台灣宇宙電波爆廣角監測實驗

BURSTT

Bustling Universe Radio Survey Telescope in Taiwan

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NSTC 國家科學及技術委員會 National Science and Technology Council

Why BURSTT?

Fast Radio Bursts (FRBs) are millisecond flashes in radio band that originate from extragalactic sources. Mechanism still unknown.

Only a small fraction (~10 percent) are known repeaters.

FRBs can be anywhere anytime

A large **dipole array** for wide FoV and sensitivity

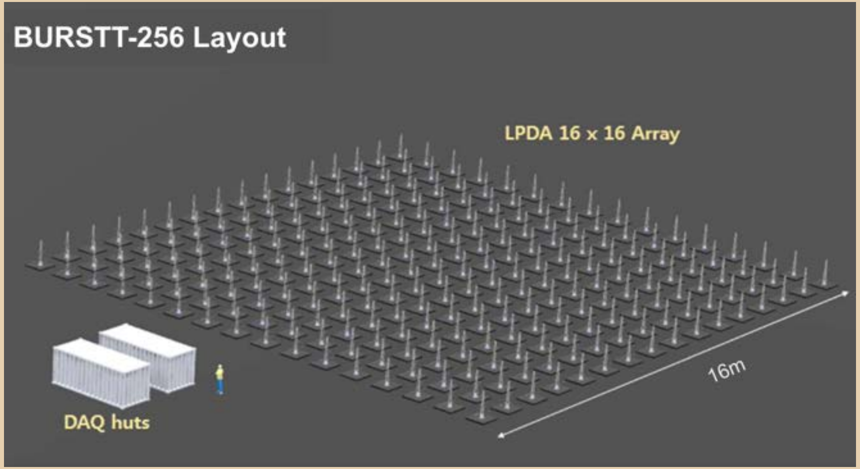
Localization with a single burst

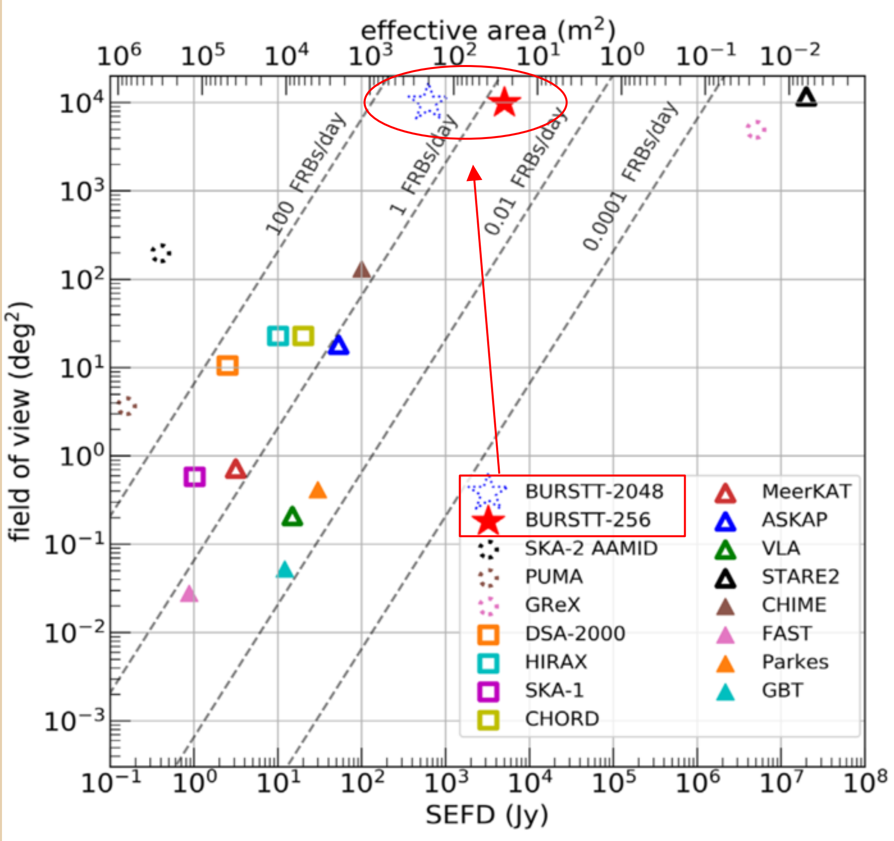
VLBI of **outrigger stations** with ring buffers of voltage data

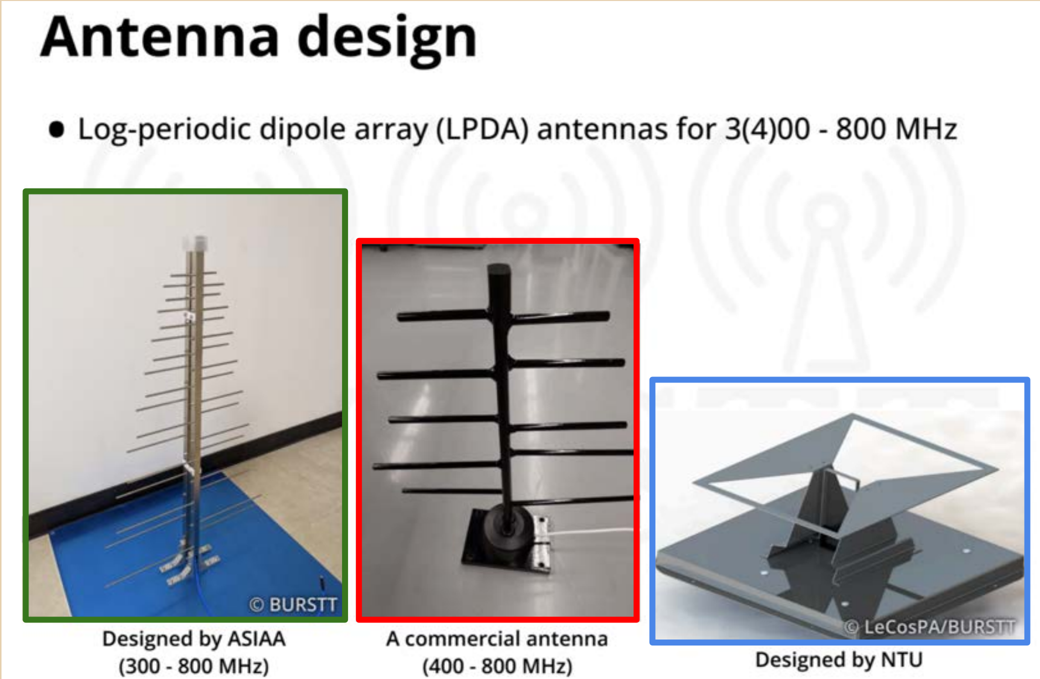
BURSTT feature

Hsiu-Hsien Lin et al. 2022, PASP, 134, 094106

- A wide-field (~10^4 sq.deg) array to detect FRB events
- VLBI localization to (1”) and better
- Detect and localize bright FRBs → near MW → best candidates for followup





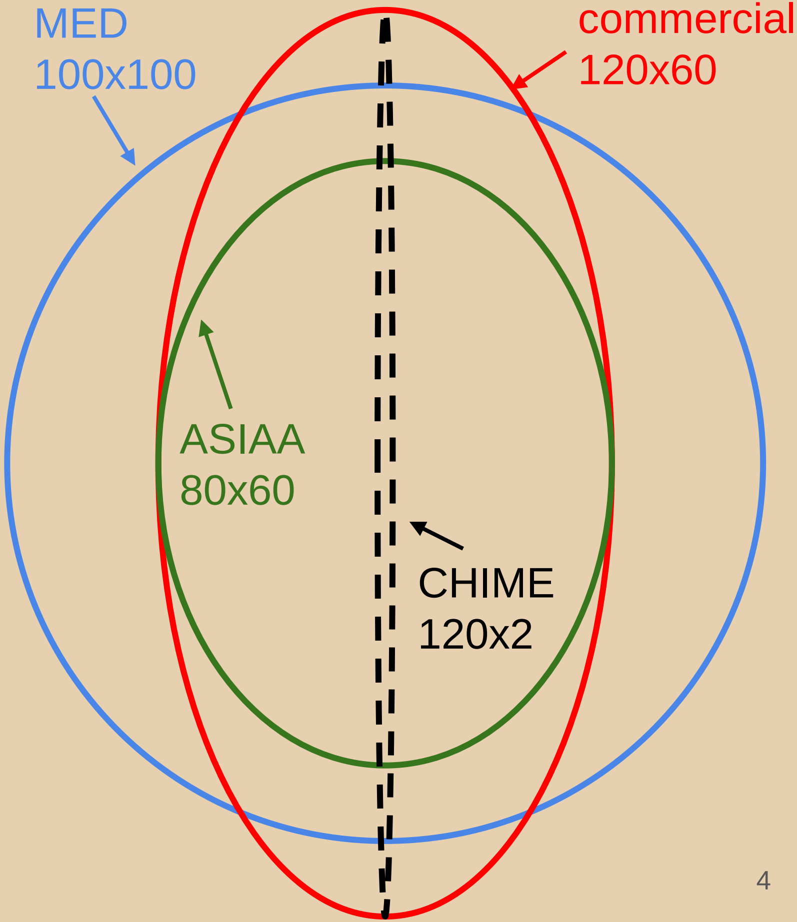


9dBi

6dBi

7dBi

Field of View (FoV)

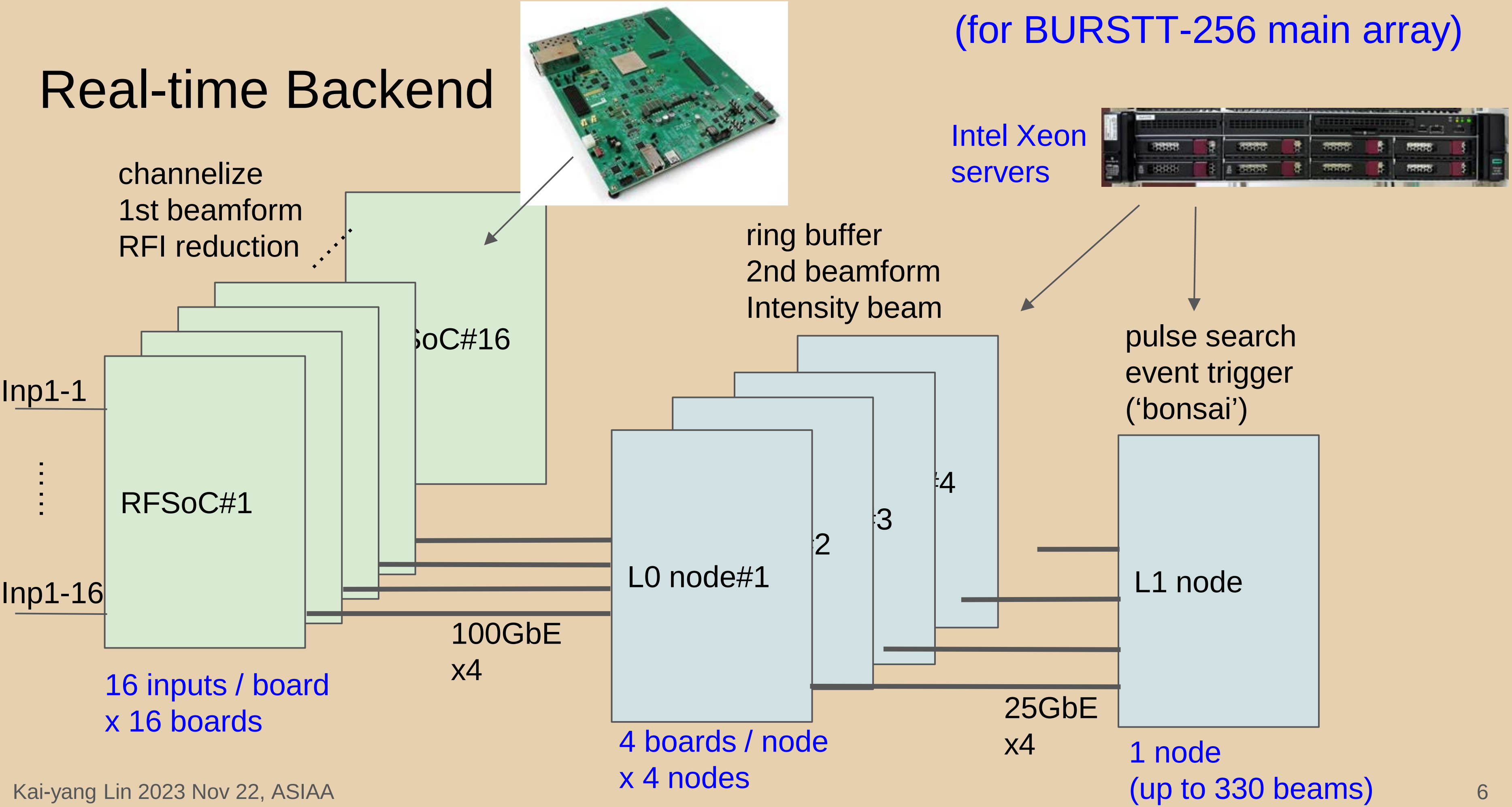


Sites of interest

100km → 1” @ 0.5m wavelength

Real-time Backend

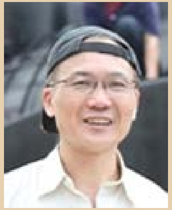
(for BURSTT-256 main array)



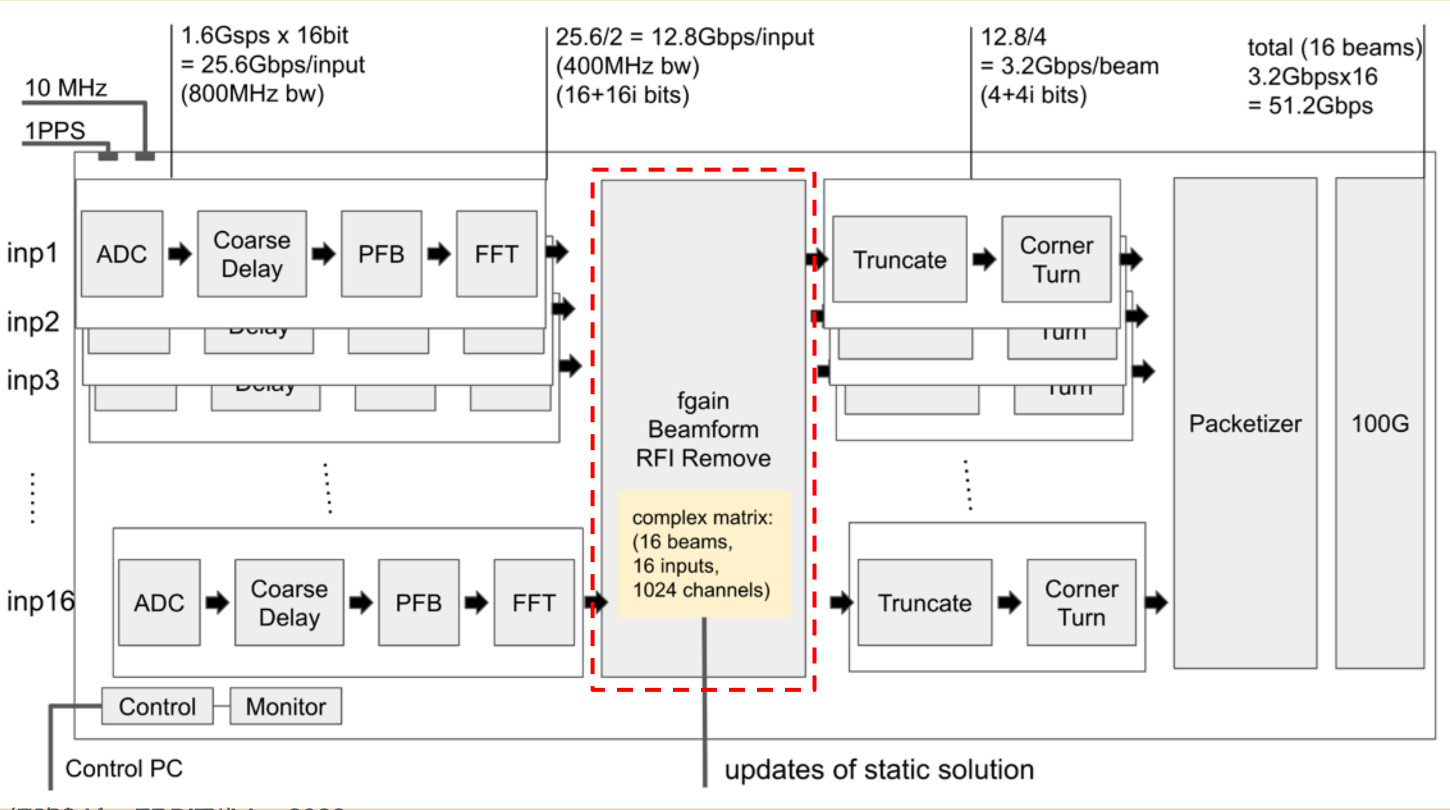
RFSoC: Xilinx Zynq UltraScale+ ZCU216

- input:
  - 16x 14-bit 2.5Gsps ADC
- output:
  - SFP28 x 4 -- QSFP28 (100GbE)
- implementation
  - CASPER library
  - 400MHz clock (demux 4) → 1600Msps
  - 800MHz bandwidth at 16-bit I and 16-bit Q
  - truncate to 4-bit I and 4-bit Q for 400--800MHz (52Gbps)

Jiang, Homin



RFSoC Functional Block Diagram

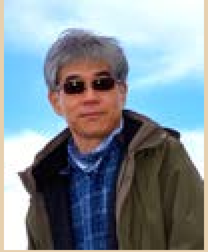


CASPER
The Collaboration for Astronomy Signal Processing and Electronics Research

Real-time Process

- 2x Nvidia ConnectX-6 Dual 100Gbps
  - 400Gbps in total
- libvma (nvidia messaging accelerator)
- 20sec baseband buffer
  - max DM ~ 1000 pc/cm^3
- 4x RFSoC @ 400MHz BW (64-ant)
  - 1TB of RAM
  - 52Gbps x 4
  - 8-12 cores needed
- Max data rate achieved:
  - 98Gbps x 4
  - for future expansion
  - 16-20 cores needed

Wang, Andrew



- Intel Xeon 6338 (Gen3 Gold) dual sock
  - 64 cores in two NUMA nodes
- 16x16 (x1024) matrix multiplication
  - assembly code
  - 12 cores per RFSoC
  - 48 cores for 2nd beamform of 256 beams
- Next gen Xeon (Gen 4) supports advanced matrix extension (AMX) → 10x to 100x faster

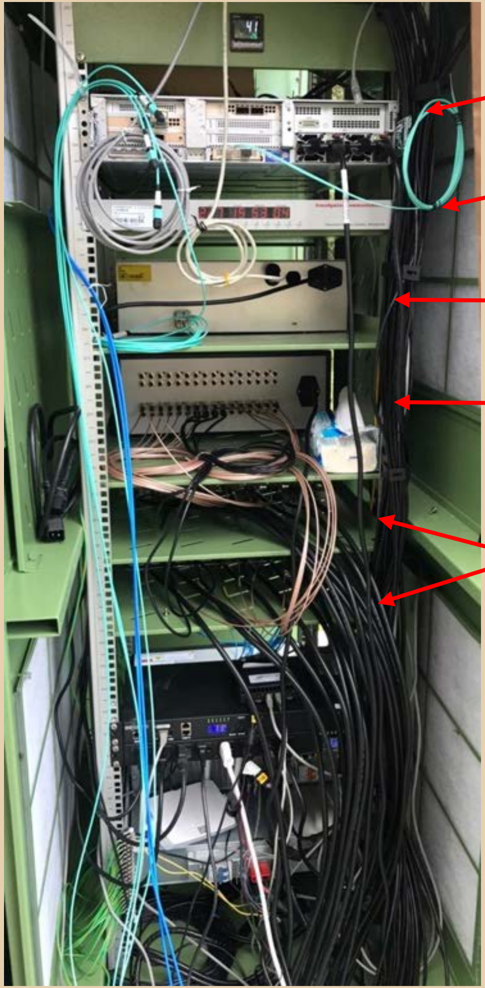
Chih-Yi, Wen

Main array in Fushan

Each row of 16 ant connected to one RFSoC → 1D beamform

RFSoC backend

with housing and 16 balun boards



L0 node

Rb GPS clock

RFSoC

power supply

bias-T, 3rd amp

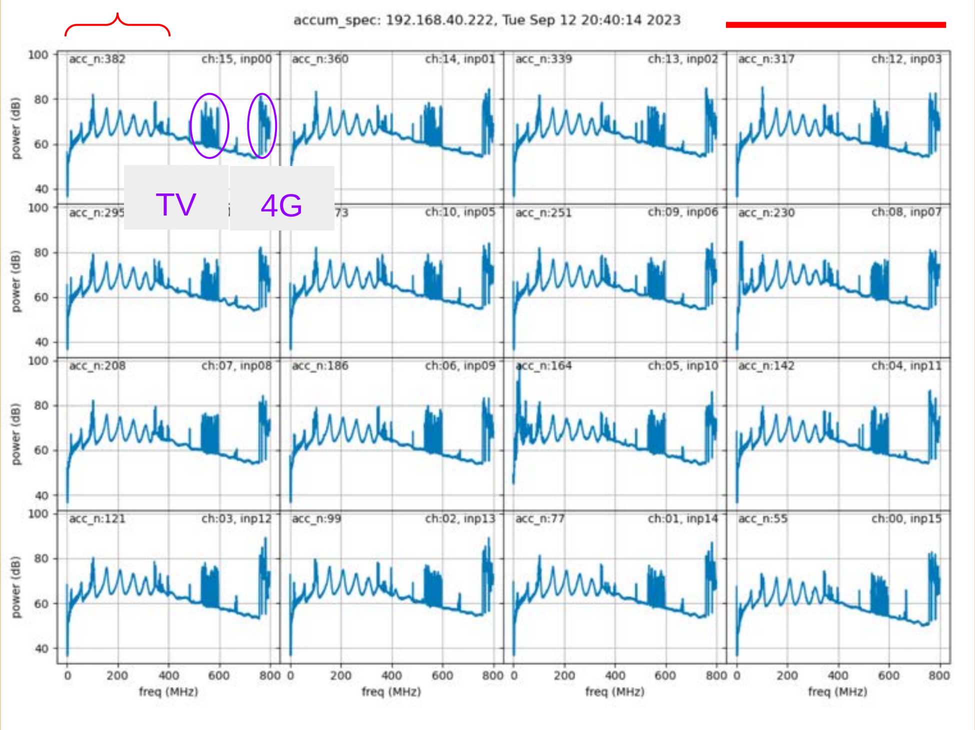
RFSoC Results from Fushan

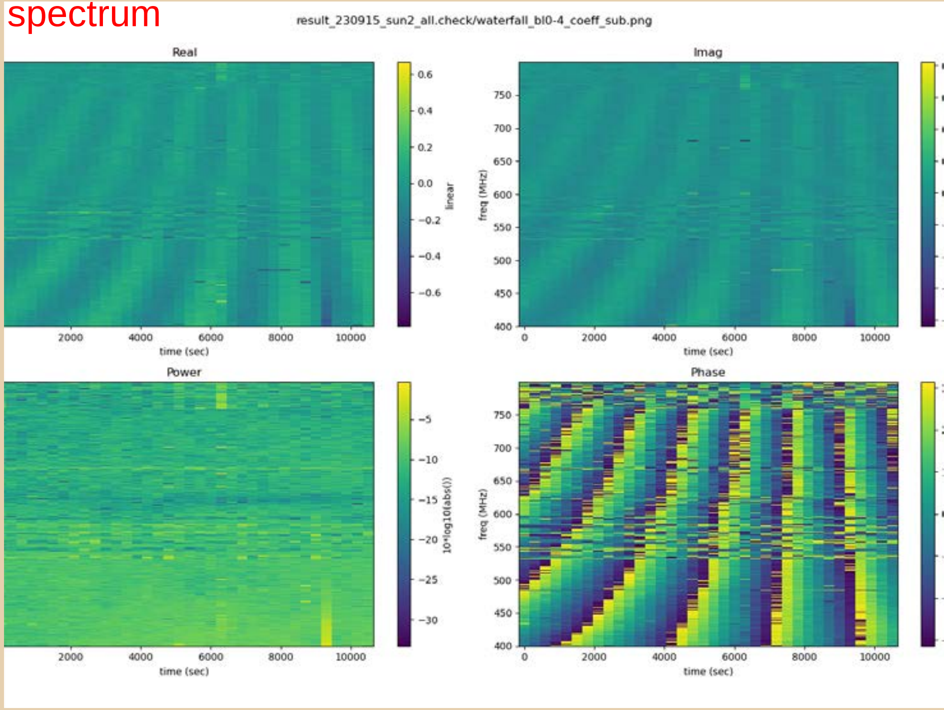
Strong reflection below 400MHz
due to commercial antenna design

sending only
400MHz out

full 800MHz
spectrum

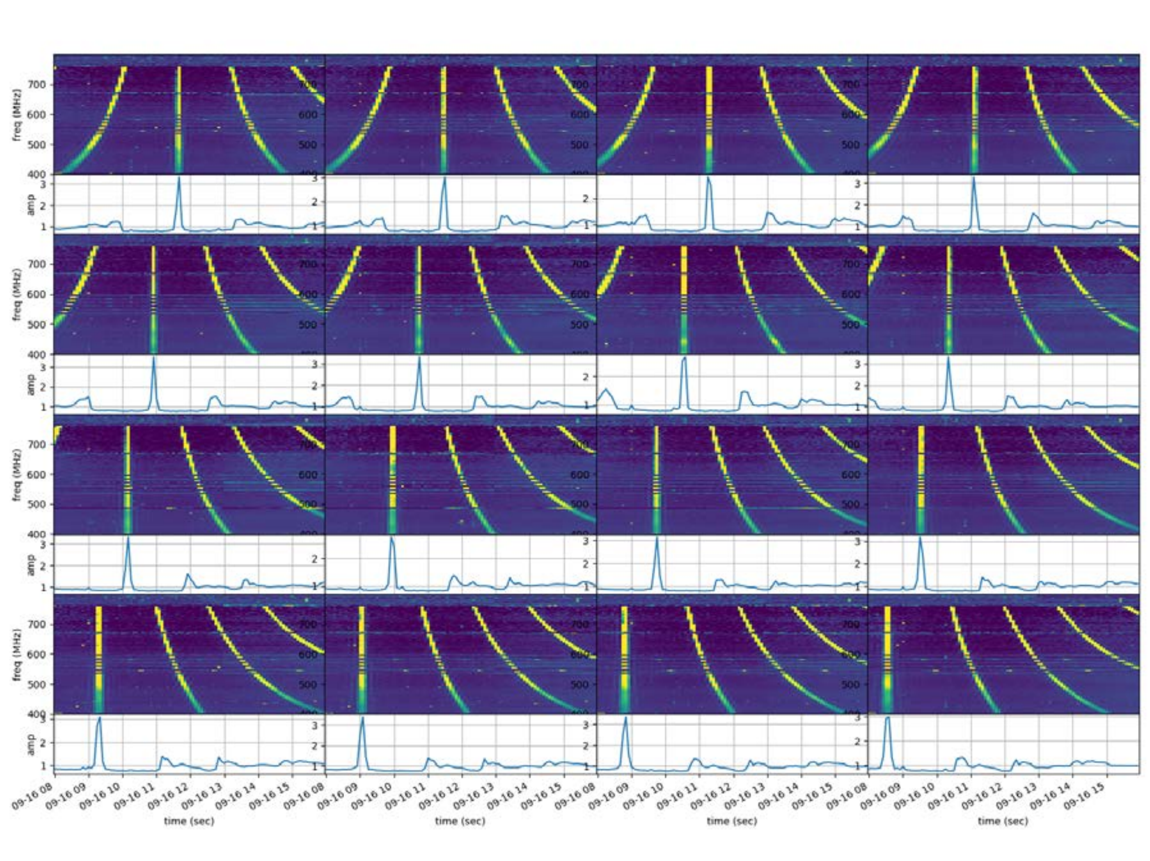
Example:
Sun fringe
4m spacing





First Beamform from Fushan

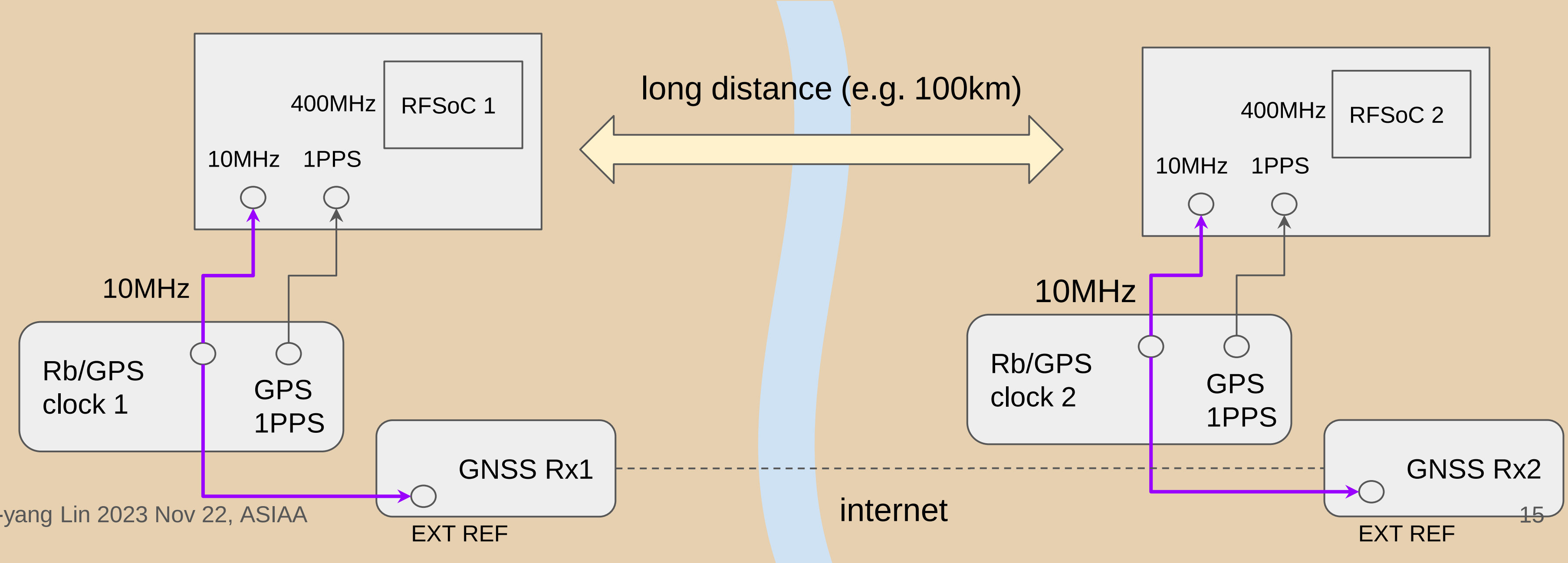
- 16 antennas → 16 beams
- Bandpass calibration done
- Use the Sun to map out the main and side lobes
- Proof of concept for front-end, back-end, and site
- 64-ant beamform WIP



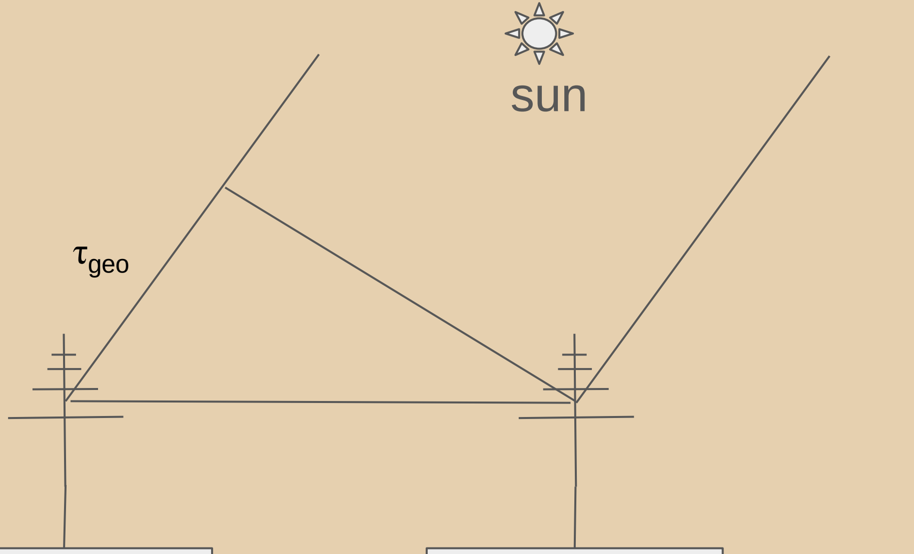
Timing for VLBI

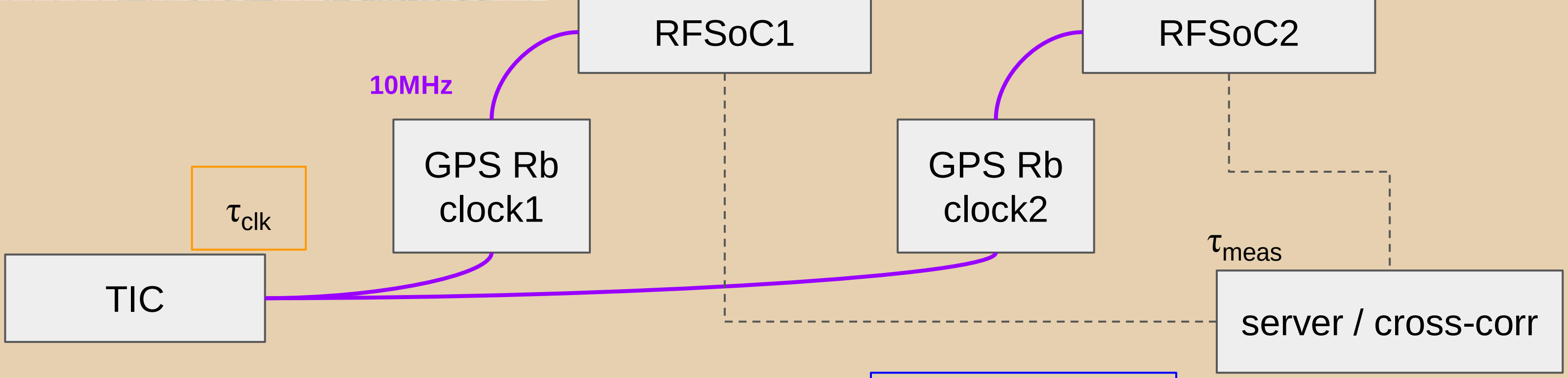
- 400MHz sampling → 2.5 ns
- 1” at 100km → 1.6 ns
- 0.1” at 1000km → 1.6ns

Timing goal: 0.2 ns



Fushan GPS test



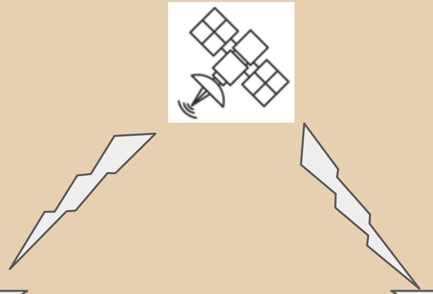


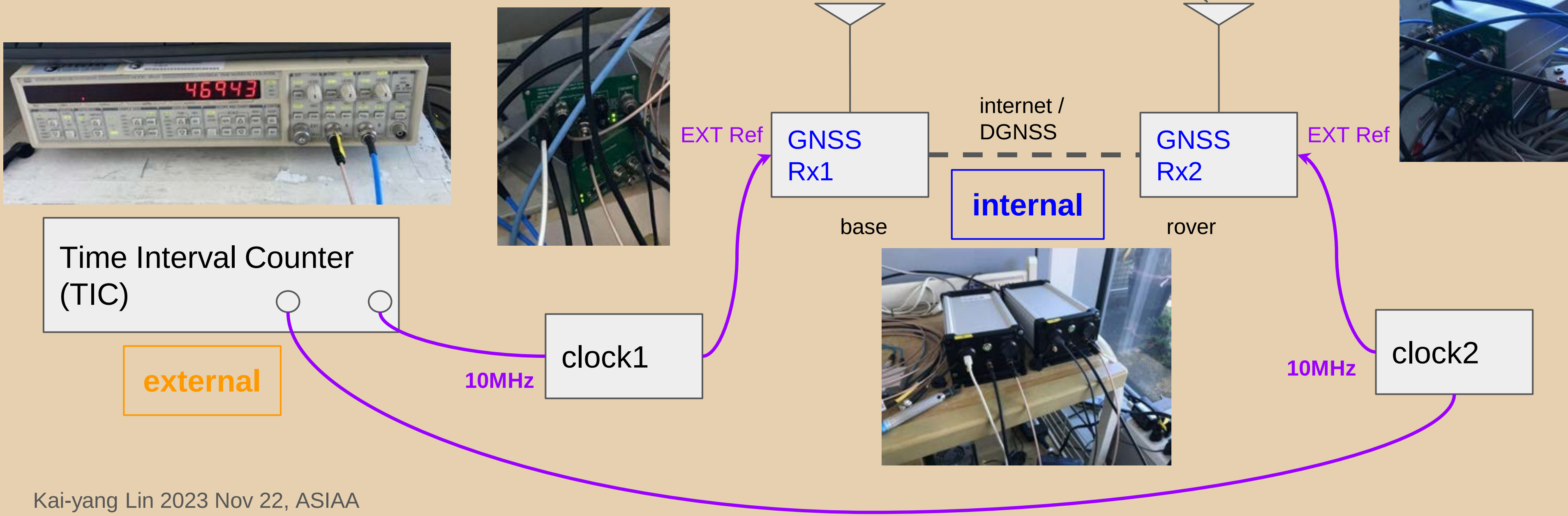
$$\tau_{clk} = \tau_{meas} - \tau_{geo}$$

GNSS Rx test setup

ppp: precise
point positioning
(offline process)

Septentrio: mosaic-T
+ Raspberry Pi
(dev: National Ocean University)

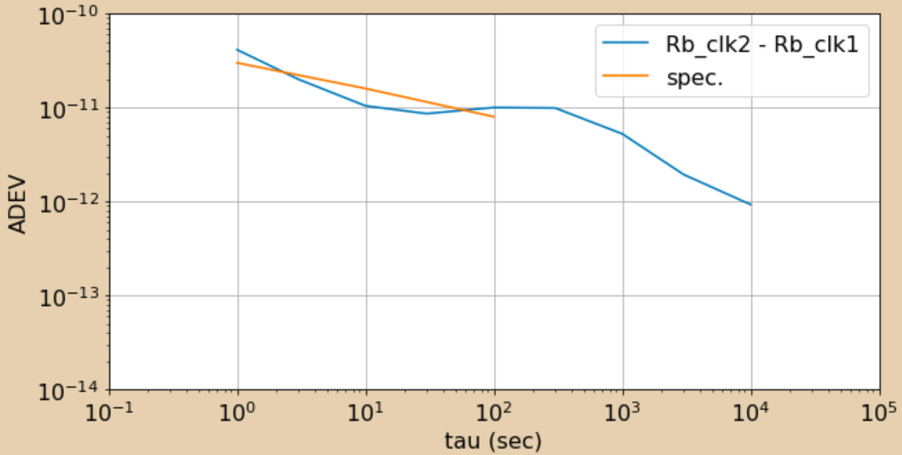


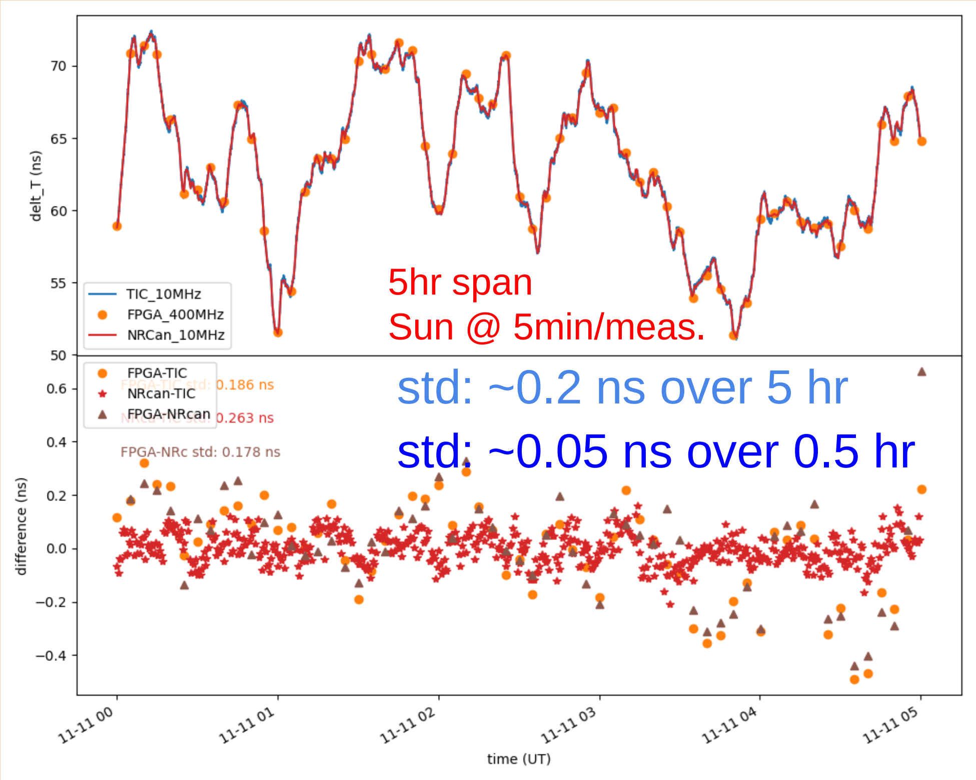


Kai-yang Lin 2023 Nov 22, ASIAA

Clock difference

- 400MHz clock diff by Sun
- 10MHz ref diff by TIC
- 10MHz ref diff by GNSS-ppp





Verification test at the same site

Summary

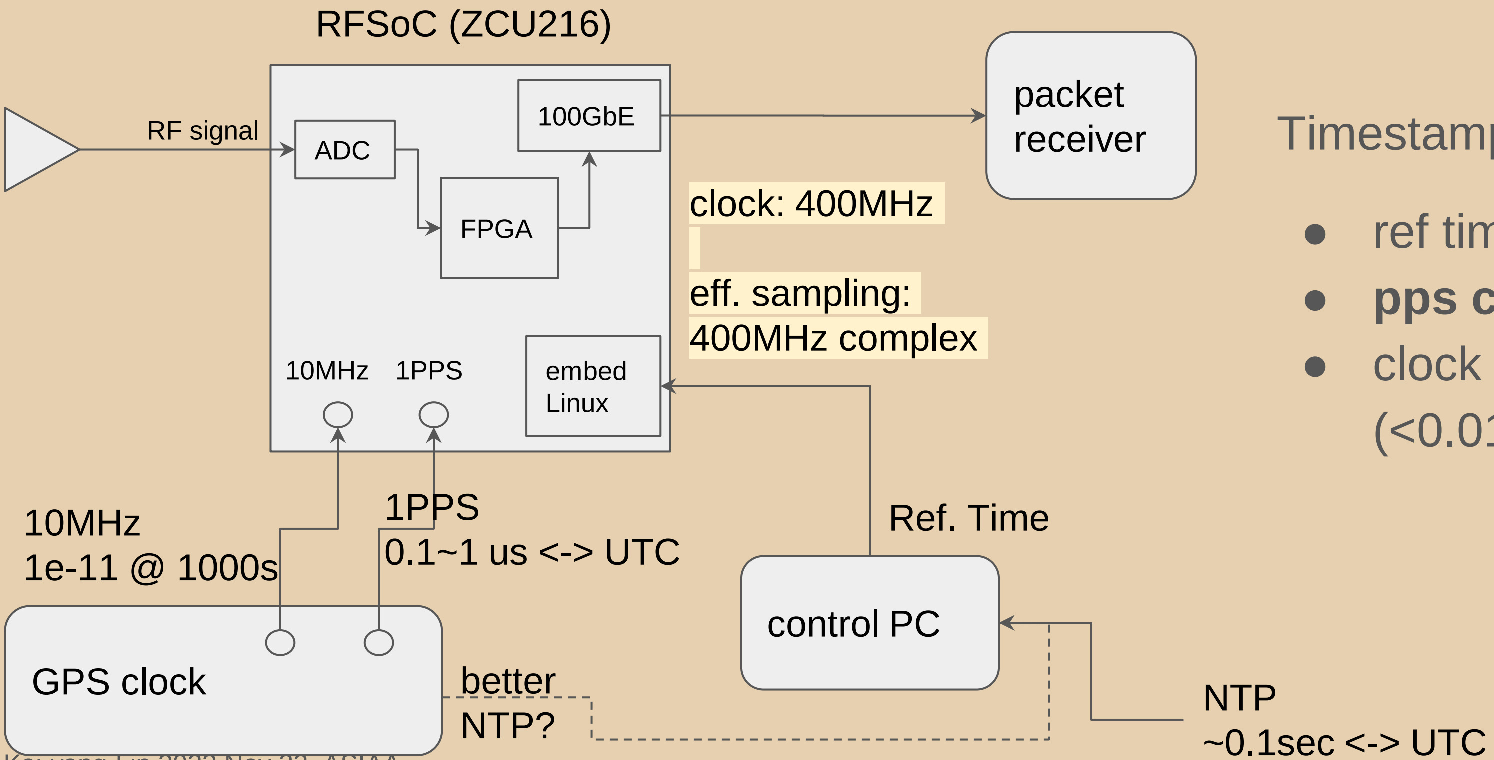
- 64/256 antennas deployed in Fushan main array
    - 16/64 antennas in Nantou outrigger array
    - site work to begin shortly in Green Island
    - negotiation for a site in Dongsha
- Sun fringe observed:
    - ~300MHz usable (between 400-800MHz)
    - Tsys ~ 90K
    - beamform successful
- VLBI timing
    - post-process data from the GNSS Rx a success
    - next to test between different sites
    - continuous estimates of the total electron content (TEC) toward various GNSS satellites at each site. potentially useful for estimating ionospheric delays of the pulses.
    - stay tuned …

Thank you!

Potential External Collaborations

- NARIT (Thailand)
    - 2-element bladeRF prototype system just received and setup in TNRO (near Chiang Mai)
- NAOJ / Mizusawa VLBI Obs. (Japan)
    - 2-element bladeRF prototype system received and will be tested near Mizusawa first
    - Plan to test in Ogasawara island later
- RRI (India)
    - Interested in setting up an outrigger station in Gauribidanuru Radio Obs. (near Bangaluru)
- UM / Radio Cosmology Lab (Malaysia)
    - Interested in searching for a site to host an outrigger station.

BURSTT backend



Timestamp Error Budget:

- ref time (integer sec)
- **pps count (~100ns)**
- clock count within 1s (<0.01ns?)

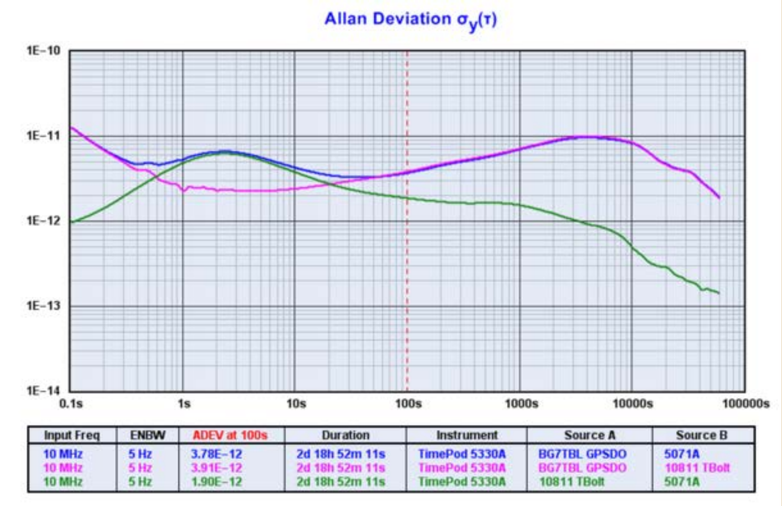
GPS Clock Allan Variance

Brandywine NFS220+

Oscillator Option	Stability -10-60 ◦C	Allan Variance 1s	10s	100s	1000s	10000s	1 day
OCXO*	$3x10^{-9}$	$2x10^{-11}$	$4x10^{-11}$	$8x10^{-11}$	$1x10^{-11}$	$5x10^{-12}$	$5x10^{-12}$
Rb1	$7x10^{-10}$	$3x10^{-11}$	$1.6x10^{-11}$	$8x10^{-12}$			$<5x10^{-12}$
Rb2	$4x10^{-10}$	$1x10^{-11}$	$3x10^{-12}$	$1x10^{-12}$			$<5x10^{-12}$
Rb/OCXO	$4x10^{-10}$	$8x10^{-12}$	$1x10^{-11}$	$3x10^{-12}$			$<5x10^{-12}$

Oscillator Option	10 MHz Phase Noise dBc 1Hz	10Hz	100Hz	1kHz	10kHz	100kHz
OCXO*	-90	-120	-140	-150	-150	--155
Rb1	-67	-85	-114	-130	-140	-140
Rb2	-80	-100	-130	-140	-150	-150
Rb/OCXO	-90	-120	-140	-150	-150	--155

BG7TBL

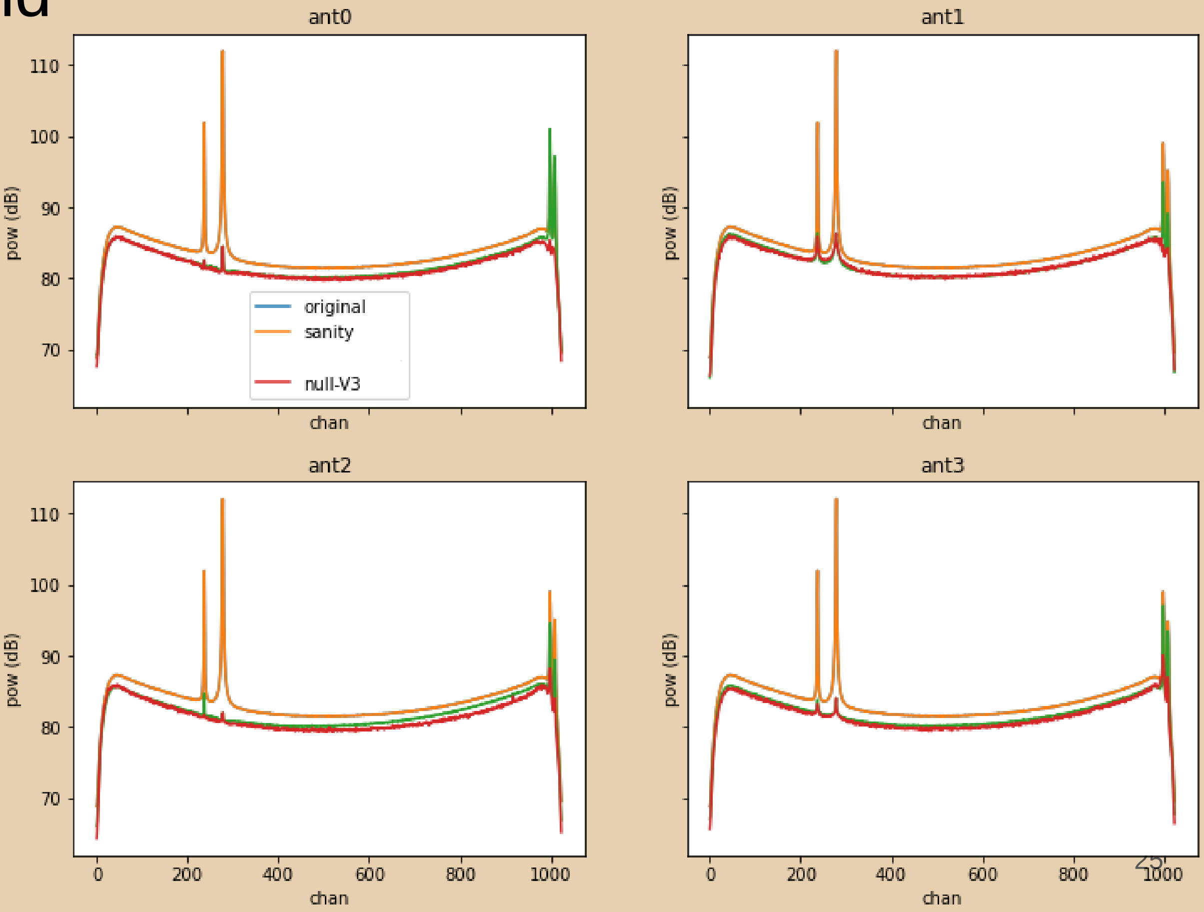


Software-Defined Radio Backend

- 2T/2R Transceiver chip
- 12-bit ADC depth
  - 2-byte real + 2-byte imag sample
- 50MHz -- 6GHz range
  - digital downconversion (DDC)
- up to 40MS/s sampling / 40MHz bandwidth (dual-channel)
  - 40MS/s*4bytes/S*2inp=320MB/s
- FPGA (default: bypass)
- USB3.0 connection to PC
  - 500MB/s data rate

Example 1: clean band

- ‘sanity’ == no nulling
- ‘null-V3’
    - each spec channel has a set of eigenvectors
    - project and remove strongest component independently
    - **20--30dB removed**



Example 2: TV bands

- ‘sanity’ == no nulling
- ‘null-V3’
  - project and remove strongest component independently
  - **~20dB removed from middle TV station**
- ‘null-V3V2’
  - remove **two** strongest eigenmodes
  - more antennas needed for complicated RFI