ALMA 2030

Overview and Working Groups

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EASC

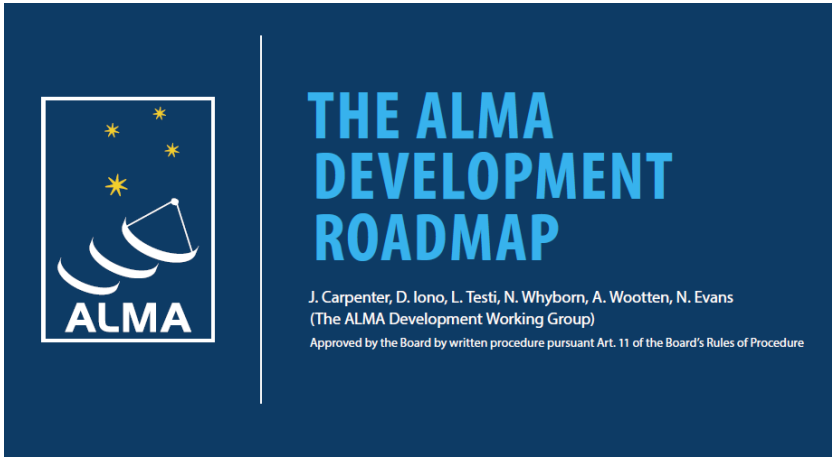
Public

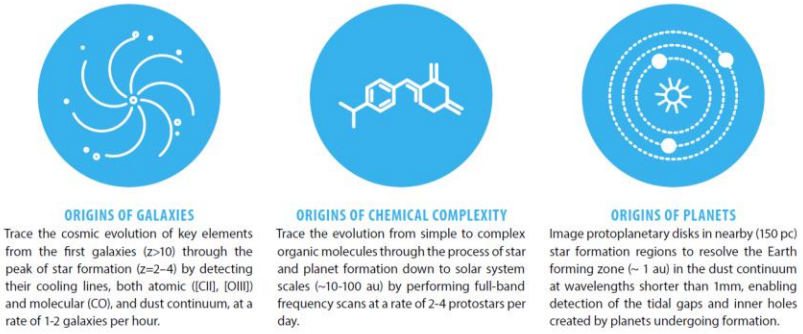
Outline

- Introduction ALMA 2030
  - The ALMA Development Roadmap
  - Implementation plan
    - Phases
- ALMA 2030 Wideband Sensitivity Upgrade
  - Summary WSU Working Groups
    - FE / Digitizer Working Group
    - Correlator Working Group
    - Signal Chain Working Group

The ALMA Development Roadmap

- Upgrading the receivers, digital system, and correlator
  - Significant gains in the observing speed can be achieved by upgrading
    i. the receivers to deliver larger IF bandwidths,
    ii. the digitizers and digital processing to allow for larger basebands and higher effective bandwidth coverage, and
    iii. the correlator to process larger bandwidths at higher spectral resolution.
- Archive development





[ALMA Development Roadmap (eso.org)]

The ALMA Development Roadmap

- Mid-term opportunities

(now it gets interesting for this audience!)

- Extended baselines
  - Factor 2-3
  - Dedicated, fixed, antennas on outer stations
- Focal plane arrays
  - Modest pixel counts (perhaps 4 to 16)
  - Improvements in elements downstream (IF transport, correlator, archive), and probably upstream (LO distribution) required
- Additional 12 m antennas
  - Original ALMA construction plan called for 64 12-m diameter antennas
- Large single dish submillimeter telescope
  - 25 – 50 m diameter
  - Multi-wavelength submillimeter cameras

ALMA 2030 Implementation Plan

- Preliminary System Implementation Concept – A Staged Approach
  - WSU Implementation Stage 1
    - Priority receiver upgrades: Band 2, Band 6v2, Band 8
    - New Digitizer
    - New Digital Transmission System, incl. AOS-OSF Optical Fibre
    - Correlator (2x current BW)
  - WSU Implementation Stage 2
    - Additional receiver upgrades: Band 7, Band 9, Band 10
    - Correlator expansion (4x current BW)
  - WSU Implementation Stage 3
    - Additional receiver upgrades: Band 1, Band 3 (if needed), Band 4/5

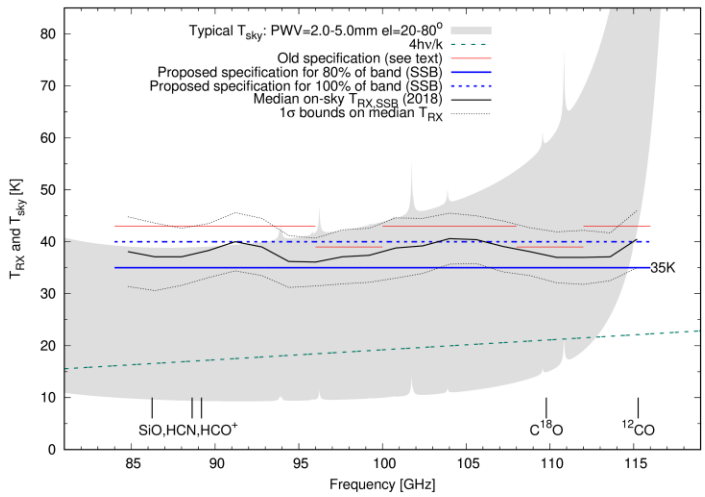
FE/Digitizer Working Group

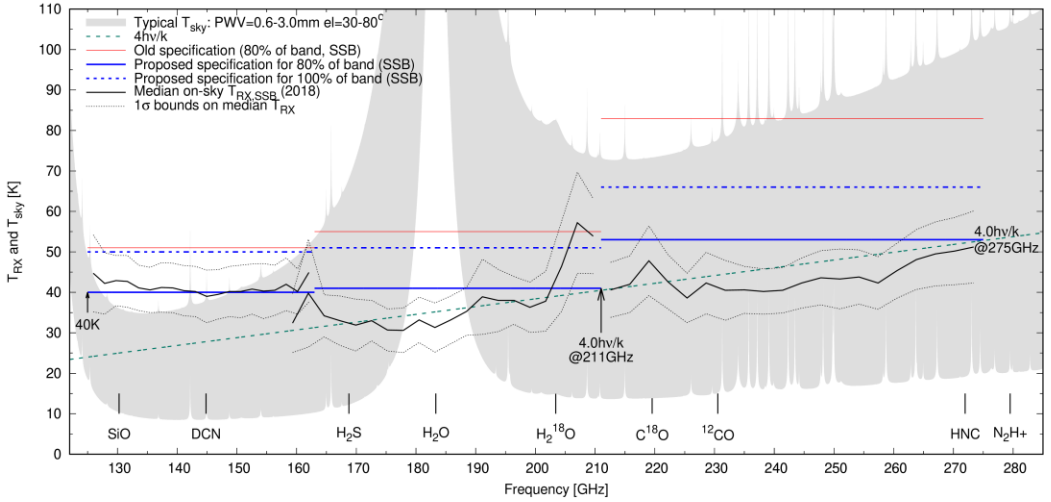
- Established in 2018 to define a consistent set of (revised) technical goals for front-end and digitiser products to realise the science goals in the ALMA2030 Development Roadmap – specifically:
  - Broaden the receiver IF range by *at least* a factor of two, and
  - Upgrade the associated electronics and correlator
- First draft report delivered to AMT 2019-06-27
- 2nd draft distributed to IxTs 2020-10-27
- Current draft delivered to IDT 2022-09-09, prior to System Requirements Review

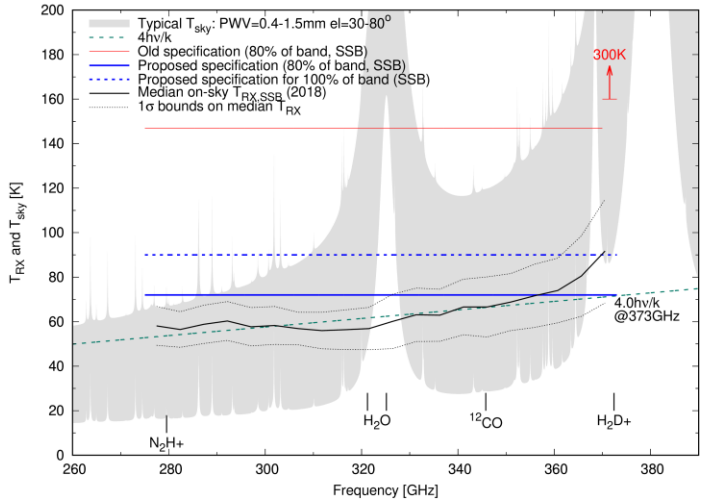
FE/Digitizer Working Group

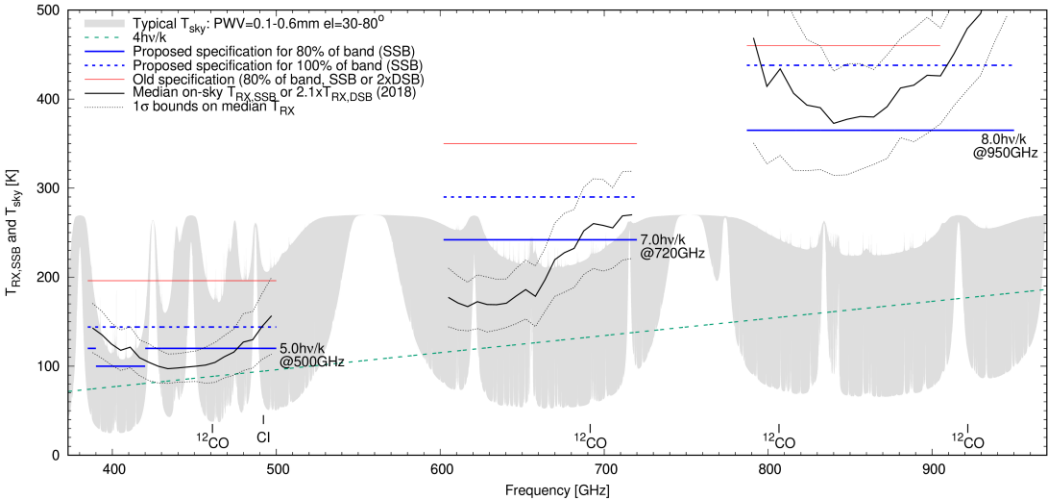
- An extensive survey made of recent developments (inc. ALMA dev studies), and current ALMA performances, to inform feasibility
- Some general points:
  - Bands 9 and 10 expected to upgrade to 2SB
  - Requirements for Bands 1 and 2 (already under development/deployment) were off-limits
  - Increasing receiver performance more important than increasing RF bandwiths; extended coverage by receiver designs to be considered on case-by-case basis and meet requirements of all covered RF band ranges
  - Digitizer (ADC) device selection highlighted as critical

FE/Digitizer Working Group: T_{RX}









FE/Digitizer Working Group: T_{RX}

		Band	T_{RX} over 80% of the RF band	T_{RX} at any frequency	T_{RX} over 80% of the RF band	T_{RX} at any frequency	
Receiver Noise Temperatures		1	28 K	32 K	N.A.	N.A.	The receiver will not be upgraded prior to the start of the 2030s.
		2	30 K	47 K	N.A.	N.A.	The receiver will not be upgraded prior to the start of the 2030s.
		3	See Comment	See Comment	35 K	40 K	The existing requirements: < 39K (averaged over all four IFs 4 GHz bandwidth at LO = 104 GHz) < 43K (averaged over all four IFs 4 GHz bandwidth for any LO setting)
		4	51 K	82 K	40 K	50 K	The existing Band 4 demonstrates performance around 40 K. Reaching 4hv/k like bands 5 – 7 is likely too ambitious, so a compromise value is suggested.
		5	55 K	75 K	41 K	51 K	The existing Band 5 demonstrates performance around 4hv/k. The proposed performance goal for 80% of the band is 4hv/k at 211 GHz and for the whole band is 5hv/k at 211 GHz.
		6	83 K	136 K	53 K	66 K	The existing Band 6 demonstrates performance around 4hv/k. The proposed performance goal for 80% of the band is 4hv/k at 275 GHz and for the whole band is 5hv/k at 275 GHz.
		7	147 K	219 K	72 K	90 K	The proposed performance goal for 80% of the band is 4hv/k at 373 GHz and for the whole band is 5hv/k at 373 GHz.
		8	196 K	292 K	100 K (390 – 420 GHz), 120 K	144 K	The proposed performance goal for 80% of the band is 5hv/k at 500 GHz and for the whole band is 6hv/k at 500 GHz. The goal is further tightened to 100 K at 390-420 GHz.
		9	175 K (DSB)	261 K (DSB)	242 K	290 K	The proposed SSB noise performance goal for 80% of the band is 7hv/k at 720 GHz and for the whole band is 1.2 × 7hv/k at 720 GHz.
		10	230 K (DSB) over 80% of the reduced frequency range 787-905 GHz	344 K (DSB)	365 K	438 K	The proposed performance goal for 80% of the band is 8hv/k at 950 GHz and for the whole band is 1.2 × 8hv/k at 950 GHz.

FE/Digitizer Working Group

- Instantaneous bandwidth:
  - *strongly recommend* to achieve 16 GHz per IF polarization/sideband
- Image rejection:
  - >15dB suppression over 90% of the IF range
  - >13dB suppression over 100% of the IF range
  - No stretch goal defined – over-constraining IRR may go against actual goal of minimising T_{sys}
- ⑩ Power variations over instantaneous BW:
  - 6.4 dB goal (6.1dB for CCA+WCA)
  - 5.4 dB stretch goal (5.1dB for CCA+WCA)

FE/Digitizer Working Group

- Digitisation recommendations:
  - Digitise whole IF at >= 40 GS/s
  - Aim to increase QE to 99% =>
    - Goal: ≥ 5 ENOB (for Gaussian noise)
    - Stretch goal: ≥ 6 ENOB (for Gaussian noise)
  - Major technological challenge
- Some other recommendations:
  - Tighten beam squint from 10% to ~2% FWHM to improve wide-field polarisation
  - Spurious signals and LO chain (YTO)
  - Out of IF band power update

Correlator Working Group

- Established Jan 2020 to define requirements for 2nd generation ALMA correlator to realise the science goals in the ALMA2030 Development Roadmap
- Workshop Feb 2020 to gather community input
  - Unanimous that architecture would be FX, not XF
  - "first-F" coarse channeliser likely needed => FFX
- Draft report delivered to AMT 2020-10-23
- Updated draft made available 2021-01-07
  - 88 pages, reflecting complexity of modern correlators and modes of operation

Correlator Working Group

- ALMA2030 science goals require at least:
  - Larger instantaneous correlated bandwidth
  - Higher correlation (quantisation) efficiency
  - Produce many more channels (spectral grasp)
  - Accurately correct larger delay rates (longer baselines)
  - Flexibility to place numerous spectral windows
- FE/DG WG recommendations on receiver instantaneous BW and digitisation were assumed
- A number of cross-subsystem concerns/uncertainties were raised e.g. data transport between digitiser and correlator

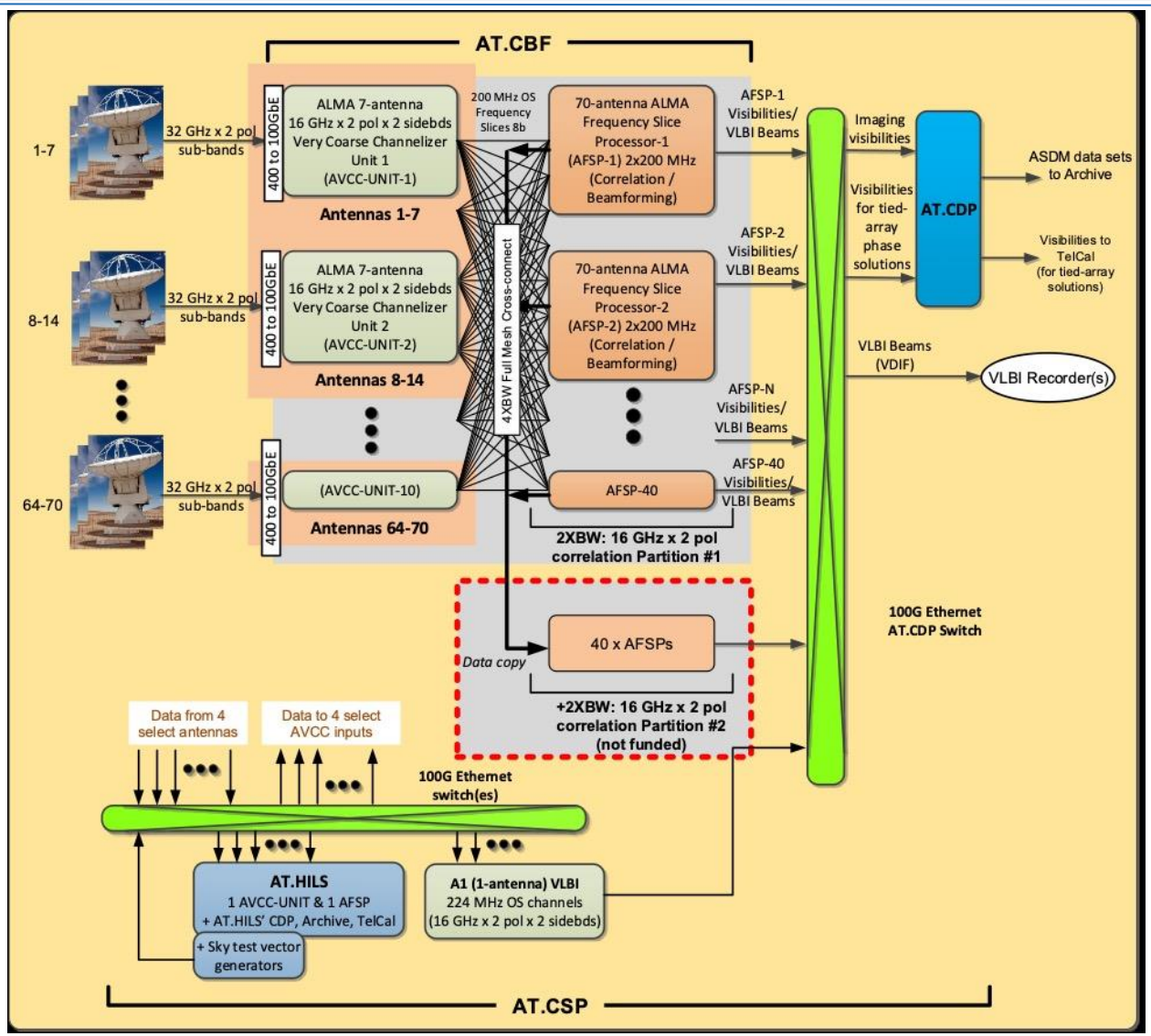
Correlator Working Group

- Some key recommendations (far from all):
  - Antenna inputs: ≥ 66 minimum, ≥ 80 goal
    - 7m array expected to be a sub-array on this correlator
  - Max. correlated BW:
    - Minimum: 8GHz per pol/sideband *but expandable*
    - Goal: usable digitised BW, expected 16GHz per pol/sideband
  - Correlation efficiency: ≥ 97.5% minimum, ≥ 98.5% goal
  - Delay tracking to support ≥ 35km baselines
  - Power consumption was left TBD at the time
  - Finest resolution:
    - < 23kHz (0.2km/s @ 35GHz) over max. correlated BW
    - < 2.3kHz (20m/s @ 35GHz) over 1.6GHz
  - Channels independent (<-60dB leakage)

2nd generation correlator

- Recently ALMA Board approved NA 2nd generation correlator project led by NRC
- Design adapted for ALMA from SKA-mid TALON prototype design – FPGA based, passive corner-turn
- Currently funded part expected to cover:
  - 16GHz per pol/sideband antenna-based processing
  - 8GHz per pol/sideband baseline-based processing
    - Expandable if/when funding available
- Antenna-based part produces 200MHz slices
- Baseline-based part does fine channelisation

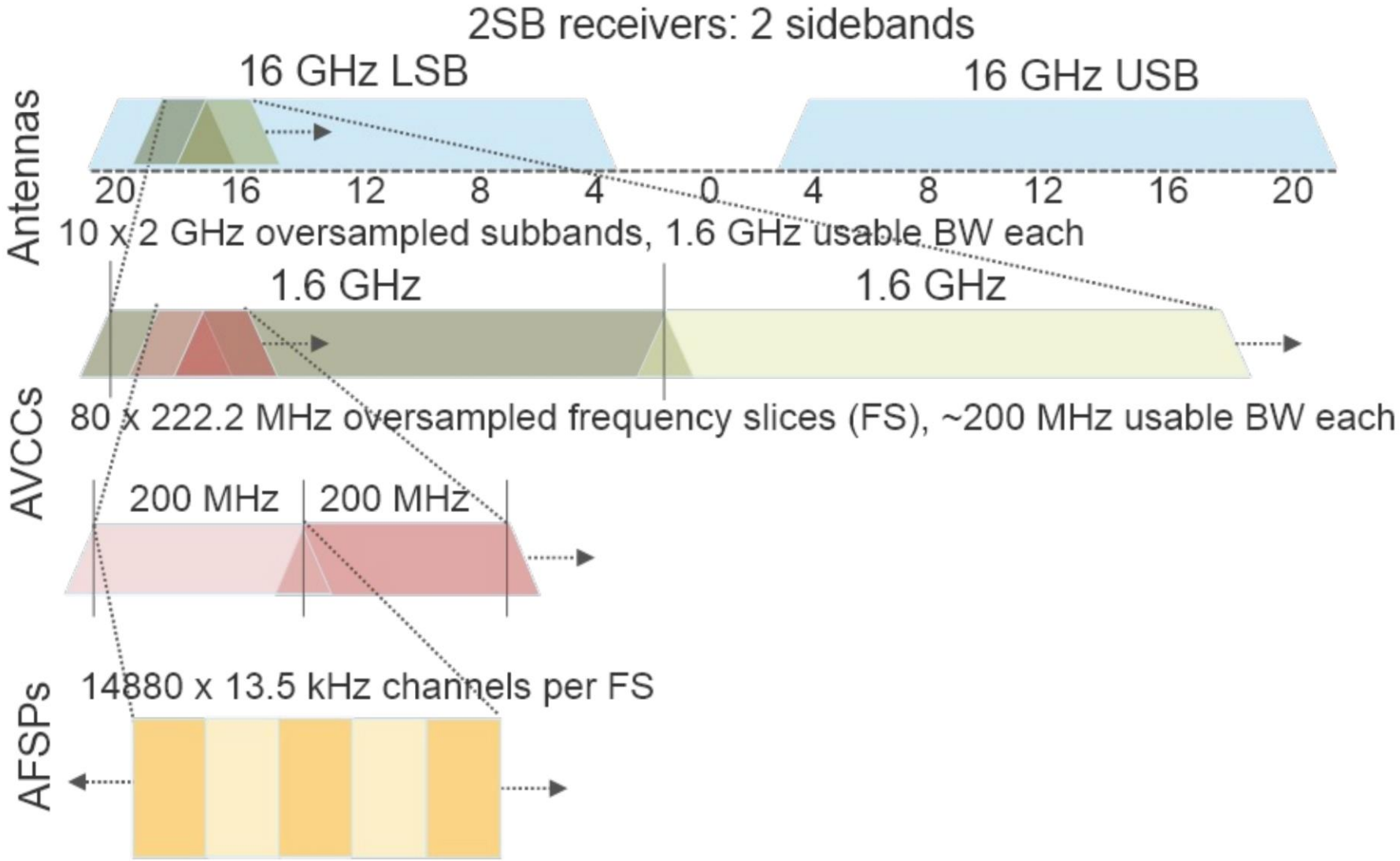
2nd generation correlator



2nd generation correlator

- Overall DSP/correlation architecture expected to be:
  - 40GS/s sampling of ~16GHz BW receiver IFs (x4)
  - DSP filterbanks connected to the digitisers in the antenna produce ~1.6--2.0GHz sub-bands
  - Sub-band data transmitted to correlator by DTS
  - TALON AVCCs produce 200.88MHz slices
  - TALON AFSPs produce 13.5kHz channels
  - CDP cluster to apply various response corrections and stitch slices/sub-bands into desired spectral windows
- => overall FFFX architecture
- 3 intimately related digital projects

2nd generation correlator



2nd generation correlator

- Policies and limitations on output data rates from the correlator are being considered based on achievable archive and offline processing capabilities
- Likely will ramp-up allowed data rates after initial offering of WSU/ALMA2030 system, as software and computing hardware allow
- WSU Data Processing, Distribution and Accessibility (DPDA) and Data Acquisition (DA) Working Groups recently formed to address such areas

Signal Chain Working Group

Charge to the Working Group

- Backend, Digitizer, and DTS Specifications
  - Charge 1 – Software Operating Environment:
    - suggest and present specifications for the software operating environment necessary to enable a new generation of backend, and data transmission systems, consistent with ALMA 2030 objectives to a System Requirements Working Group (to be established) and ICT for consideration.
  - Charge 2 – Backend:
    - develop and present specifications for a new generation of backend systems, consistent with ALMA 2030 objectives, and with the specifications proposed by the FEWG.
  - Charge 3 – Data Transmission System:
    - shall develop and present specifications for a new generation of data transmission system, consistent with ALMA 2030 objectives, and with the specifications proposed by the FEWG and CorrWG.

Signal Chain Working Group

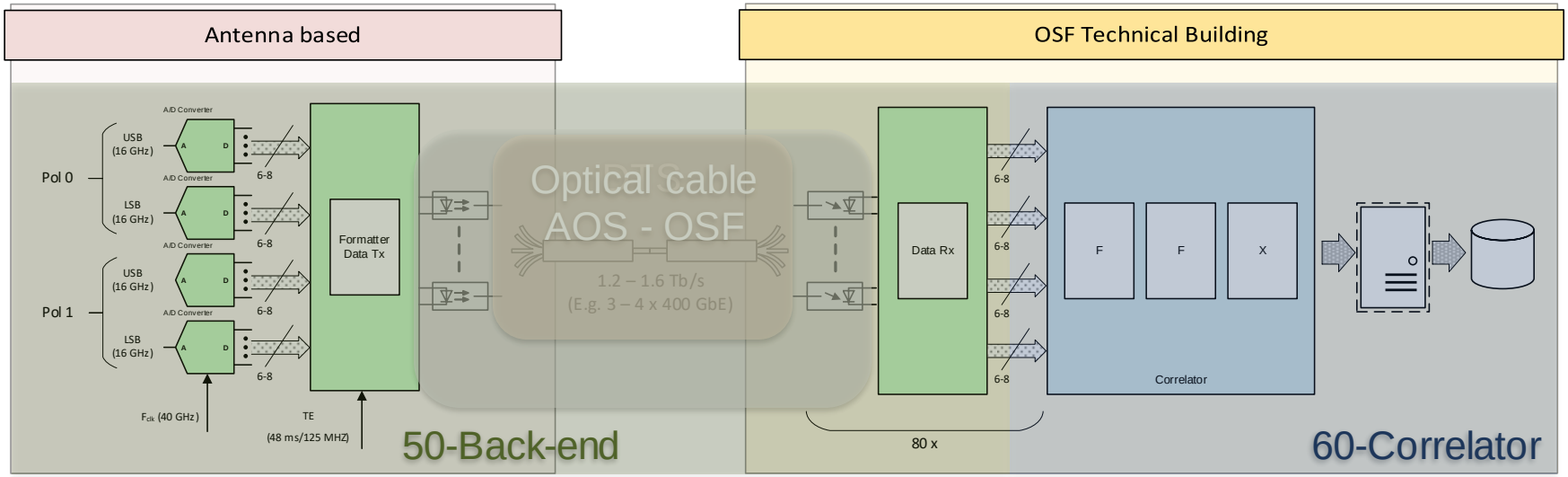
Charge to the Working Group (cont.)

- Charge 6 – System:
  - consider all derived specifications by the FEWG, the CorrWG, including the potential Correlator locations, and this WG and assess if additional System Requirements applicable to the part of the system between FE and Correlator are necessary towards the ALMA 2030 objectives. If this is the case, the working group shall specify the necessary additional requirements.
- Charge 7 – Interfaces:
  - assess the existing interfaces between FE, Digitizers, BE, DTS and Correlator and shall identify the interfaces and related ICDs to be updated in relation to the update of the Technical System Requirement towards the ALMA 2030 objectives. They shall assess the impact of the updated requirements on the interfaces between the part of the System between FE and Correlator and the rest of the ALMA system, which shall be assessed further by a System Requirements Working Group (to be established) and the IET, ICT and ISOpT, as relevant.
- Charge 8– Frequency and Timing distribution:
  - provide an initial assessment on the architecture and requirements related to frequency and timing distribution in the ALMA 2030 System Architecture. The full assessment is out of the scope of the SCWG and will be followed up in studies related to other aspects of the ALMA2030 planning, such as the implementation of Extended Baselines.

Signal Chain Working Group

System architecture perspectives

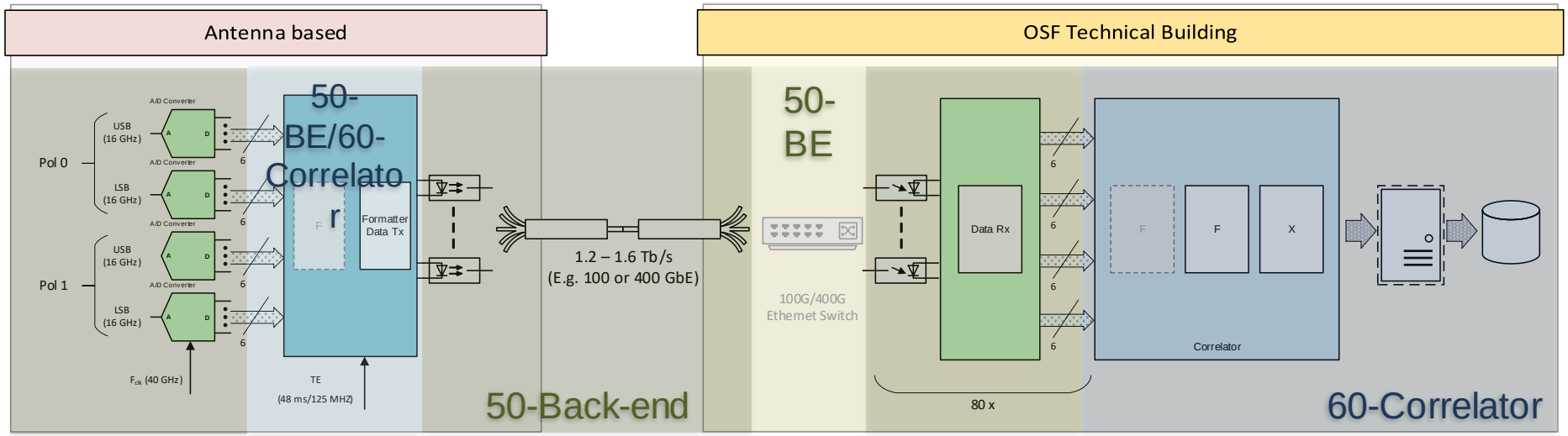
- Strawman ALMA 2030 architecture
  - COTS optical DTS (DCI)
    - Asynchronous
    - 6 - 8 bits/sample
    - Data rate 1.2 – 1.6 Tb/s per antenna
    - Standard packet data protocol
    - ~80 km span
  - One Baseband per sideband/pol
    - 16 GHz per baseband
  - Correlator
    - 66 – 80 antennas (inc. ACA 7m array)
    - FFX configuration
    - Located at OSF Building



Signal Chain Working Group

System architecture perspectives

- Alternative ALMA 2030 architectures
  - Correlator
    - 66 - 80 antennas
    - (F)FFX configuration
    - “First F” might be a, tuneable, filter-bank or Digital Down Converter
    - Physically distributed among Antennas, OSF Building and possibly AOS Technical Building
  - COTS Optical DTS
    - 100 GbE or 400 GbE (TALON-DX has 100GbE ingress)
    - Might use 100G/400G Ethernet switch to interface 400 GbE DTS to TALON-DX
    - Sending time-series data saves data rate rather than sending spectral ones
      - Adjacent channel overlap / process gain



Signal Chain Working Group

SCWG Recommendations

- ALMA 2030 Correlator to be located at OSF Building
  - Lower construction and operational costs
  - Faster problem diagnosis and repair due to easy access
  - Allows integration concurrent with normal operations
    - No room for a second full array correlator at AOS Building during commissioning period
  - "First F", e.g. Digital Down-converter or filter-bank. Might be installed at antennas
    - Suggested by LAB/UdB study / supported by NRC 2nd Gen Correlator proposal
    - Topic of further analysis and review. Needs holistic system view, cost optimization!
- Digital Transmission System based on COTS
  - 400 GbE standard (e.g., IEEE 802.3cw / OIF 400ZR)
  - Asynchronous data transport (needs time-stamped data from digitizers)
  - min. 6 bits/sample - stretched goal 8 bits/sample
    - What is the FE/DIG stretch goal?
  - Installation of new optical cable between AOS and OSF buildings
    - 96 / 192 optical fibres
    - Highly desirable for cost effective and future proof operations
    - Costs are manageable, 2-3 MUS$

Signal Chain Working Group

SCWG Recommendations (cont.)

- Electrical power consumption
  - ALMA 2030 electrical power consumption can be generated by a single gas turbine (requires meeting stretch goal correlator power consumption)
- Upgraded IF Switch, integrated with digitizers, is essential
  - 16 GHz instantaneous bandwidth, e.g. 2 – 20 GHz to accommodate different IF bands from receivers
- Timing distribution (48 ms TE signal) needs improved uncertainty performance to support asynchronous DTS (iow. lower jitter)
  - Current frequency / timing distribution is in principle capable of delivering required performance using the existing 125 MHz system clock
- To minimize Observatory down-time a deployment of ALMA 2030 sub-systems concurrent with normal observations is advocated
  - ALMA 2030 Correlator needs to be in a different location from current equipment → OSF Building
  - Availability of second optical cable between AOS and OSF Buildings
  - Current DTS fiber DWDM system should be untouched by the new DTS
  - Peak electrical power demand during integration and commissioning might require use of 2nd gas turbine (102 % capacity)

Thank you for your attention

ALMA 2030 / WSU

Digitizers / Signal path / Correlator

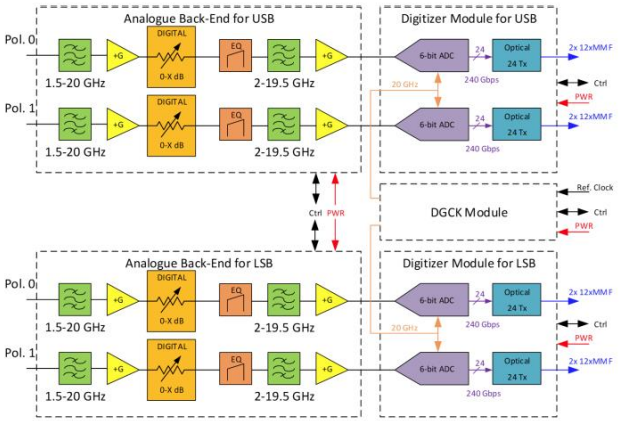
Gie Han Tan

EASC

Public

Digitizers

- Digitizers
  - Keysight (Micram)
  - Bandwidth: DC – 20 GHz
  - Sampling clock: 40 GHz
- DSP
  - Channelizer (1st F) / Formatter at antenna
  - FPGA based
  - Intel Stratix 10 family



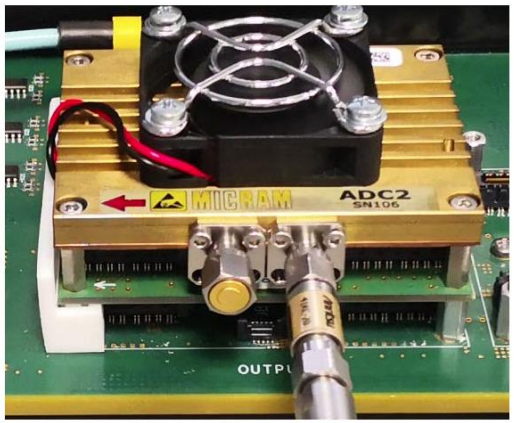
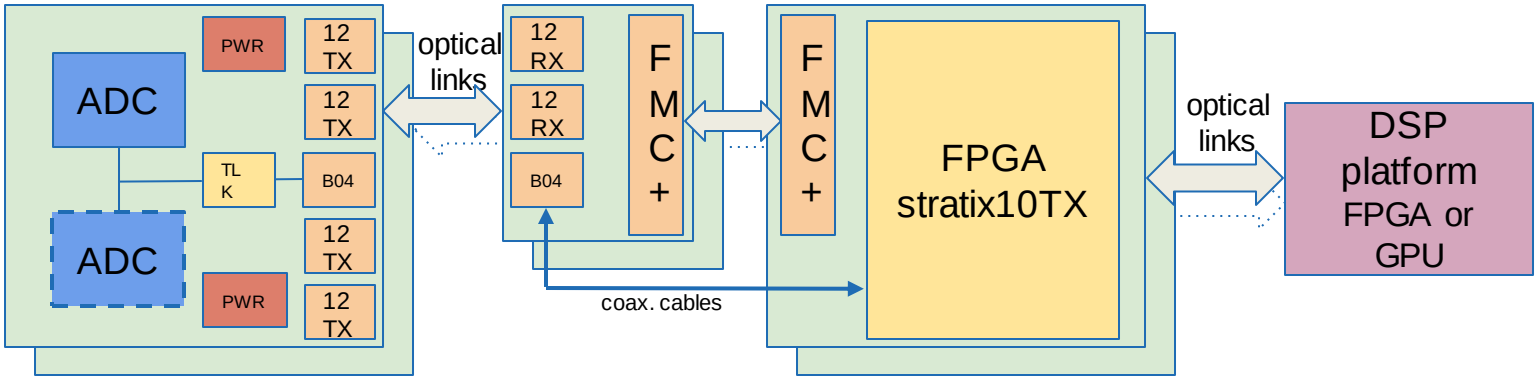


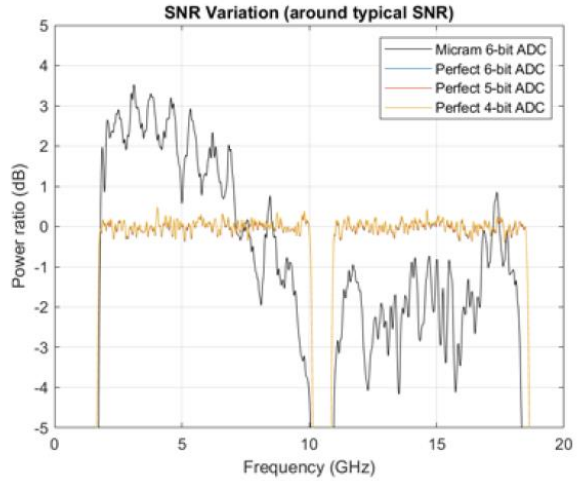
Figure 3: Digitizer assembly based on Micram 6-bit ADC module at 40 GSps

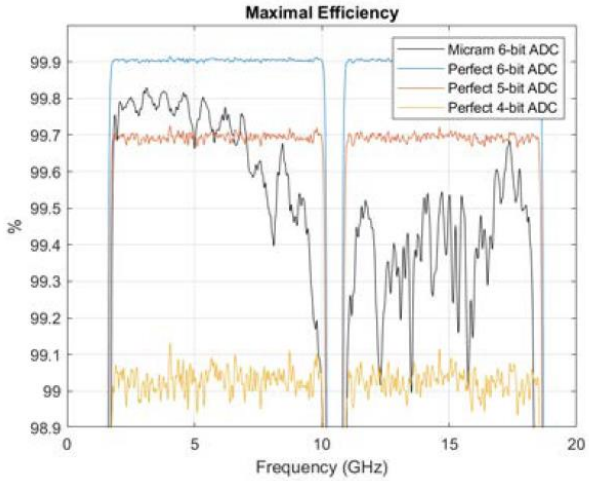


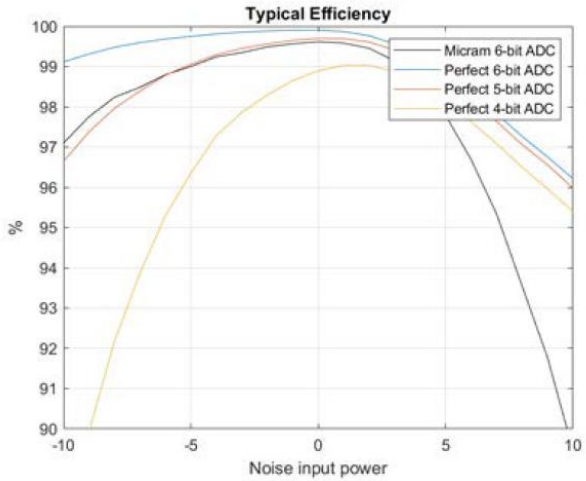
Diagrams courtesy of LAB/UdB

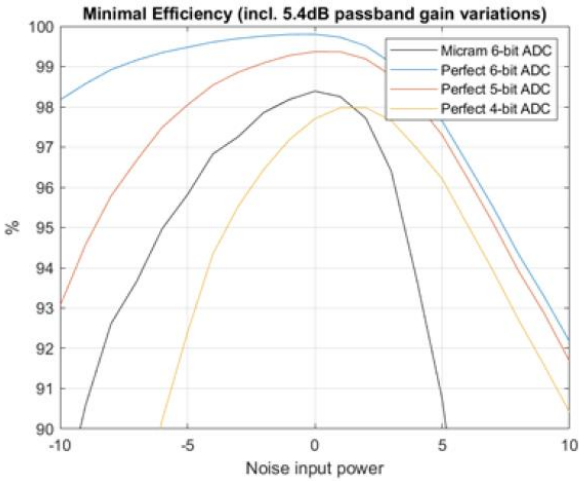
Digitizers (cont.)

- Efficiency measurements
  - Sampling clock: 40 GHz





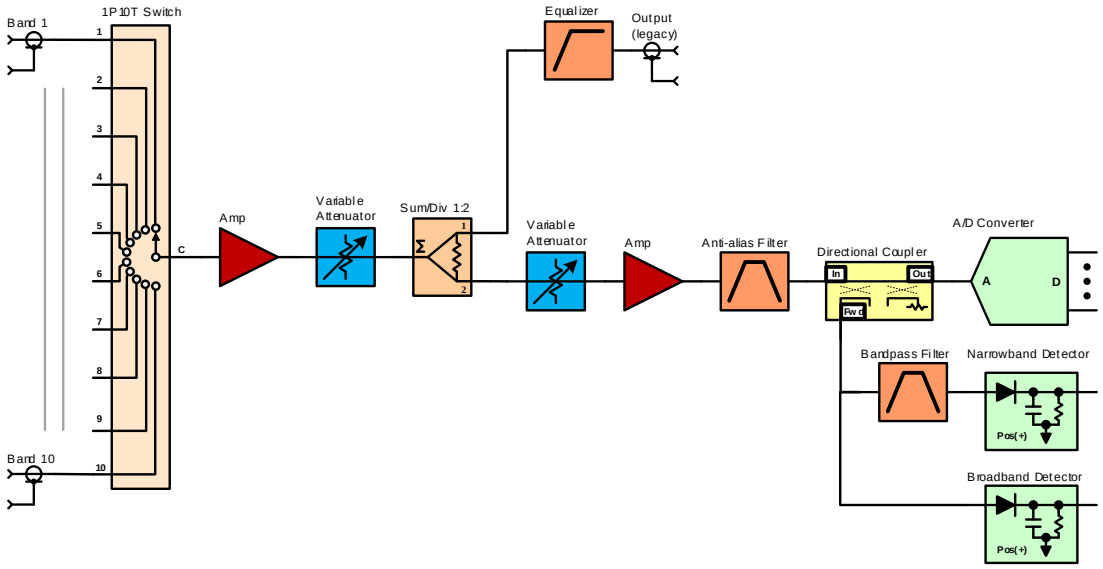


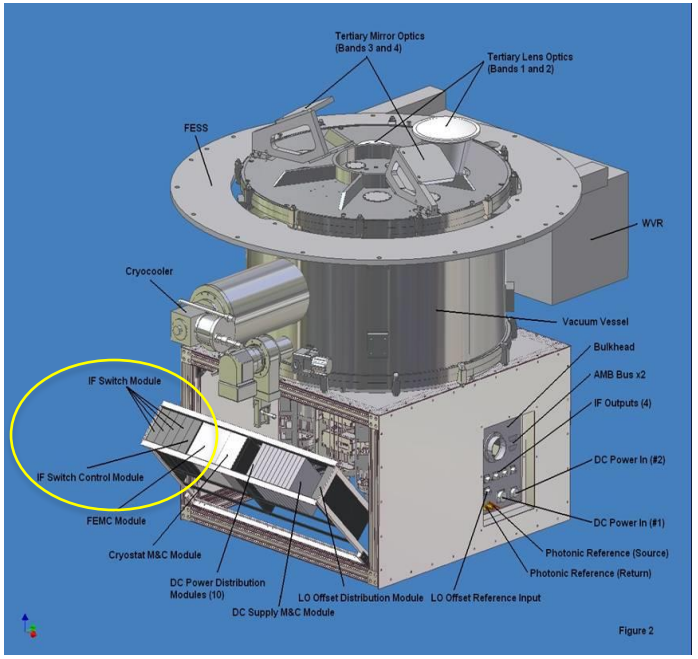


Diagrams courtesy of LAB/UdB

Signal chain / analogue

- FE Assembly / IF Switch (ALMA 2030 Strawman)
  - 16 GHz BW
  - Integrated Digitizer
  - Integrated power detectors (wide / narrow band)
  - Analog IF output for legacy BE sub-system
  - Dedicated WG is analyzing Digitizer/1st F/DTS locations





Signal chain / Digital

- Digital Transmission System
  - COTS solution
  - 400 GbE
  - Asynchronous, packet based
- New AOS-OSF optical cable to be installed
  - >96 fibres (one/two per antenna)

II-VI

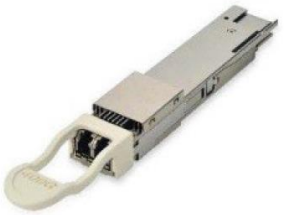
Product Brief

High Tx Output Power 400G QSFP-DD-DCO Transceiver – ZR

FTCD3323E1PCL

PRODUCT FEATURES

- Digital Coherent Optics module, QSFP-DD form factor, Type 2A
- IEEE 400GE or 4×100GE Ethernet host interface
- Coherent 400G optical interface based on OIF 400ZR implementation agreement
- High Tx output power (0dBm) enabling:
  - Unamplified DWDM links > 40km
  - Unamplified single wavelength links > 80km
- Dispersion limited transmission reach up to 120km
- Full C-band tunable, 75GHz or 100GHz grid
- Case temperature range 0°C to 70°C



APPLICATIONS

- Data center interconnect
- Metro / edge networks