21cm global spectrum measurement on the ground and on the lunar orbit

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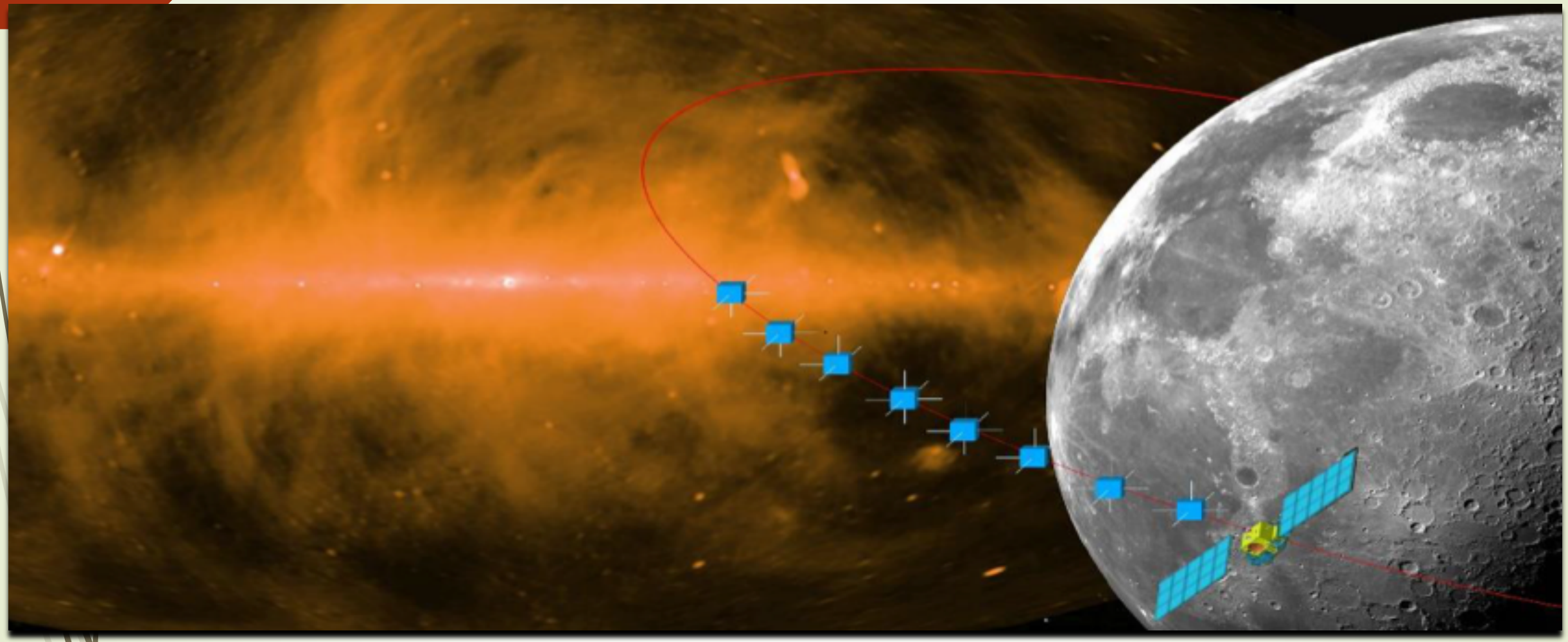
National Astronomical Observatory, Beijing

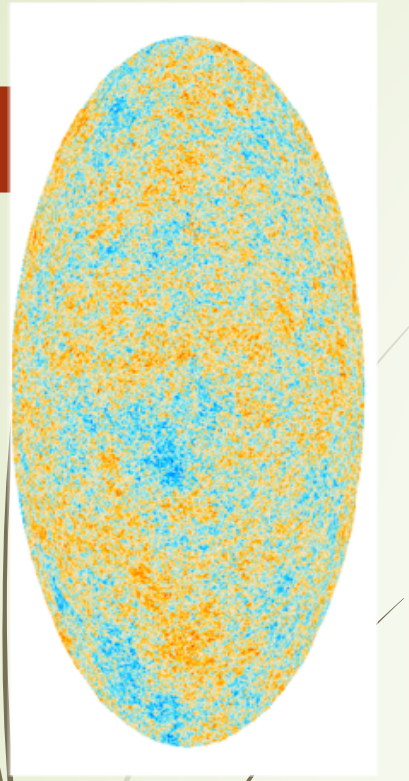
INP, Osay, Oct 2019

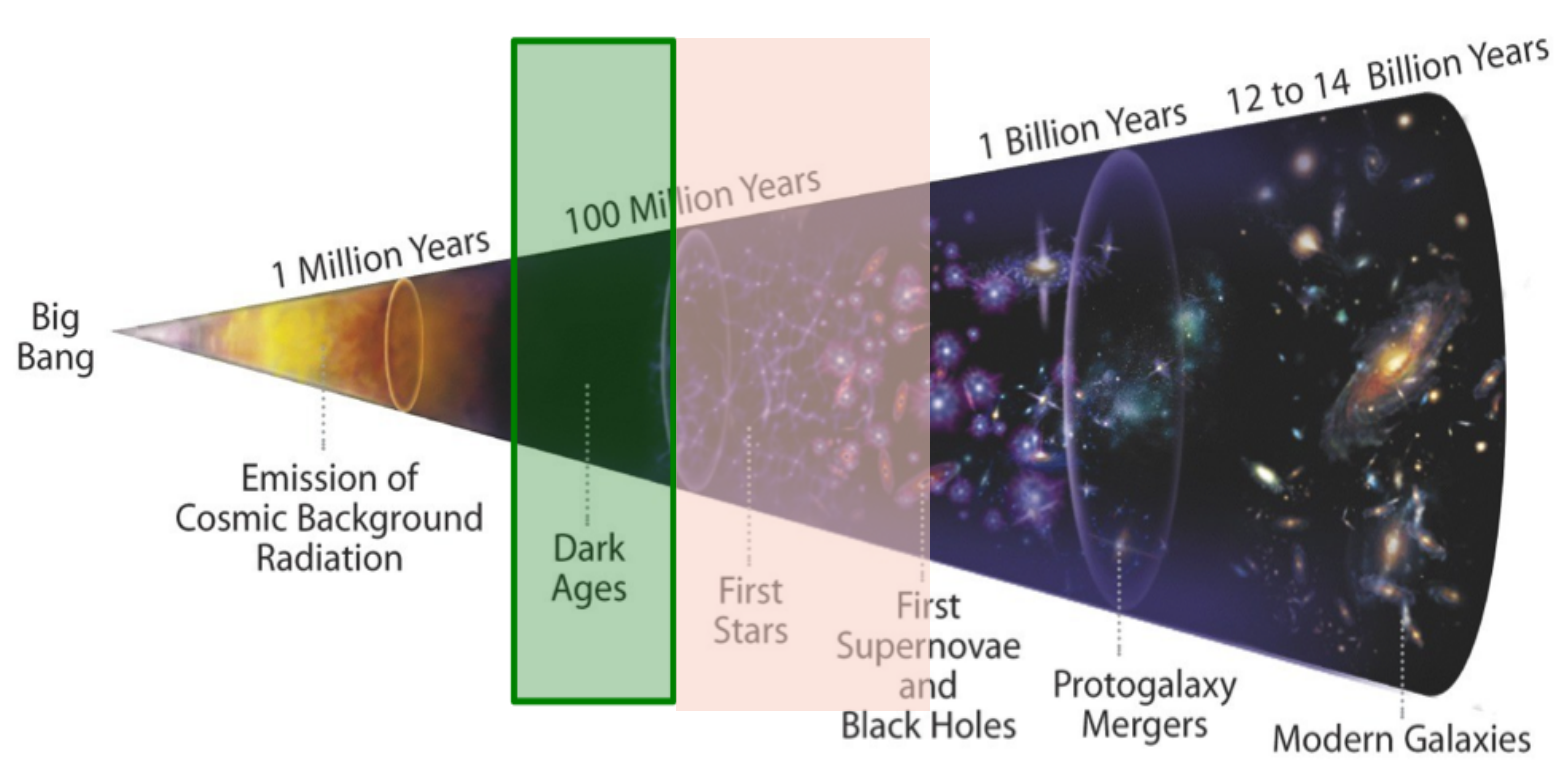
Overview of whole project

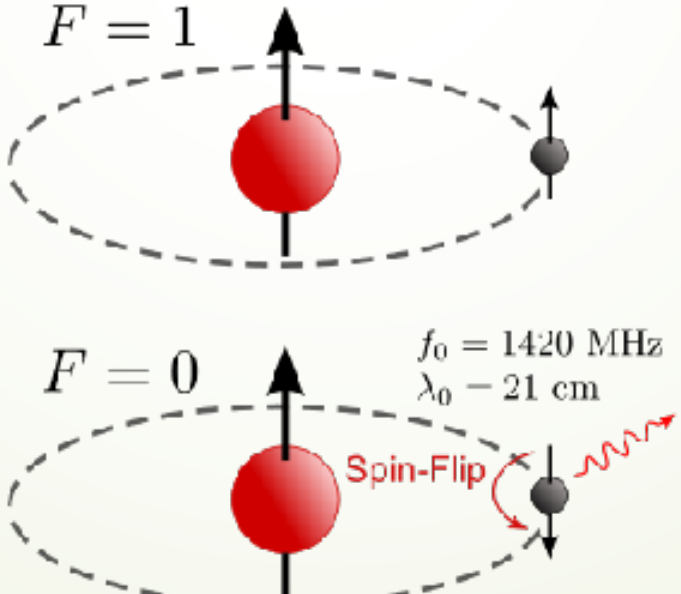
Long wavelength array on lunar orbit (re-study program)



- Whole sky imaging at frequency below 30MHz
- Global spectrum measurement at frequency below 120MHz

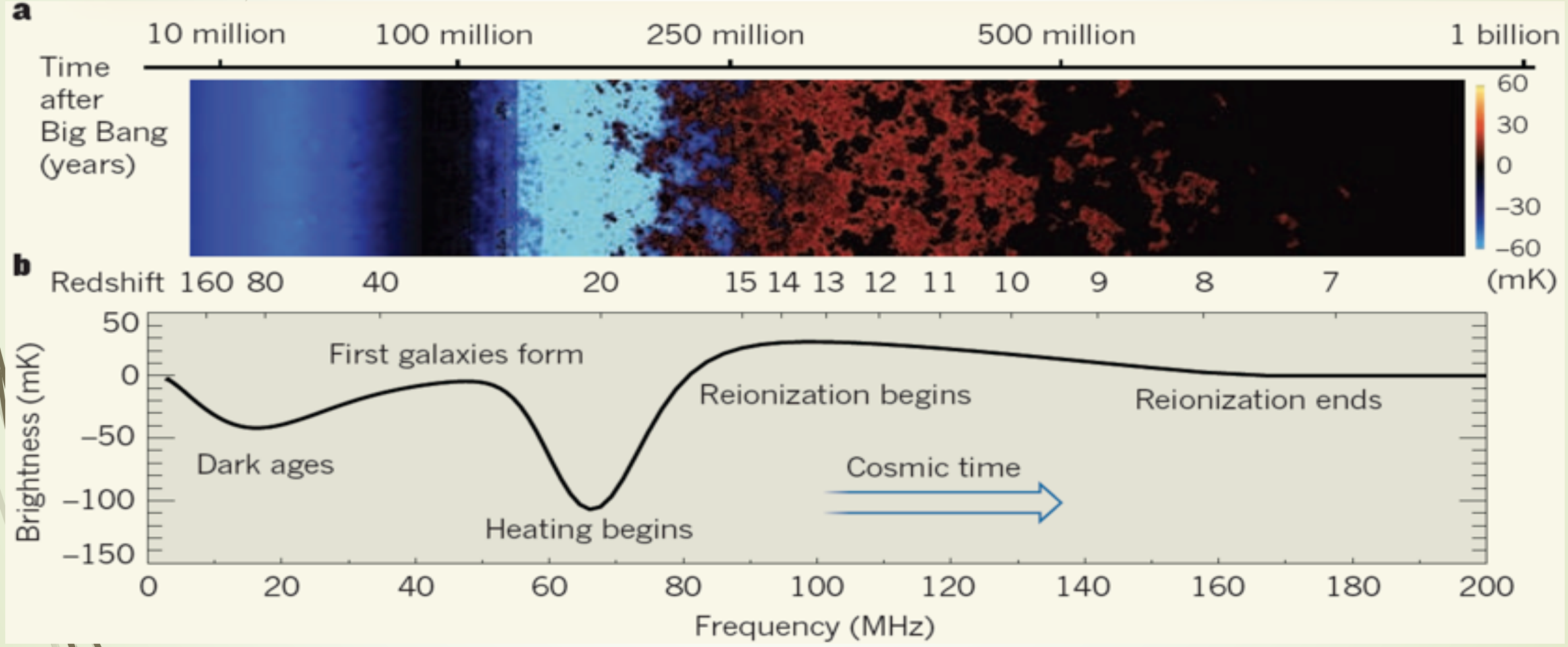


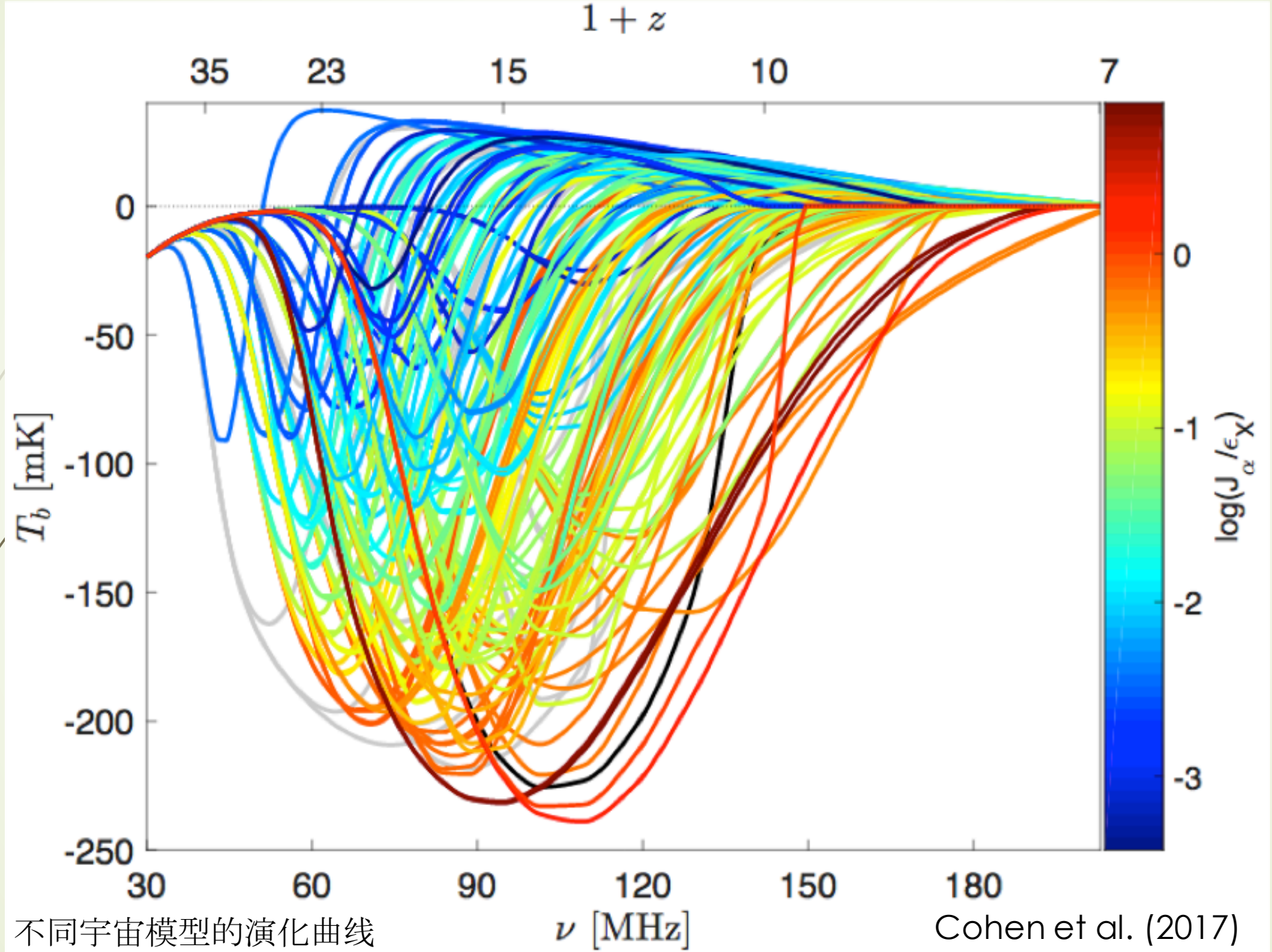




Light of dark age
--21cm spectrum line

21cm global spectrum @ dark age,cosmic dawn, reionization epoch





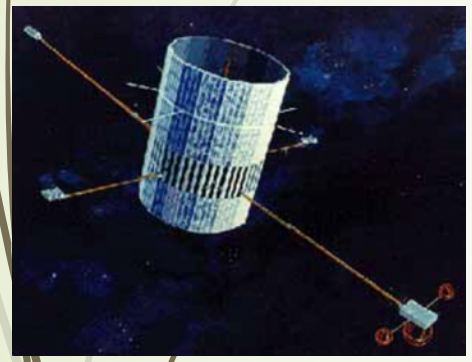
不同宇宙模型的演化曲线

Cohen et al. (2017)

Spectrum measurement on satellites

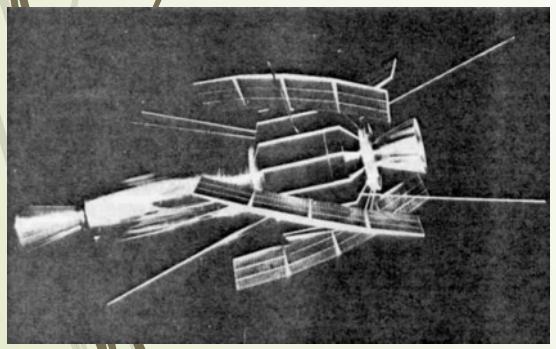
Radio Astronomy Explorer

RAE-A（1968,
0.2 to 20 MHz
near earth orbit）

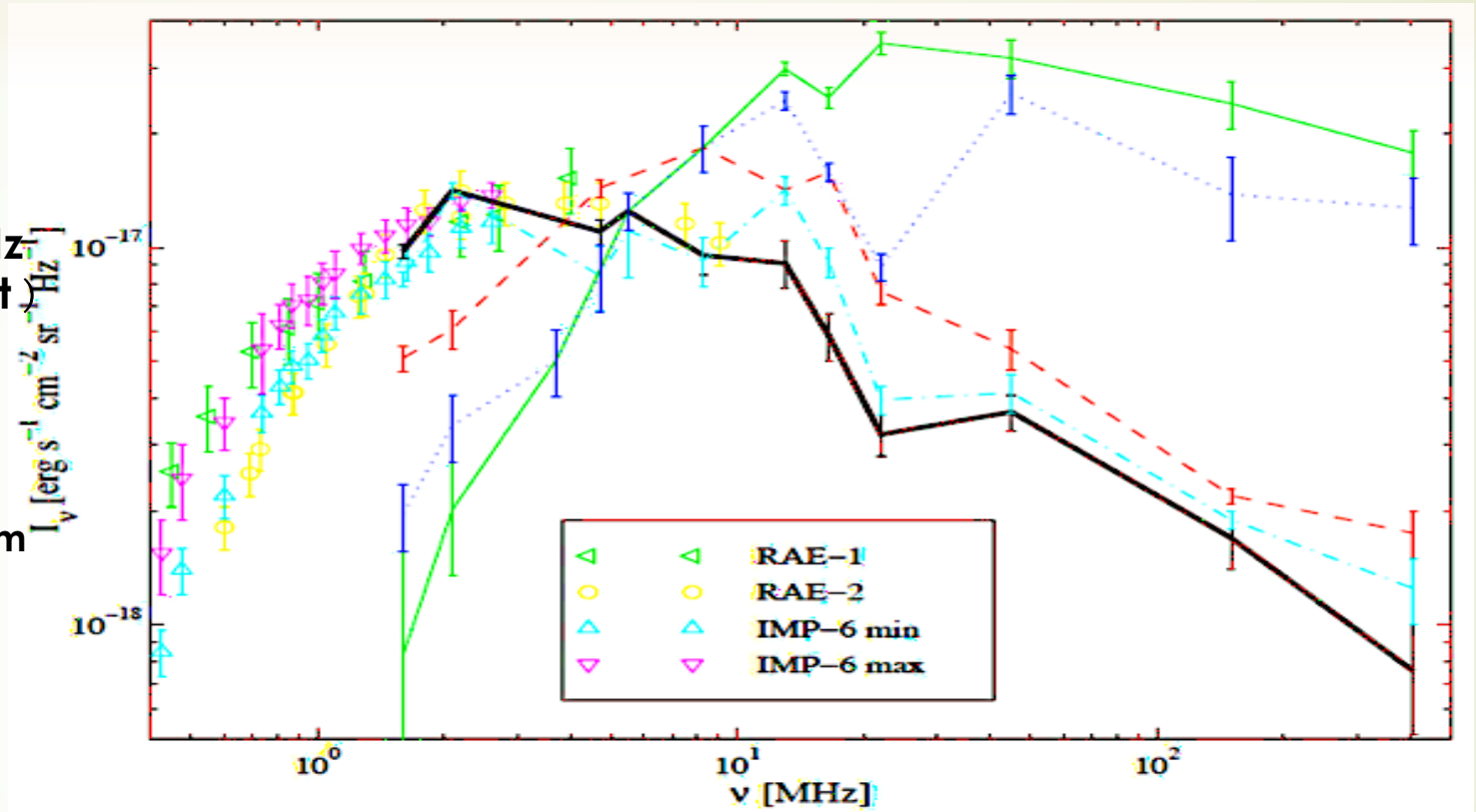


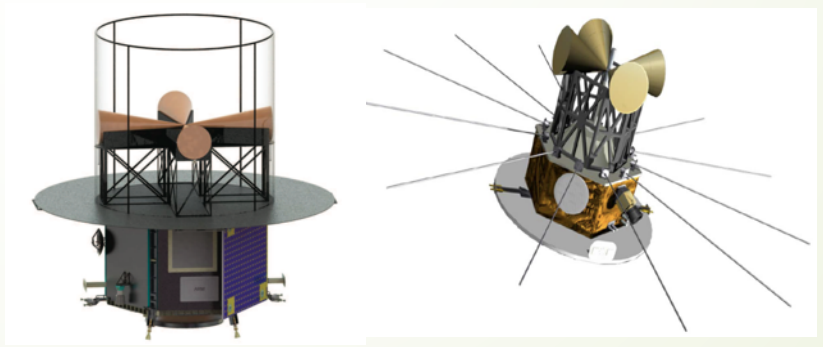
Interplanetary
Monitoring Platform

IMP-6 (1971)



RAE-B(1973, lunar orbit,
25 kHz to 13.1 MHz)

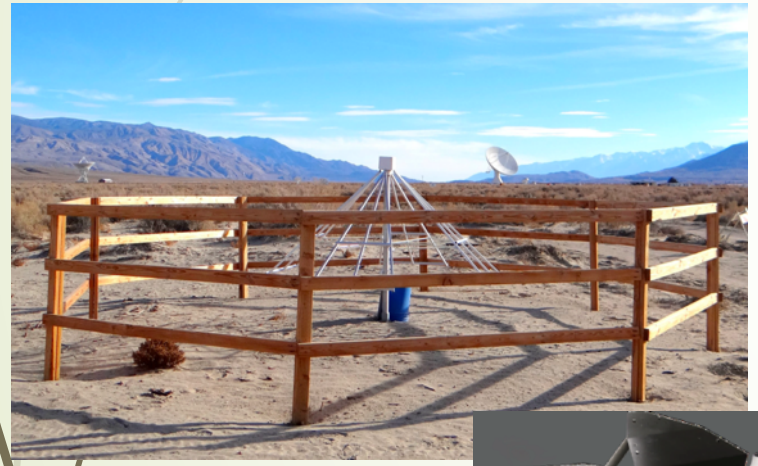




DARE(NRAO,40-120MHZ，lunar oribit)

21cm global spectrum – Ground experiment

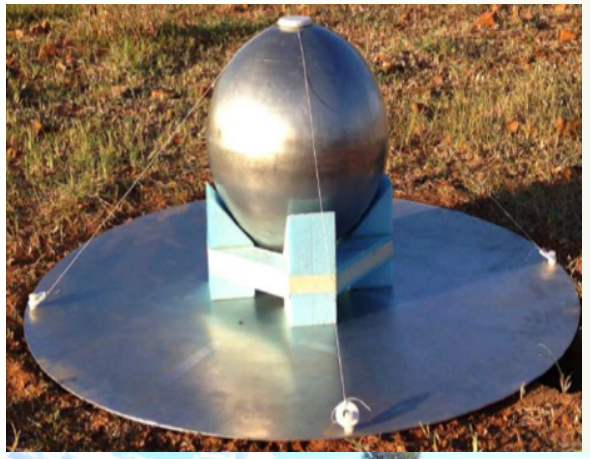
SCI-HI



LEDA

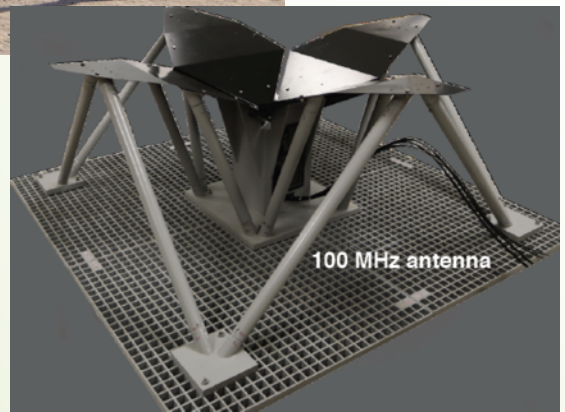
SARAS2

EDGES



BIGHORN

PRIMZ



21cm global spectrum-ground experiment-EDGES

nature
International journal of science

An absorption profile centred at 78 megahertz in the sky-averaged spectrum

Judd D. Bowman ✉, Alan E. E. Rogers, Raul A. Monsalve, Thomas J. Mozdzen & Nivedita Mahesh

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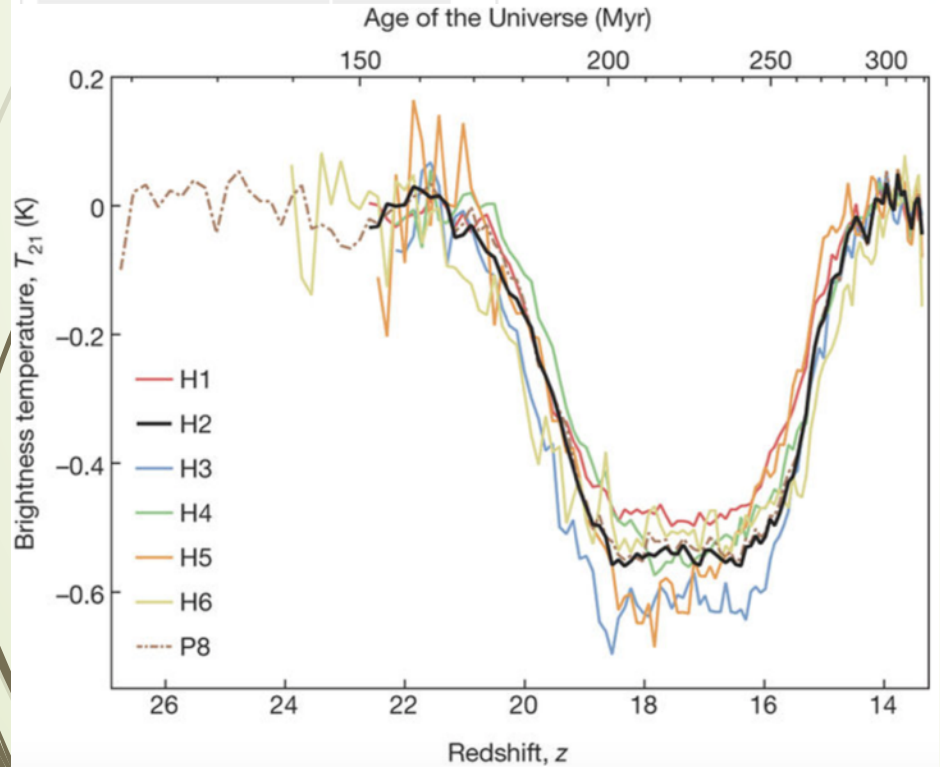
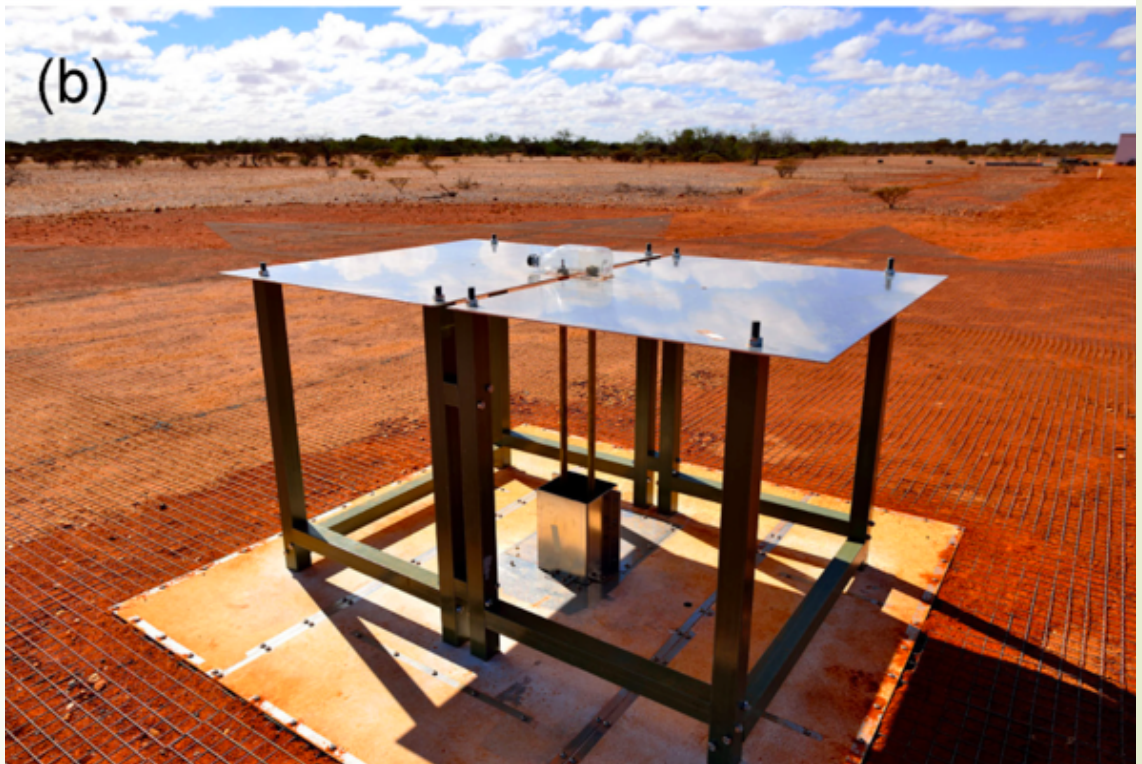
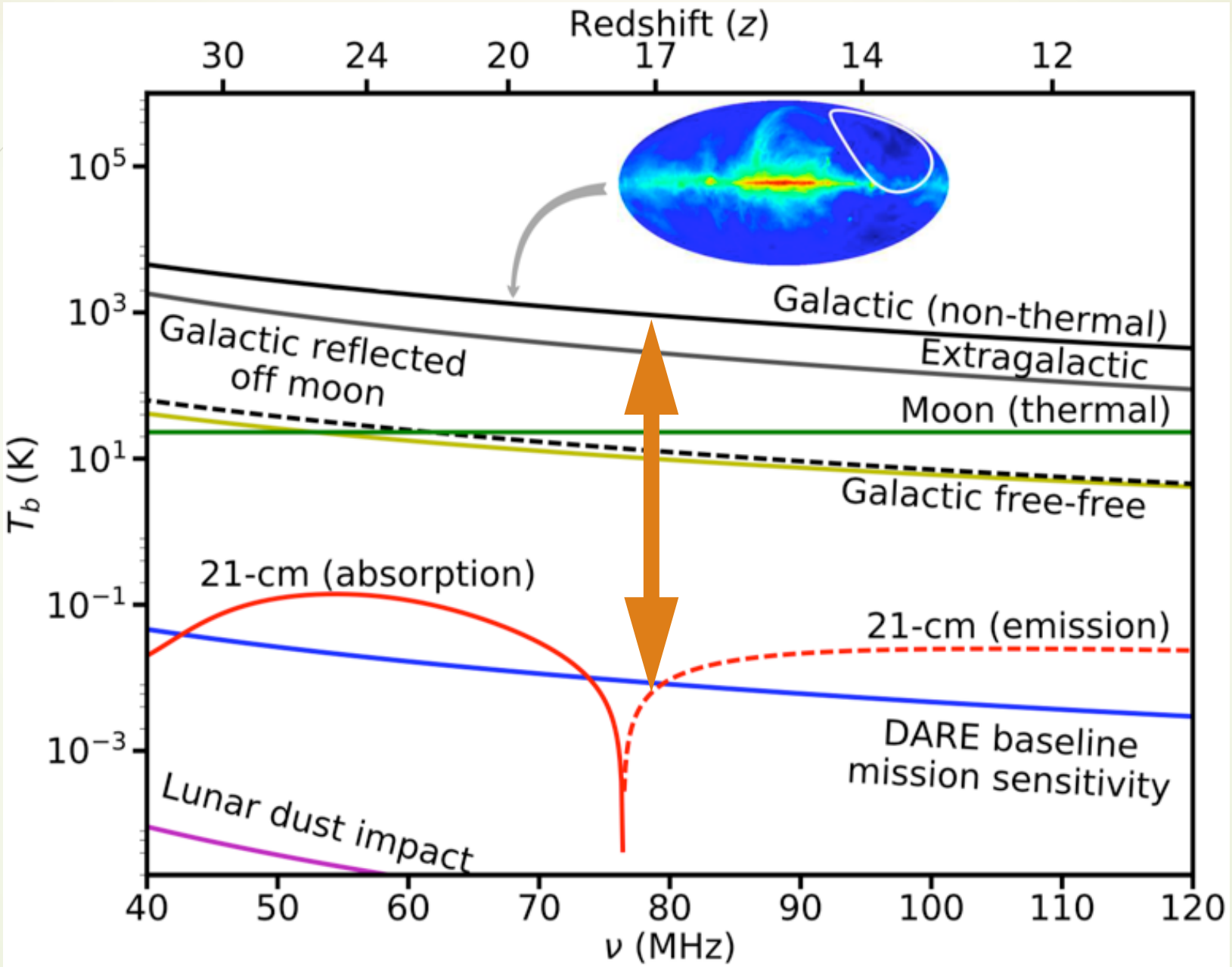
Astronomical instrumentation | Cosmology

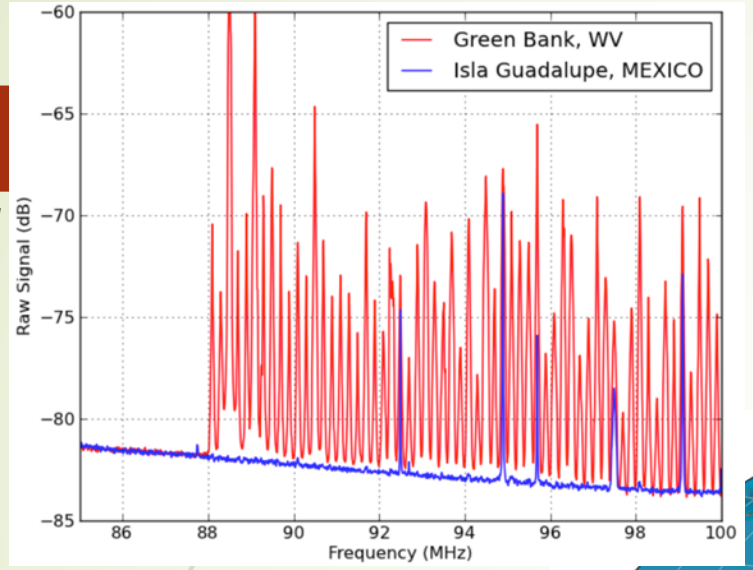


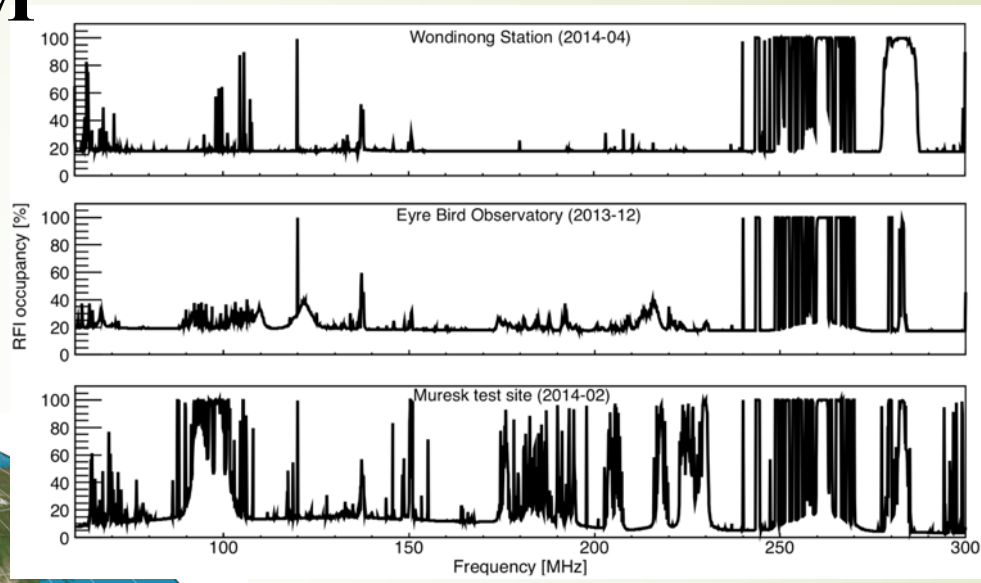


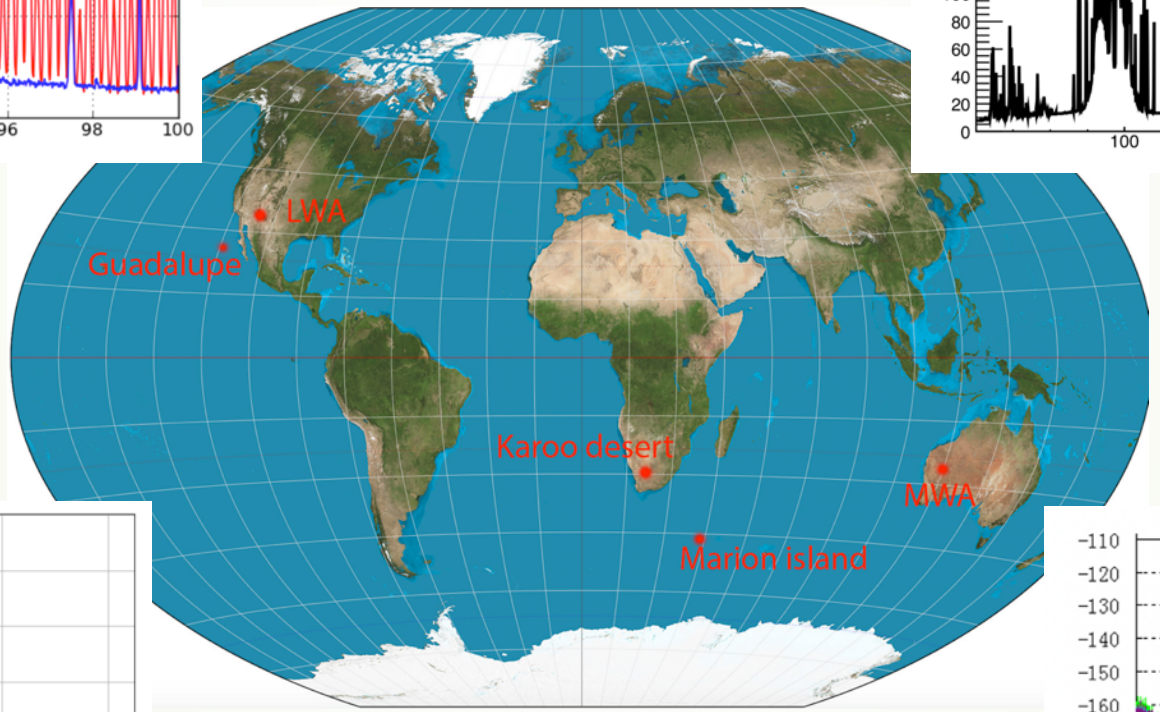
Difficulties of 21cm global spectrum measurement

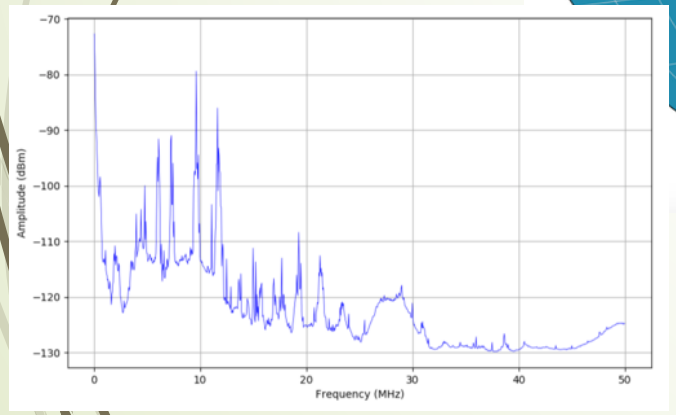


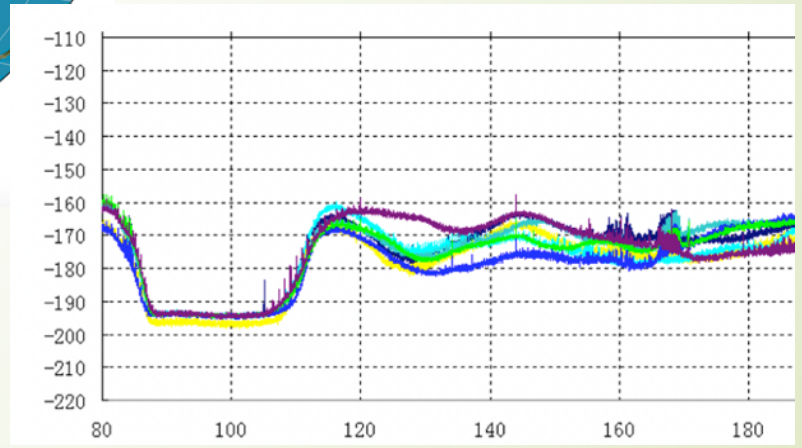
RFI problem in GSM







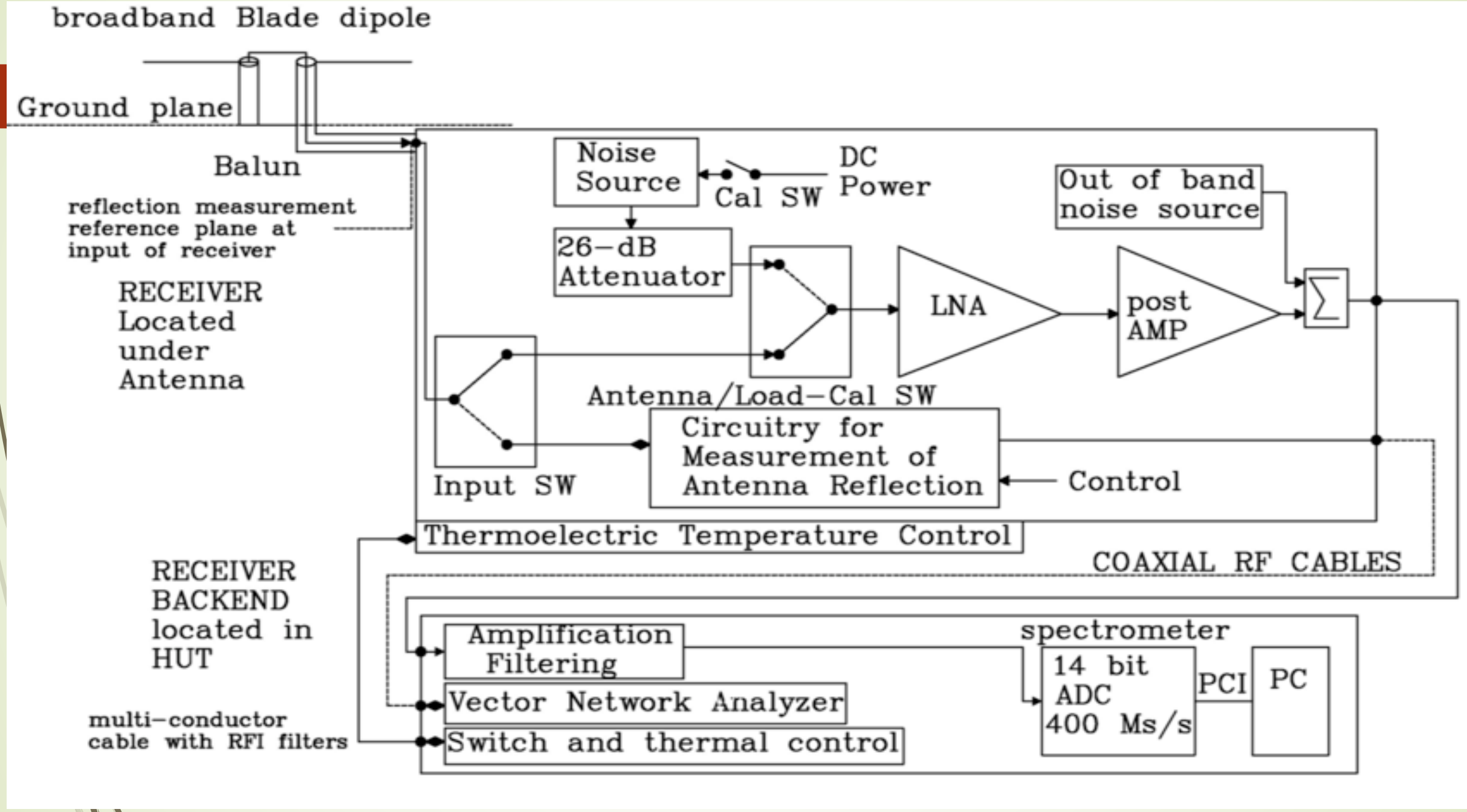




Most popular designs

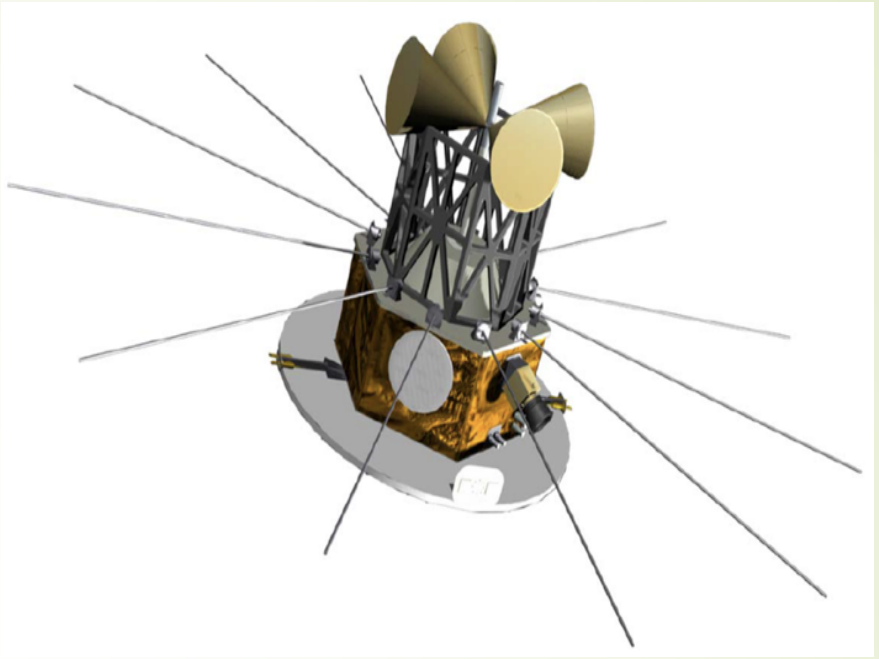
(1)Small wide-beam antenna

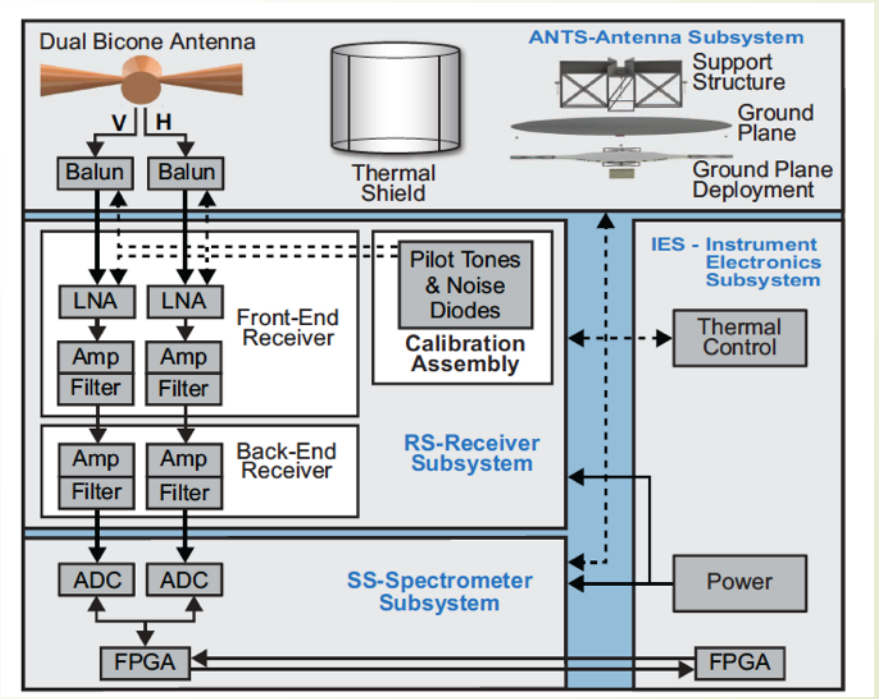
(2)Dicke switch spectrometer

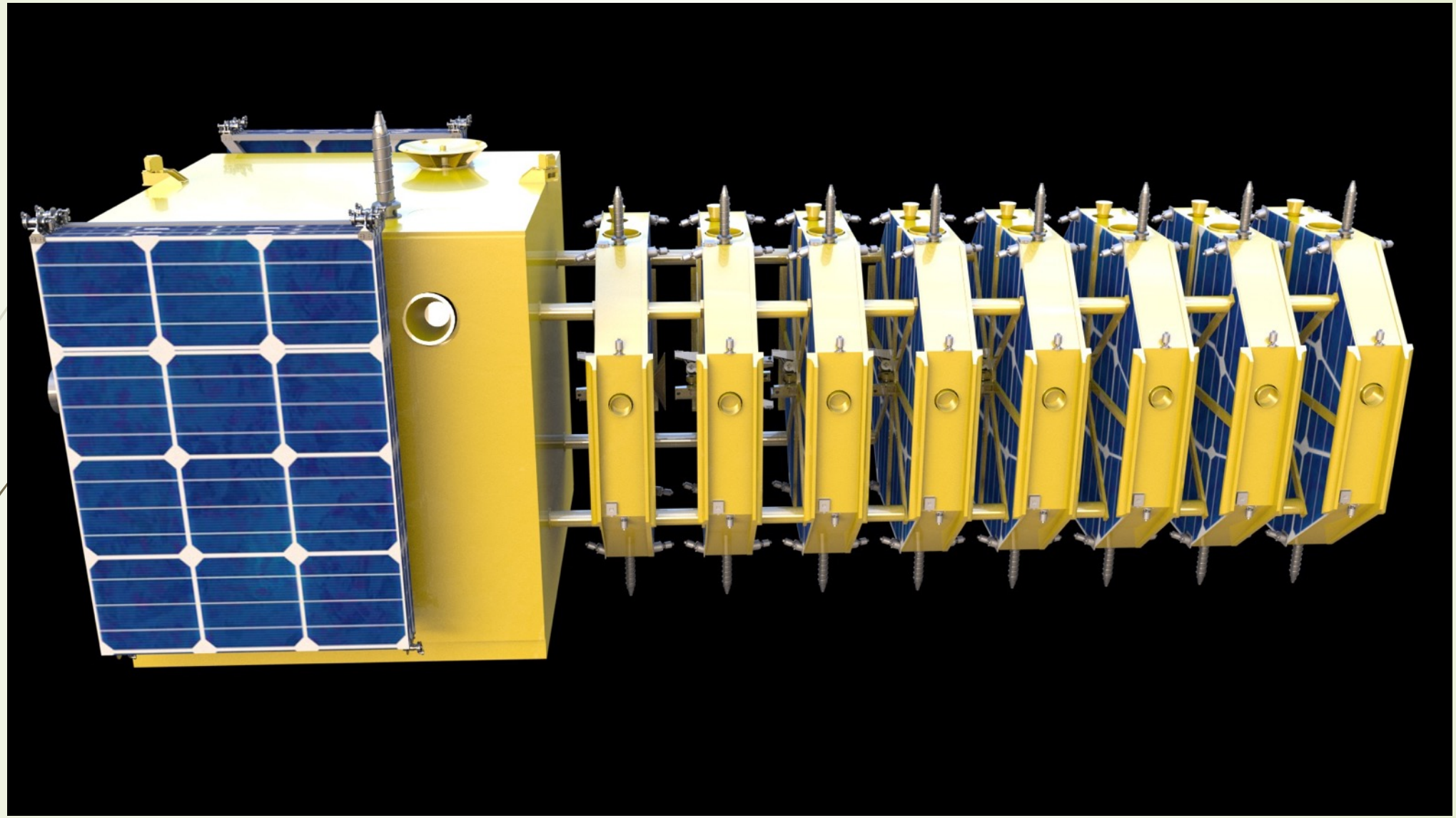

broadband Blade dipole
Ground plane
Balun
reflection measurement reference plane at input of receiver
RECEIVER Located under Antenna
Noise Source
Cal SW
DC Power
26-dB Attenuator
Out of band noise source
LNA
post AMP
Antenna/Load-Cal SW
Input SW
Circuitry for Measurement of Antenna Reflection
Control
Thermoelectric Temperature Control
COAXIAL RF CABLES
RECEIVER BACKEND located in HUT
Amplification Filtering
Vector Network Analyzer
Switch and thermal control
spectrometer
14 bit ADC 400 Ms/s
PCI
PC
multi-conductor cable with RFI filters

DARE


1.6m
ARM

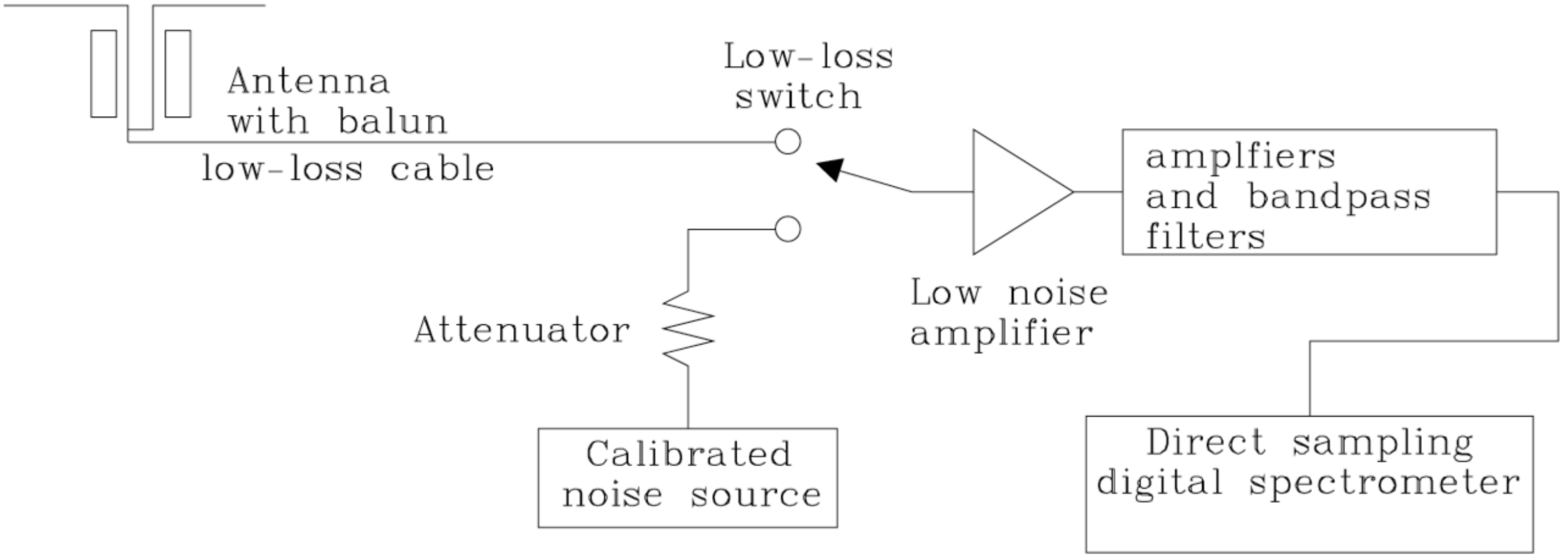



Dual Bicone Antenna
V
H
Balun
Balun
Thermal Shield
ANTS-Antenna Subsystem
Support Structure
Ground Plane
Ground Plane Deployment
LNA
LNA
Amp
Filter
Amp
Filter
Front-End Receiver
Pilot Tones & Noise Diodes
Calibration Assembly
IES - Instrument Electronics Subsystem
Thermal Control
Amp
Filter
Amp
Filter
Back-End Receiver
RS-Receiver Subsystem
ADC
ADC
SS-Spectrometer Subsystem
Power
FPGA
FPGA



- **Size of antenna**
- **Smoothness of respond**
- **Bandwidth required**

Perfect matching system with Dicke switch
might not be a best solution for small satellite project



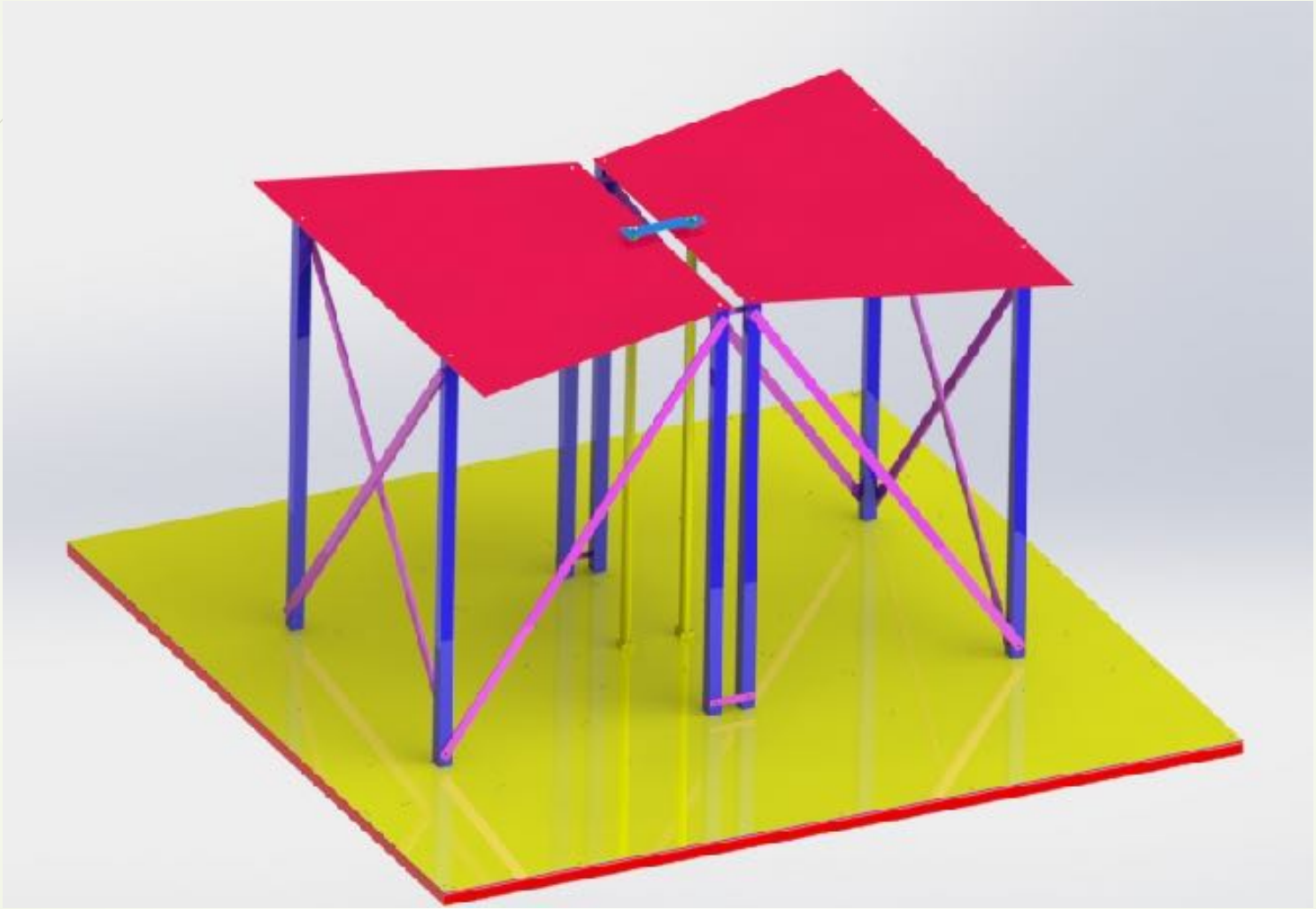
Calibration Eq :

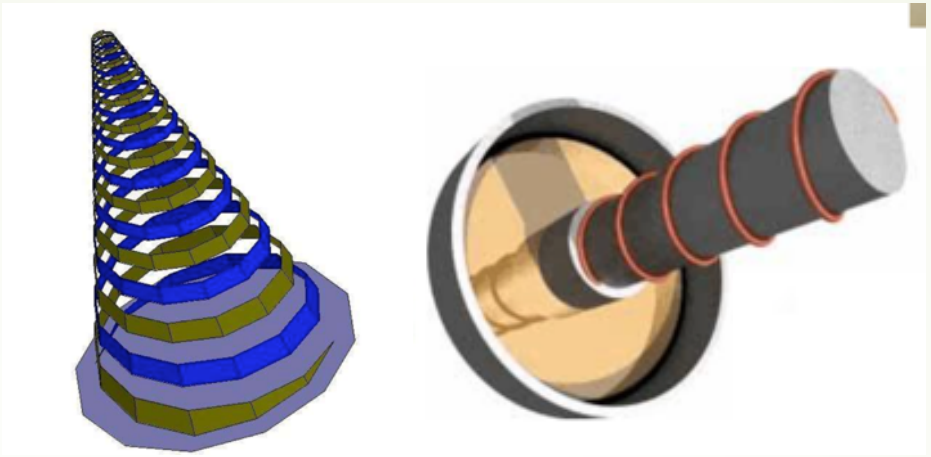
$$P_0(\nu) = g(\nu)[P_{load1}(\nu) + P_{amp}(\nu)]$$

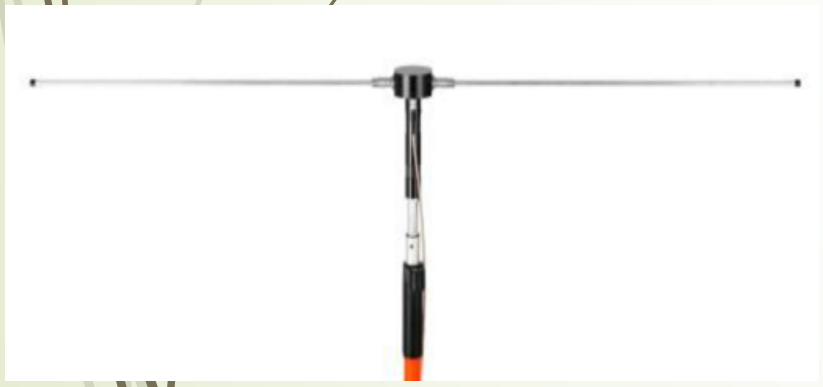
$$P_1(\nu) = g(\nu)[P_{load}(\nu) + P_{amp}(\nu)]$$

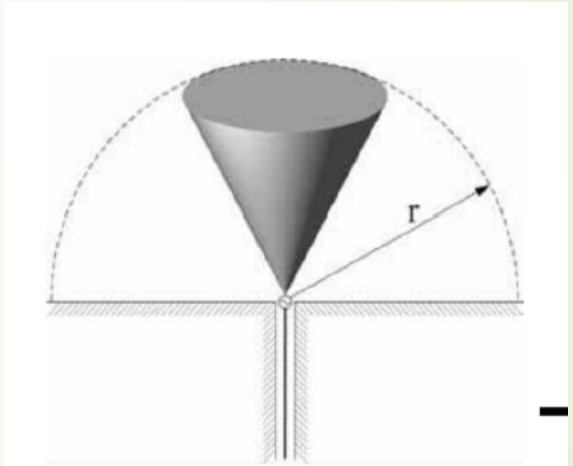
$$P_2(\nu) = g(\nu)[P_{ant}(\nu) + P_{amp}(\nu)]$$

$$T_{ant}(\nu) = T_{load1}(\nu) + [T_{load}(\nu) - T_{load1}(\nu)][P_2(\nu) - P_0(\nu)]/[P_1(\nu) - P_0(\nu)]$$









Conical Monopole Antenna

Plan B: Differential measurement system —partial matching system (SARAS)

- Small size, resonance frequency is out of band
- Smooth response
- High-order correction
- Not fully understand how poor S11 is acceptable

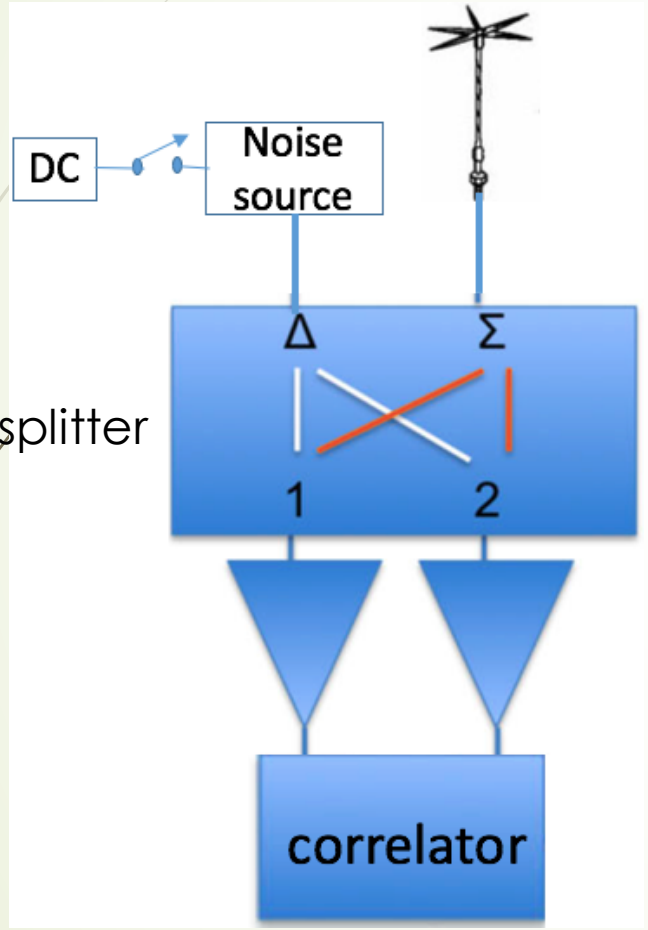
Plan C: High input impedance LNA measure system ---mismatching system (High-Z)

- High-impedance LNA (OP)
- E-field measurement
- Small-size antenna
- broad band
- Very smooth response of OP
- Can't fully test the response of system

Plan B: Differential measurement system

Plan B

Differential measurement system



Power splitter

Port 1 : Va+Vns+Vn1
Port 2 : Va-Vns+Vn2
Correlator : <Va+Vns+Vn1 | Va-Vns+Vn2>=Ta-Tns

$$T_{\mathrm{OBS0}} = G_1 G_2^* g^2 (T_A - T_{\mathrm{REF}})$$
$$T_{\mathrm{CAL0}} = G_1 G_2^* g^2 (T_A - T_{\mathrm{CAL}})$$

Plan B

Antenna :

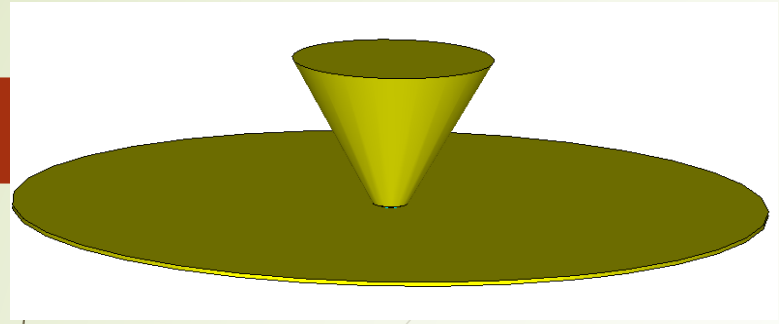
- Small size, resonance frequency is out of band
- Smooth response

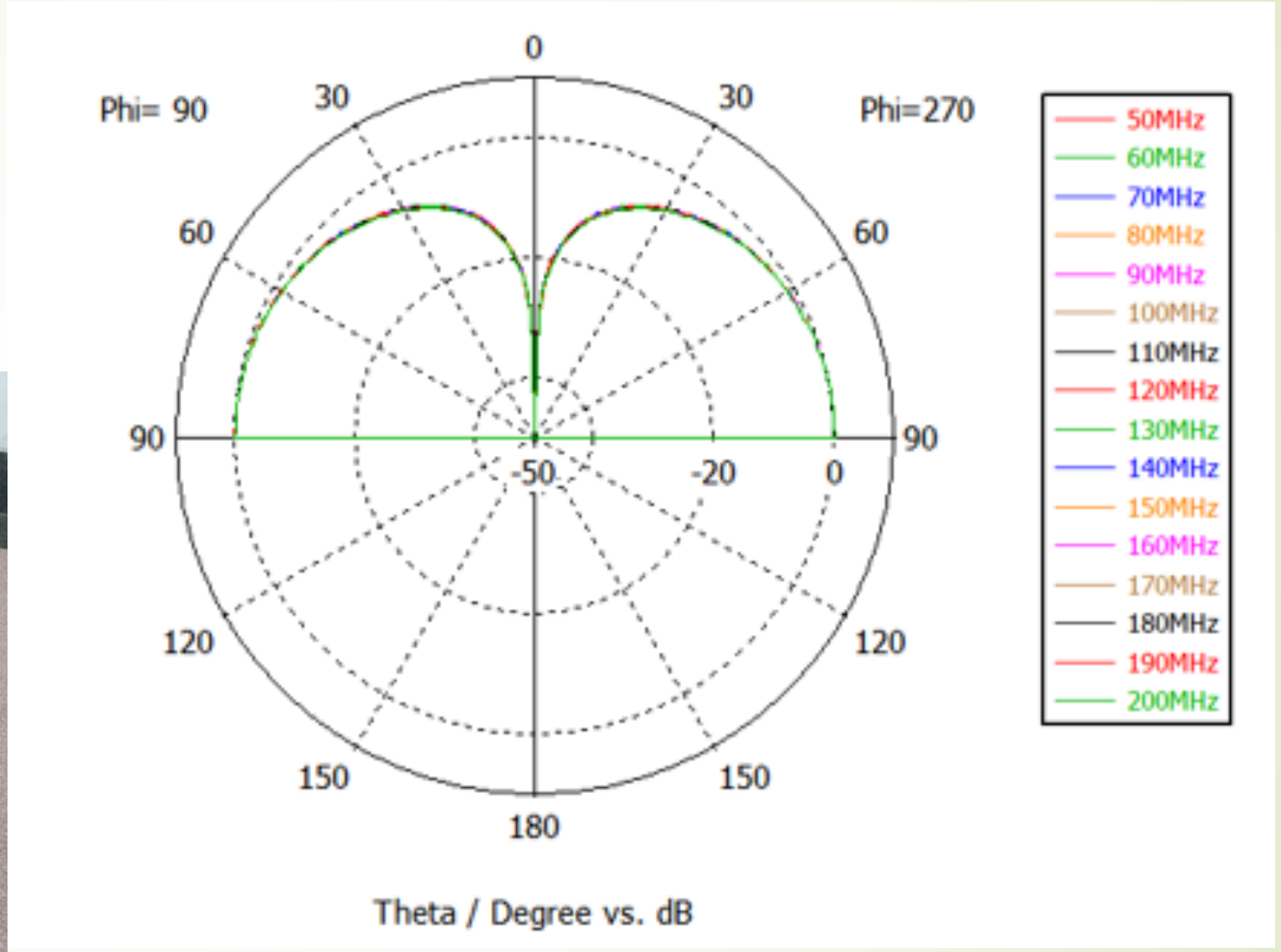
Receiver :

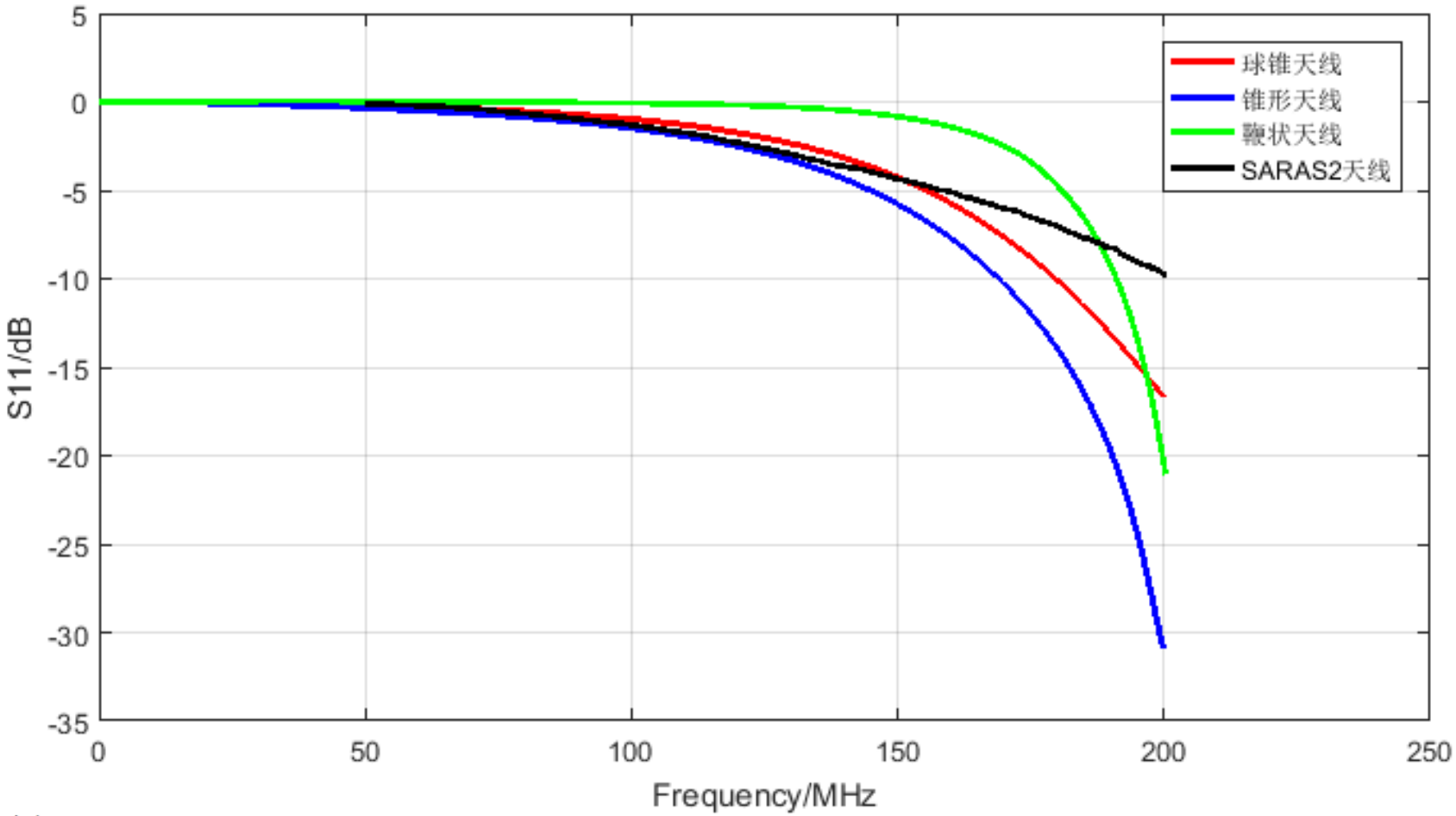
- 2-way correlator for differential measurement
- High-order correction

Merits :

- Remove the system noise at the zero order
- Perfect Matching is not necessary
- Remove some crosstalk in the receiver system




0
30
30
Phi= 90
Phi=270
60
60
90
90
-50
-20
0
120
120
150
150
180
50MHz
60MHz
70MHz
80MHz
90MHz
100MHz
110MHz
120MHz
130MHz
140MHz
150MHz
160MHz
170MHz
180MHz
190MHz
200MHz
Theta / Degree vs. dB

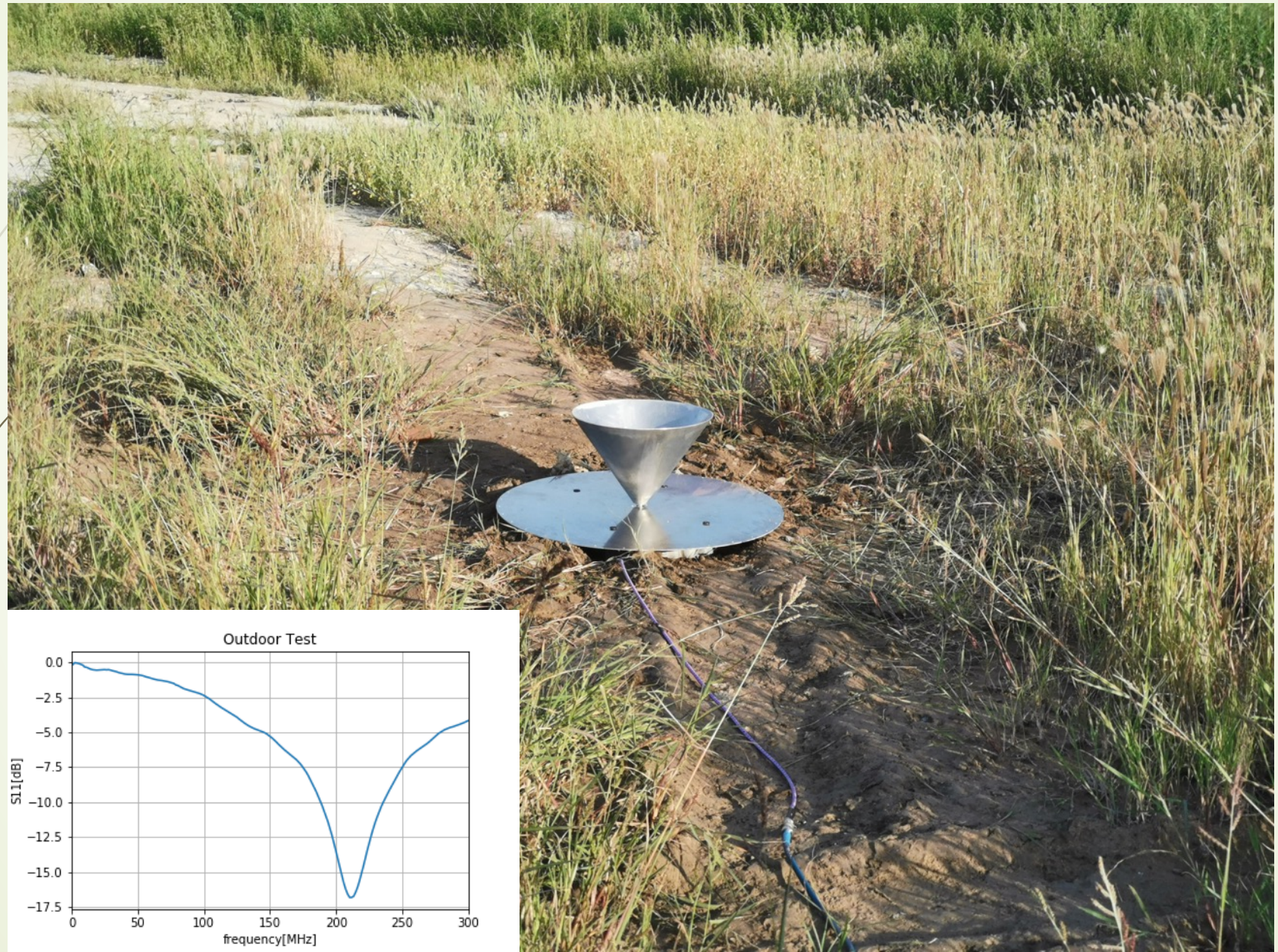


球锥天线的具体尺寸如下：

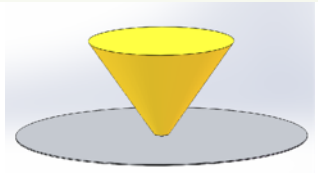
球		锥		
半径	截断后的高度	锥上底	锥下底	锥高
12cm	18cm	20.78cm	3.46cm	15cm

锥型天线

锥		
锥上底	锥下底	锥高
40cm	4cm	26cm



Outdoor Test
S11[dB]
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
0
50
100
150
200
250
300
frequency[MHz]



antenna

Analog receiver

Thermostatic system

microwave Switch system

load/terminator

calibrator

matched receiver

matched transistor

filter

90/180° Hybrid junction

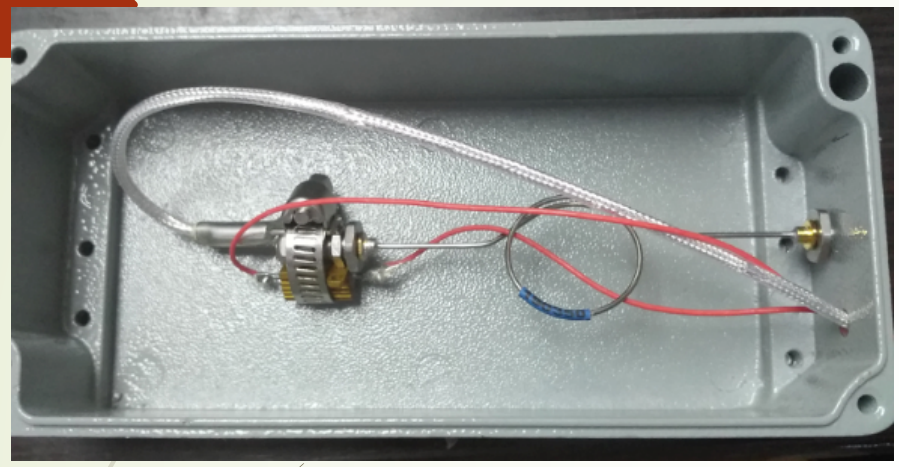
cross switch

VNA system

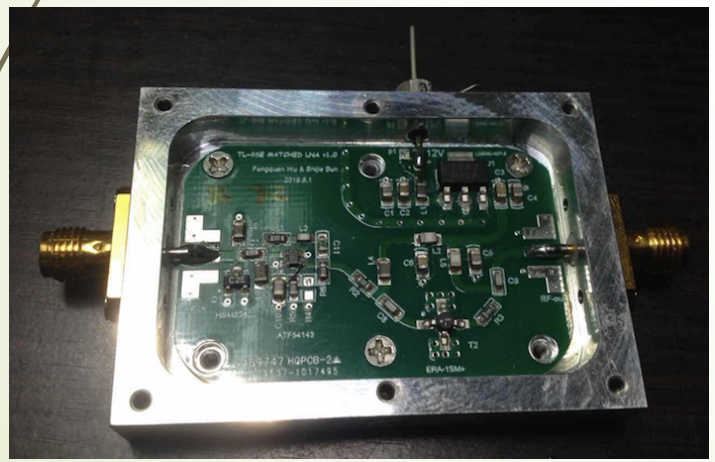
noise source

DC

Digital correlation spectrometer




KEYSIGHT
87222C
DC TO 26.5 GHz
TRANSFER SWITCH
POSITION A: 1-2, 3-4
POSITION B: 1-4, 2-3
MADE IN MALAYSIA



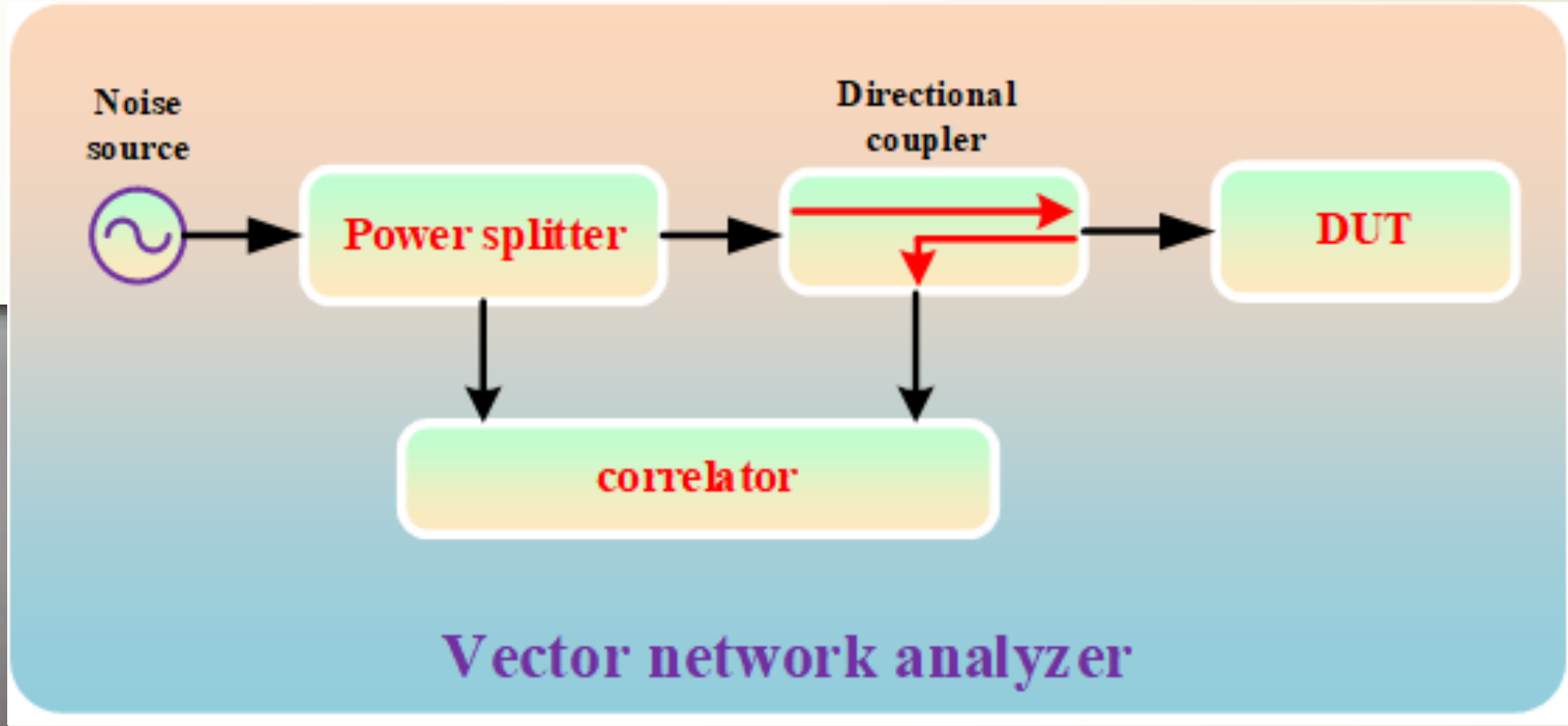

tyco / Electronics
MACOM
96341
H-9
2-2000 MHZ
0043
A
B
C
D
180°
0°
0°
0°

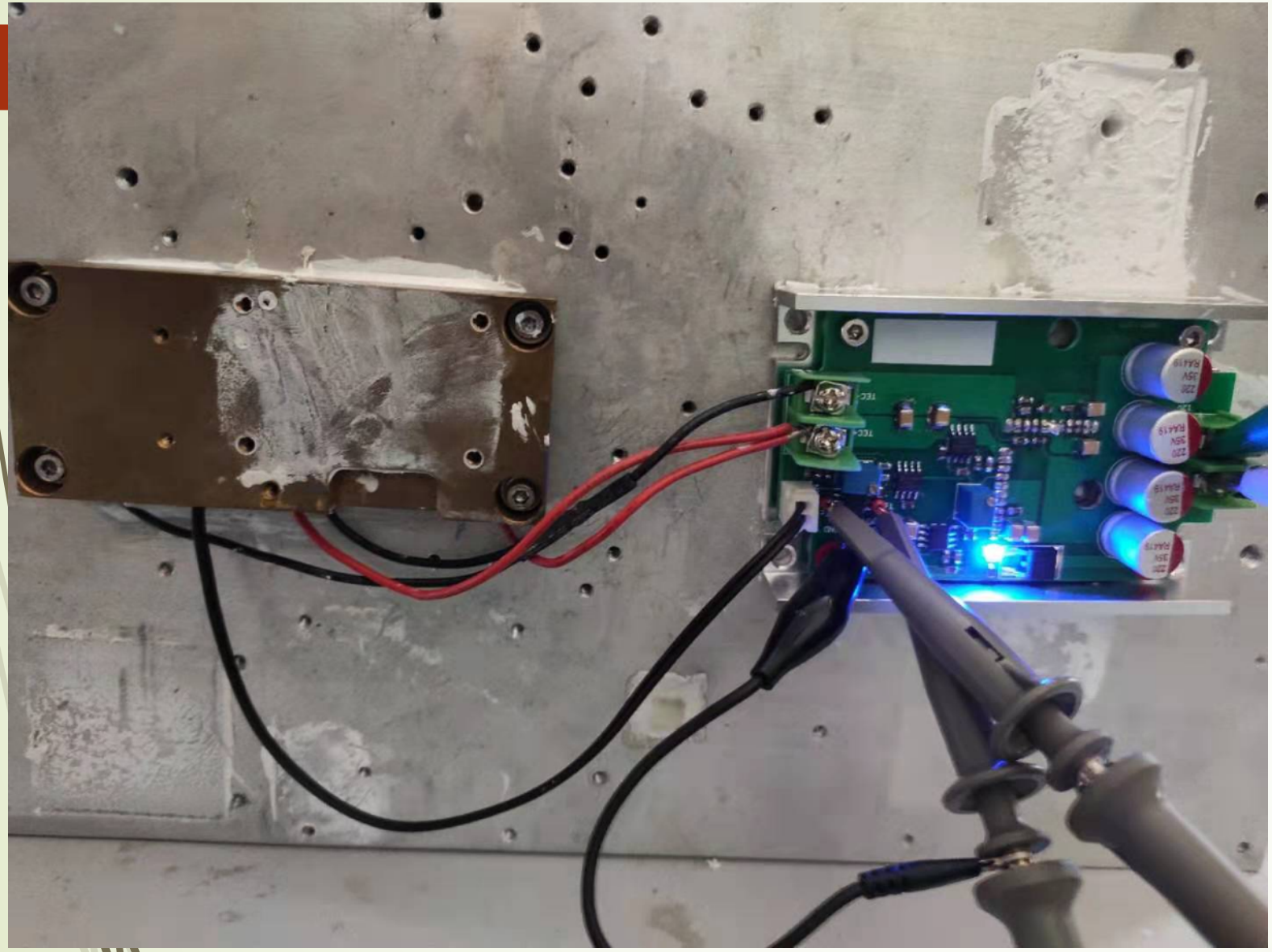
VNA

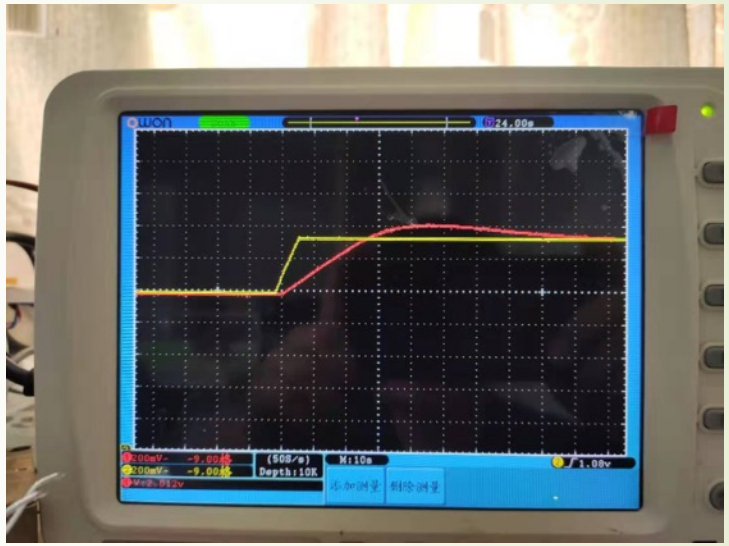

Anritsu
MS46121B
USB VNA
Frequency Range:
150 kHz - 6 GHz

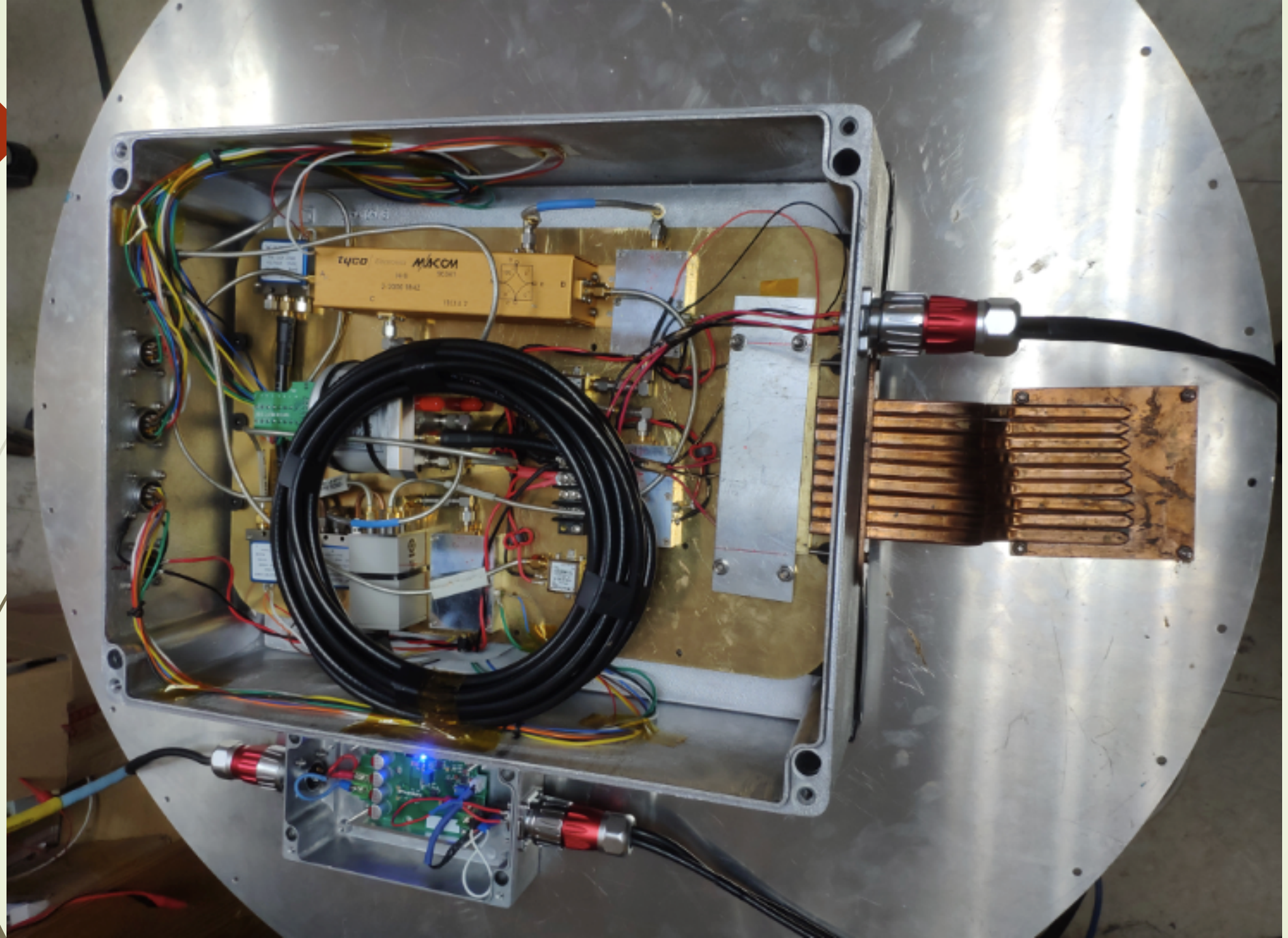

Agilent
86205A
300 kHz-6 GHz
50 Ω DIRECTIONAL BRIDGE
MADE IN MALAYSIA


COPPER MOUNTAIN
TECHNOLOGIES
US 9,291,657
R60
VECTOR REFLECTOMETER
1MHz - 6GHz
0070418

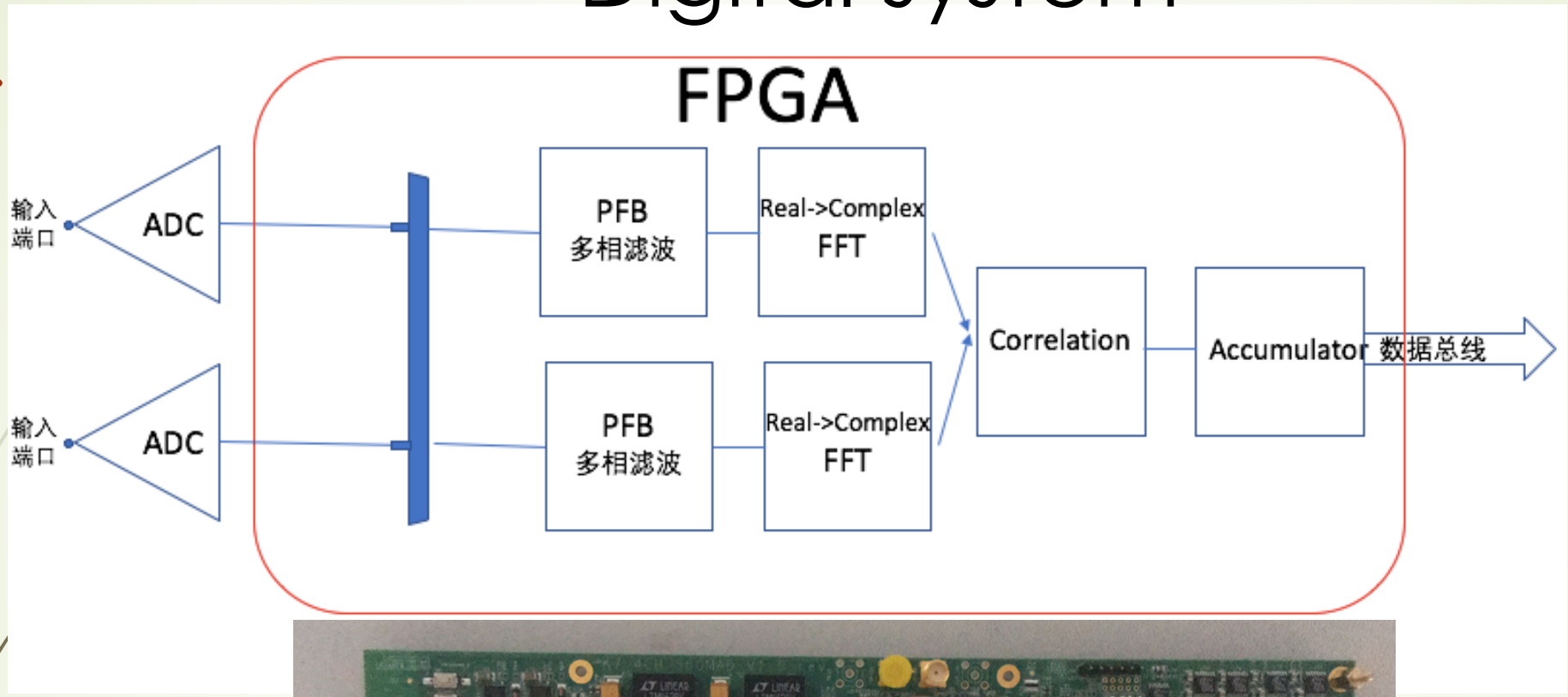

Noise source
Directional coupler
Power splitter
DUT
correlator
Vector network analyzer

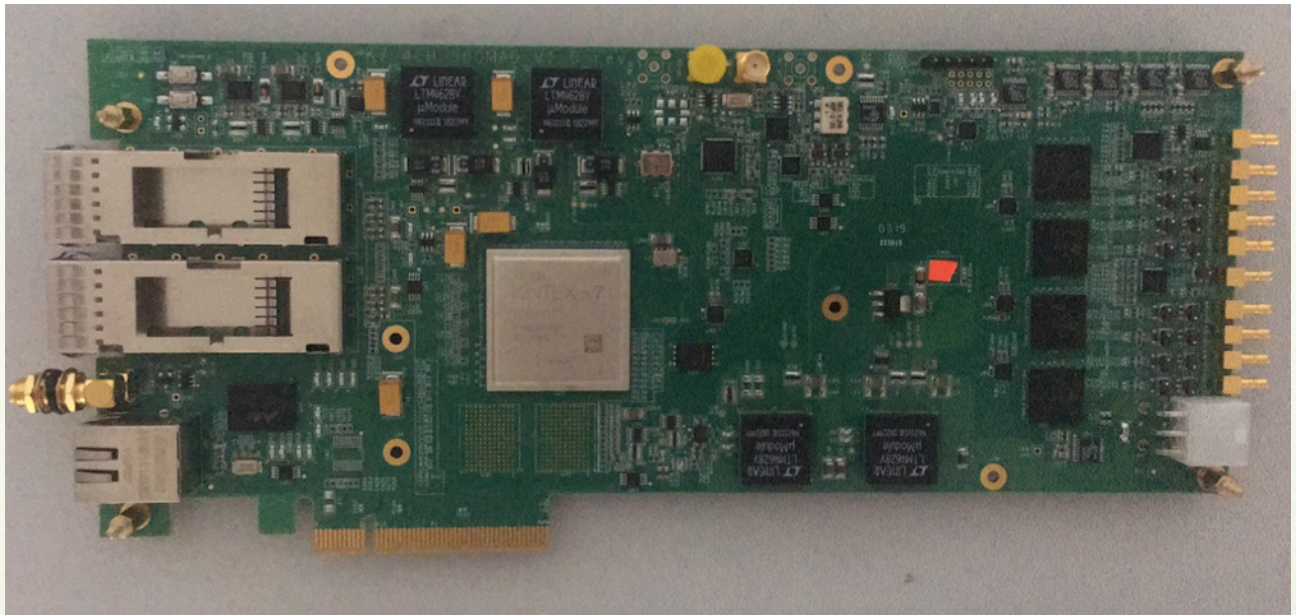


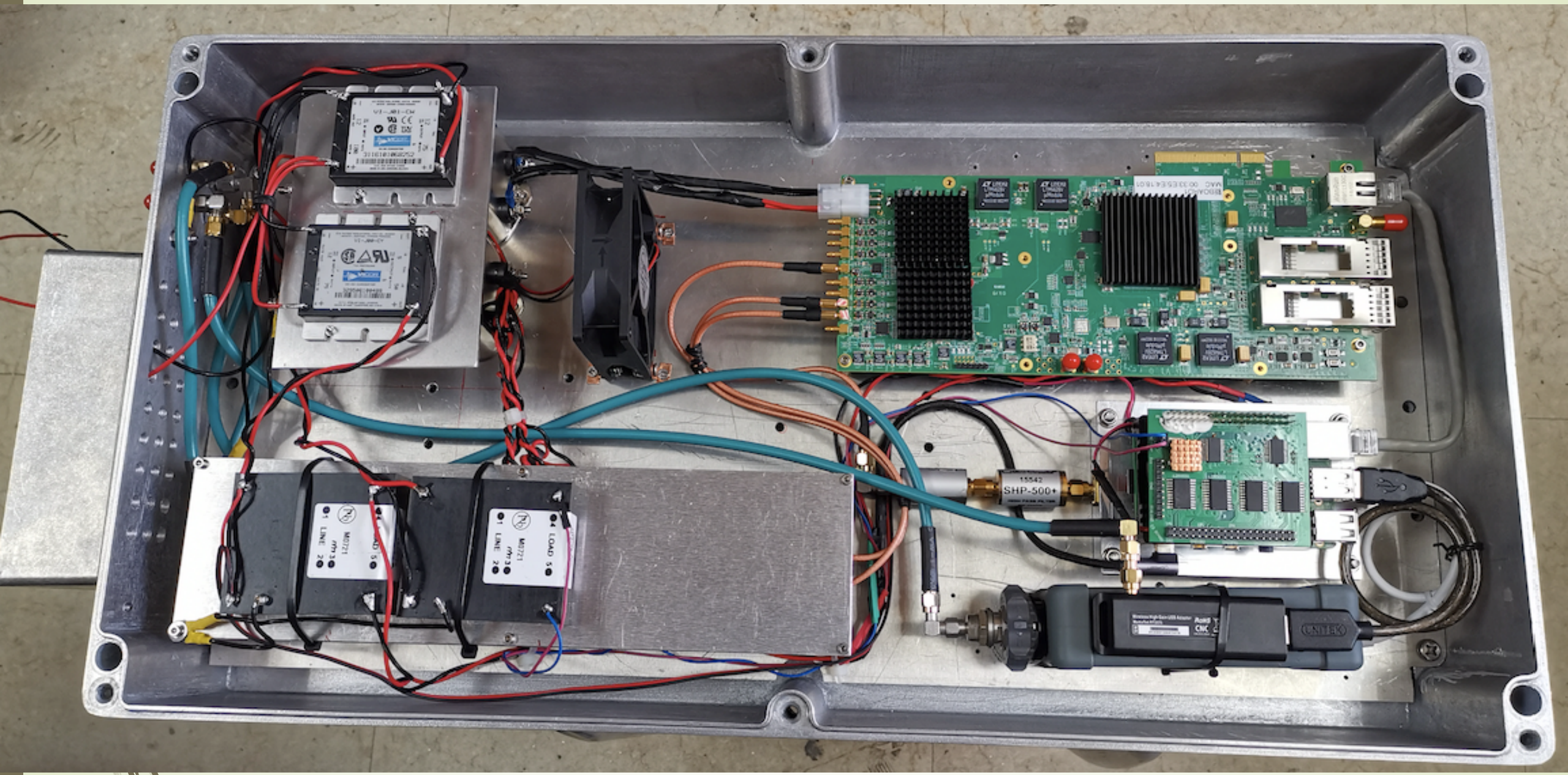

24.00s
(5GS/s)
Depth:10K
M:10s
1.00v


tyco
MACOM

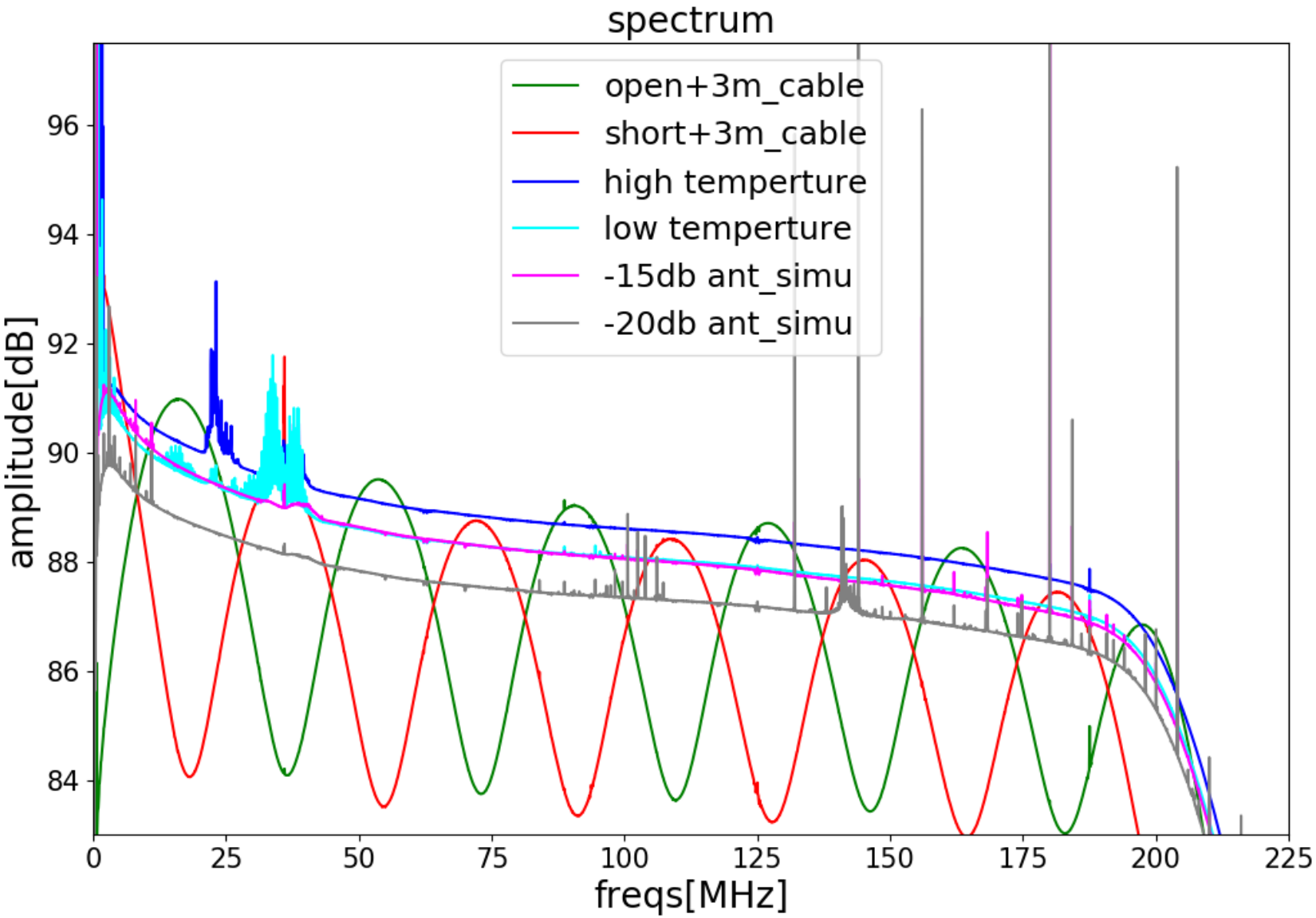
Digital system



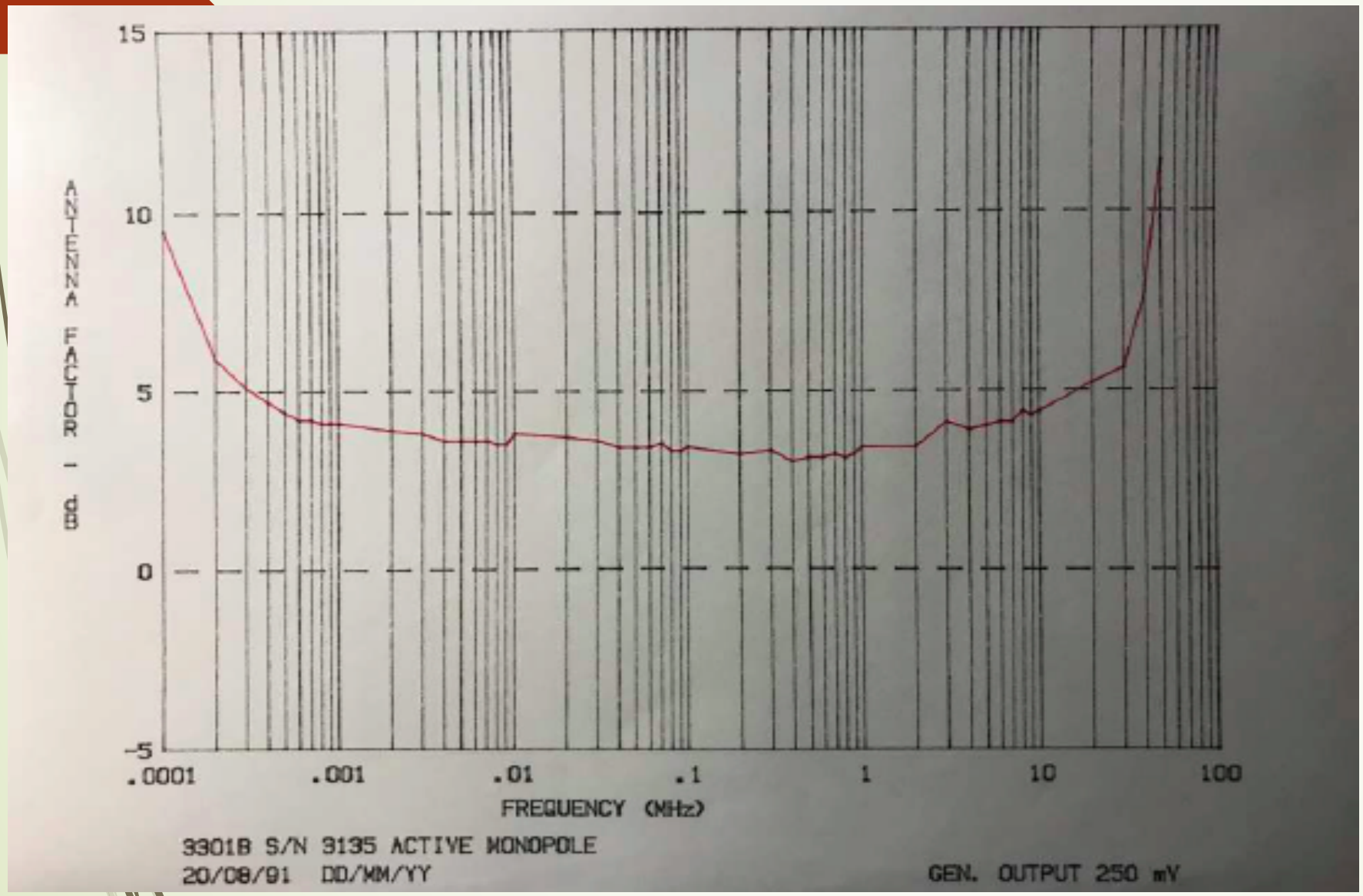


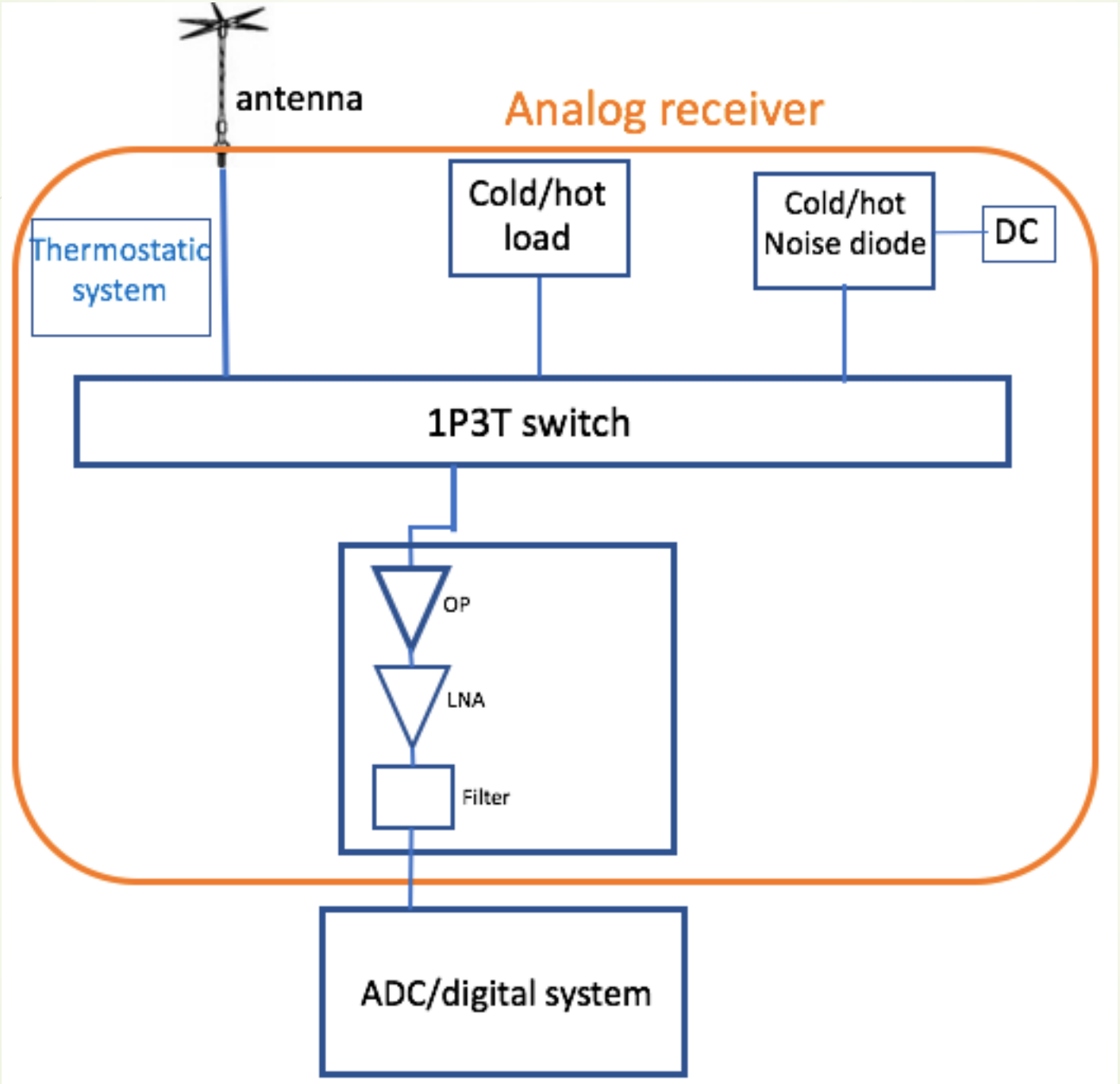

11542
SHP-500+
LOAD
LINE

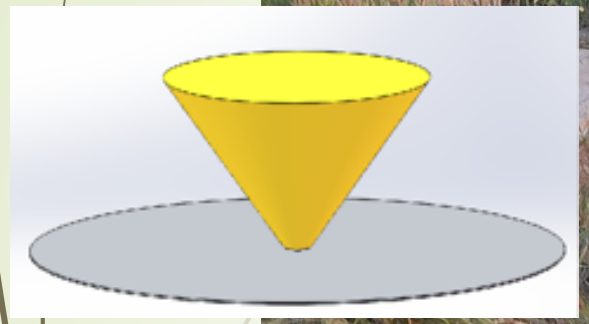
Laboratory testing

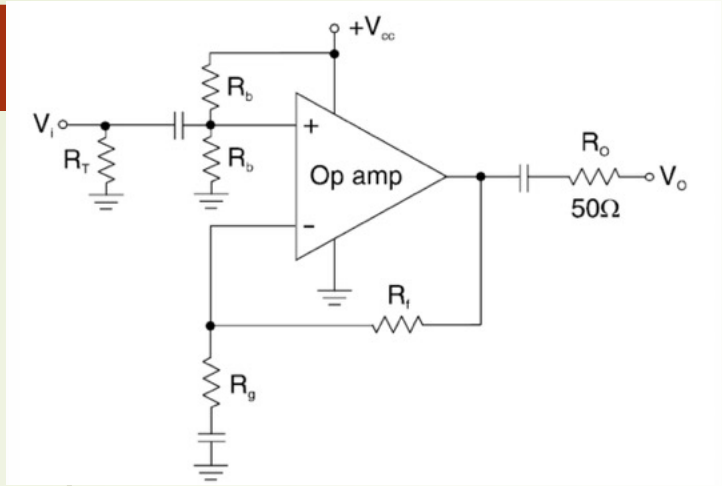


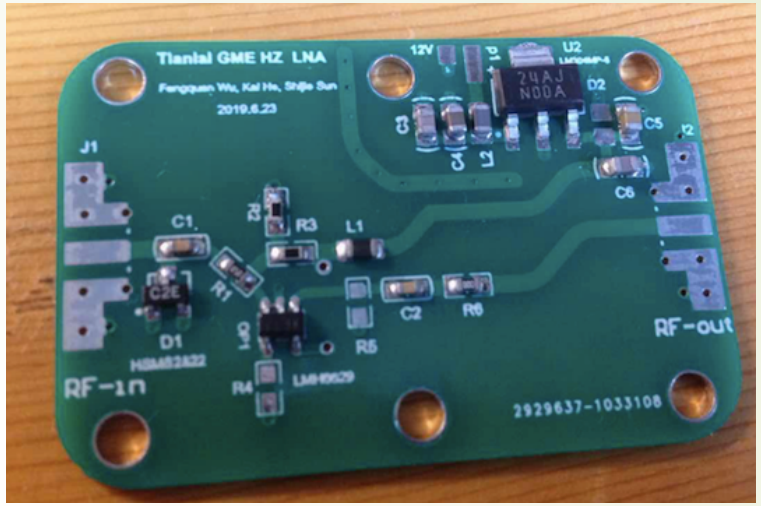
Plan C: High input impedance LNA system

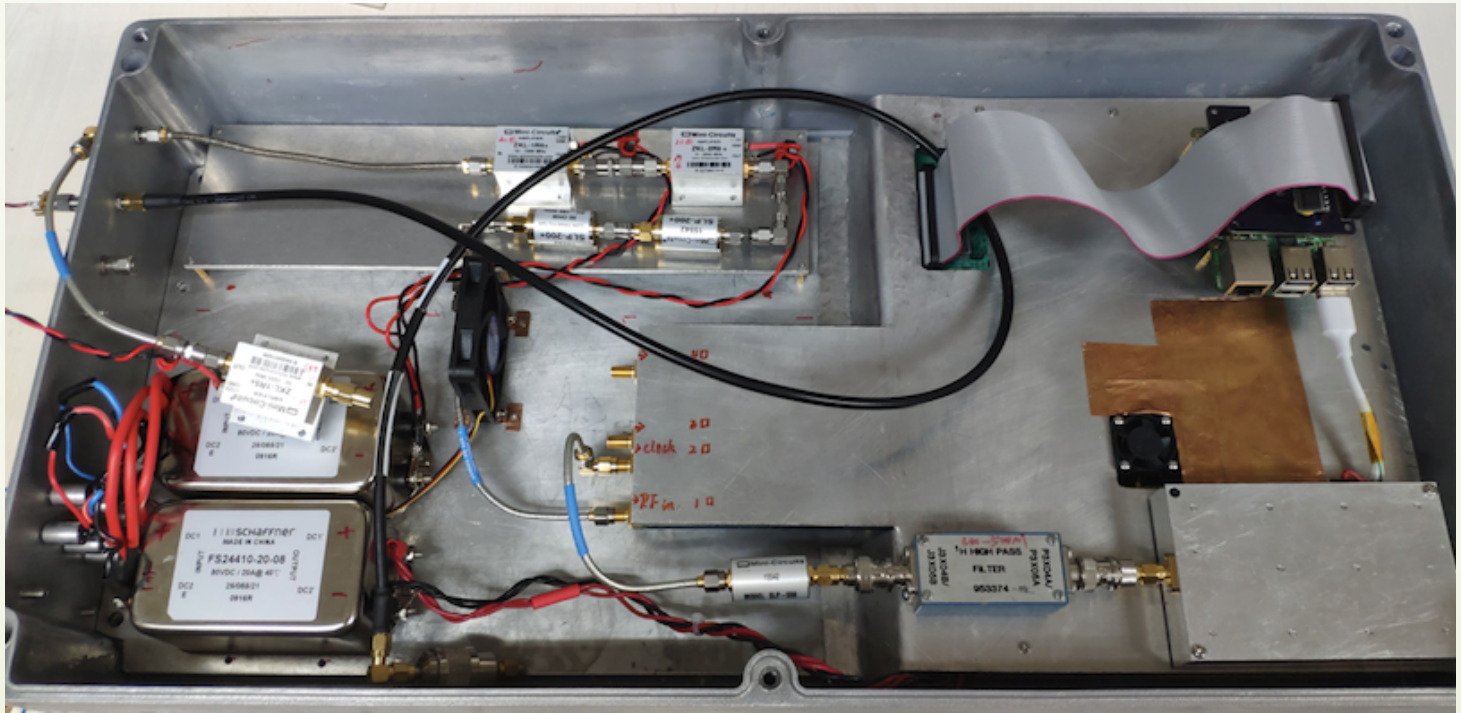

15
10
5
0
-5
ANTENNA FACTOR - dB
.0001
.001
.01
.1
1
10
100
FREQUENCY (MHz)
3301B S/N 3135 ACTIVE MONOPOLE
20/08/91 DD/MM/YY
GEN. OUTPUT 250 mV

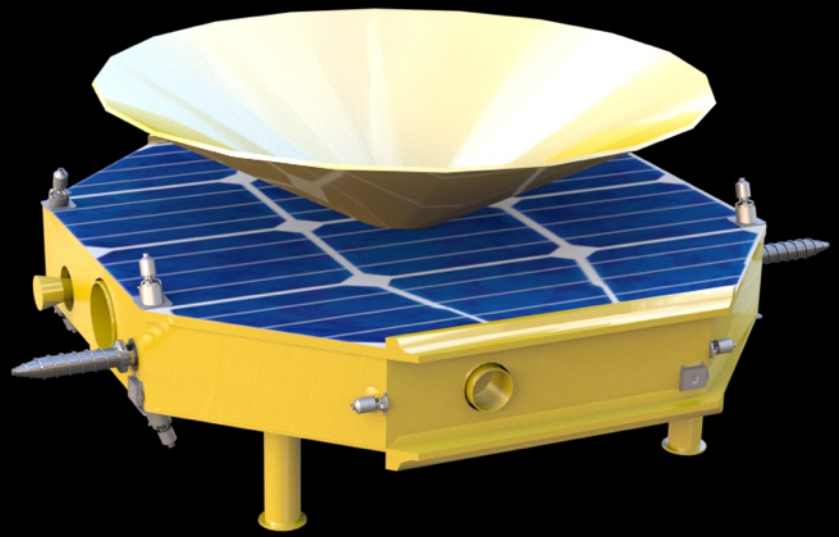

antenna
Analog receiver
Thermostatic system
Cold/hot load
Cold/hot Noise diode
DC
1P3T switch
OP
LNA
Filter
ADC/digital system

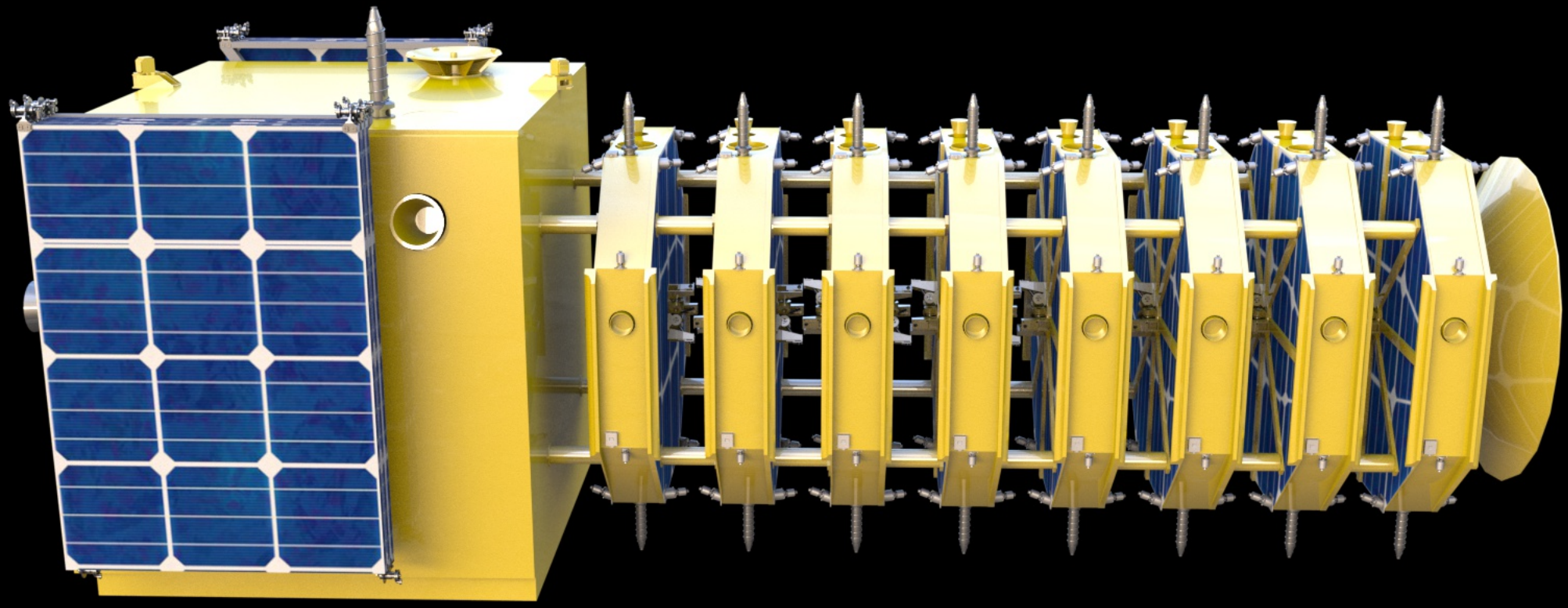



+Vcc
Rb
Vi
RT
Rb
Op amp
Ro
Vo
50Ω
Rf
Rg


Tianlai GME HZ LNA
2019.6.23
12V
U2
24AJ
N00A
D2
C5
C6
J1
C1
R2
R3
L1
C2E
R1
C2
R6
D1
R5
R4
RF-in
RF-out
2929637-1033108


FS26410-20-08
RF in





Summary

- This is three-year pre-study program for payload of 21cm global spectrum measurement system
- Through the development and experiment, hope to break through the vase neck of 21cm global spectrum measurement
- Most interesting thing is to search for unknown unknowns
- Collaboration is welcome!

Thanks !