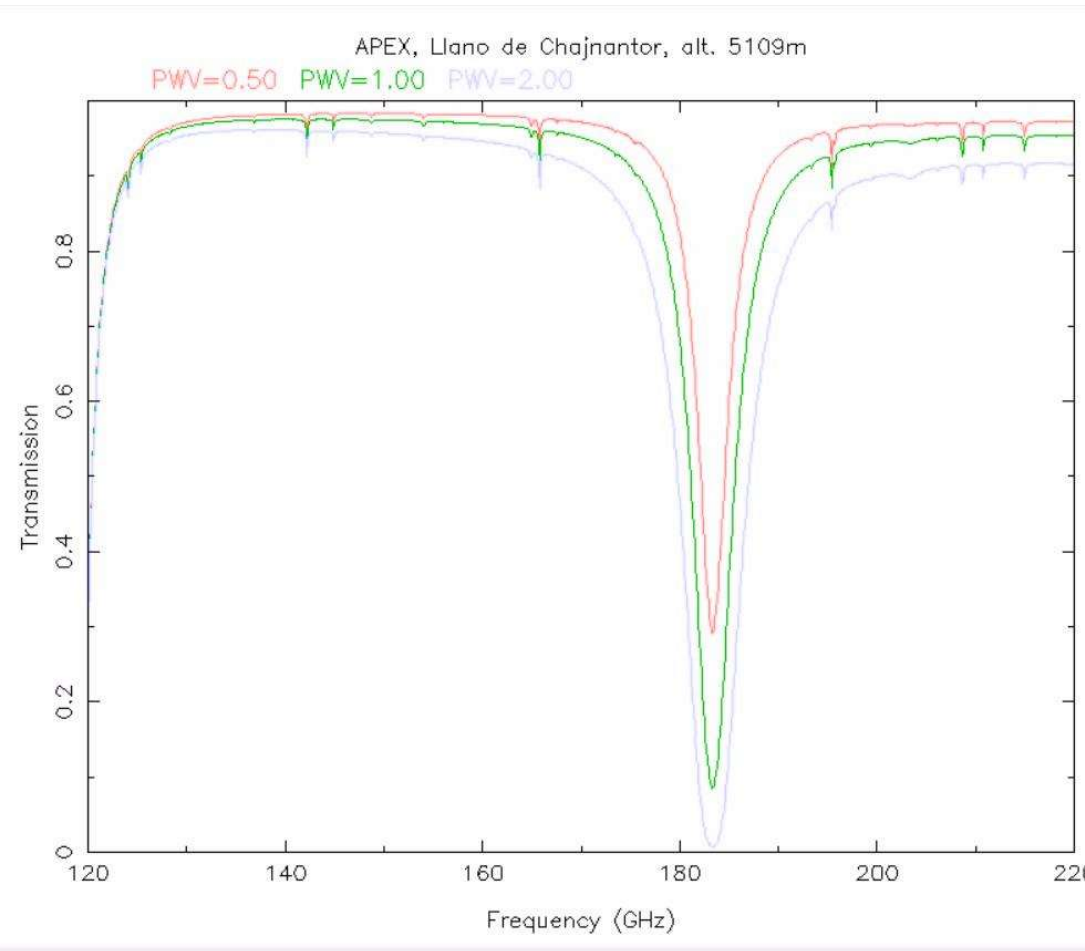


W/G-Diplexer-Based Receiver Band Combining?

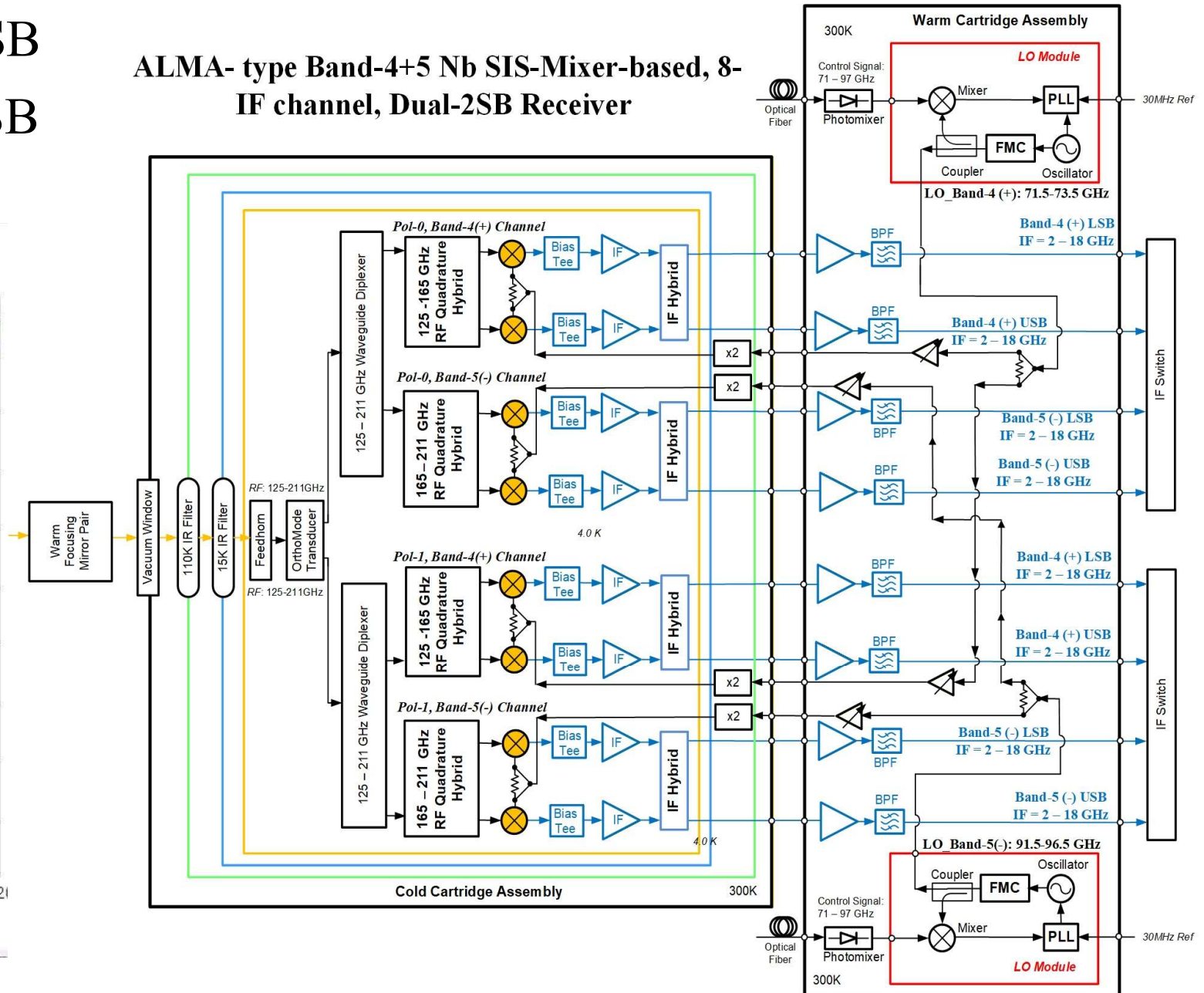
- Suggested by Prof. Andry Beryshev (Univ. Groningen).
- Initial study on (Band-4+ Band-5), (Band-6 + Band-7) presented in *ISSTT2026*, Santiago de Chile this March.
- Same as the idea proposed by Boon-Kok Tan (Univ. Oxford) in *SPIE ATIC2026*, “Band-splitting diplexer-hybrid for dual-band simultaneous–observing sideband-separating heterodyne mixers,” *SPIE*-14156-115
 - Combine the neighboring receiver bands by diplexer, ALMA Band-5+Band-6 simulated
- Reinhardt von Brandis-Martini, “Concept design for concurrent quad-band sideband separating downconverter,” *SPIE*-14156-25
 - Illustration by using commercially available MMW GaAs Schottky diode mixers, quadrature hybrids, and power dividers to illustrate band-combining below 100 GHz
 - “Quad-band sideband separation” = 4SB
- Basic idea and benefits –
- (1) to recycle as many RF and LO waveguide components as possible from the existing ALMA (or planning ALMA2030) receivers, reduce the development and production cost of the front-end components
- (2) keep the same 20-GHz IF as ALMA2030, but could double instantaneous bandwidth, no need of developing new backend (digitizer and correlator), only need to duplicate another batch of IF switches, ADCs and correlators.

ALMA2040 Band-4+5 4SB Receiver

- 125–165GHz: 40GHz channel: 2SB
- 165–211GHz: 46GHz channel: 2SB
- either tunable or fixed LO

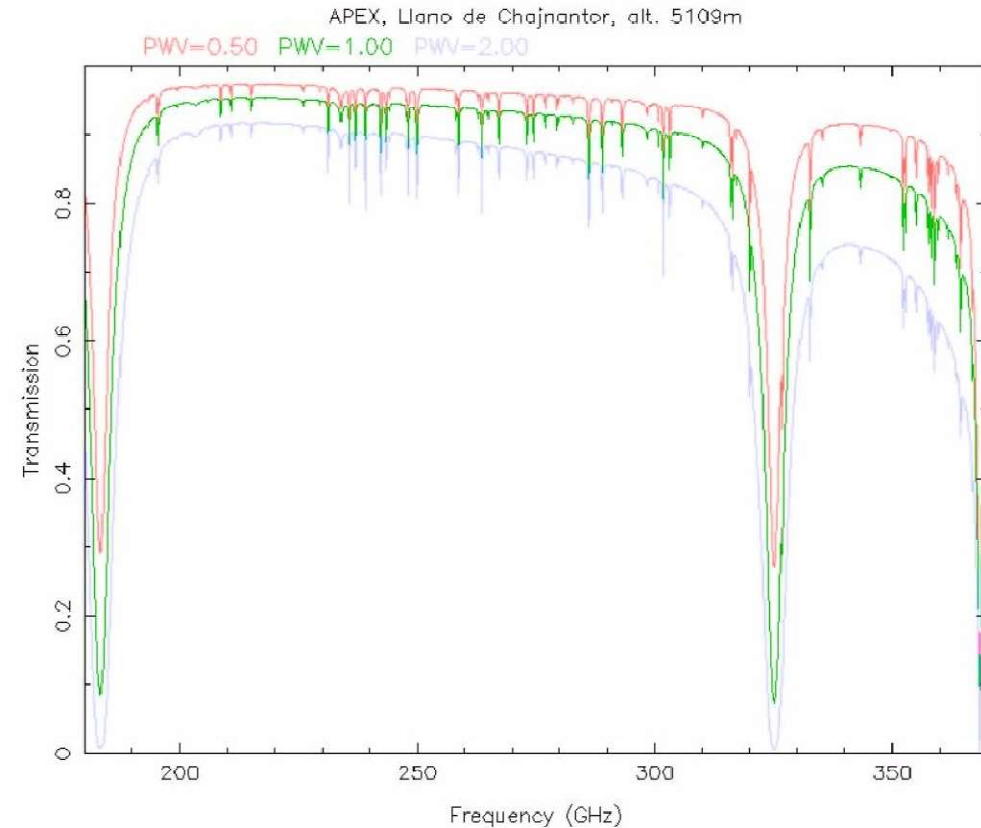


ALMA- type Band-4+5 Nb SIS-Mixer-based, 8-IF channel, Dual-2SB Receiver

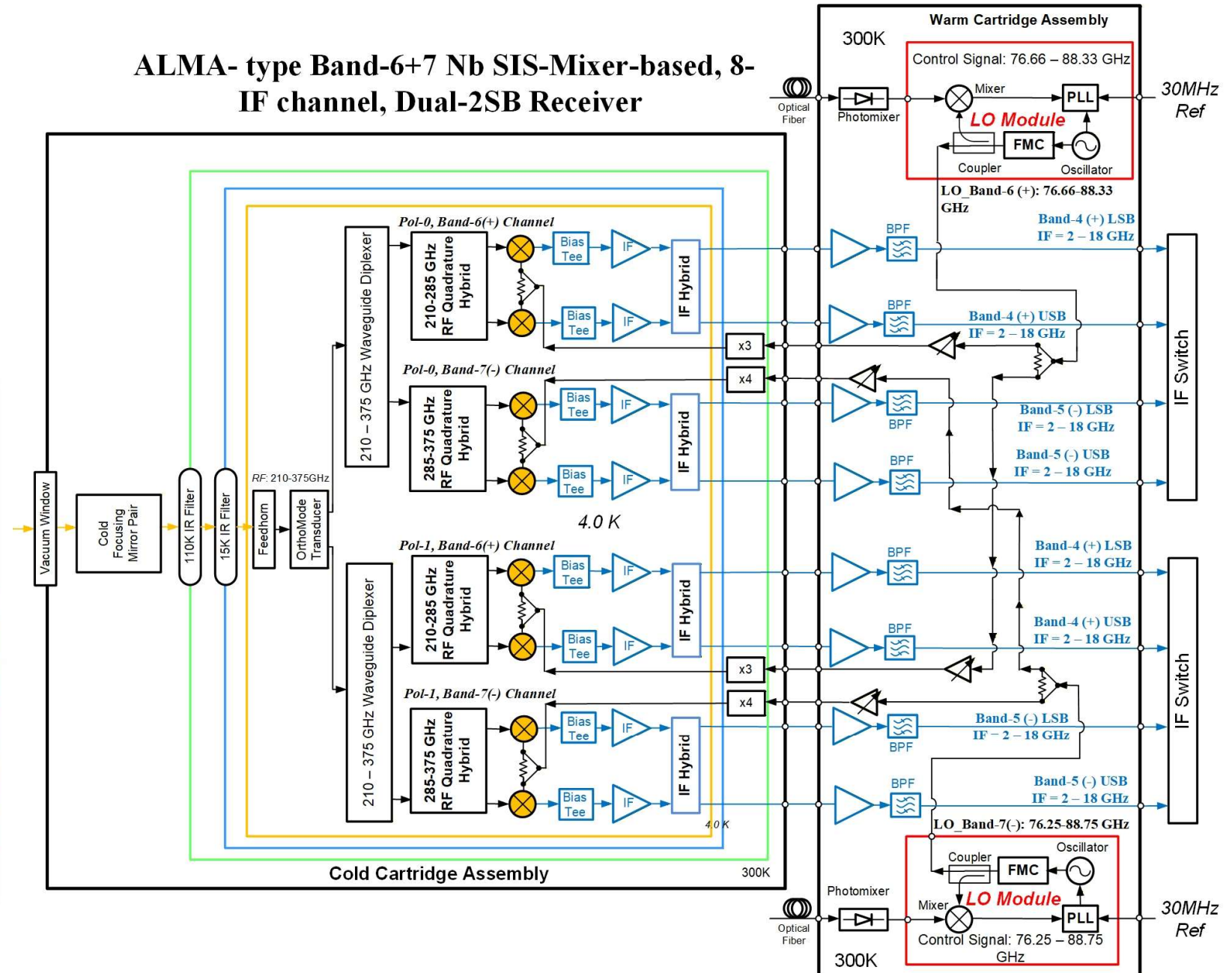


ALMA2040 Band-6+7 4SB Receiver

- 210–285GHz: 75GHz channel: 2SB by tunable LO
- 285–375GHz: 90GHz channel: 2SB by tunable LO
- Cascaded diplexer-diplexer with 2SB mixers to achieve 8SB with full instantaneous 160GHz BW (210 – 370GHz) is possible

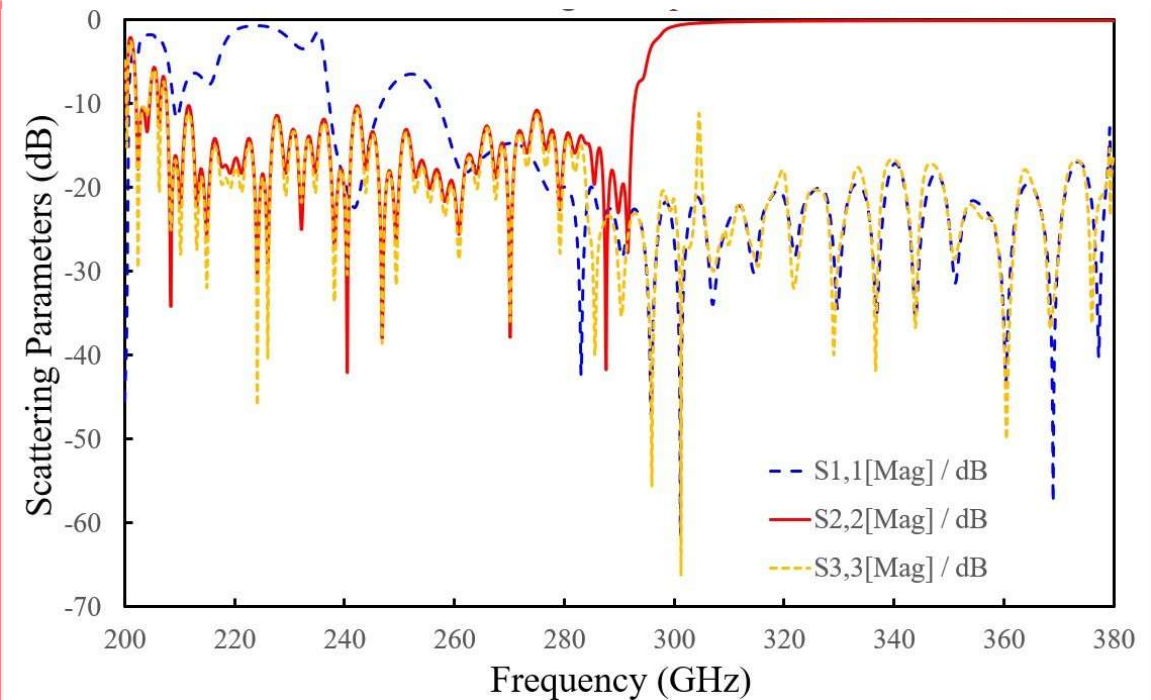
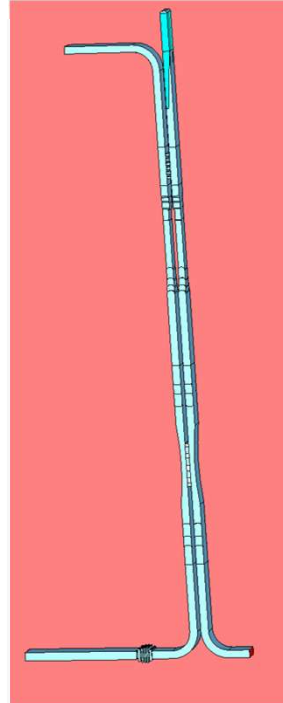
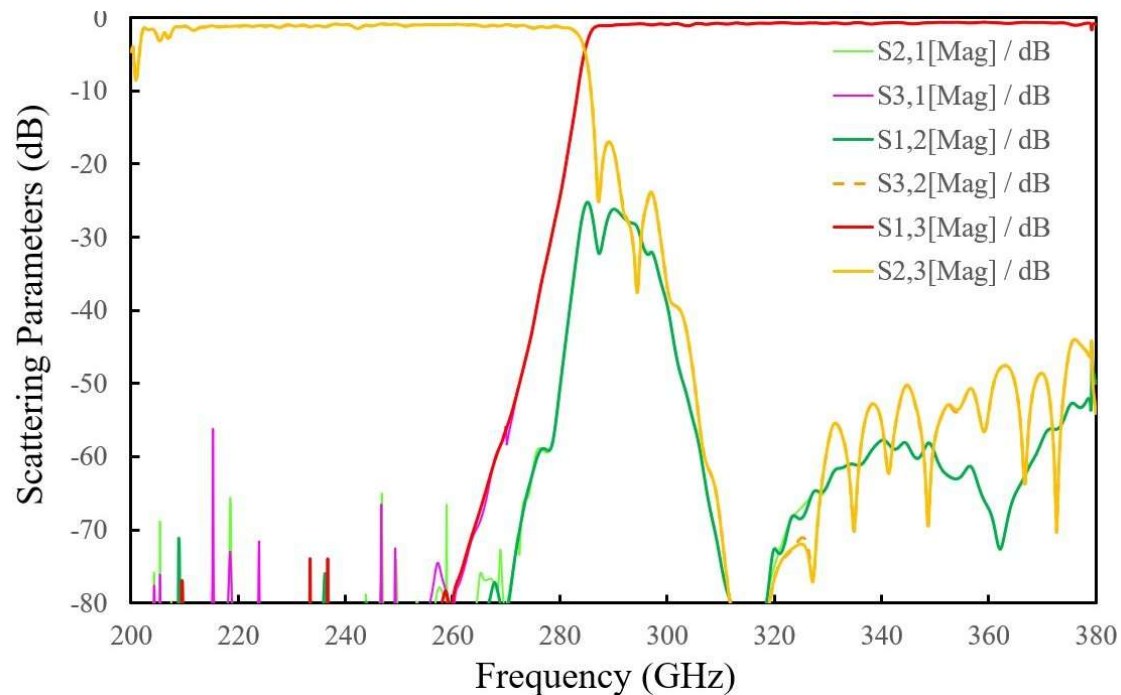


ALMA- type Band-6+7 Nb SIS-Mixer-based, 8-IF channel, Dual-2SB Receiver



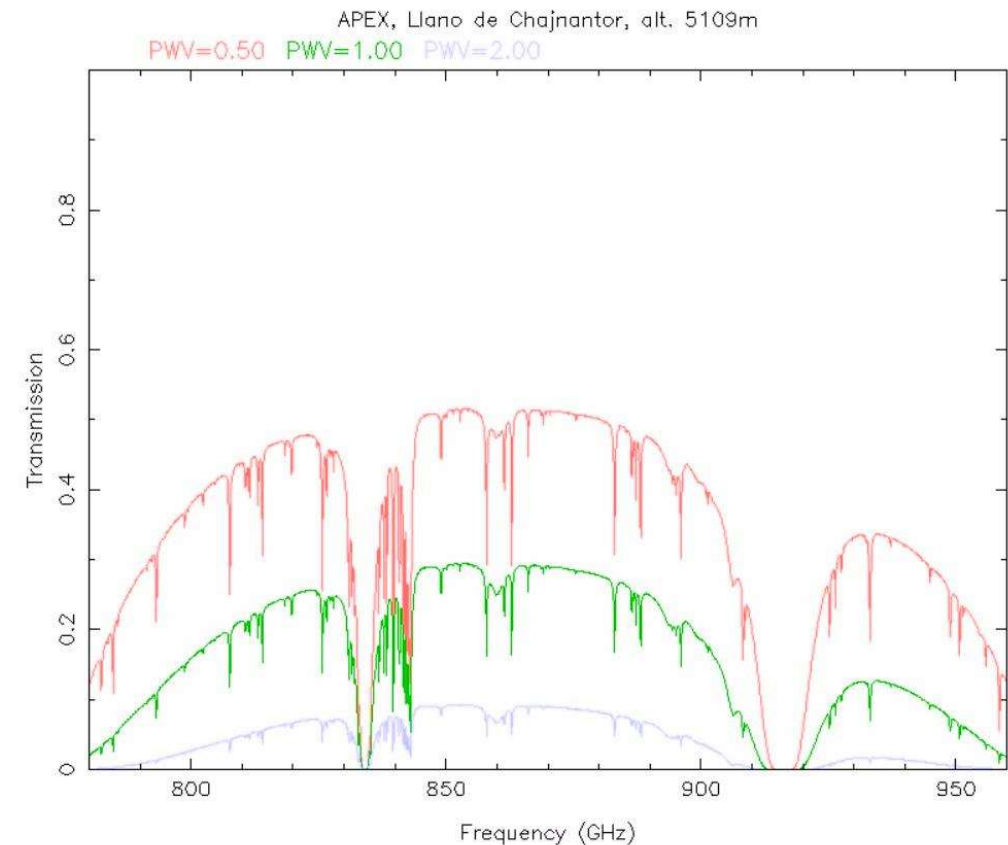
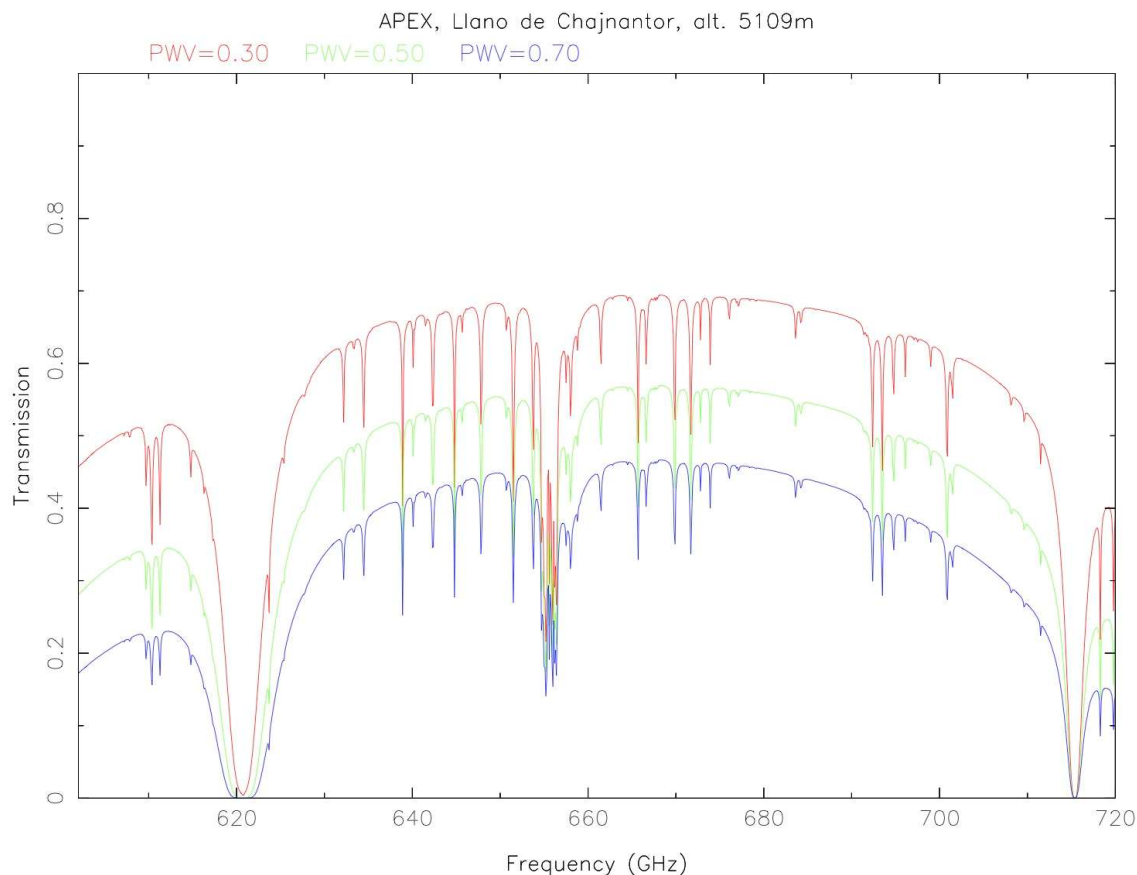
Simulated Design on the Band-6+7 Diplexer

- WR-3.1 non-standard waveguide (TE_{10} mode cutoff frequency = 190.5GHz), the single-model propagation up to 381GHz.
- The transmission coefficients are typically 1 to 2 dB in passband. The in-band reflection coefficients are typically < -17 dB for high-frequency port and < -13 dB for low-frequency port. The corner frequency is 284.7 GHz, where the transmission from common port to lower- and higher-frequency ports are both equal to **-4.5 dB**. Considering the transmission coefficient > -2 dB, the actual pass band for lower frequency port is 209–283GHz, and for higher frequency port is 285.7–375GHz, where there is **a 2.7-GHz frequency gap in between.**



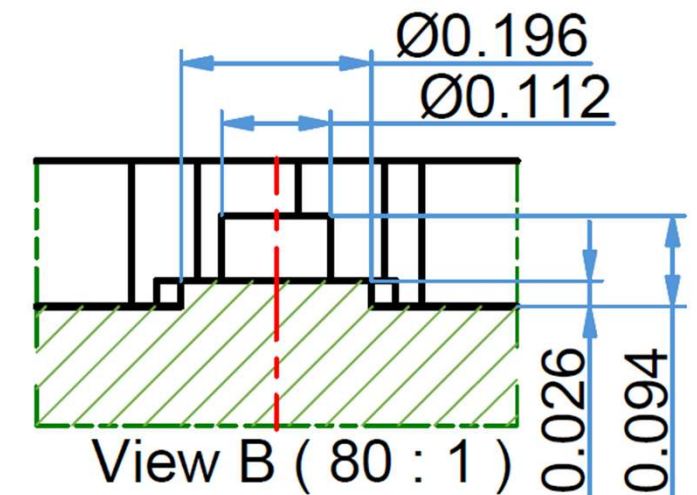
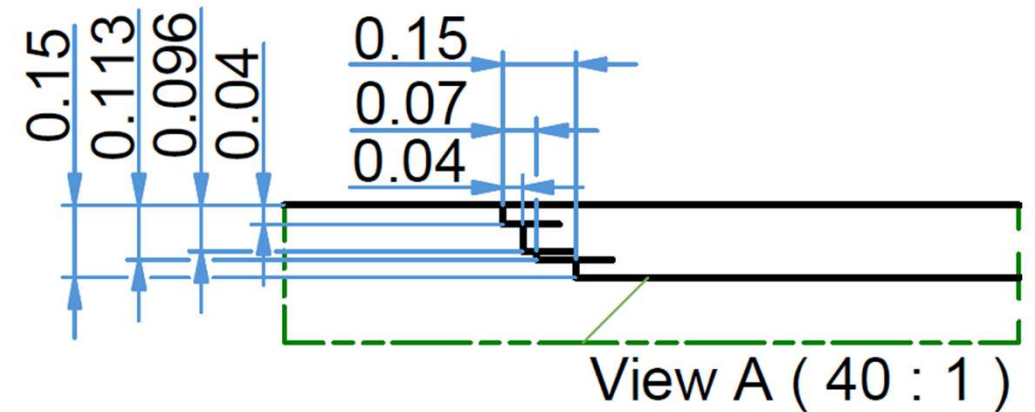
Band-9 and Band-10: Atmospheric Windows

- 600 – 720 GHz (left) and 780 – 960 GHz (right), with 60 GHz gap. The idea of band-combining of the two bands with waveguide diplexer is to promote the efficiency of observation on these two frequency bands.
- Set the diplexer corner frequency ~ 750 GHz, useful frequency: 600 – 725GHz, 780 – 960 GHz is possible.



WR-1.2 Turnstile Junction OMT

- WR-1.2 waveguide could provide TE_{10} single mode propagation (cutoff frequency = 492GHz) from 600 - 960GHz, for which band combining of 600 – 720 GHz and 780 – 950 GHz is possible.
- Required components cover 600- 960 GHz: (1) feedhorn, (2) OMT, (3) diplexers
- Direct scaling of the mechanical dimensions from the 67 – 116 GHz (WR-10 waveguide) turnstile junction OMT as initial study.
- Two step turnstile junctions, bottom: 26- μm thick, 196- μm diameter; top: 68- μm thick, 112- μm diameter.
- Rectangular waveguide cross section: 300 μm x 150 μm
- Machining error < 1 μm is required.
- Alternative solution: **planar OMT based on NbN or NBTiN superconducting microstrip?**



Recycle Present / New Band-9/10 Receivers

- Legacy Band-9 and Band-10 receivers: wire-grid polarizer to separate sidebands, double-sideband mixer scheme.
- Demonstration of the 2SB Band-9 SIS mixers by Univ. Groningen/ NOVA: 600–720GHz WR-1.5 RF quadrature hybrids, LO divider-coupler is presented
 - Ronald Hesper, Andrey Khudchenko, Andrey M. Baryshev, Jan Barkhof, and Fausto Patricio Mena, “A high-performance 650-GHz sideband-separating mixer—design and results,” *IEEE Trans. THz Sci. Tech.*, vol. 7, no. 6, pp. 686 – 693, Nov., 2017.
- Demonstration of the 2SB Band-10 SIS mixers is also presented.
 - Andrey Khudchenko , Ronald Hesper , Andrey M. Baryshev, Jan Barkhof, Kirill Rudakov, Daniel Montofré, Duc van Nguyen, Valery P. Koshelets , Pavel N. Dmitriev, Michael Fominsky , Christopher Heiter, Stefan Heyminck, Rolf Güsten, and Bernd Klein, “Design and performance of a sideband separating SIS mixer for 800–950 GHz,” *IEEE Trans. THz Sci. Tech.*, vol. 9, no. 6, pp. 532 – 539, Nov., 2019.
- To constructed diplexer band-combining Band-9 + Band-10 receiver, most of the receiver RF components from legacy Band-9 and Band-10 receivers **could not be** recycled; cold LO x9 frequency multiplier chains and warm E-/W-band LO power amplifiers may be recycled to serve for new receivers.

Technical Challenge for Band-9+10 4SB Receiver

- The main technical challenge: low-loss waveguide components fabrication for > 600 GHz.
- Dry-etching process on silicon with gold-plating surface finish could be the initial solution for waveguide OMT and WR-1.2 waveguide diplexer.
- Prof. Boon-Kok Tan suggest to fabricate **Aluminum microstrip on quartz substrate planar circuit type diplexer**, instead of waveguide structure.
- A further study of superconducting thin-film coating on metallic or Si waveguide to form superconducting W/G components may be required.
- Corrugated feed to cover 600- 950 GHz? Corrugated feeds for 600 -700 GHz and 780- 900 GHz are possible. If scaling the Band-2 (67 -116GHz) or Band-4+5 (125 - 211GHz) horns to 600- 950GHz: scaling by factor $8.4 / 4.75$, the problem encountered during fabrication is the very thin and deep corrugation – fragile teeth; developing broadband smooth-wall horn may be required.
- Separate designs of 600 – 720 GHz / 780 – 950 GHz waveguide quadrature hybrids have been produced during the demonstrated in the 2SB SIS mixers.

Suggestion & Summary

- Suggested signal bandwidth for ALMA2040 receivers:
- Band-1, 30-52GHz, 22-GHz BW
- Band-2, 67-117GHz, 50-GHz BW
- Band-4 to Band-7, 125–370GHz, 240-GHz BW by
 - 4SB receiver (diplexer + 2SB Rx for 2 channels) for 125- 205GHz, and
 - 8SB receiver (diplexer-diplexer cascaded + 2SB Rx for 4 channels) for 210 – 370GHz.
 - 5-GHz gap for 205 -210 GHz by dichroic quasi-optical diplexer
- Band-8, 380-500GHz, 120GHz BW by
 - 6SB receiver (triplexer + 2SB Rx for 3 channels)
- Band-9+10 4SB receiver, 20GHz BW per sideband, 80GHz BW, a pair of tunable LO frequencies
- $22+50+240+120+80 = 512\text{GHz}$ (B1+B2+B4-7+B8+tunable B9+10) or
- $50+240+120+102 = 512\text{GHz}$ (B2+B4-7+B8+ 5SB partial B9)
- $32+240+120+120 = 512\text{GHz}$ (B3+B4-7+B8+ 6SB full B9)