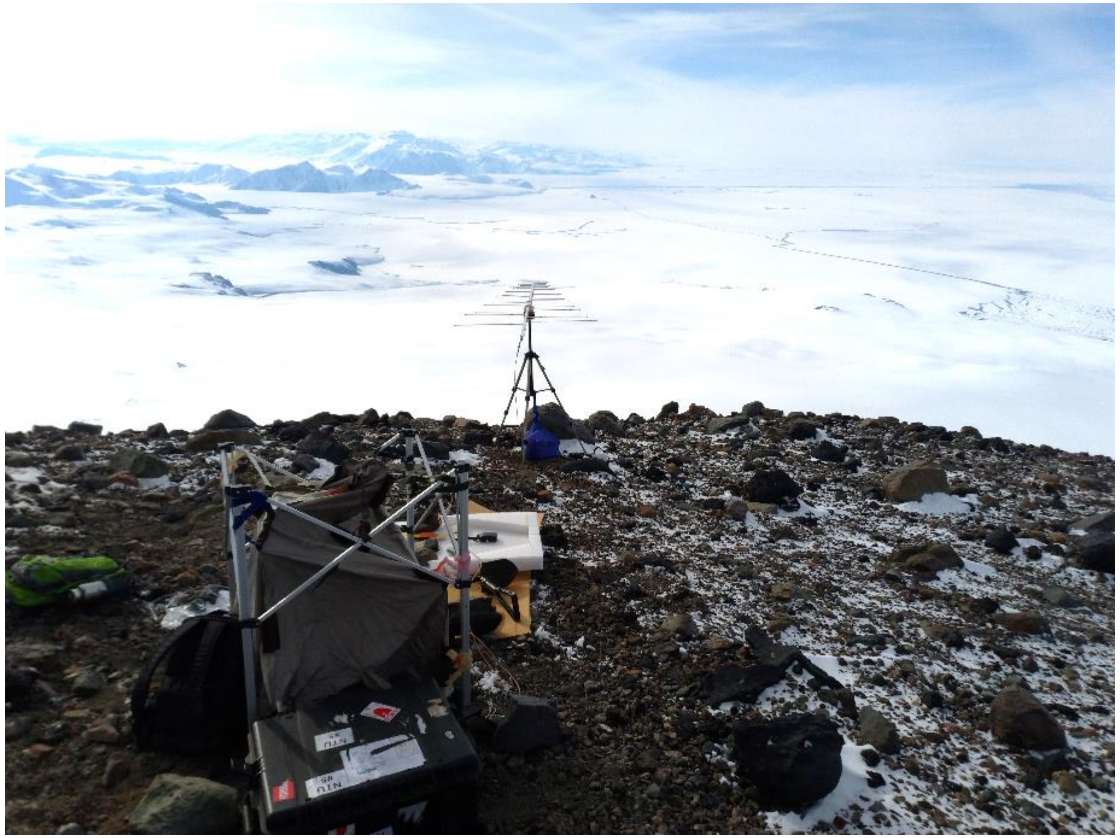




Introduction on Radio-Frequency (RF) Receiver and Survey

Shih-Hao Wang (王士豪)

ASIAA & NTU LeCosPA

2025/07/30

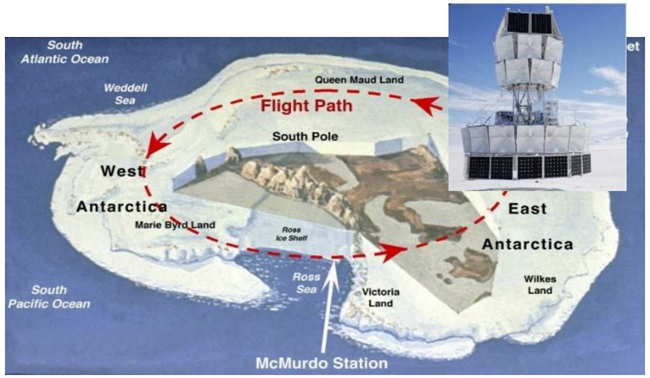
BURSTT

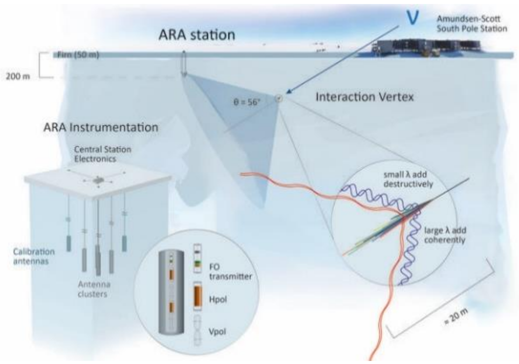
太魯閣
TAROGE
Taiwanese Astroparticle Radiowave Observatory for Geosynchrotron Emission

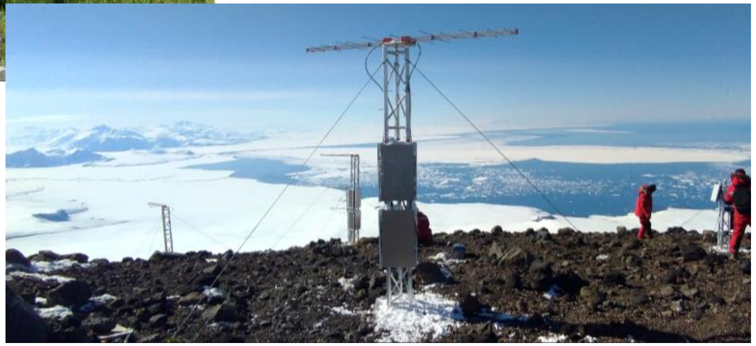
About NTU lab

- We build antenna arrays to detect radio pulses from unknown phenomena:
  - f =100-1000 MHz (wavelength: 3-0.3 m)
  - with 10+ year experience
  - Lead by Prof. Jiwoo Nam
- TAROGE project on high mountains in Taiwan and Antarctica
  - ~1-10 ns duration pulse from air shower generated by ultra-high energy (>10^{17} eV) cosmic rays and neutrinos
- BURSTT project in Taiwan
  - fast radio bursts with ~1 ms duration

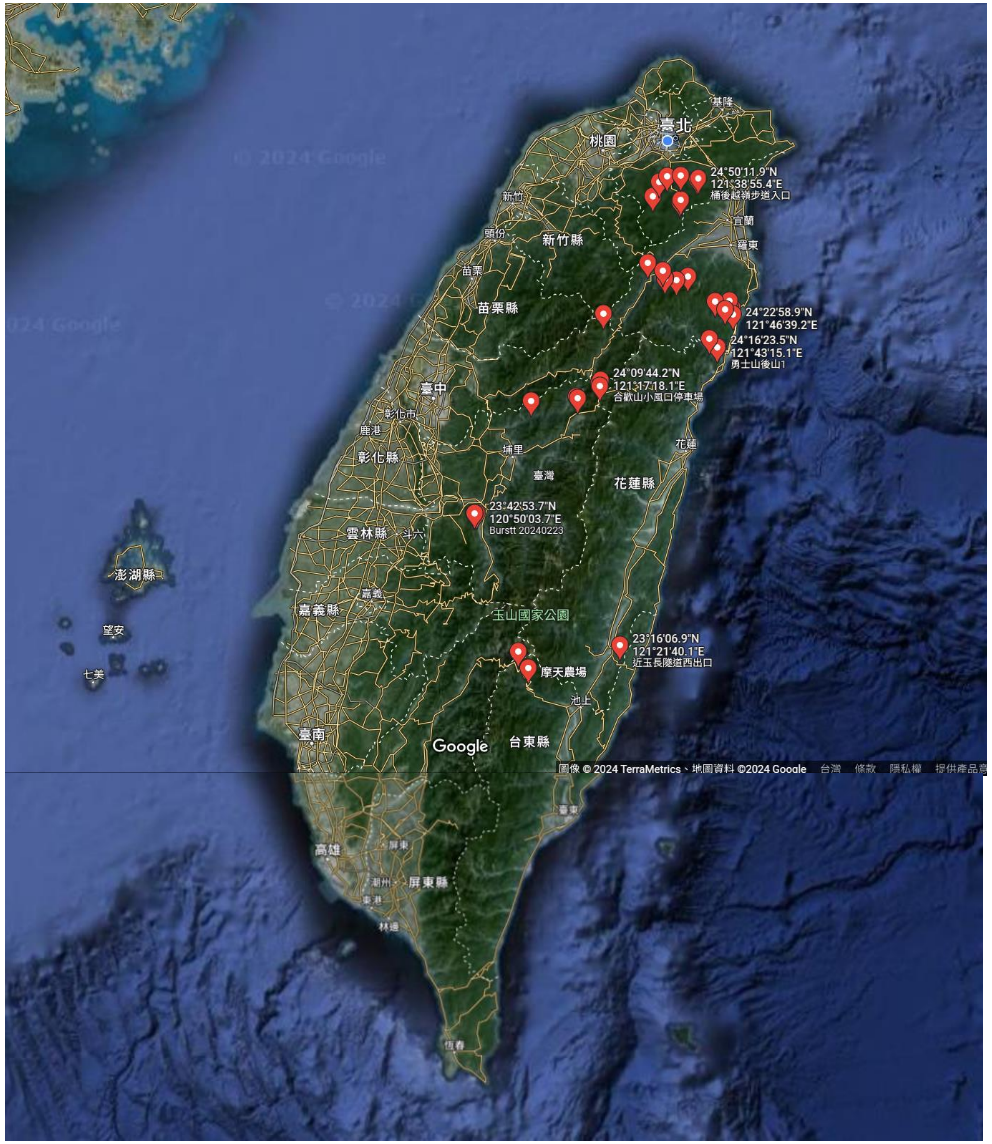
→ We need radio-quiet sites for detecting these pulses efficiently







Places we surveyed



Eastern & central Taiwan

Pamir Mountains, Xinjiang, China

Antarctica

Moore’s bay, Ross Ice Shelf

Jang Bogo station & Mt. Melbourne

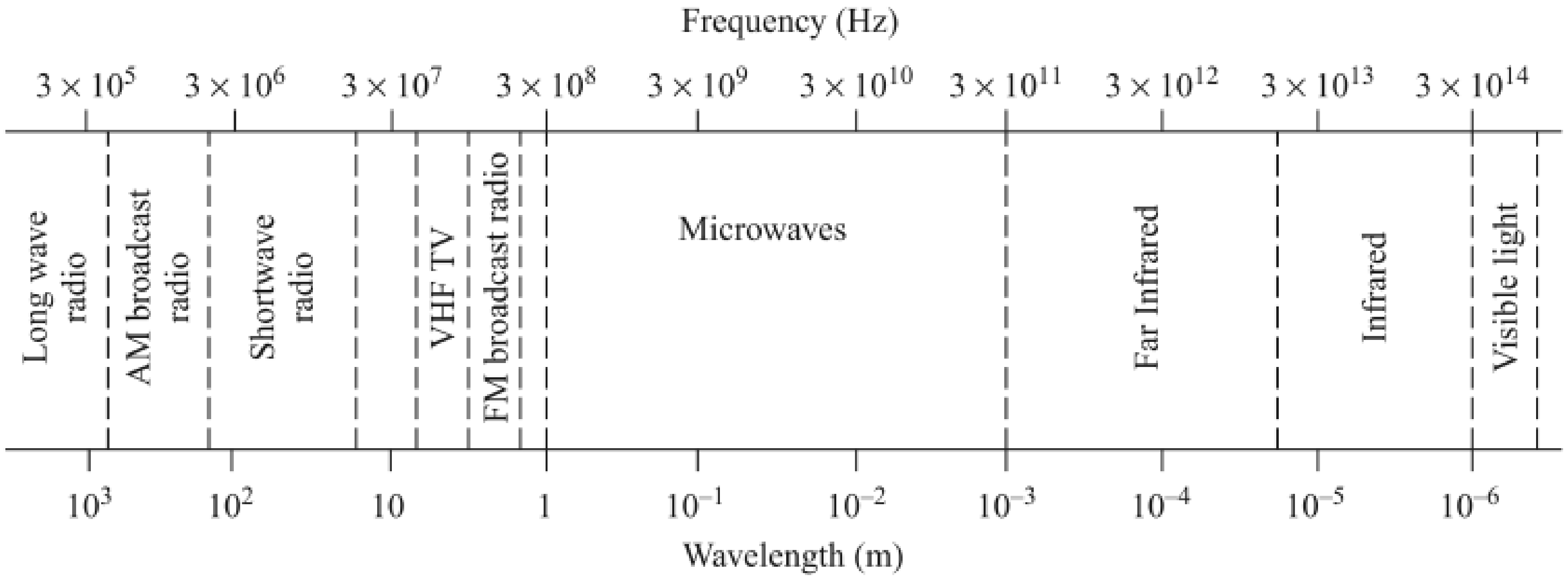
I’ll share the empirical survey method we developed

Site survey in Mongolia

Jul 2025

Q. Where to build UHF radio telescope?

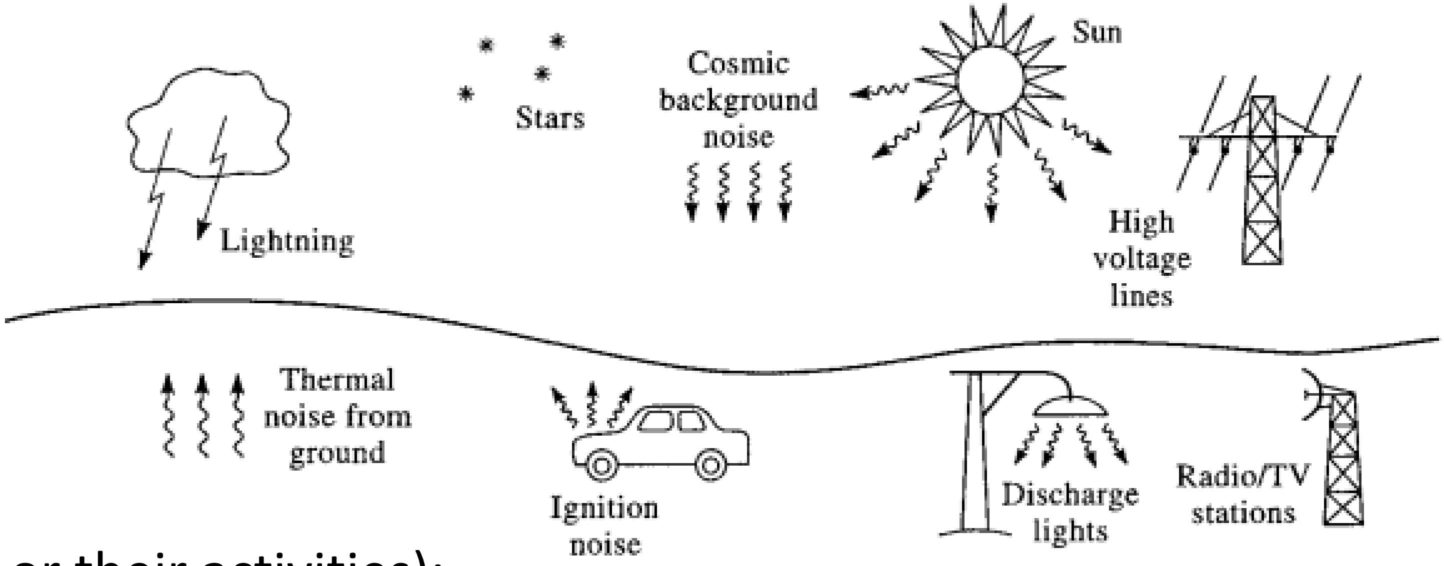
Ultra-high frequency (UHF)



- frequency: 300-3000 MHz   wavelength: 1-0.1 m
  - antenna size ~wavelength λ → easily handled
- signal easier to be processed
  - vs microwave
- mature technology for decades
- but also means Radio-Frequency Interference (RFI)

Radio-Frequency (RF) interference (RFI)

credit: D. Pozar, “Microwave Engineering”



- “Light pollution” in RF
- Noise sources
  - Natural:
    - Sun, Galactic, lightning, CMB
  - Anthropogenic (caused by humans or their activities):
    - intended: communication, navigation,
    - unintended: electric spark, switching
- Noise characteristics
  - narrow band (continuous wave, CW) / broadband (impulsive)
  - recurring / sporadic

usually intended, with high power → compromise the sensitivity

usually unintended → cause false trigger

- Goal: looking for a site with the lowest anthropogenic noise

  → need to understand which the major sources are

Site requirements

1) Radio quiet: Far from human activity, isolated area surrounded by mountains etc.

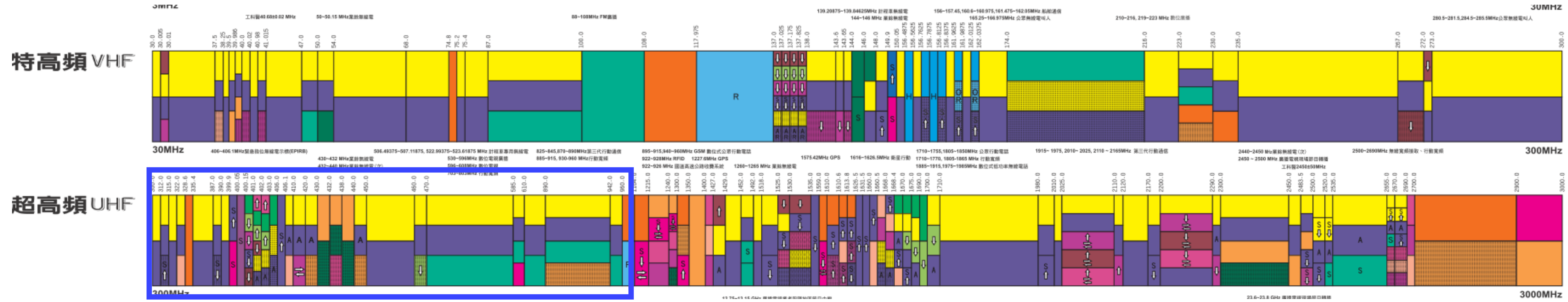
2) Accessibility: Road must be available to the site.
   - Paved road is preferred.

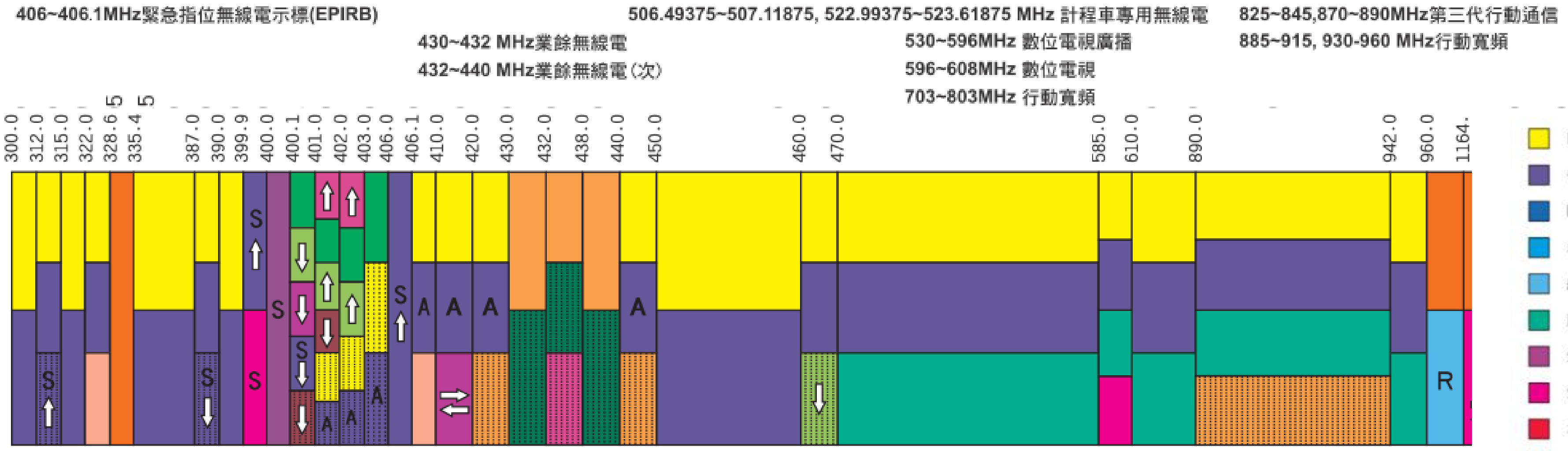
3) Area: Large enough area to build antenna array
   - SH: at least ~ 20 $\times$ 5 m for 64 antennas for BURSTT outrigger

4) Infrastructure: AC power, internet
   - operation room if possible

- requirement 1) is conflicted with others. It's almost impossible to find a place to fulfill all of these.
- Survey pre-selected sites first, then extend it if any interesting place is found during visit.

中華民國頻率分配圖 FREQUENCY ALLOCATIONS OF REPUBLIC OF CHINA





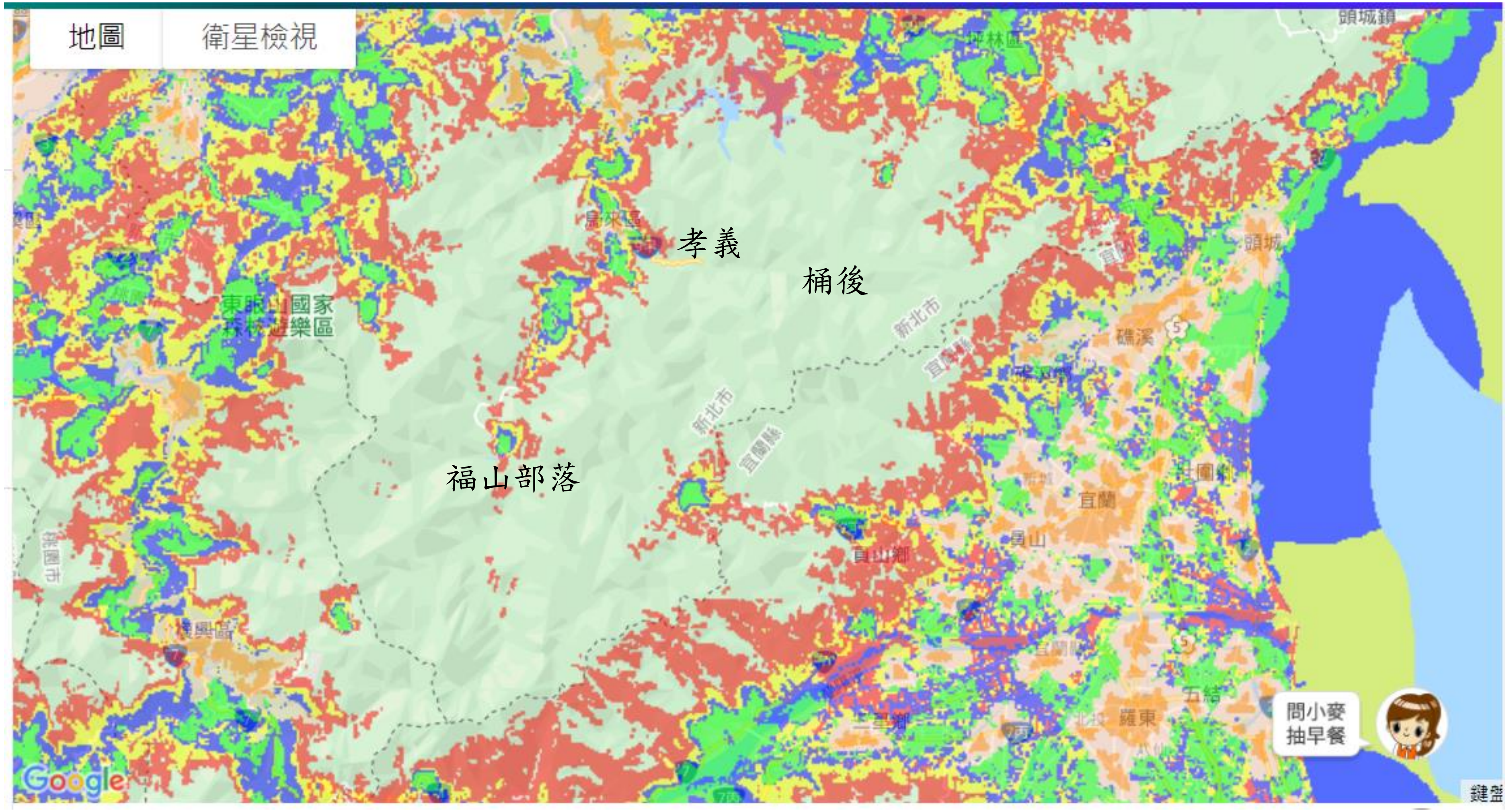
Ref: 2016/02 ver

→ Intended man-made RFI

國家通訊傳播委員會
NATIONAL COMMUNICATIONS COMMISSION
中華民國一〇五年 二 月
註：由於圖面有限，所繪製頻譜圖內各項業務分配空間，並未完全依據其在頻譜中之所佔實際比例.
詳細分配資料請參閱「中華民國頻率分配表」，或查詢國家通訊傳播委員會網址，http://www.ncc.gov.tw/

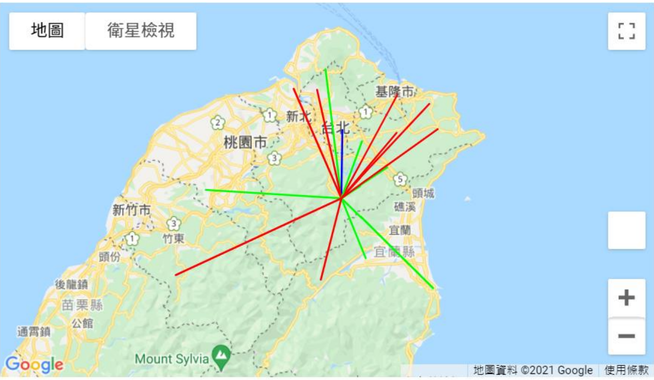
4G LTE coverage

- Taiwan Mobile (TWM)
  - source :[台灣大哥大 - 用戶服務：查詢行動上網網路涵蓋率 (taiwanmobile.com)]()



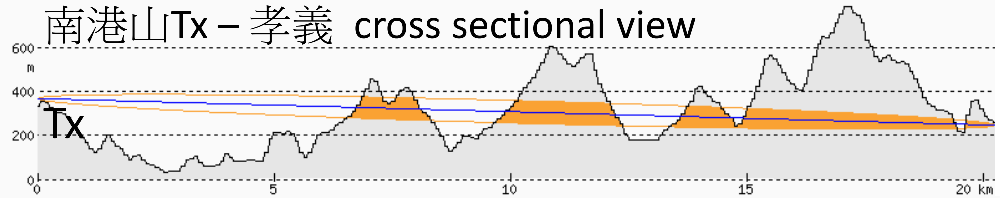
Digital TV

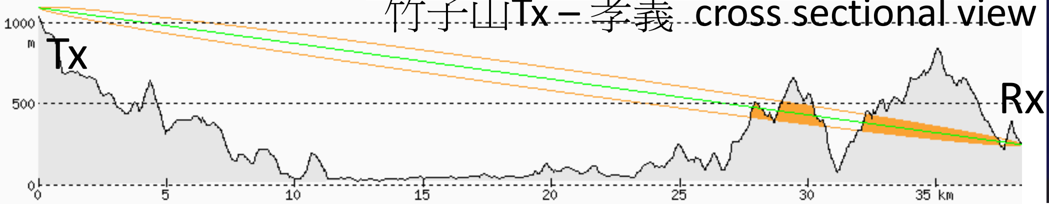
- channel interval ~12 MHz
  - 中視 533 MHz
  - 公視 545 MHz
  - 民視 557 MHz
  - 原客台 569 MHz
  - 台視 581 MHz
  - 華視 593 MHz
- still detectable even with no line of sight to transmitters
  - propagate by diffraction



本服務由 Kenny Kuo 自 2008/7/19 起熱情提供，資料歡迎引用但請註明出處。

線條顏色說明 : 藍色表示信號較強;綠色表示信號中等;紅色表示信號較弱 以上皆忽





dashed circle: estimated range of main station from this survey

Vietnam 4G & 5G mobile network

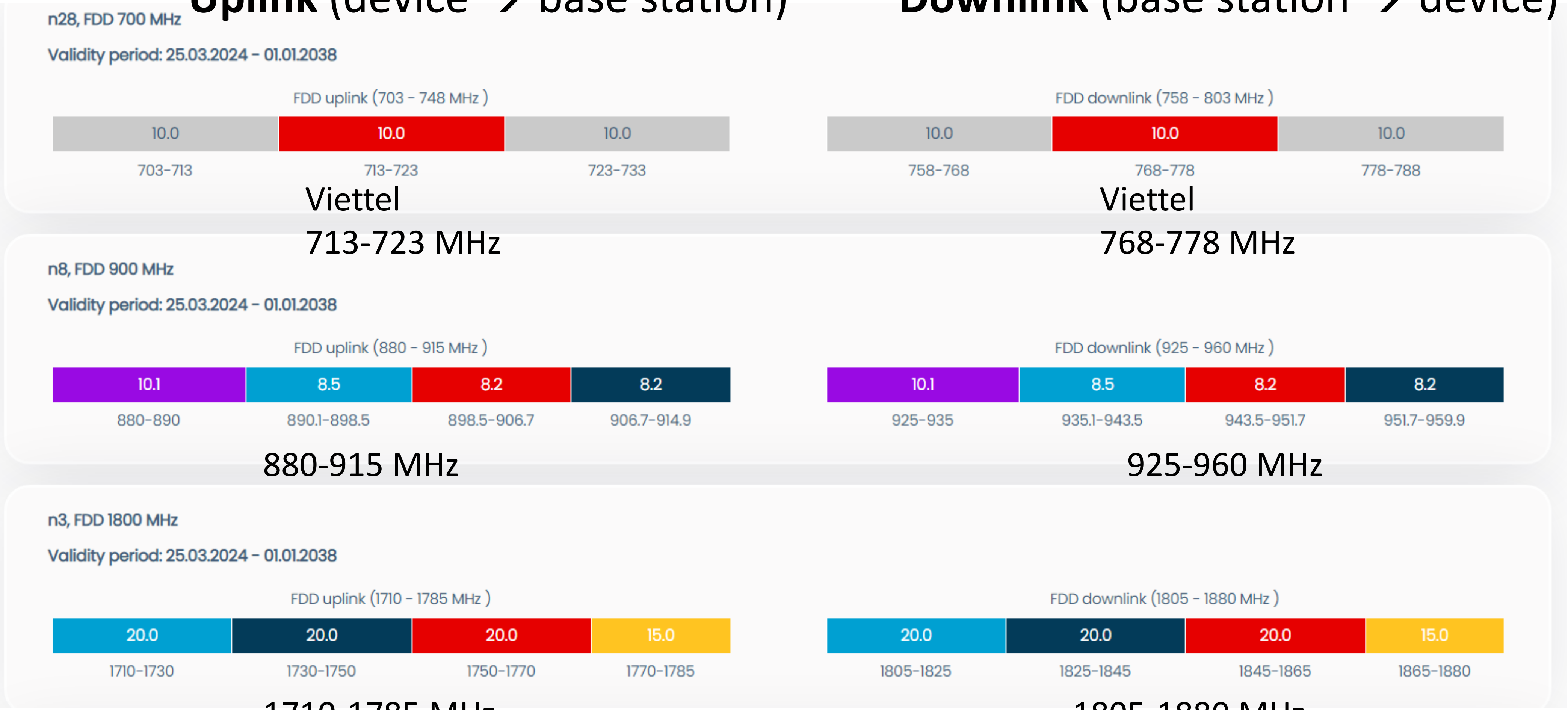
Vietnam

Ref: https://www.spectrum-tracker.com/Vietnam

G mobile | Mobifone | Vietnamobile | Viettel | Vinaphone | Not allocated

mobifone 30 viettel vinaphone

Uplink (device → base station) **Downlink** (base station → device)



Viettel 713-723 MHz

Viettel 768-778 MHz

880-915 MHz

925-960 MHz

1710-1785 MHz

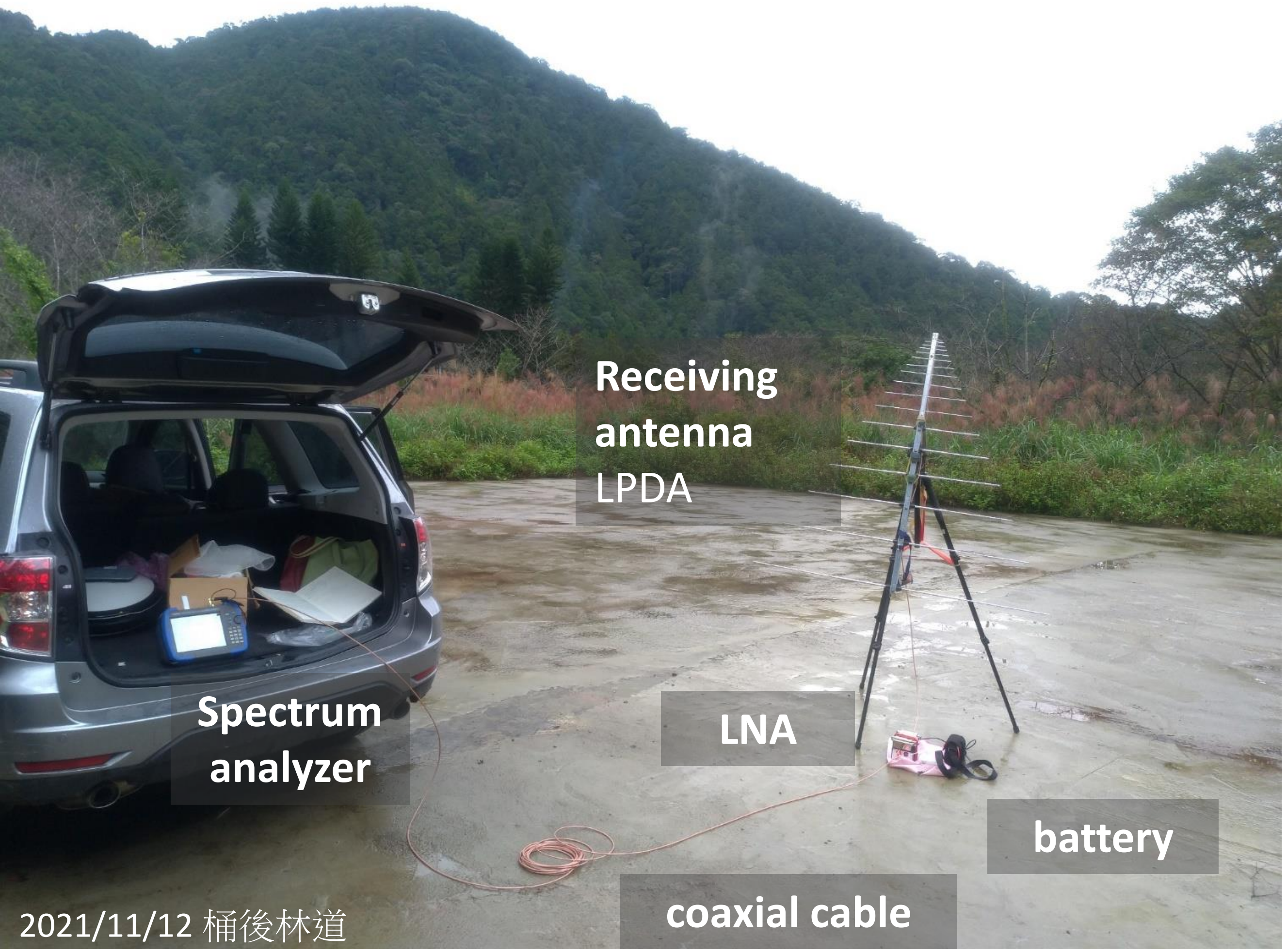
1805-1880 MHz

Let's check it out later!

and other higher frequency bands…

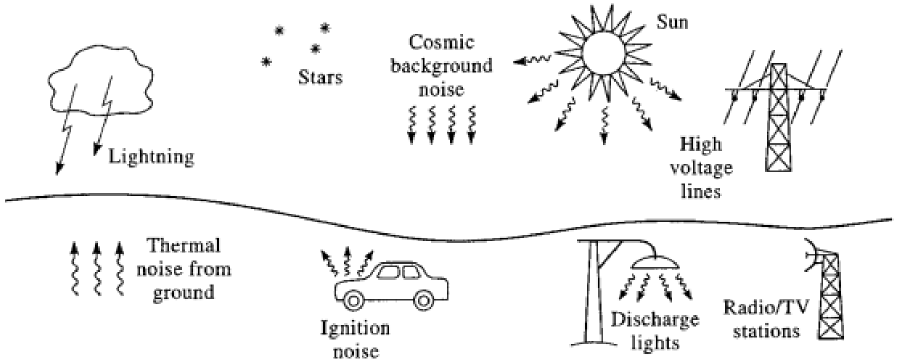
RF survey instruments

portable and with self-generated RFI minimized



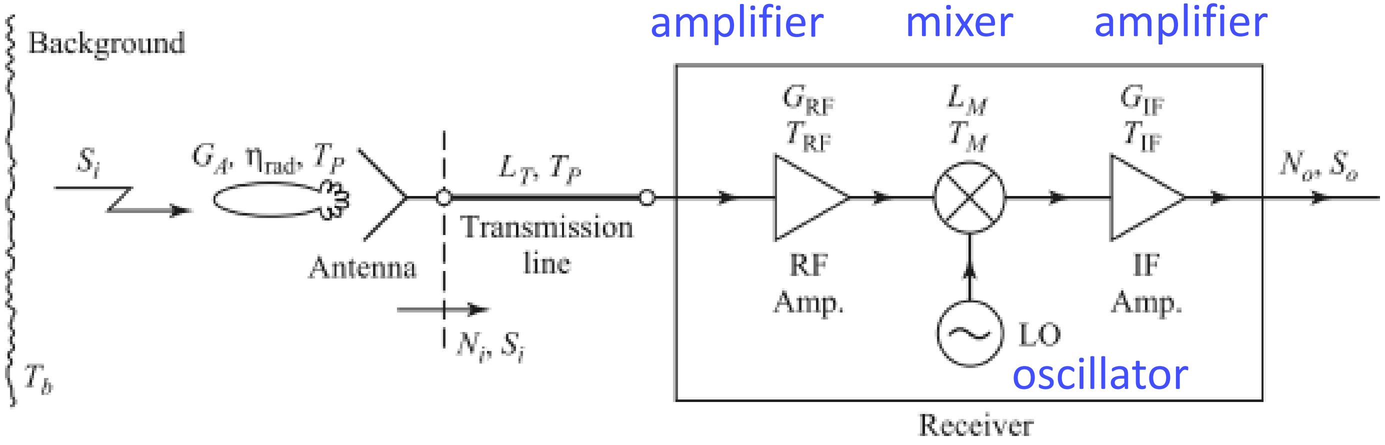
- **LPDA antenna**
  - wideband: 105-1300 MHz
  - directional: ~12 dBi gain; for identifying noise sources
- **Filters**
  - **prevent RF instruments from saturation**
  - high-pass / low-pass / notch
  - FM radio (80-120 MHz), walkie-talkie (~140 MHz), 4G-LTE mobile (>700 MHz)
- **Low noise amplifier (LNA)**
  - **boosts received signal power from antenna >> instrumental noise**
  - 50-1000+ MHz, ~64 dB gain, T_{Rx}~100K
- **Coaxial cable and adapter**
- **Lead-acid battery & switch box**
  - no RFI
- **Spectrum analyzer (SA)**
  - measure power spectrum

System noise temperature T_{sys}



frequency down-conversion

low-noise amplifier   mixer   amplifier



oscillator

- thermal noise: all objects with T > 0 K generate noise
  - $k_B = 1.380649 \times 10^{-23}$ m^2 kg s^{-2} K^{-1}
  - B: bandwidth
  - $T = 300$ K, $B = 1$ MHz $\leftrightarrow$ $\boldsymbol{P_n}$**= -114 dBm / MHz**

$$\boxed{\text{noise power } P_n = k_B T B}$$

for radio

- noise power $\leftrightarrow$ equivalent system noise temperature
  - for characterizing noise (whether thermal or not)
  - RF instrument has its own noise

similar to brightness temperature

$$\boxed{P_n = k_B T_{sys} B}$$

$$T_{sys} \equiv T_A + T_{Rx}$$

noise received by antenna

intrinsic noise of receiver (Rx)

Ref: D. Pozar, “Microwave Engineering”

RF Front-end module
(BURSTT-64 Nantou station)

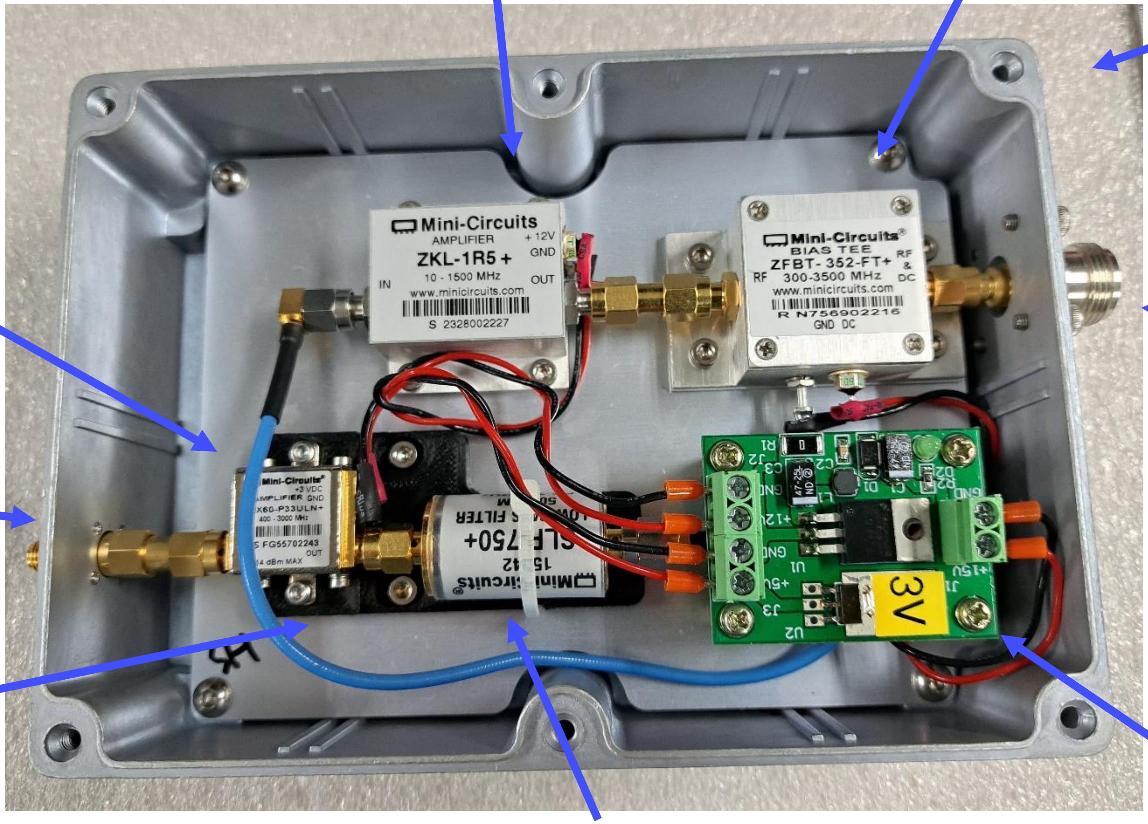
2nd-stage amplifier
- ~40 dB gain

Bias-T
- combine / decouple RF signal and DC power

Low noise amplifier (LNA)
- 1st-stage amplifier
- ~20 dB gain

Input from antenna
- SMA F-F adapter

coaxial cable assembly
- 0.085” cable



Chromium conversion coating
- keep aluminum surfaces conductive
- corrosion resistant

Output to backend
- N-M to SMA-F adapter

EMI-shielding form-in-place gasket (box cover)
- seal the gap between box and cover
- prevent RFI leakage

750 MHz Low-pass filter
- suppress 4G-LTE signal
- Mini-Circuits SLP-750+

Power distribution board
- voltage regulators convert to different DC outputss

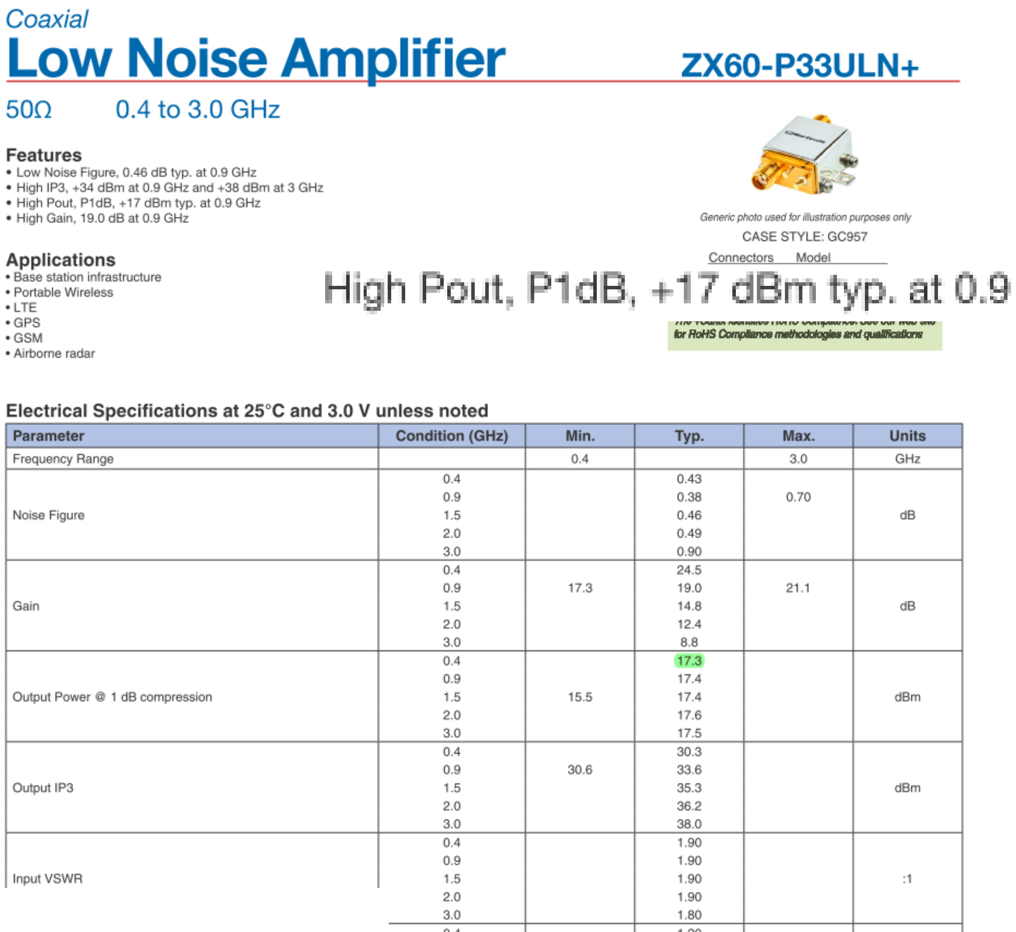
RF Amplifier

- Gain: how much the signal power is amplified (in dB)

$$10\log_{10}\left(\frac{P}{P_0}\right)\ \mathrm{dB}$$

- Caution: check out max input and output power before use!
  - amplifier can get fried

- special type: low-noise amplifier (LNA)



Coaxial

Low Noise Amplifier ZX60-P33ULN+

50Ω 0.4 to 3.0 GHz

Features
- Low Noise Figure, 0.46 dB typ. at 0.9 GHz
- High IP3, +34 dBm at 0.9 GHz and +38 dBm at 3 GHz
- High Pout, P1dB, +17 dBm typ. at 0.9 GHz
- High Gain, 19.0 dB at 0.9 GHz

Generic photo used for illustration purposes only

CASE STYLE: GC957

Connectors Model

Applications
- Base station infrastructure
- Portable Wireless
- LTE
- GPS
- GSM
- Airborne radar

High Pout, P1dB, +17 dBm typ. at 0.9 GHz

for RoHS Compliance methodologies and qualifications

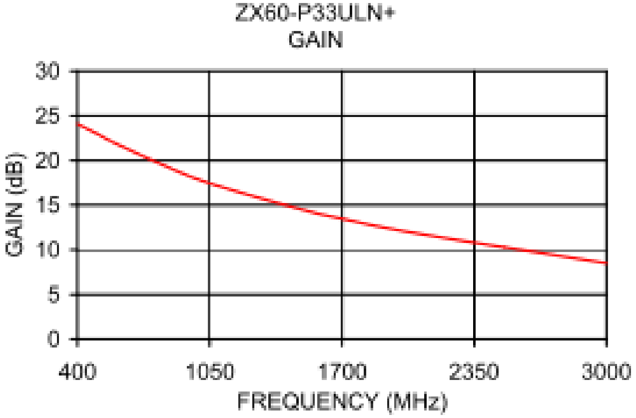
Electrical Specifications at 25°C and 3.0 V unless noted

Parameter	Condition (GHz)	Min.	Typ.	Max.	Units
Frequency Range		0.4		3.0	GHz
Noise Figure	0.4		0.43		dB
	0.9		0.38	0.70	
	1.5		0.46		
	2.0		0.49		
	3.0		0.90		
Gain	0.4		24.5		dB
	0.9	17.3	19.0	21.1	
	1.5		14.8		
	2.0		12.4		
	3.0		8.8		
Output Power @ 1 dB compression	0.4		17.3		dBm
	0.9		17.4		
	1.5	15.5	17.4		
	2.0		17.6		
	3.0		17.5		
Output IP3	0.4		30.3		dBm
	0.9	30.6	33.6		
	1.5		35.3		
	2.0		36.2		
	3.0		38.0		
Input VSWR	0.4		1.90		:1
	0.9		1.90		
	1.5		1.90		
	2.0		1.90		
	3.0		1.80		
	0.4		1.20		:1
	0.9		1.20		
	1.5		1.30		
	2.0		1.30		
	3.0		1.30		
	0.4-3.0		4		dB
		—	3.0	—	V
		—	56	67	mA

Mini-Circuits®

0166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

REV. B
ECO-000670
ZX60-P33ULN+
ED-16209
SK/RS/CP
191212
Page 2 of 4



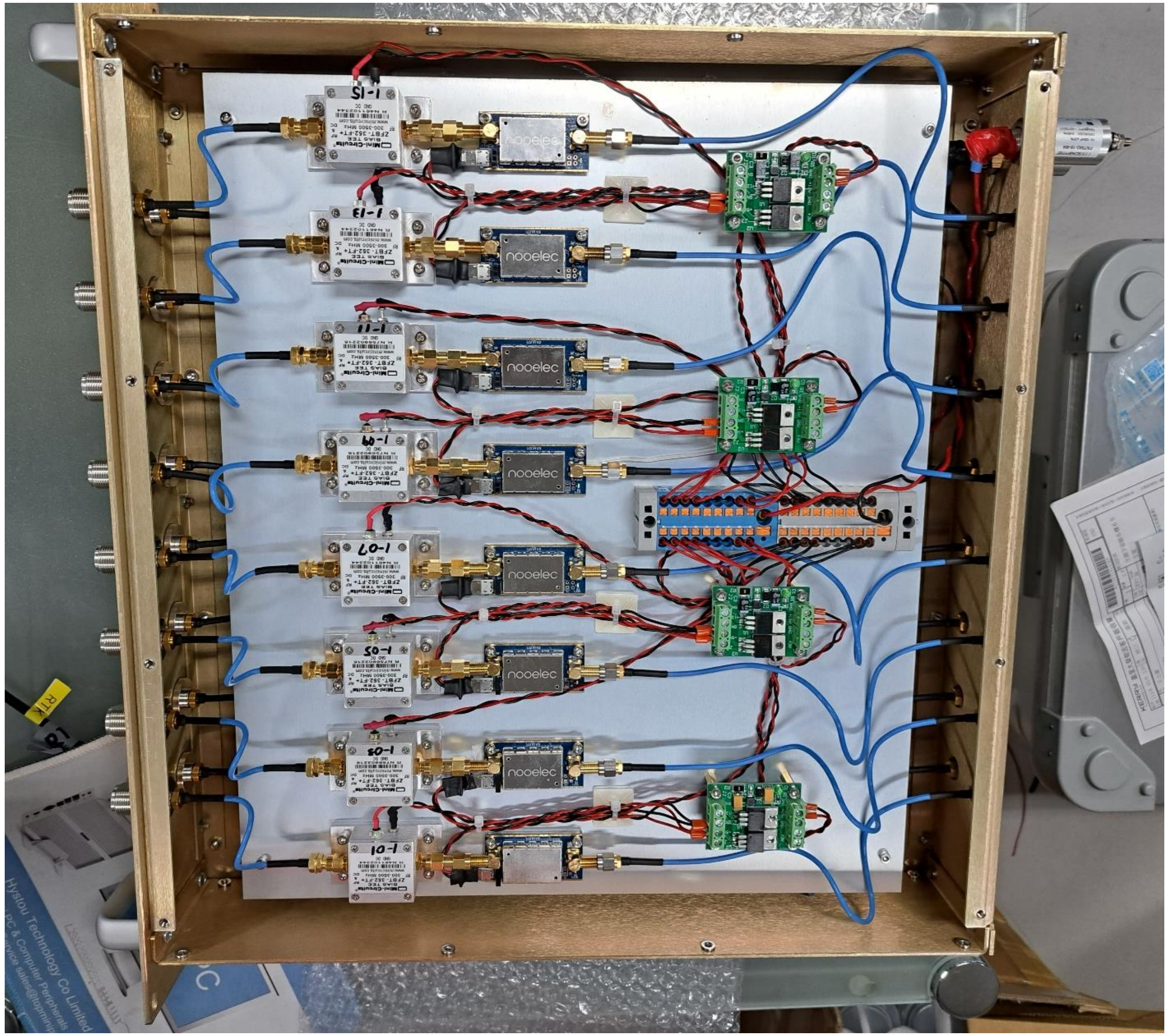
Bias-T module
(BURSTT-64 Nantou station)

3rd-stage amplifier
- ~24 dB gain

Power distribution board
- voltage regulators convert to different DC outputss

Input from RF front-end
- N-M to SMA-F adapter

Bias-T
- combine / decouple RF signal and DC power



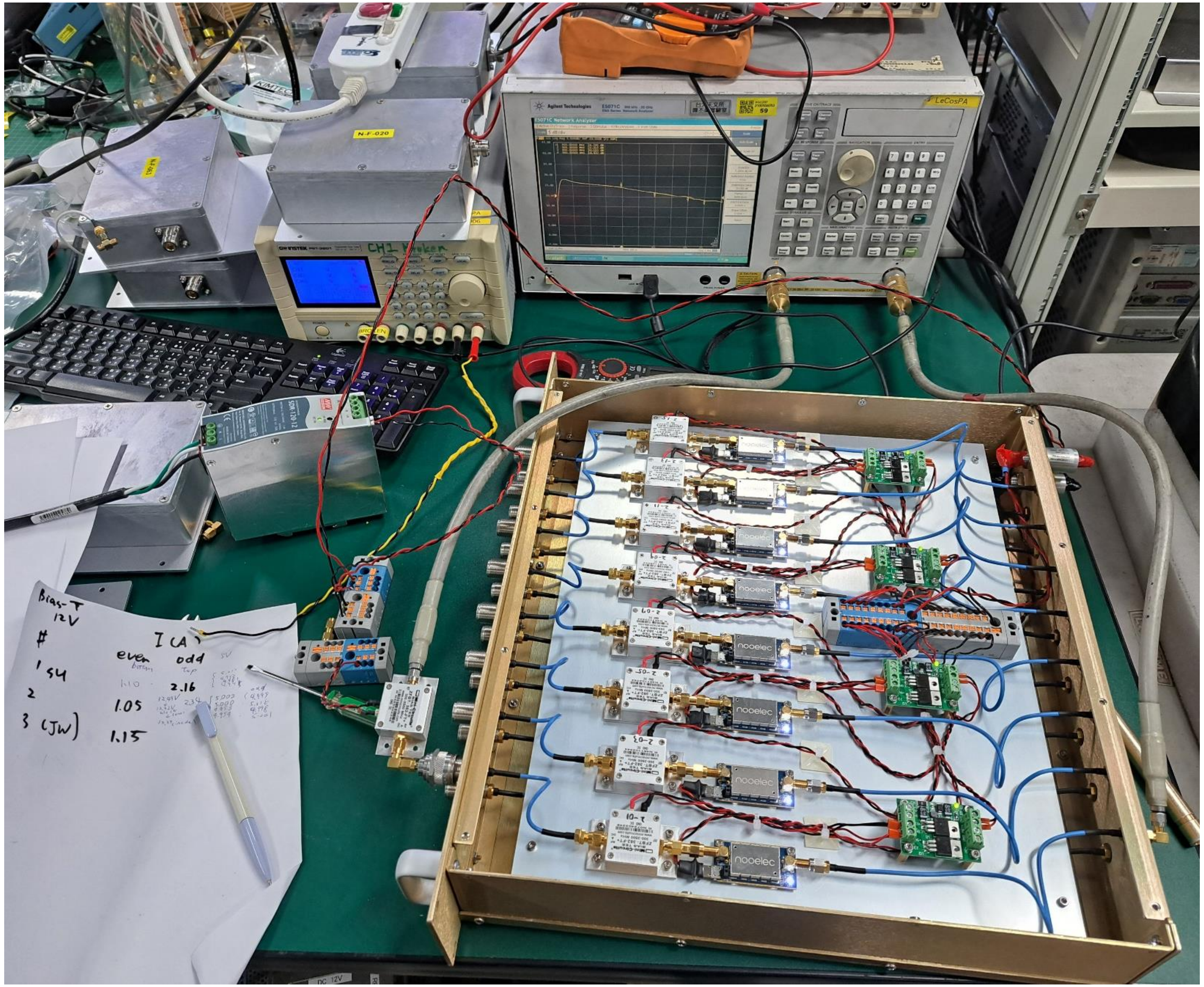
DC feedthrough filter
- suppress RFI through power line

Output to FPGA
- SMA F-F adapter

Calibration

- vector network analyzer
  - transmit and receive
  - measure transmission and reflection coefficients (S parameters) of device under test

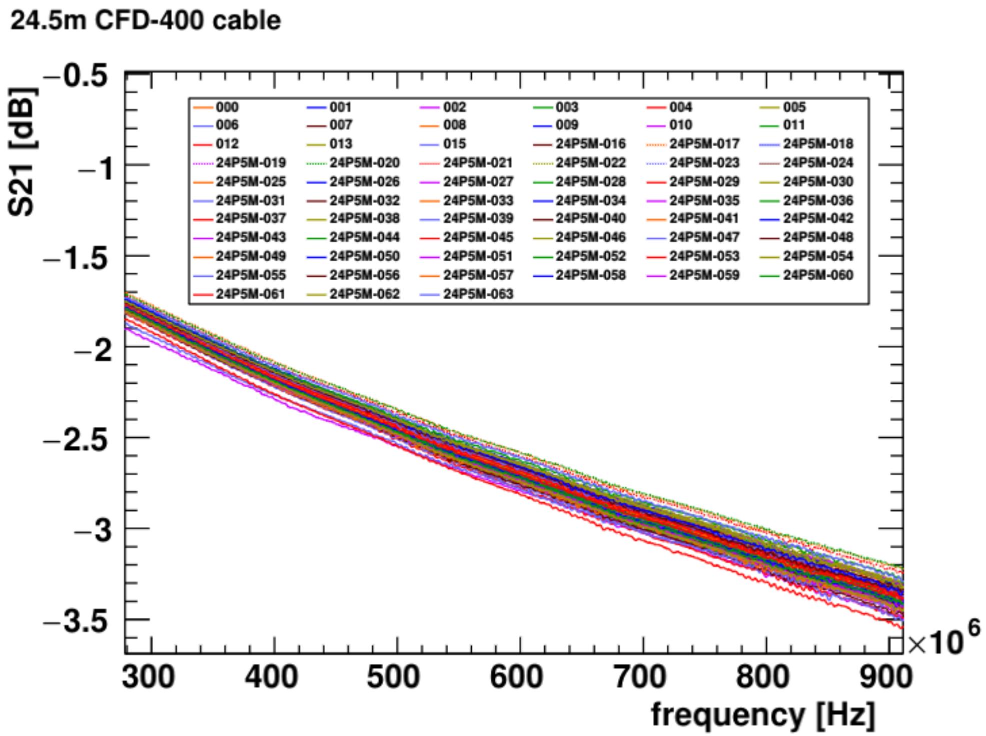
Network analyzer



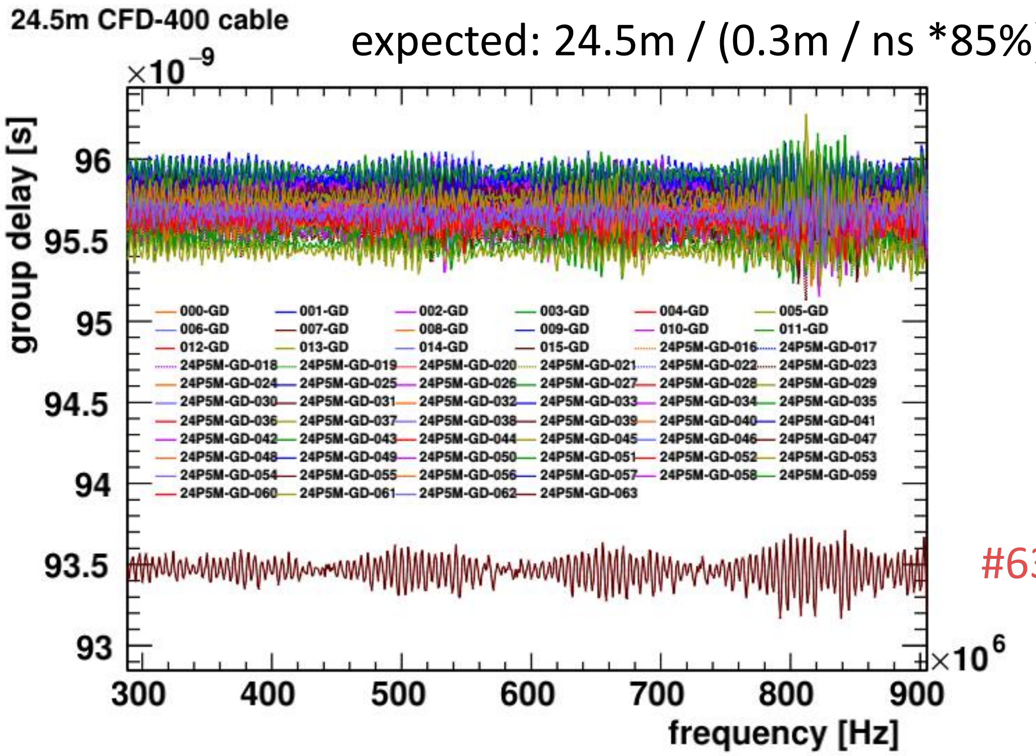
bias-T module under test

24.5m CFD-400 cable calibration

- for connecting front end to surge protector
- insertion loss: 2-3 dB at 400-800 MHz
  - ~0.3 dB variation between channels
- group delay: ~0.5 ns (~12 cm) variation between channels
  - consistent with specs ~96 ns
  - except #63: 93.5 ns → ~64 cm shorter than others → to be replaced



expected: 24.5m / (0.3m / ns *85%) = 96 ns

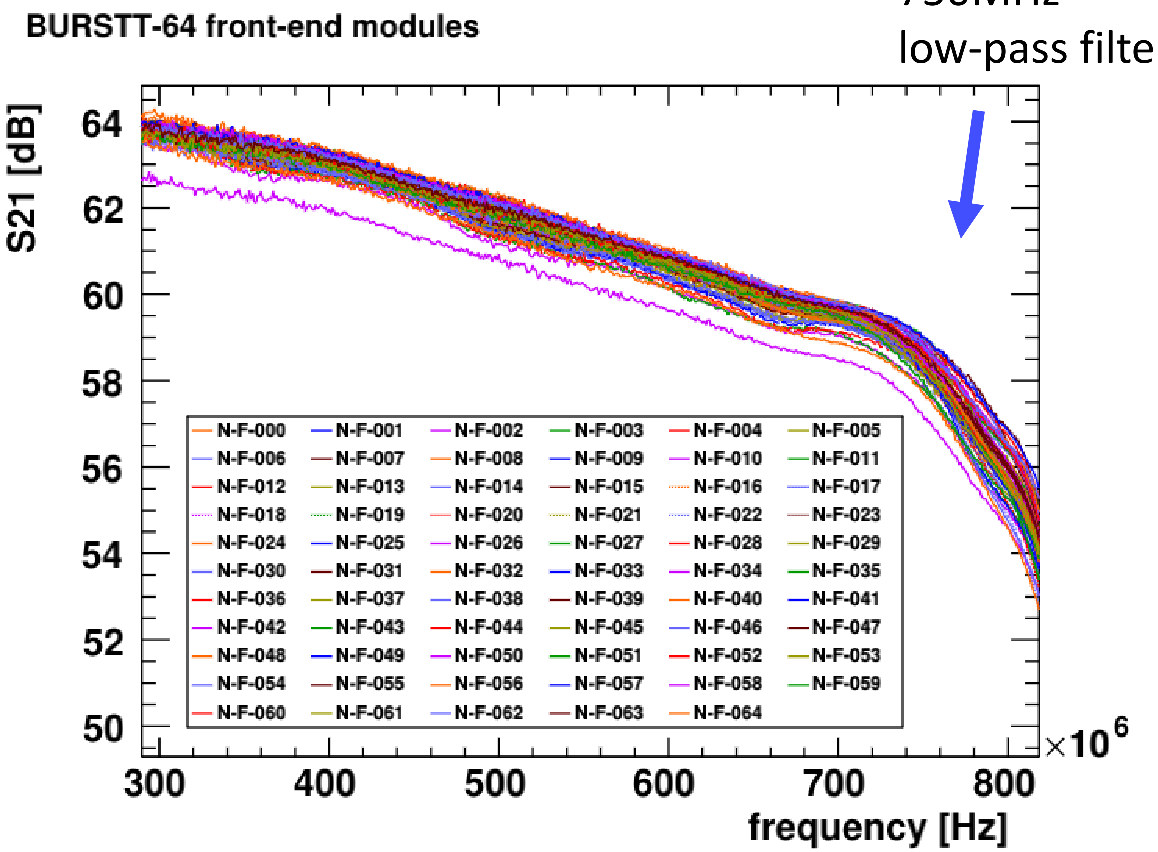


#63

Front-end modules

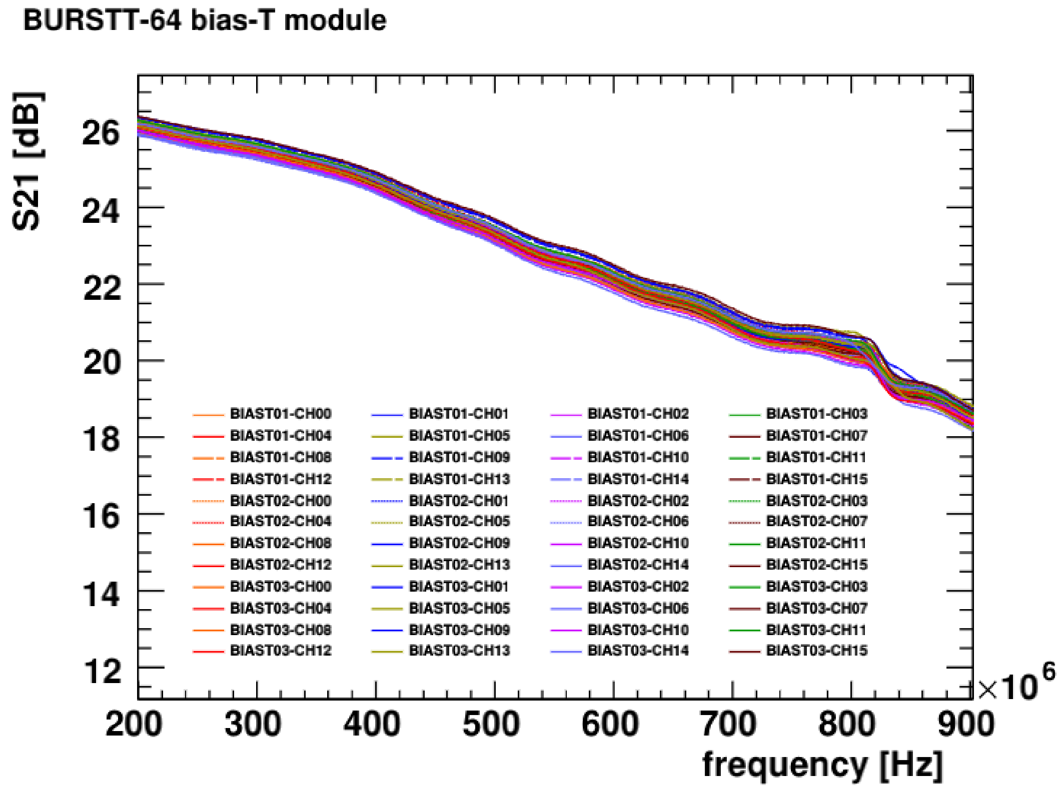
- 64-54 dB gain at 400-800 MHz
  - ~1 dB variation between channels

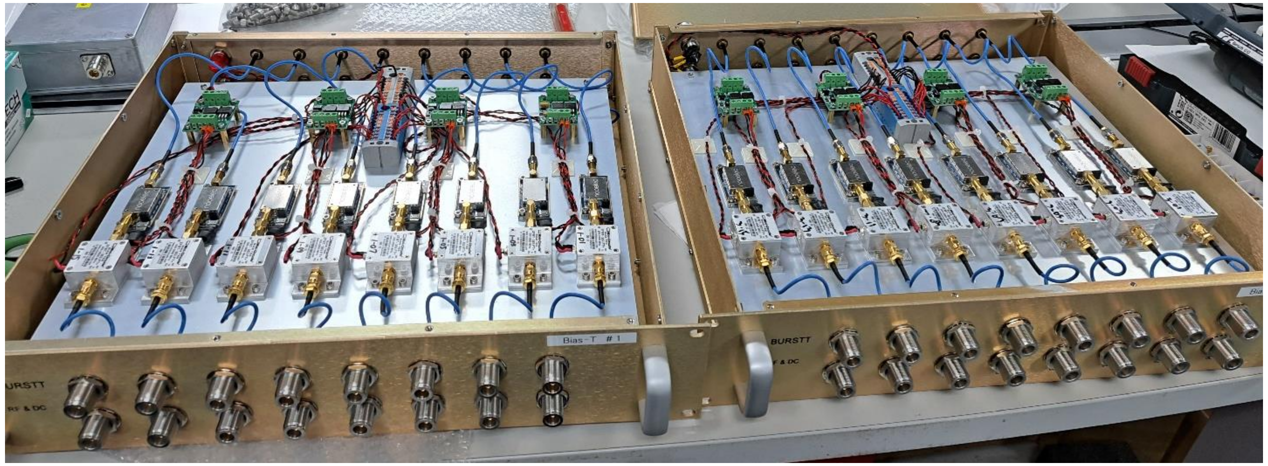
750MHz
low-pass filter

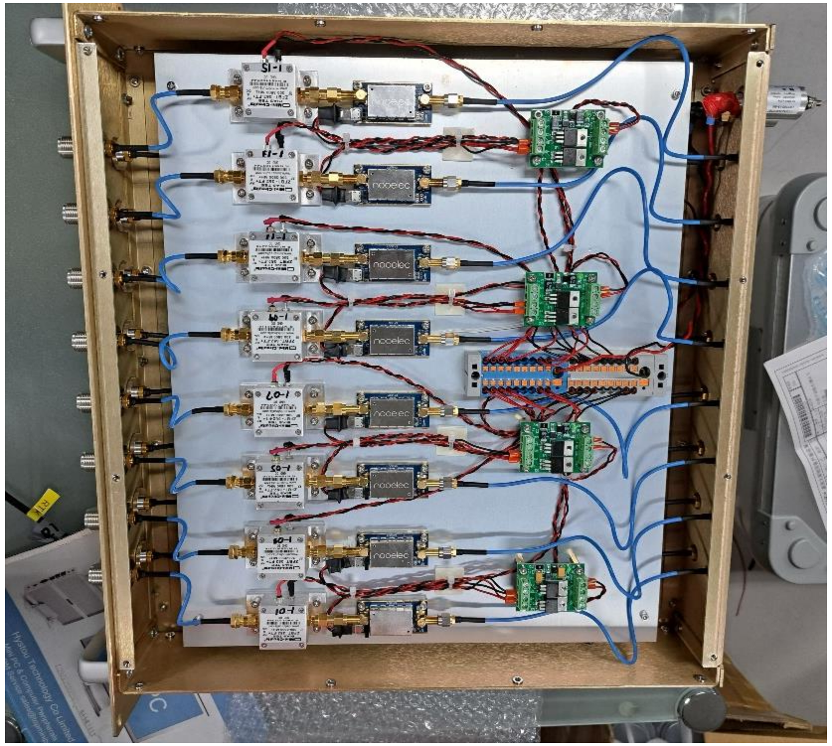


Bias-T module

- 24-20 dB gain at 400-800 MHz
  - ~0.5dB gain variation between channels

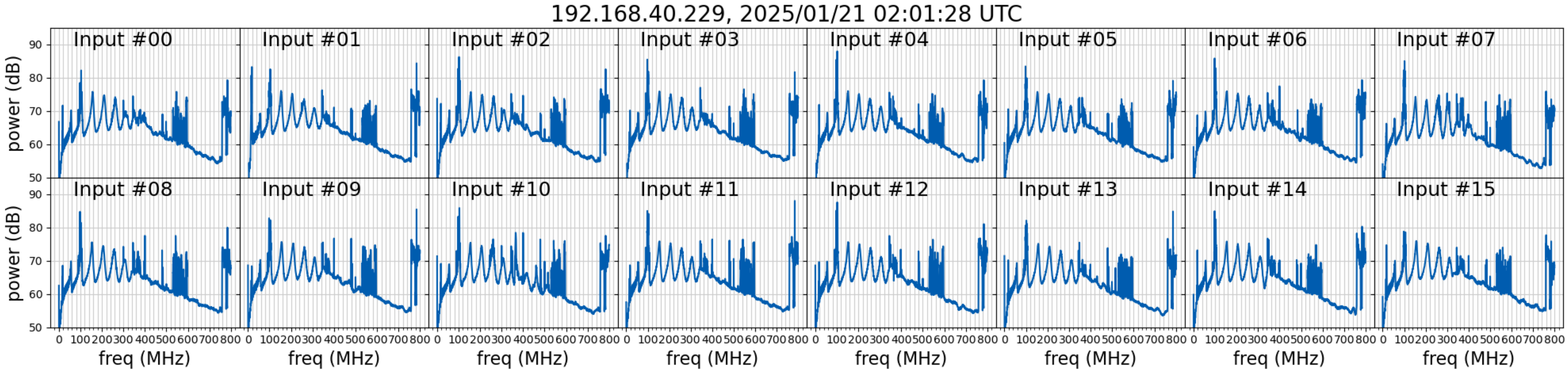




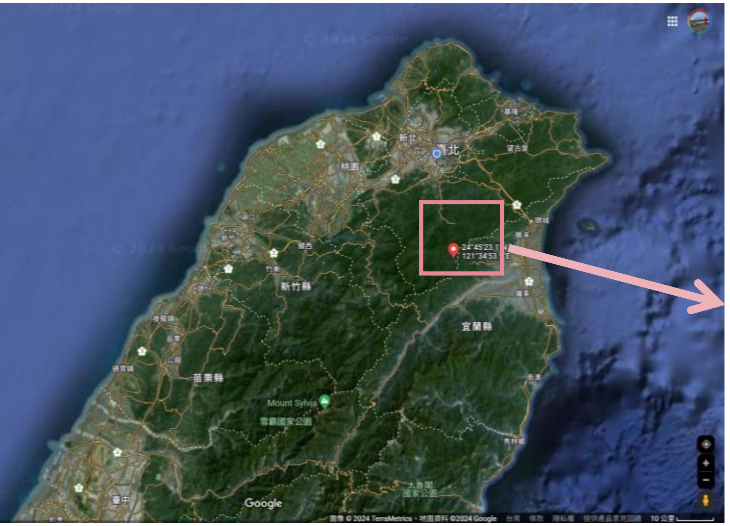


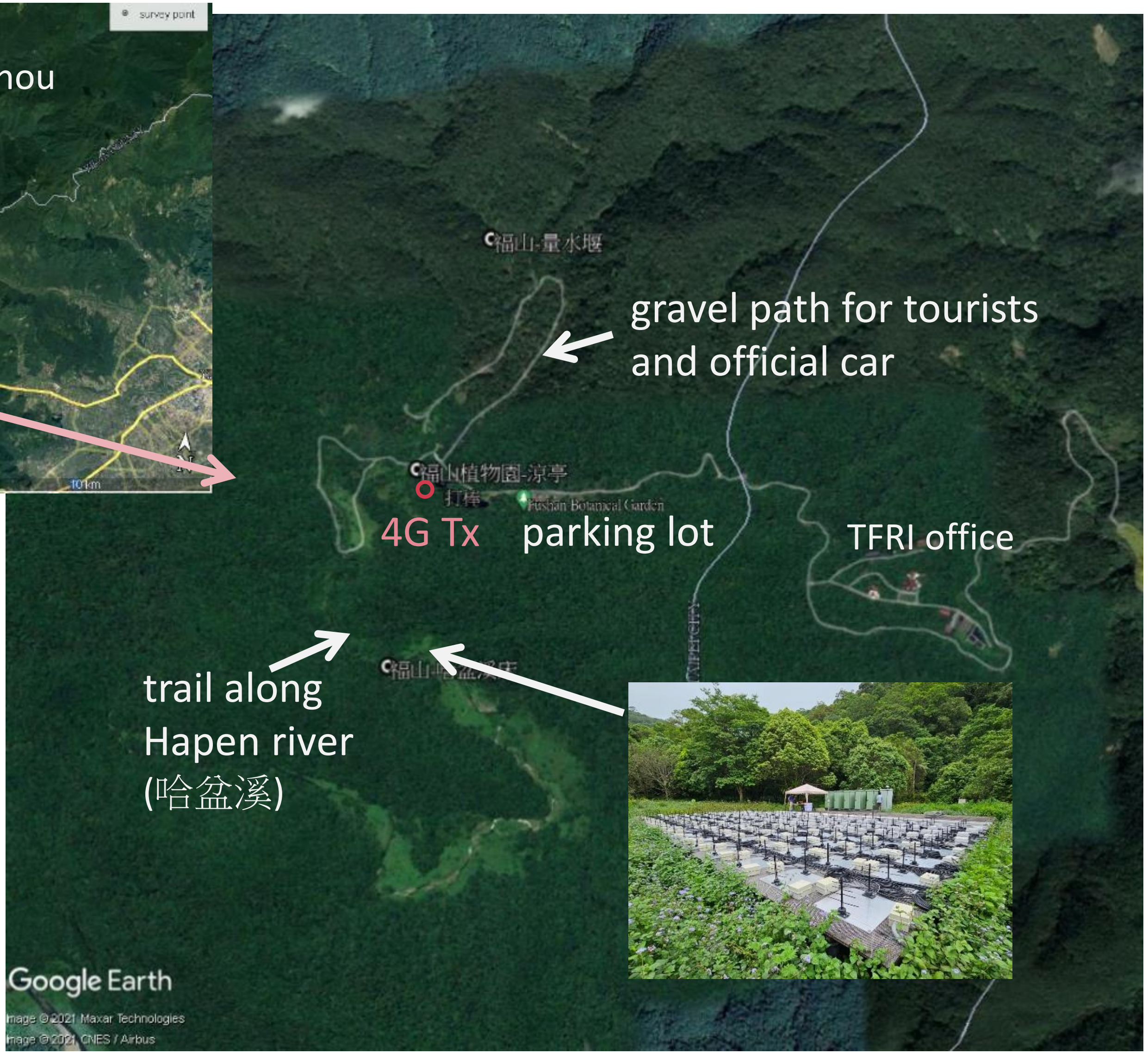
assembled and calibrated by JW, Hiroto, SH, Sujin

BURSTT Fushan



Case: Fushan botanic garden 福山植物園





- RF Survey in 2021/11-12
- primitive forest with low population
  - ~10 staff, and < 500 visitor/day
- infrastructure available
  - managed by Taiwan Forestry Research Institute (TFRI, 林試所)
- selected as BURSTT main station
  - 2022/10 – 2024/06: 256 antennas deployed

official site [林業試驗所 福山研究中心 - 研究中心 - 行政院農業委員會林業試驗所 (tfri.gov.tw)]

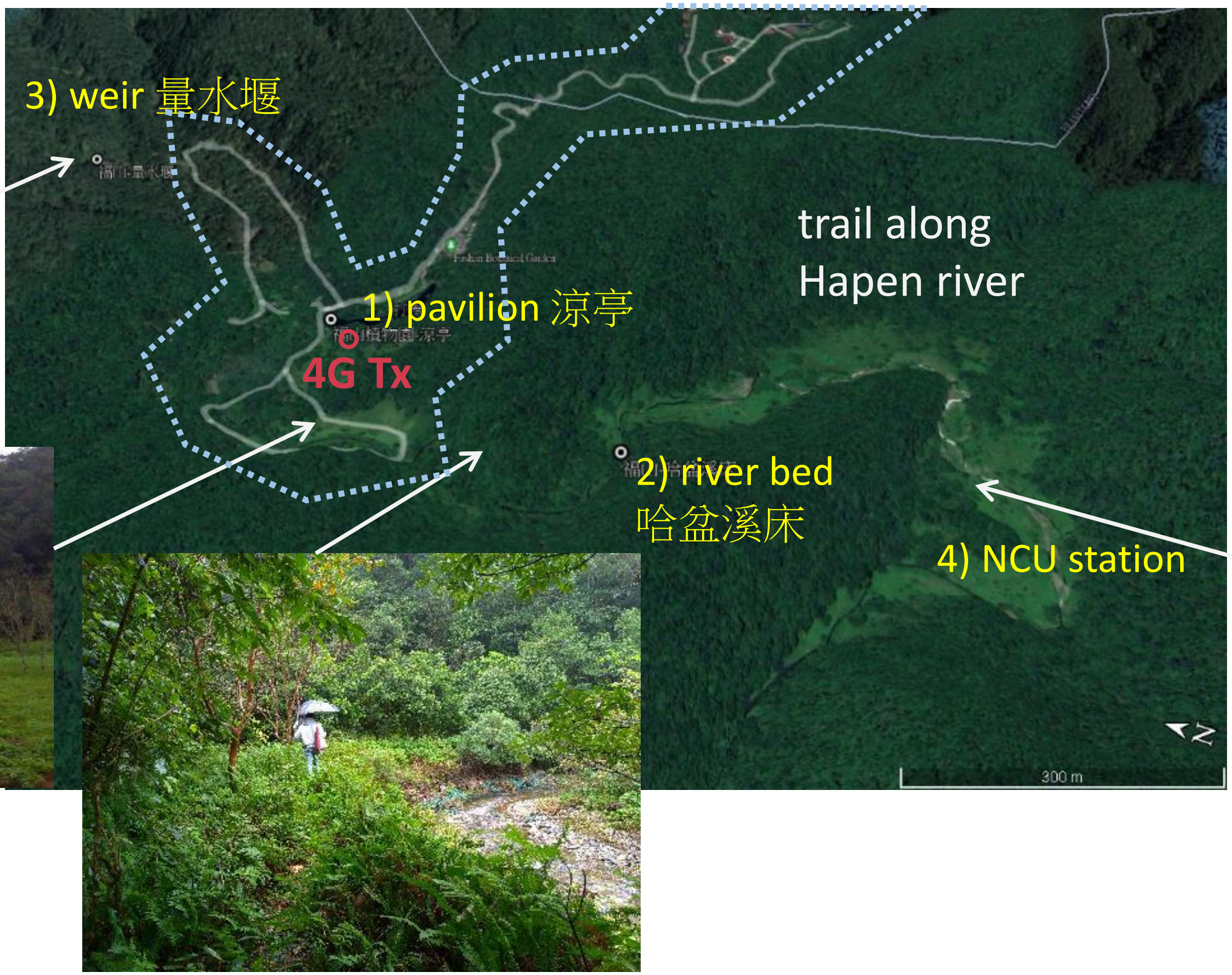
4 survey points

- avoid 4G transmitter and tourist area

- auto geoscience station of NCU around riverbed
  - electricity available

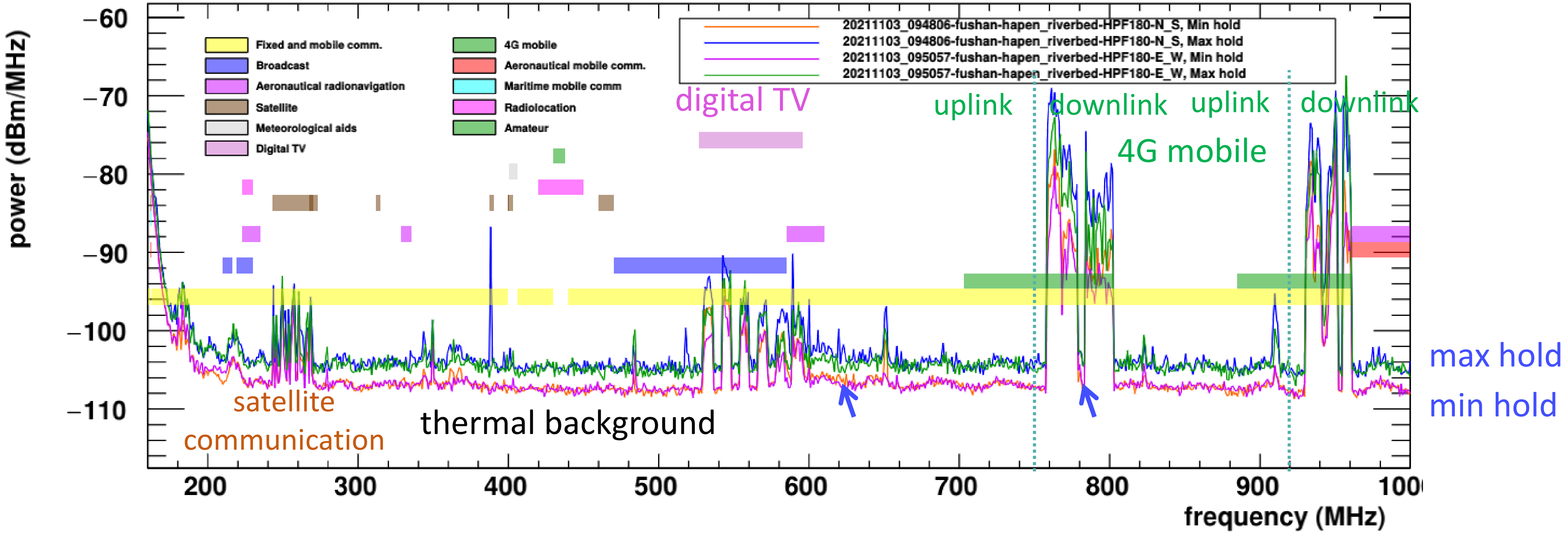







Hapen riverbed (哈盆溪床)

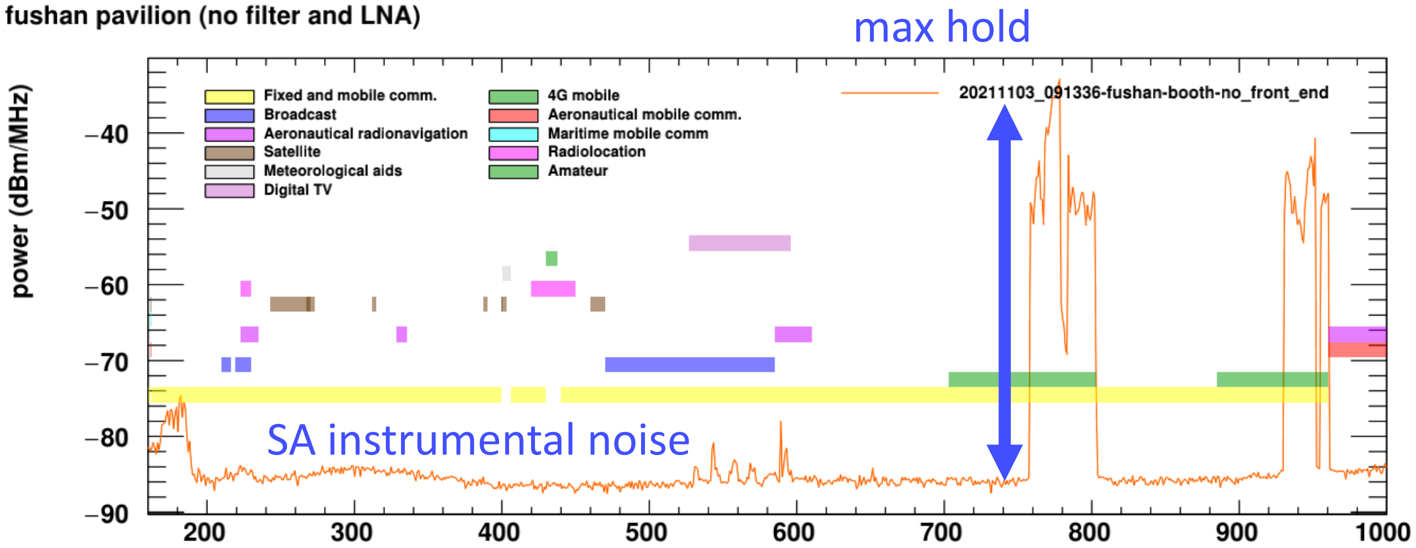
- on the way to NCU auto geoscience station
- Digital TV signal detectable
  - no line of sight to TV transmitters → propagate via diffraction
- 4G signal from transmitter in the garden



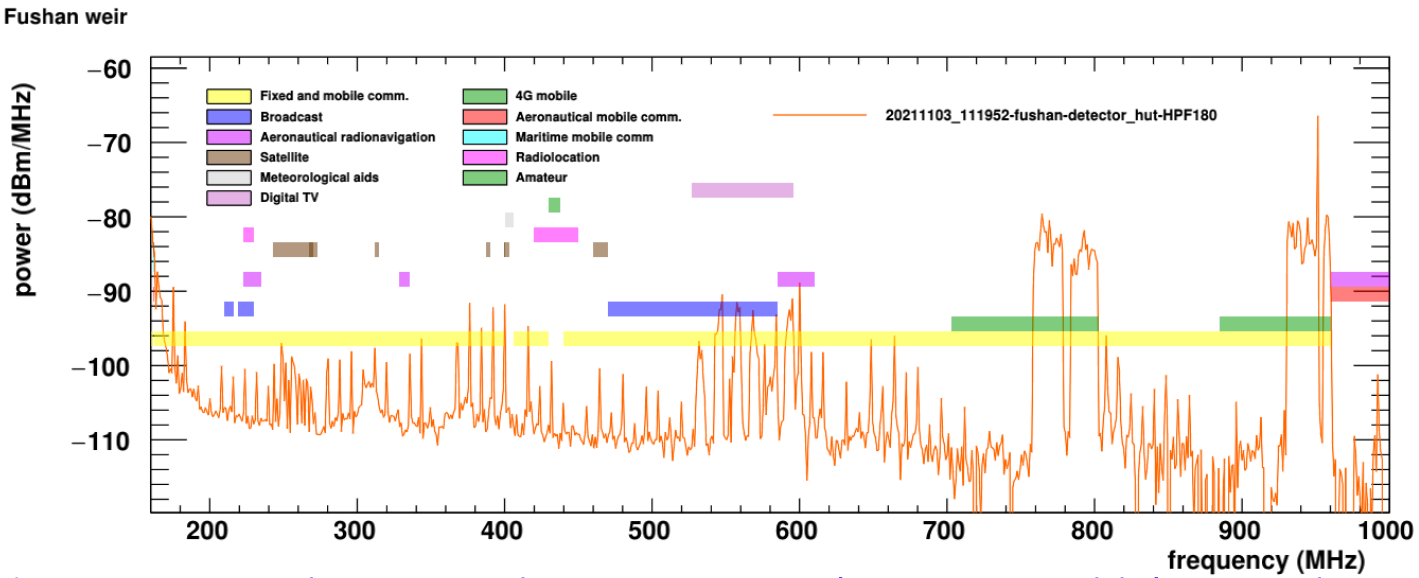
mode: positive peak , RBW:50kHz, SA noise & (HPF+LNA+cable) gain subtracted

2 of them are noisy

- at pavilion
  - without filter & LNA (saturated)
  - strong 4G, ~70 dB above thermal
  - → avoid nearby area
- at weir
  - various detectors around the hut
  - periodic peaks in spectrum implies periodic pulses
    - switching noise



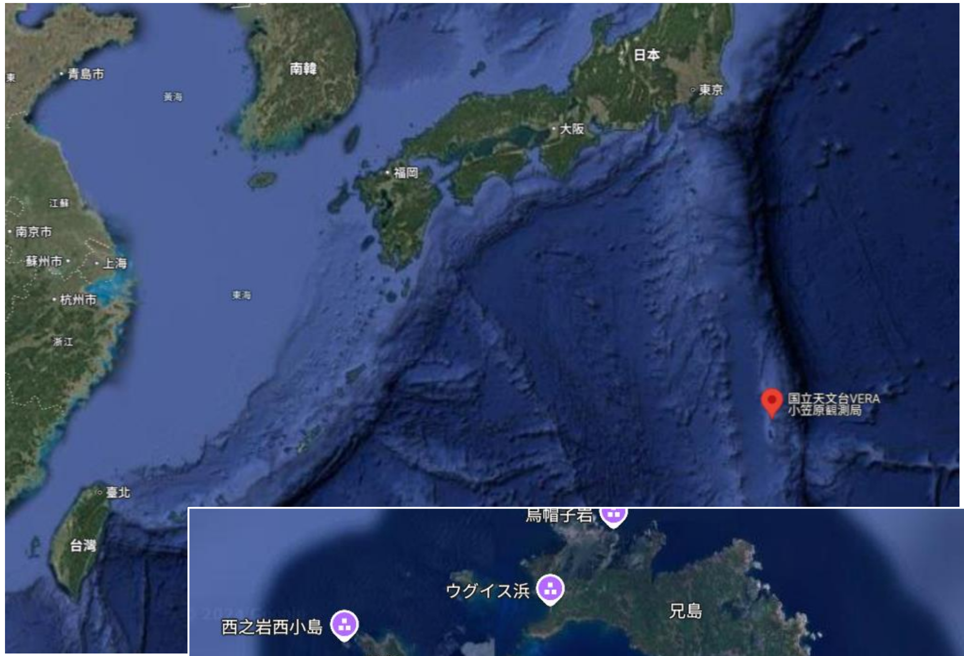
SA noise ~86 dBm/MHz > Rx noise floor: -114 dBm/MHz

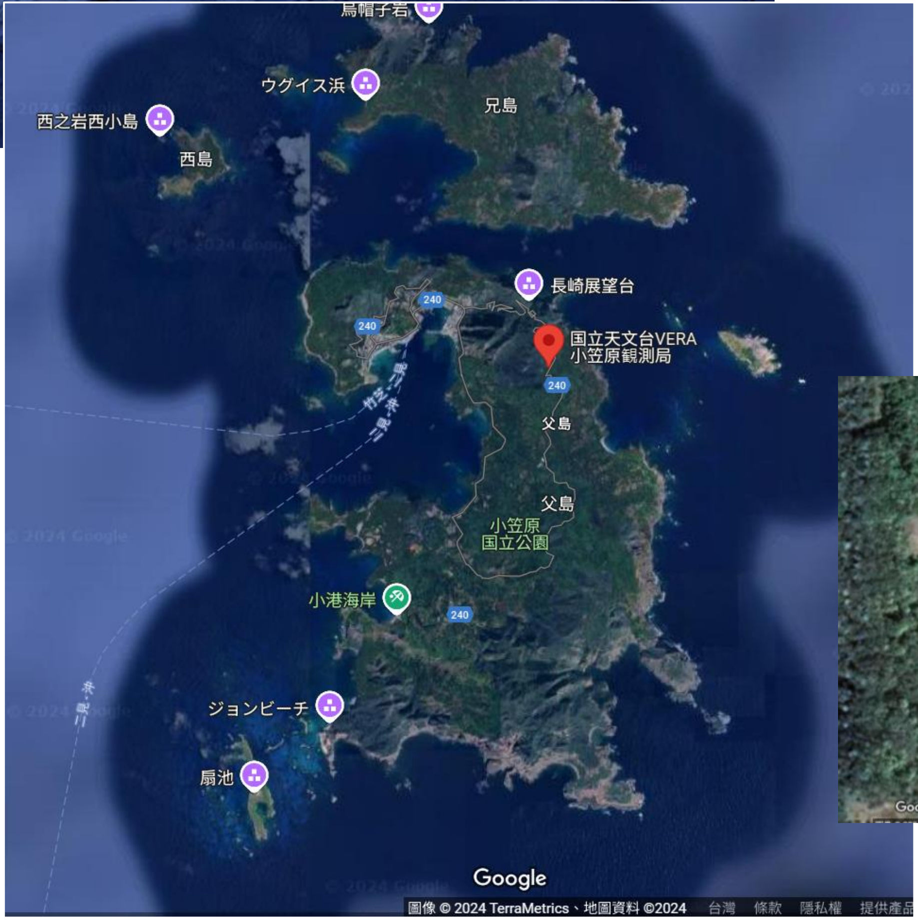


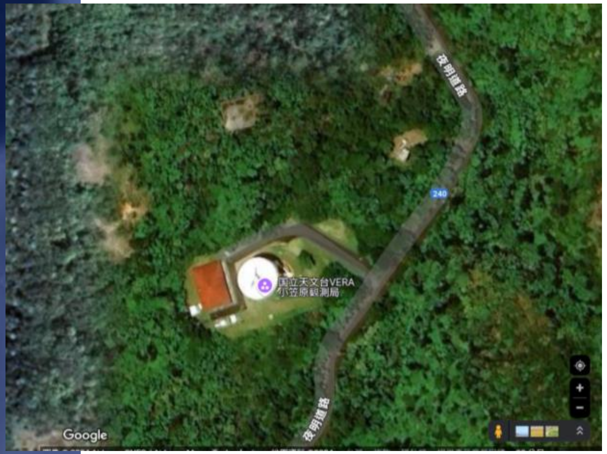
mode: positive peak , RBW:50kHz, SA noise & (HPF+LNA+cable) gain subtracted

Chichijima, Ogasawara Islands
小笠原諸島:父島

- ~1000 km from Tokyo
- National park, area: 24 km^2
- population: ~2000
- mountainous volcanic island:, 200-300 m high
- NAOJ VERA observatory with 20m radio telescope
  - BURSTT outrigger station: 16-antenna prototype

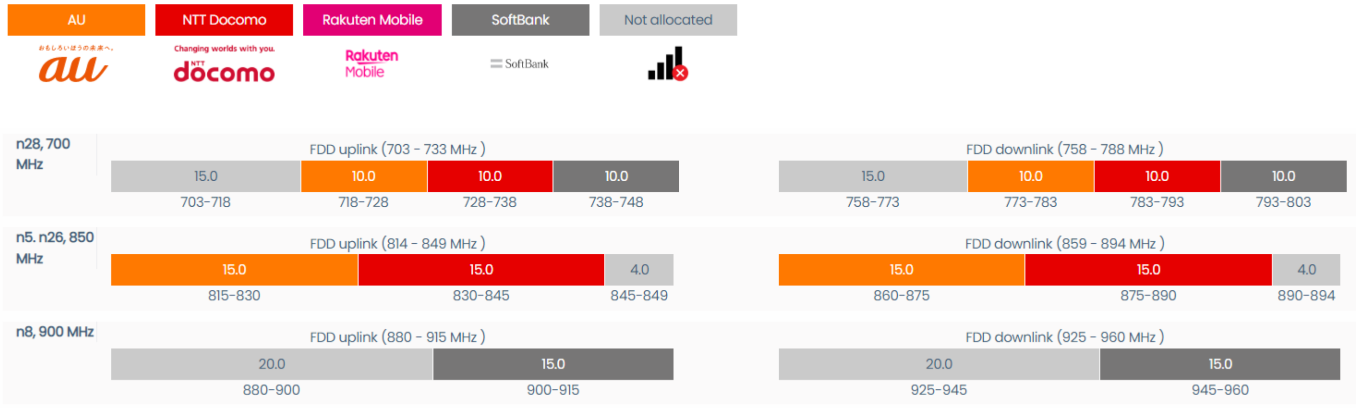


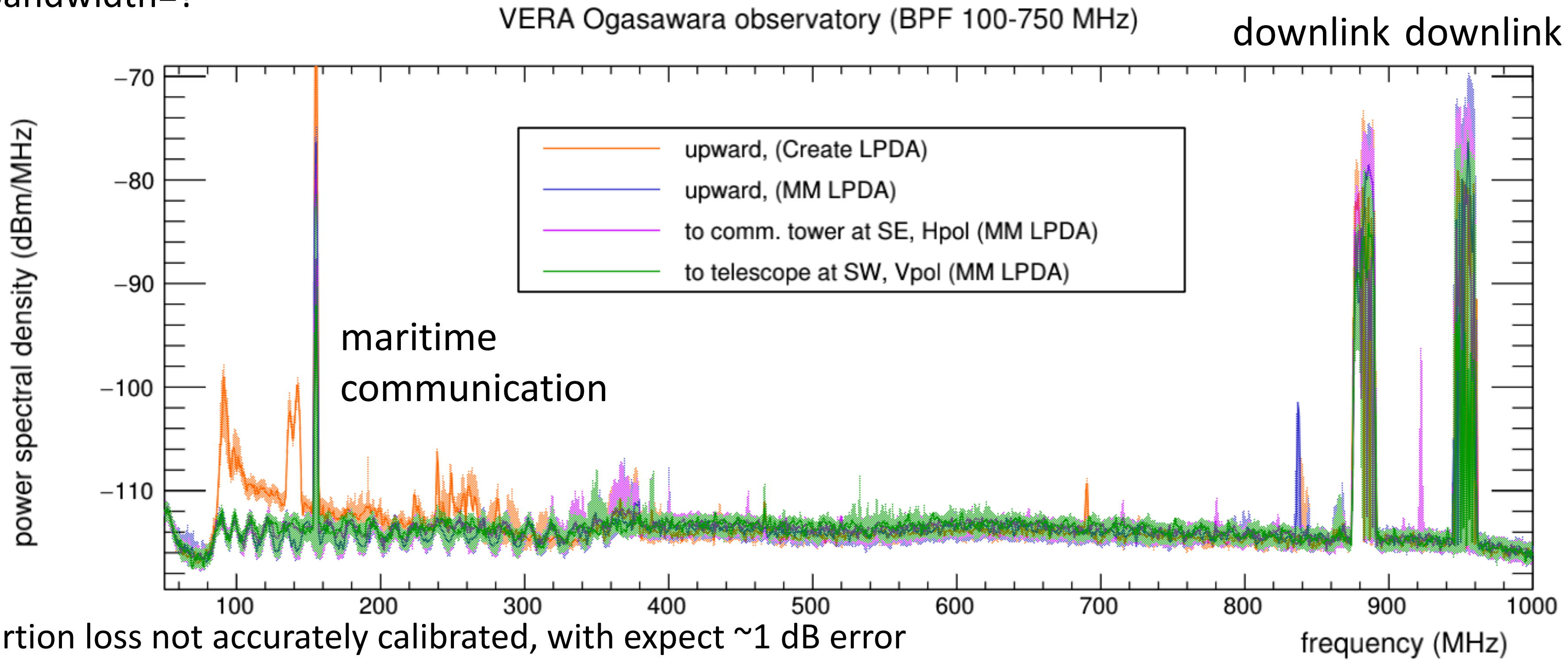




Case: Ogasawara Islands (2024/11)

- Rx: MobileMark LPDA
- 400-800 MHz band mostly clean
  - 350-400 MHz RFI from VERA telescope
- major noise from
  - 4G mobile: ~-70 dBm/MHz, ~30 MHz bandwidth
  - 155 MHz CW: maritime communication ~-75 dBm/ MHz, bandwidth=?



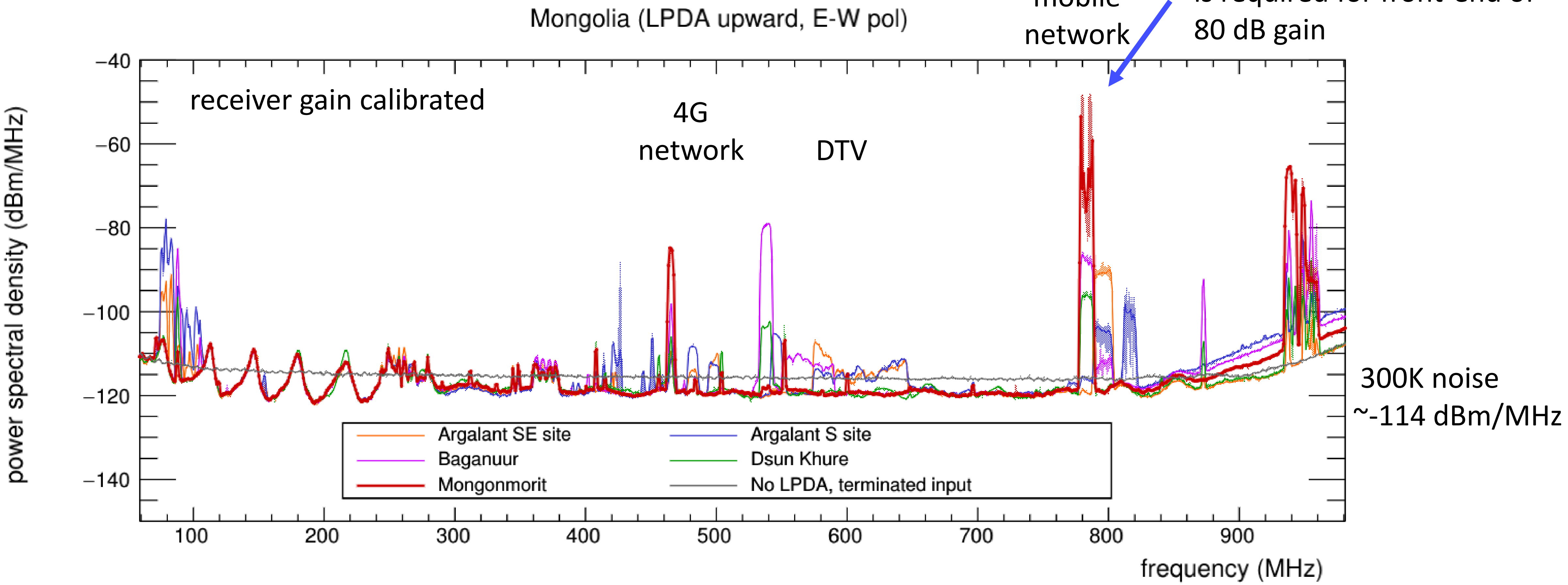


cable insertion loss not accurately calibrated, with expect ~1 dB error

Case: RF spectra at Mongolian sites

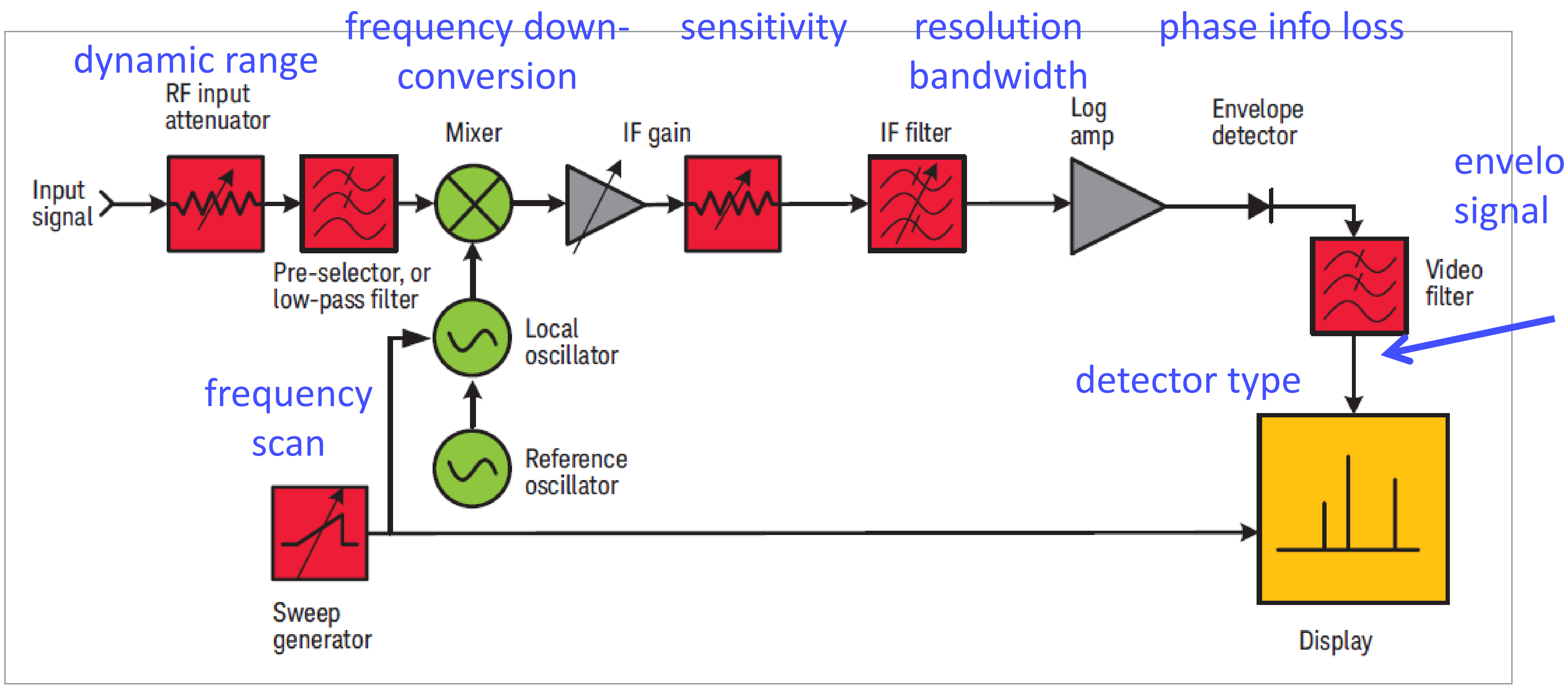
- Away from Ulaanbataar, DTV signal diminished
- Receiver gain calibrated with vector network analyzer
  - RG400 cable + BURSTT FEM + bias-T + CFD400 cable
- still telecomm tower in view, G-mobile at 460 MHz

will saturate 2nd or 3rd amp (output P1dB ~ + 15 dBm) better low-pass filter or further away from Tx is required for front-end of 80 dB gain



Spectrum analyzer design

- a super-heterodyne receiver
    - similar to AM/FM radio receiver, but only measure amplitude



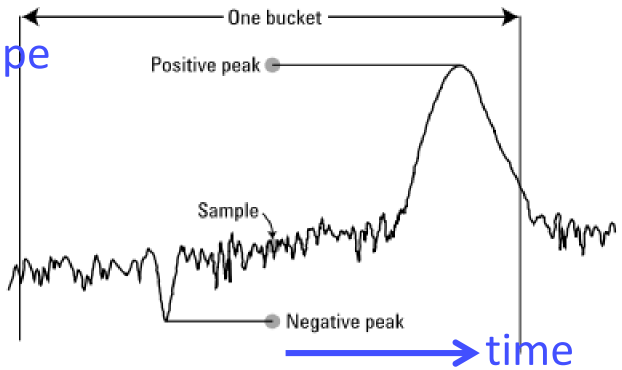


Figure 2-19. Trace point saved in memory is based on detector type algorithm

[Spectrum Analysis Basics - Part 2: What's in a spectrum analyzer? | Keysight Blogs]
https://www.youtube.com/watch?v=cZtkULAIF_k Fundamentals of Spectrum Analyzer Design
https://www.youtube.com/watch?v=PkmhX0wjk4Q&t=3s Spectrum Analyzer Detection Modes

Techniques with spectrum analyzer (SA)

- multiple traces with different detection types
  - faster measurement
- choice of pre-amplifier and input attenuator
  - avoid saturation of mixer input level
  - lower SA effective noise temperature
- 3 ways of averaging
  - longer sweep time + RMS average
  - averaging over all sweeps (log average < RMS average)
  - use video bandwidth (VBW) ~0.1 resolution bandwidth (RBW) for smoothing
- RBW selection
  - frequency span / number of points: picket fence effect

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https://www.youtube.com/watch?v=PkmhX0wjk4Q&t=3s Spectrum Analyzer Detection Modes

Next: Hand-on session

- Characterize RF components
  - → What need to be aware of?
- Assemble survey instruments
- Measure RFI and compare
  - at both urban and suburban environments