30 Apr. -4th May 2017 TOW@ Haystack

RFI Influence, Survey for Broadband VLBI

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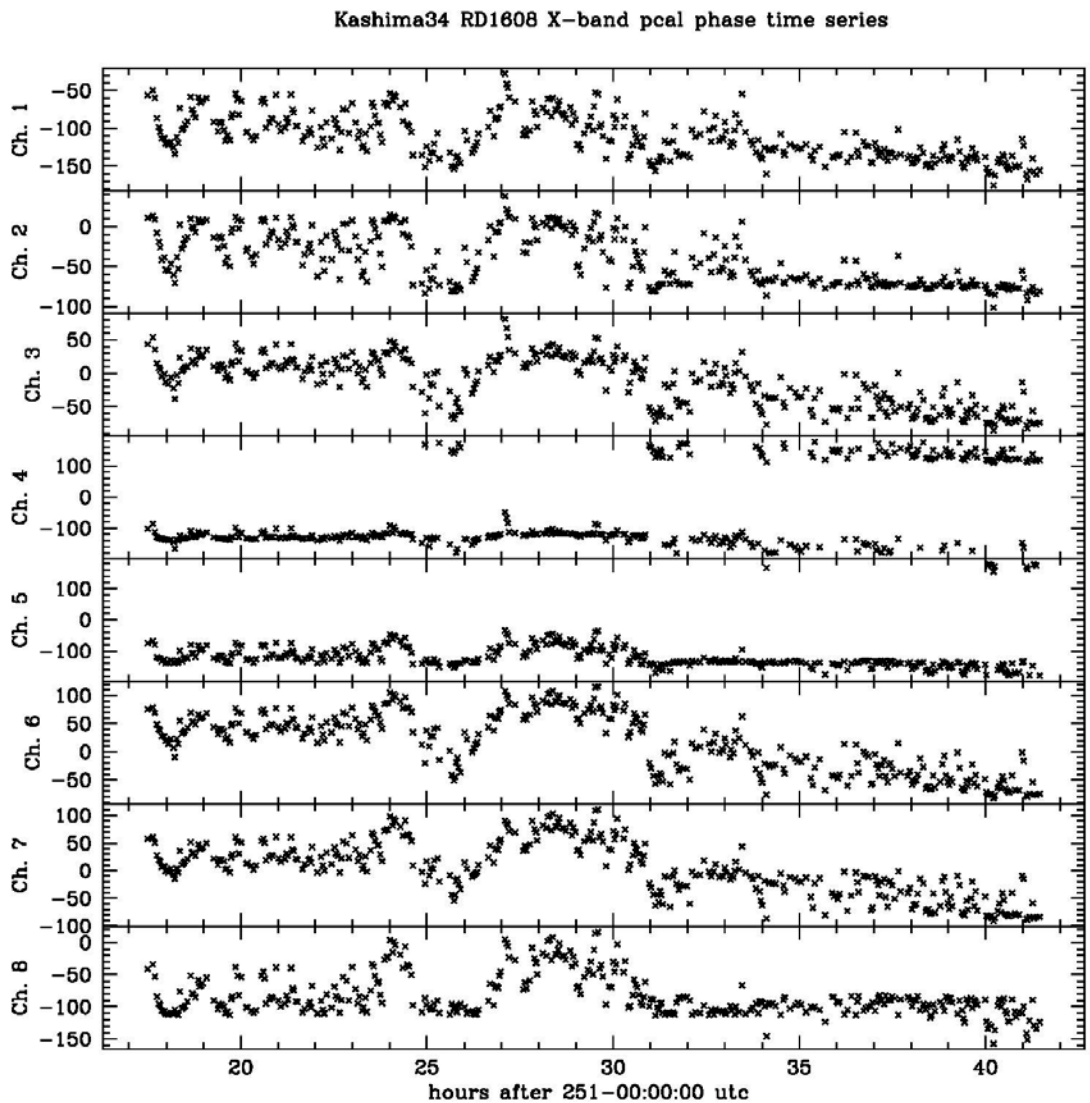
  - Robustness to RFI: Advantage of RF-Direct sampling
- Experience of Serious RFI to Saturate LNA

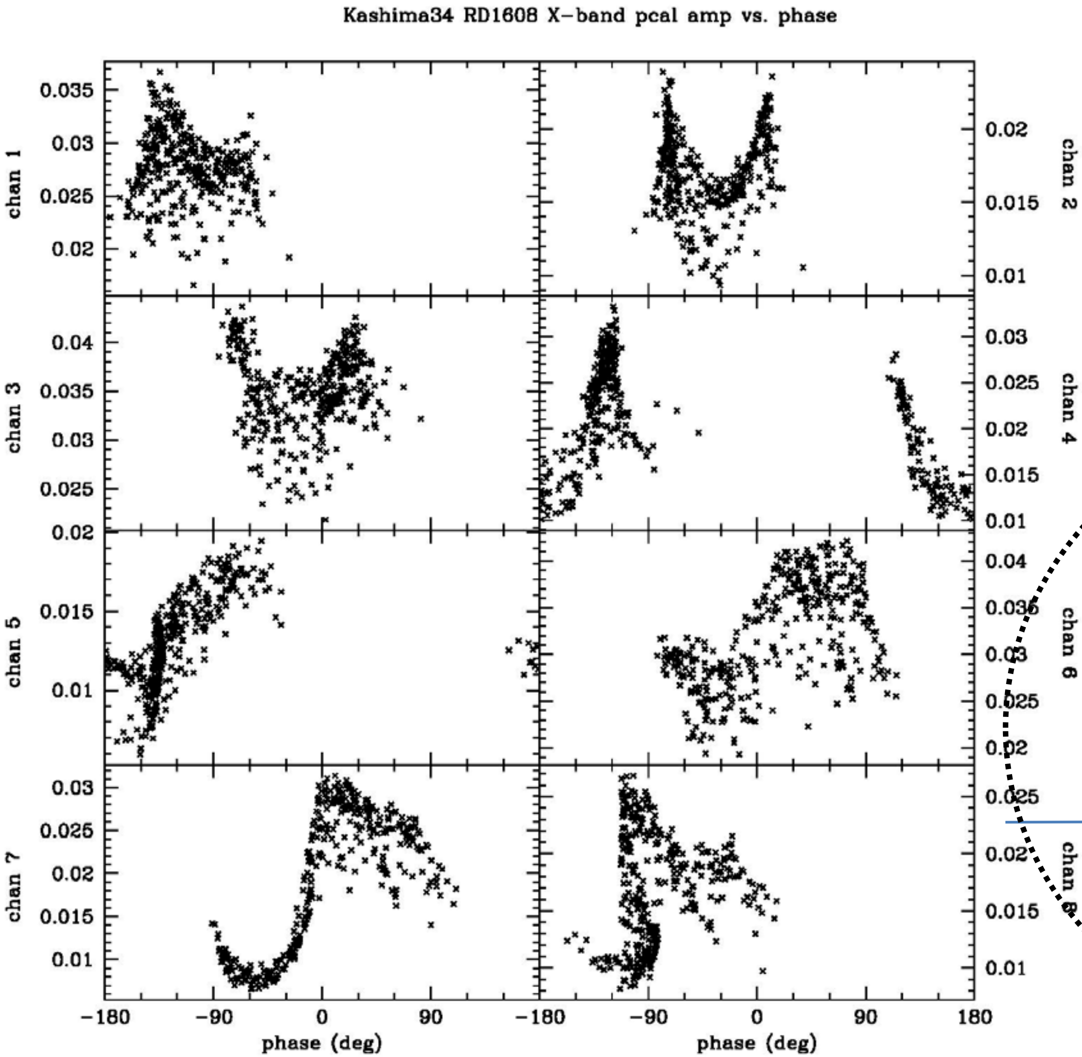
RFI to Phase-cal signal@Kas34



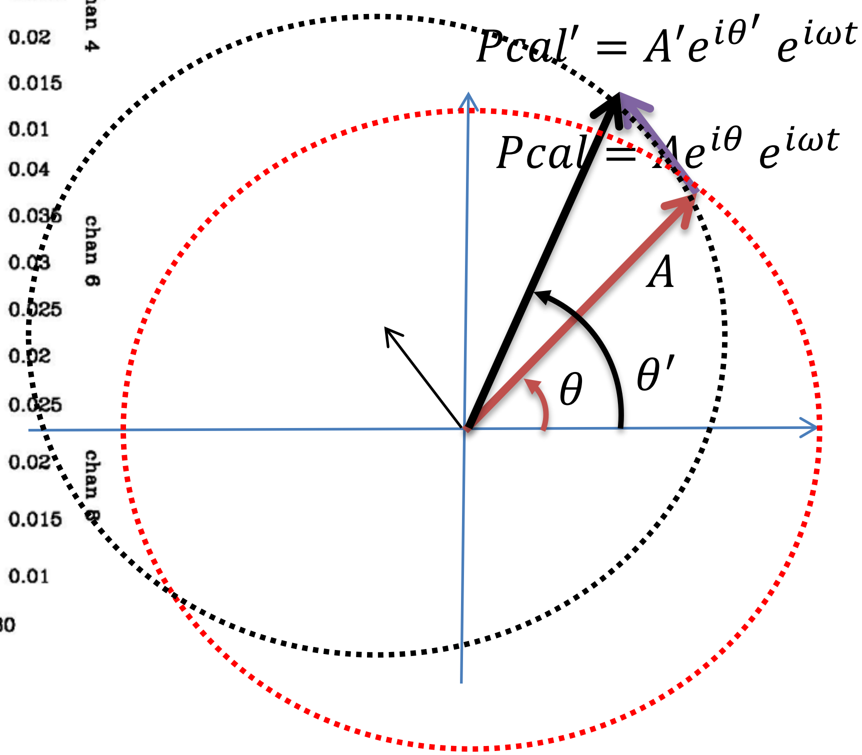
Time vs Phase

Suggested by MIT/C.Brian

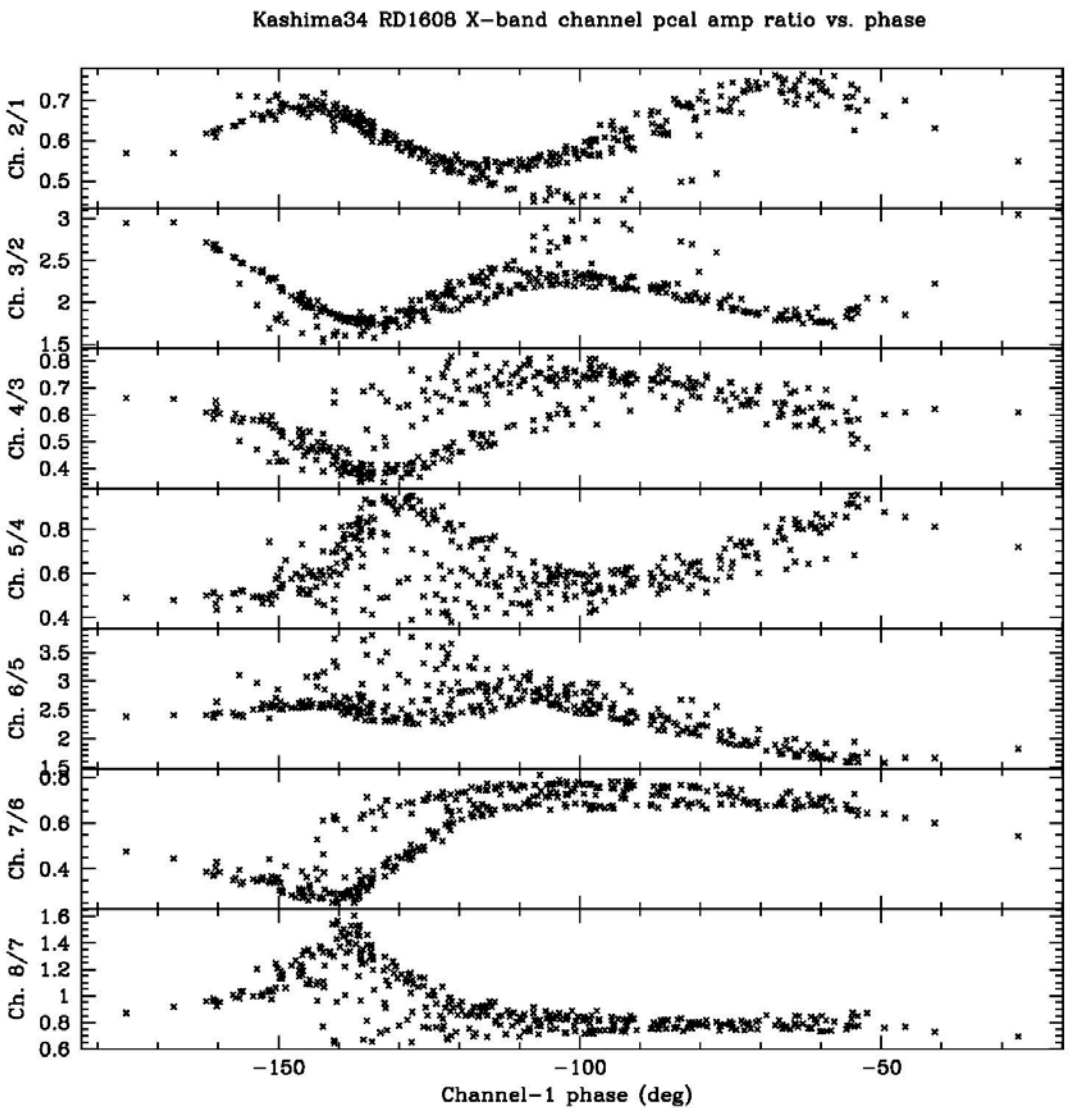
RFI to Phase-cal signal@Kas34



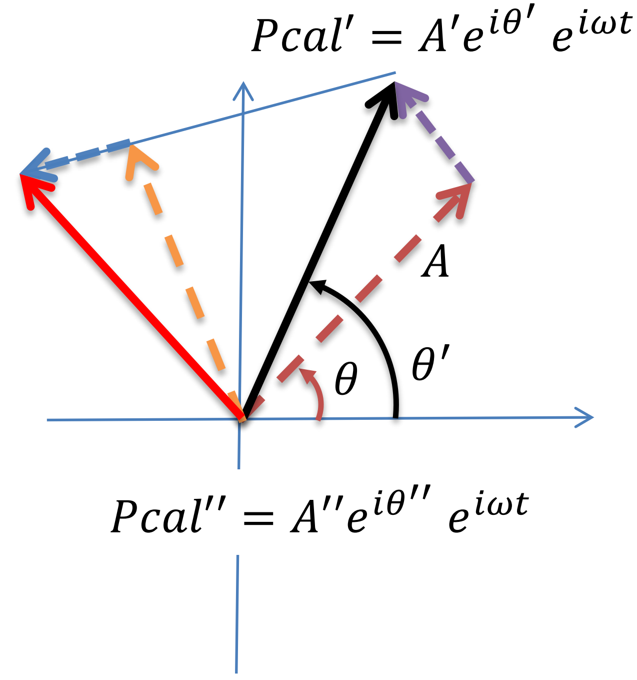
Phase vs Amp Suggested by MIT/C.Brian



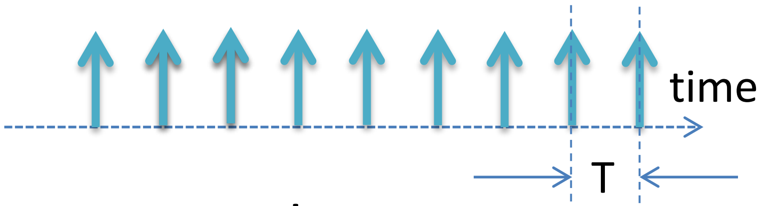
RFI to Phase-cal signal@Kas34



Phase vs Amp Ratio
Suggested by
MIT/C.Brian



RFI to Phase-cal signal@Kashima34m



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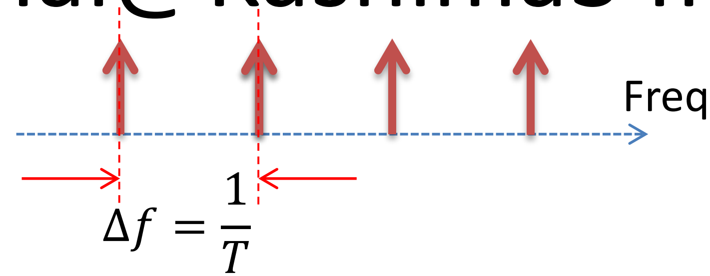
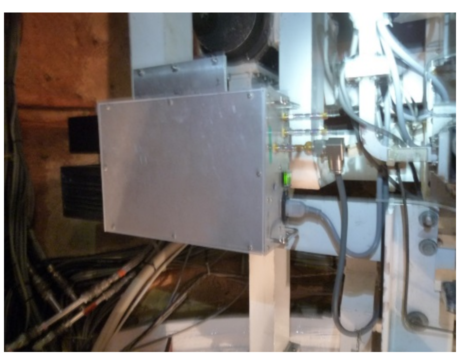
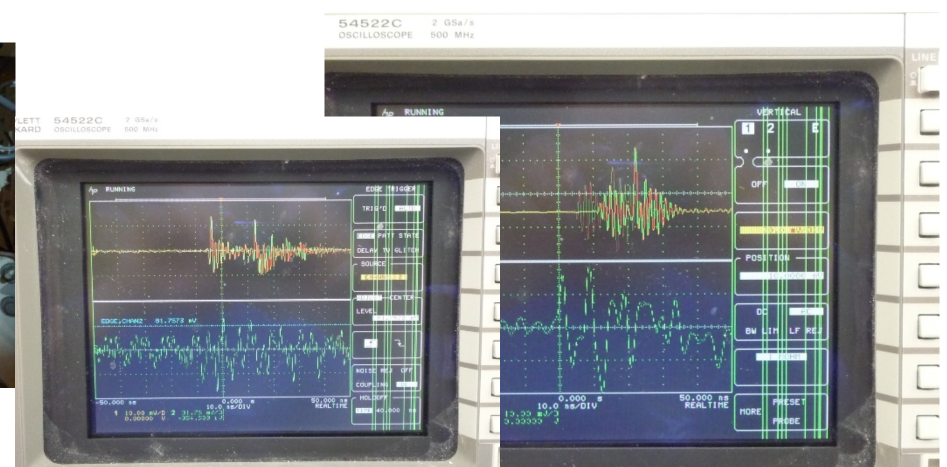
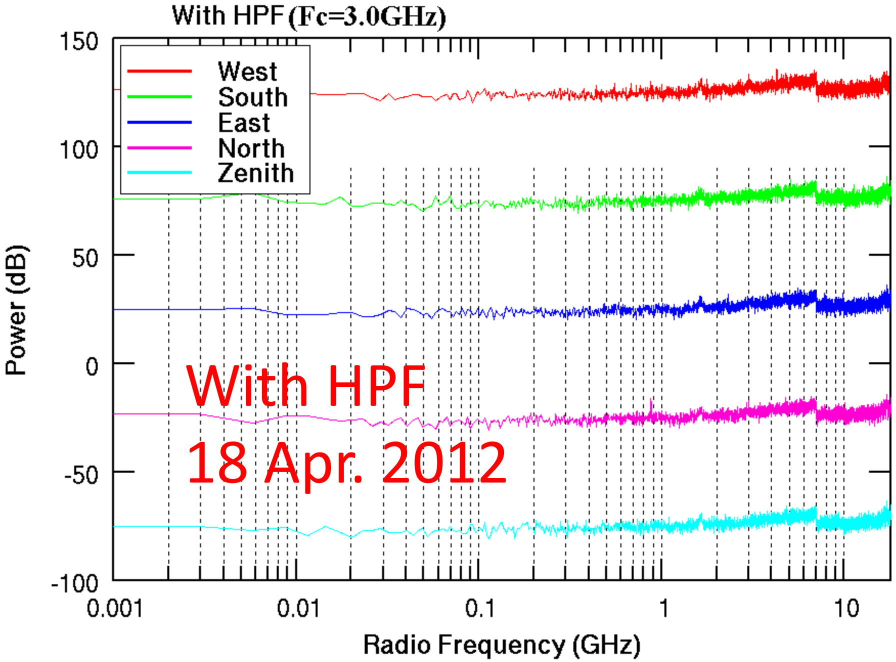


- Suspected causes are
  - A) Re-entry of emission from Pcal antenna unit into the receiver feed.
  - B) Contamination of Pcal signal by distorted signal.
- Investigation:
  - We wrapped Pcal antenna unit by aluminum foil to suppress emission. Though no significant improvement. Thus cause A) seems to be rejected.
  - Pcal pulse signal shape in time domain might resulting cause B), just in case.

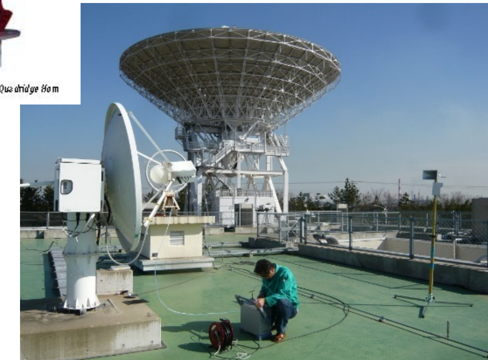


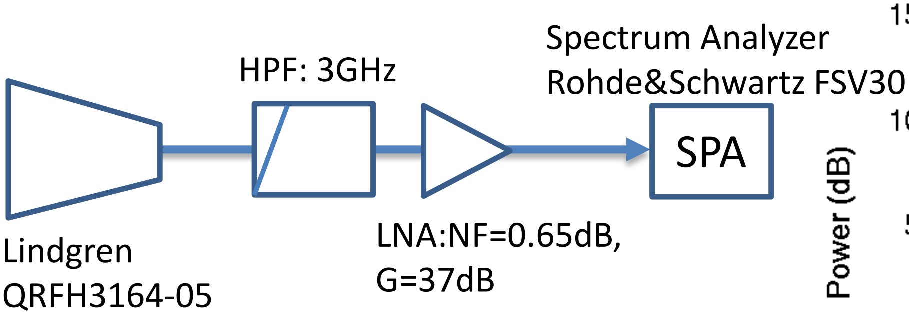


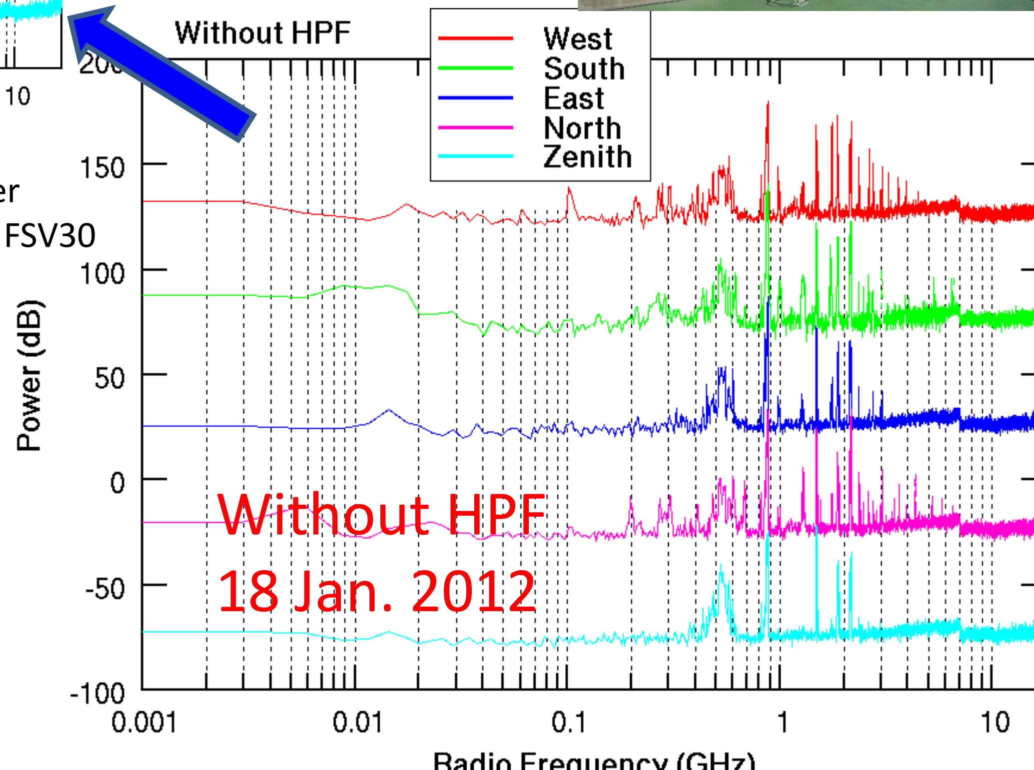
Lesson from Broadband Observation



RFI@1.6m MARBLE1
EST-Lidgren 3164-5
Broadband Antenna
RBW=500kHz



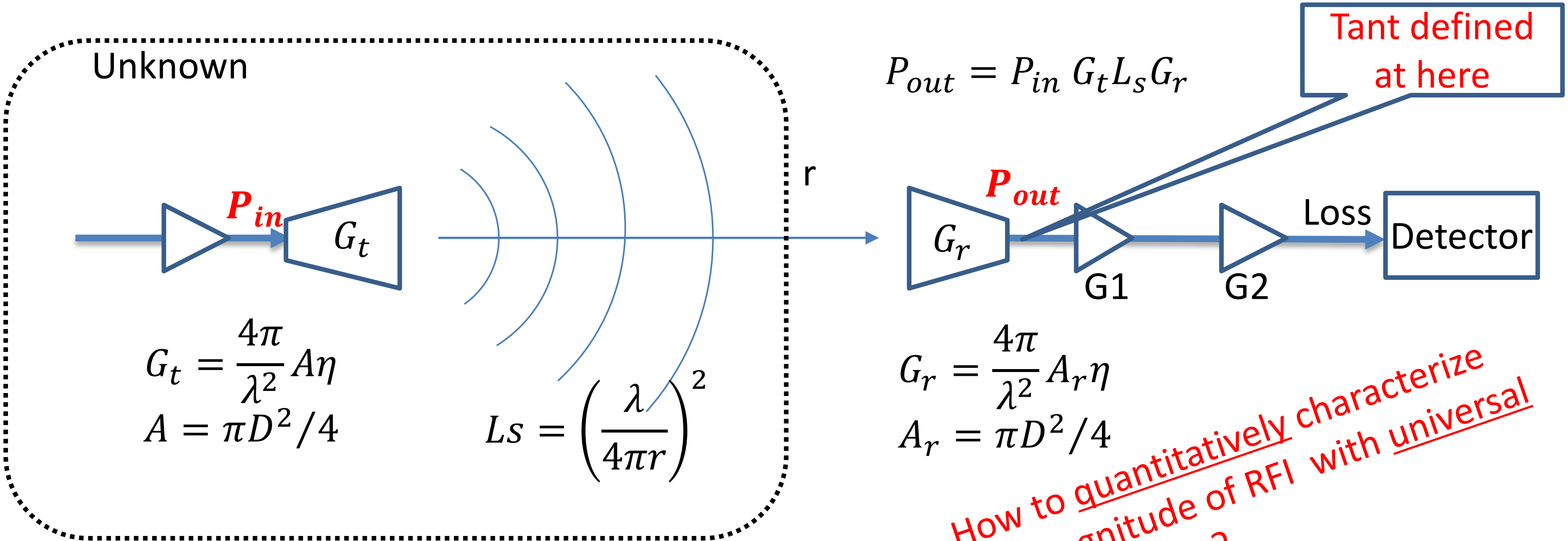




RFI(Mag:50dB) is eliminated by HPF(3GHz)
At initial stage of MARBLE1.6m
(Broadband antenna)

High Pass Filtering is Necessary!!

External RFI Measurement



How to quantitatively characterize the magnitude of RFI with universal representation?

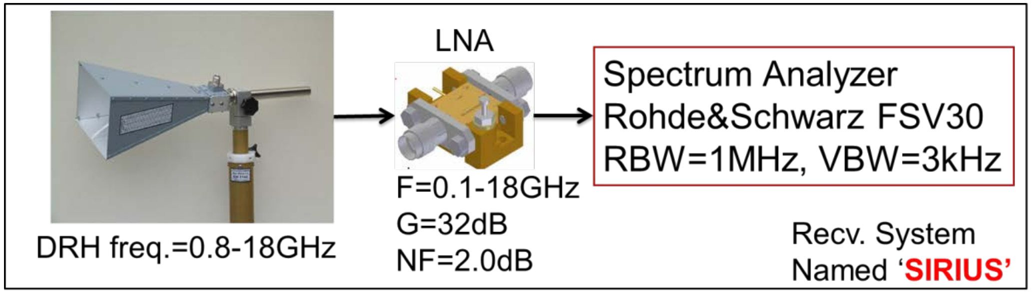
Conditions:

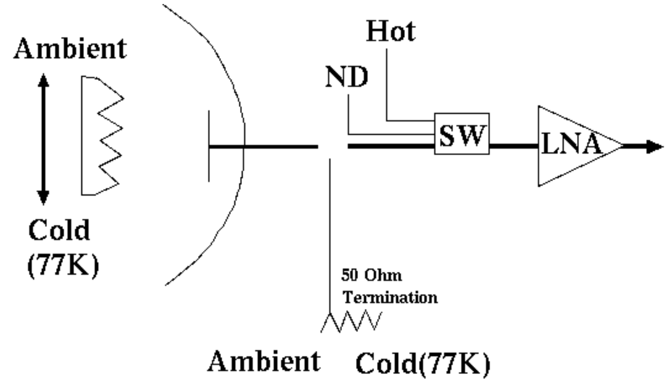
- Receiving power of RFI at Antenna feed depend on G_r
- Receiving power of RFI at Detector depend on Gr,G1,G2,and Loss of the receiver.
- Ratio of RFI power w.r.t. noise level depend on the receiving bandwidth.

Our Strategy:

- We use RFI input power defined by Antenna temperature after calibration of receiver gain under the condition the receiving system works in linear response region..
- Advantages: Free from RBW of measurement, Easy to understand the influence for radio telescopes.
- Drawback: Antenna temperature depend on the antenna gain used for measurement.

Tsky,Trx Measurement by Y-factor



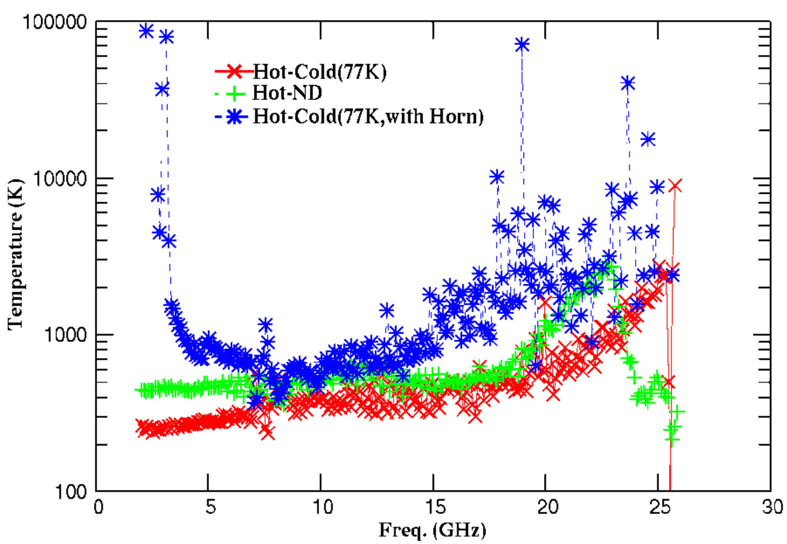


$$Y_1 = \frac{P_{ND}}{P_{Hot}} = \frac{T_{rx} + T_{ND}}{T_{rx} + T_{Hot}}$$

$$Y_2 = \frac{P_{Sky}}{P_{Hot}} = \frac{T_{rx} + T_{Sky}}{T_{rx} + T_{Hot}}$$

$$T_{rx} = \frac{T_{ND} + Y_1 \cdot T_{Hot}}{Y_1 - 1}$$

$$T_{Sky} = Y_2 \cdot (T_{rx} + T_{Hot}) - T_{rx}$$



Equipment:

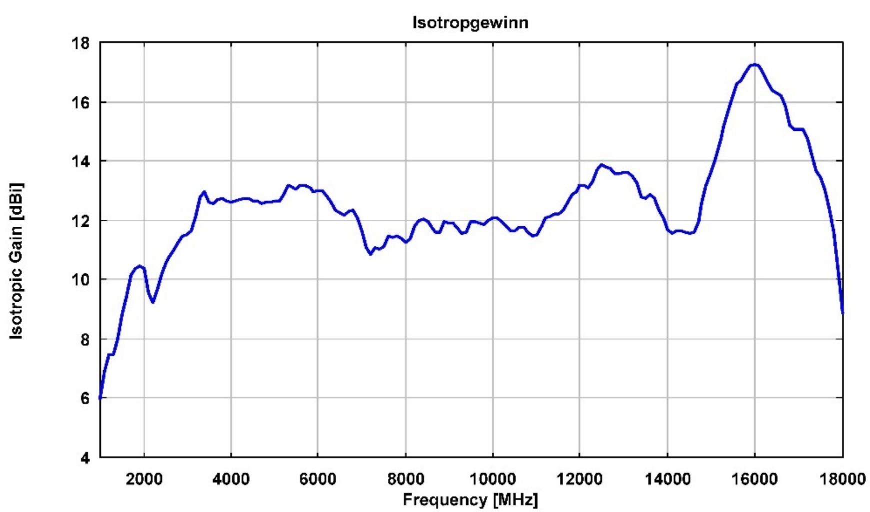
- FEED: Schwarzbeck BBHA-9120D (0.8-18.5GHz)
- LNA:B&Z BZP118UD1(G=32dB, NF=2dB, f=0.1-18GHz)
- Spectrum Analyzer: Rohde&Schwarz FSV30

Measurement Condition:

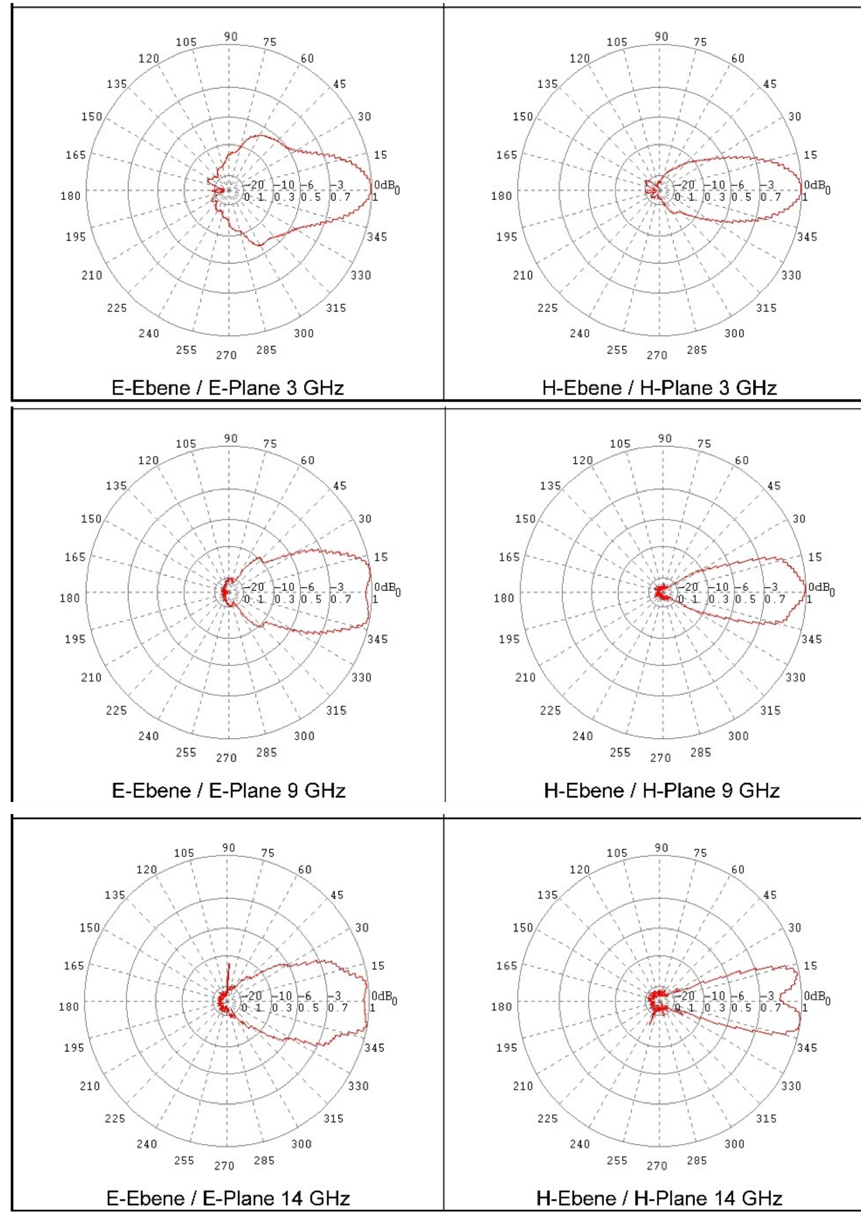
- Polarization-V(all sites), H(NMIJ)
- North/East/South/West Directions

SchwarzBeck9120D Double Ridged Horn

Beam width ~ 30 deg.



Beam pattern of survey antenna



Broadband RFI Survey Sites

NICT-HQ(Koganei)

RF of 2nd Building. Communication Antenna for TWSFTT(14GHz), Other emission from experimental system of NICT Labs.

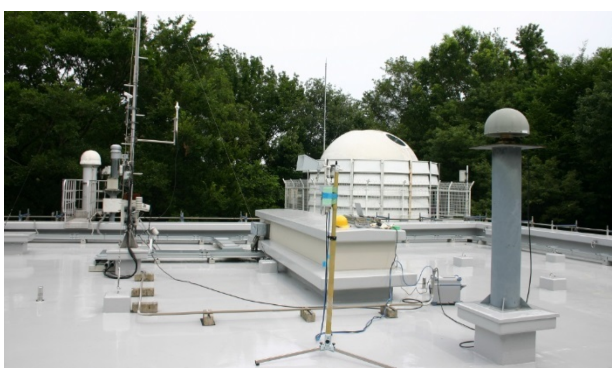
NMIJ(Tsukuba)

Communication Antenna for TWSFTT(not used).

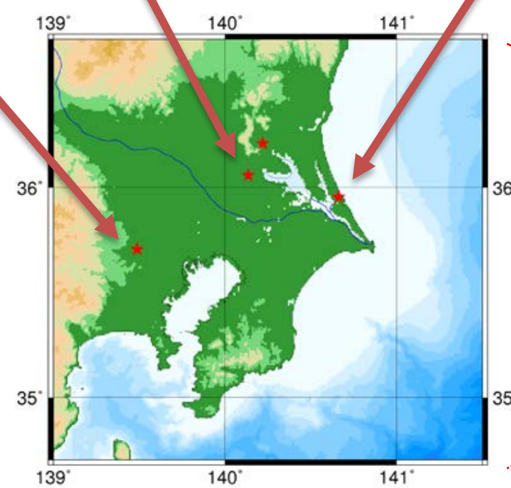
NICT (Kashima)

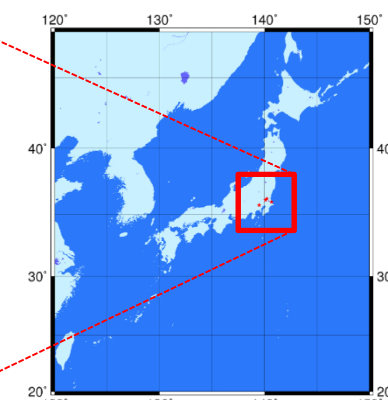
Roof Floor of Kashima 34m VLBI station Building.

NICT-HQ(Koganei 11m)

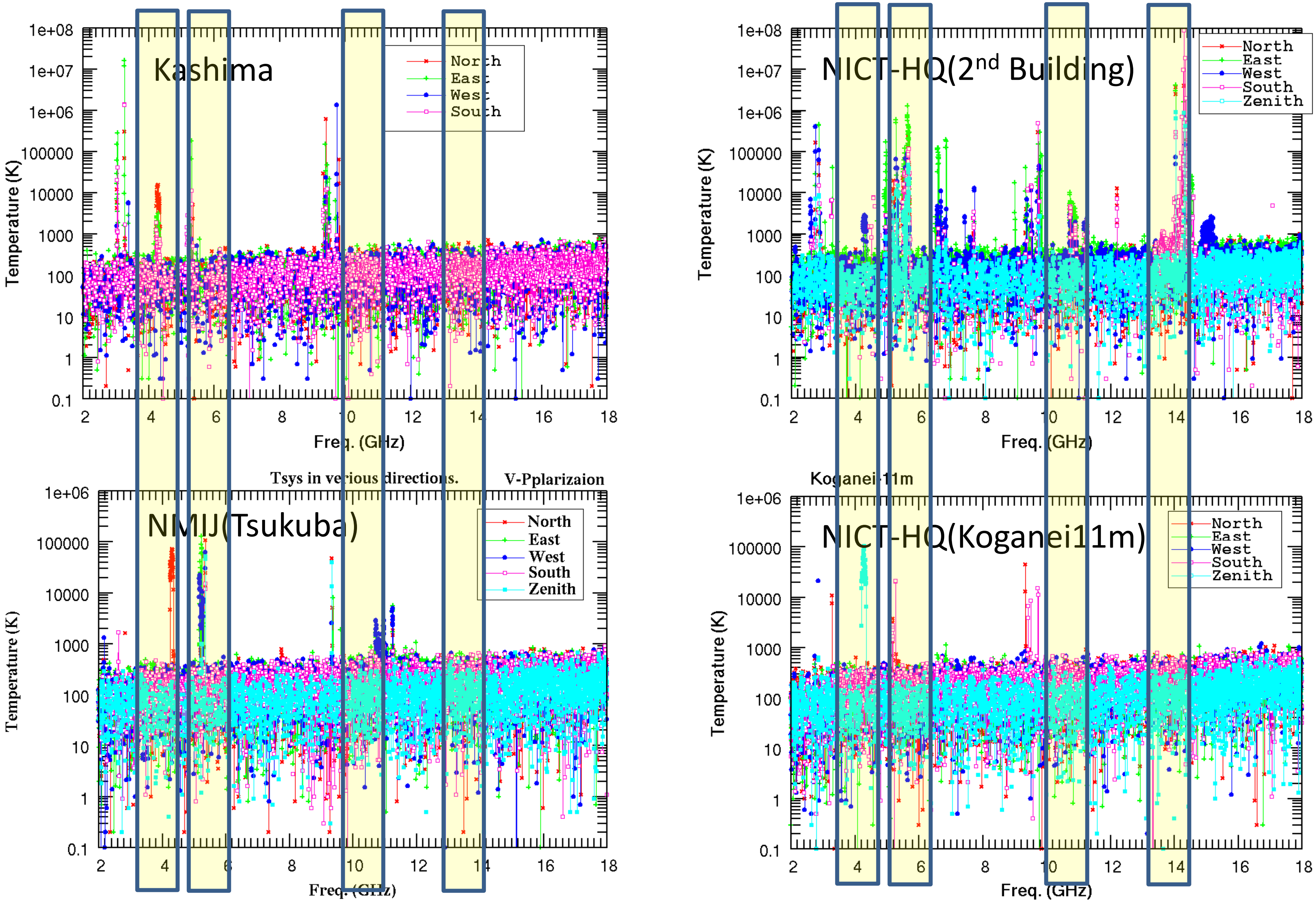


Roof Floor of Koganei 11m VLBI station Building. Relatively quiet. Surrounded by trees.



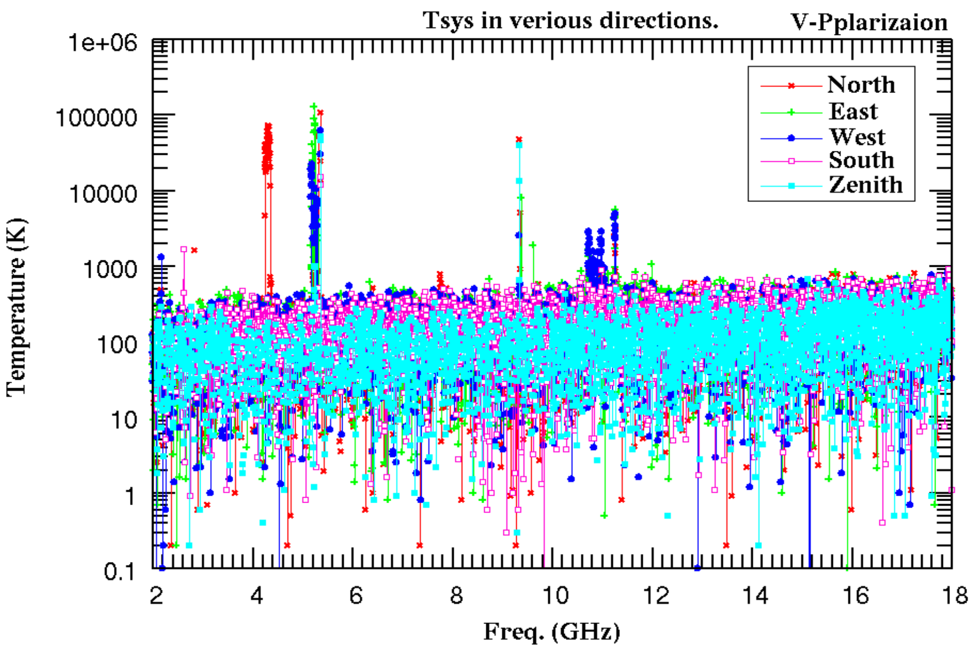


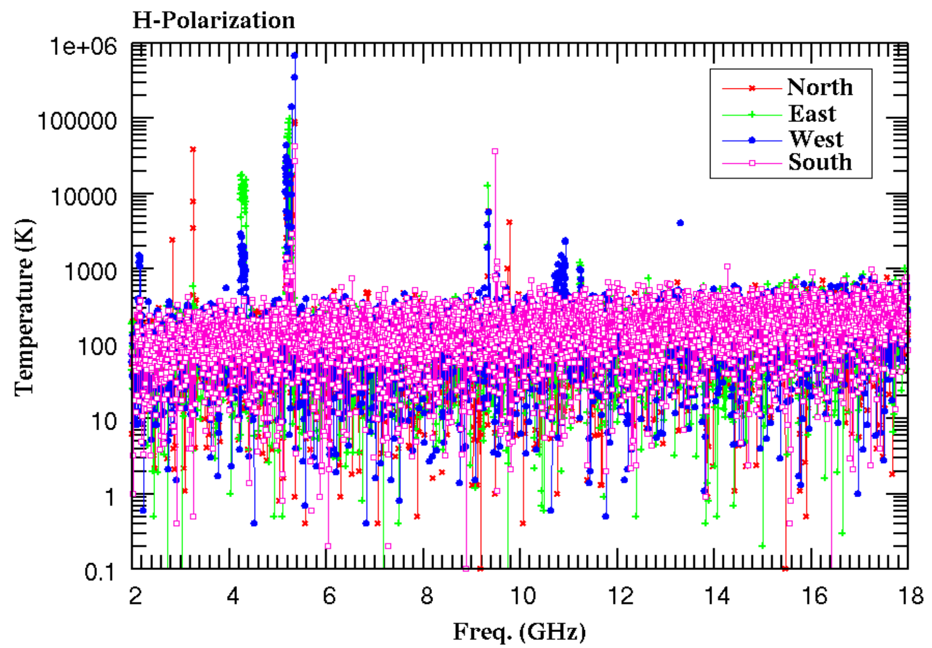
V-Polarization



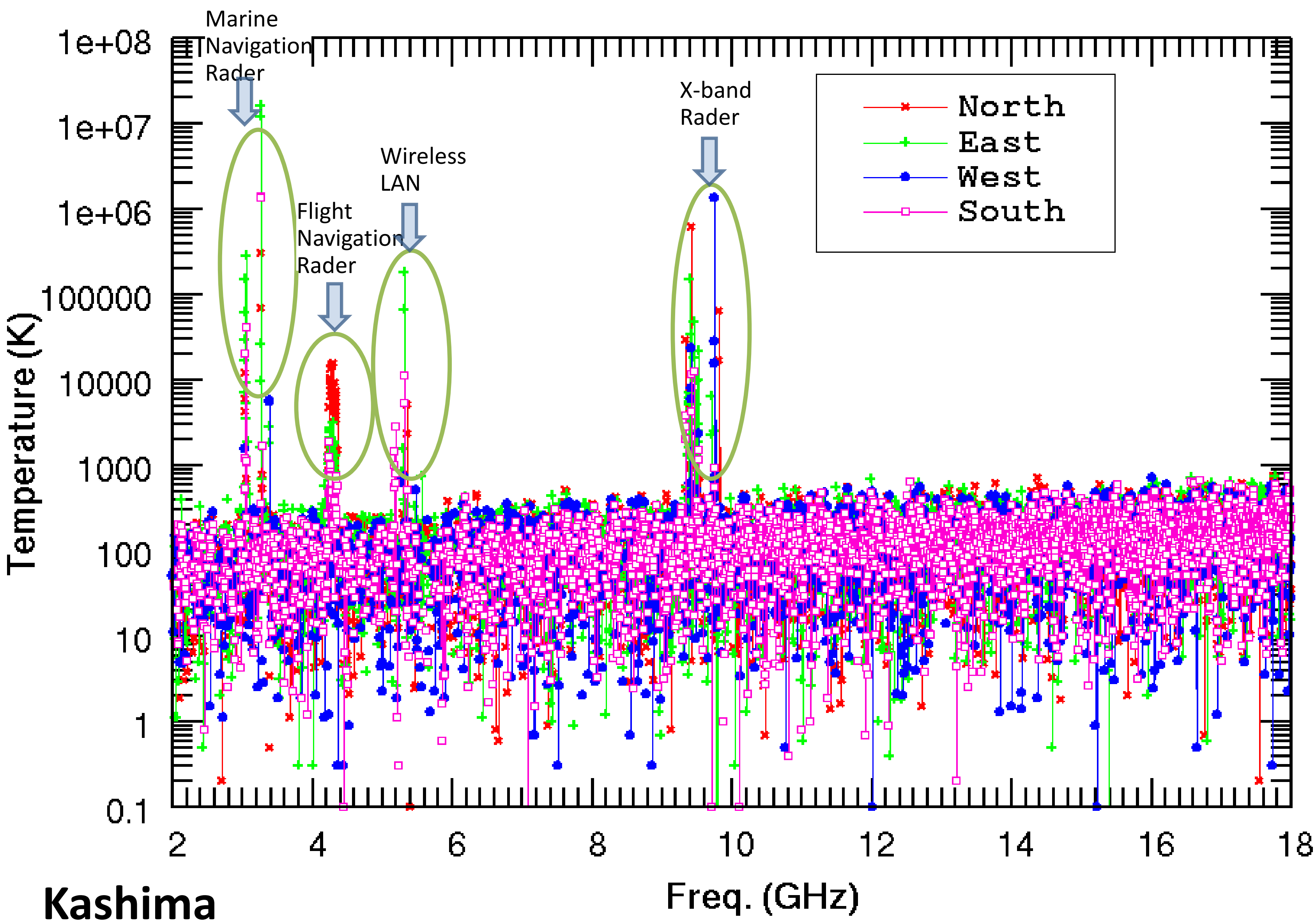
V/H-Polarization Comparison (NMIJ@Tsukuba)

There were no significant difference on V/H Polarization.



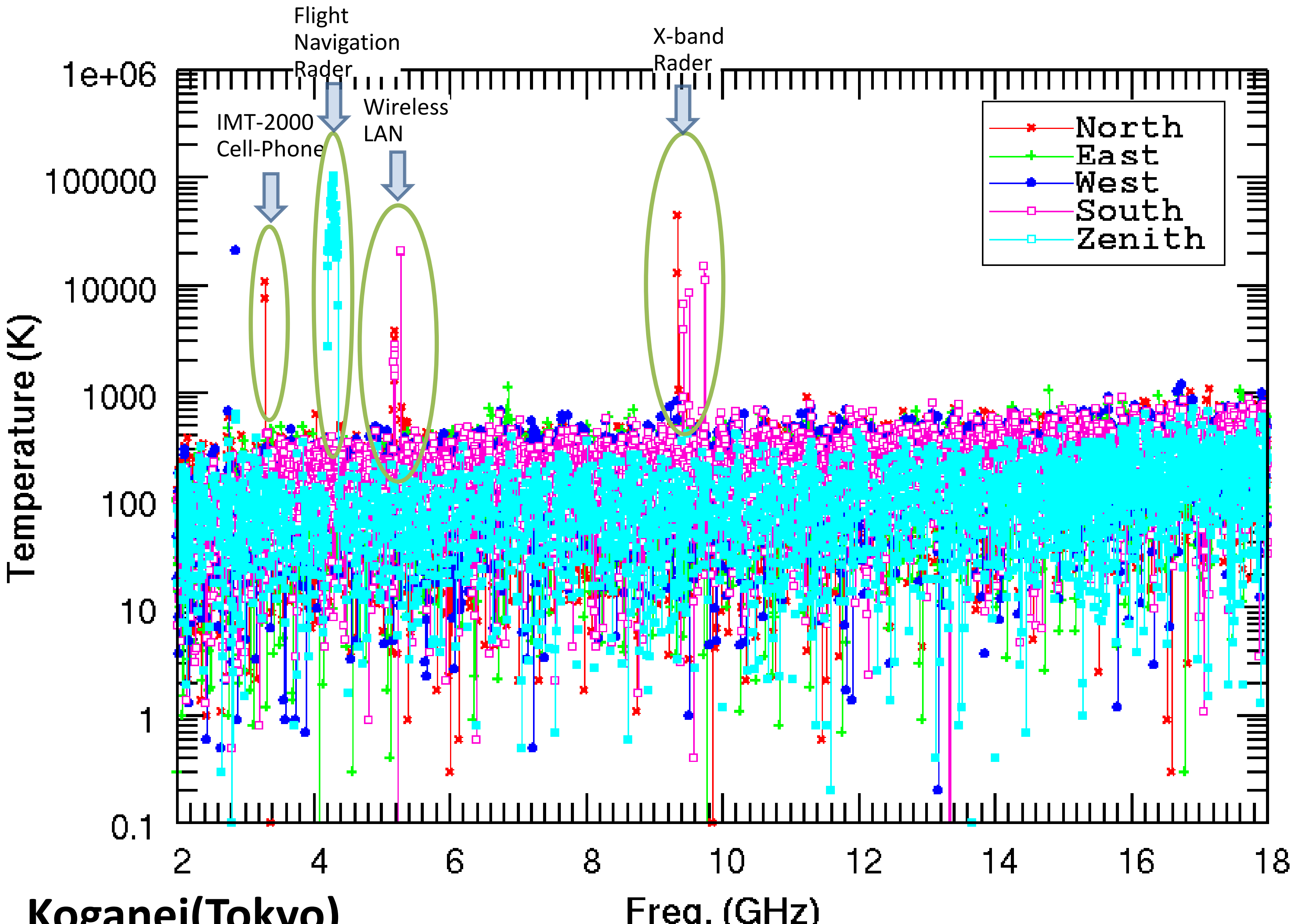


Speculation of IRF Sources



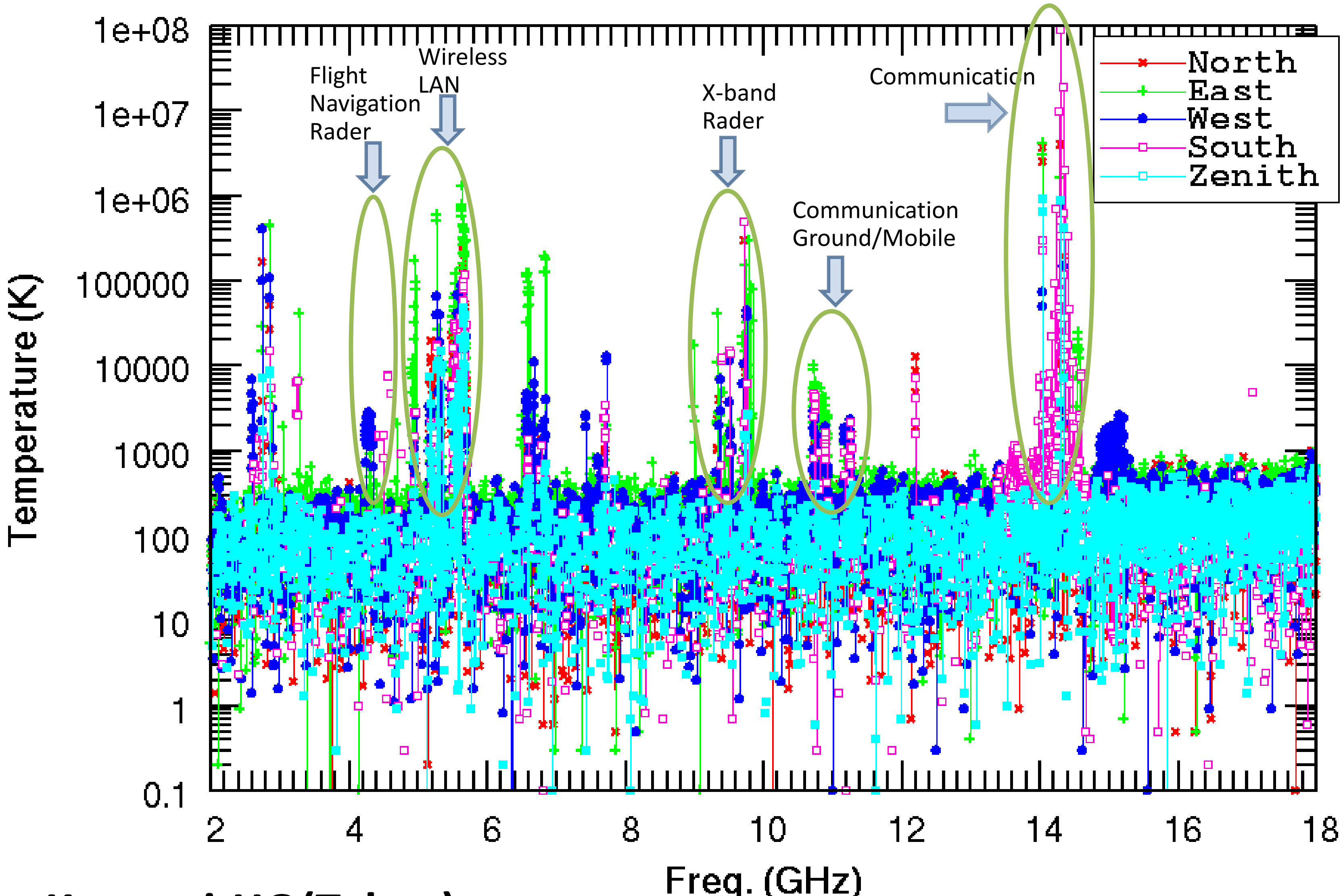
Kashima

Speculation of IRF Sources



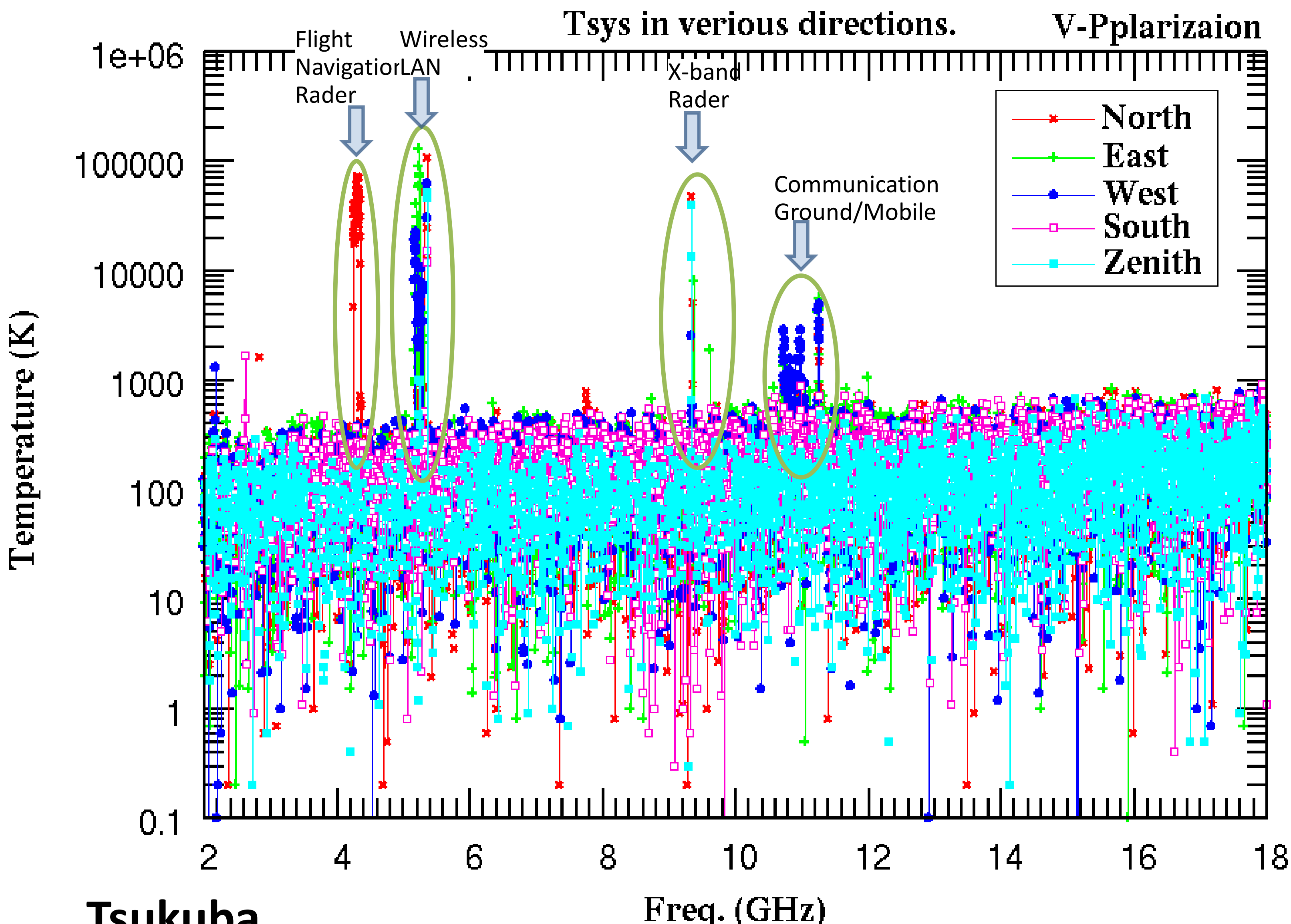
Koganei(Tokyo)

Speculation of IRF Sources



Koganei-HQ(Tokyo)

Speculation of IRF Sources



Tsukuba

Sources of RFI

- Cell phone and its base station. (1.48GHz 1.9GHz, 2.2GHz)
- 3.0 - 3.4 GHz: Marine Navigation Rader
- 4.25-4.35 GHz: Flight Navigation Rader (Altimeter)
- 5.15-5.35 GHz: Wireless LAN
- 9.35-9.45, 9.7-9.8 GHz: X-band Rader (Weather, Marine)
- 11.7-12.2 GHz: Broadcasting Satellite
- 12.2-12.75 GHz: Communication Satellite
  - But this may not be so serious since probability of the beam couping is low.
  - But actually it may happen.

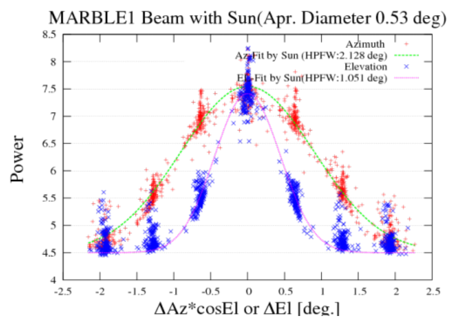
Influence of RFI from Satellite Signal

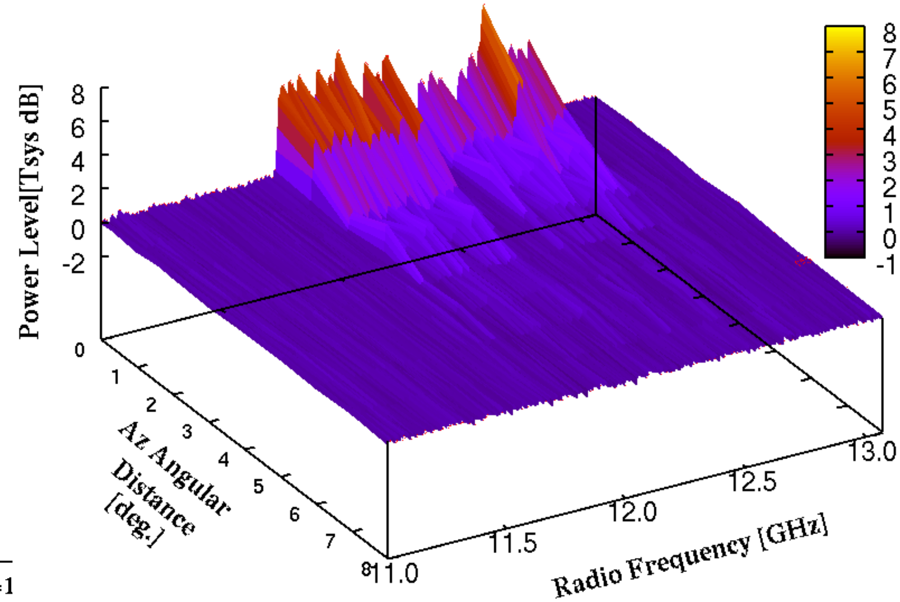
Broadcasting Satellite

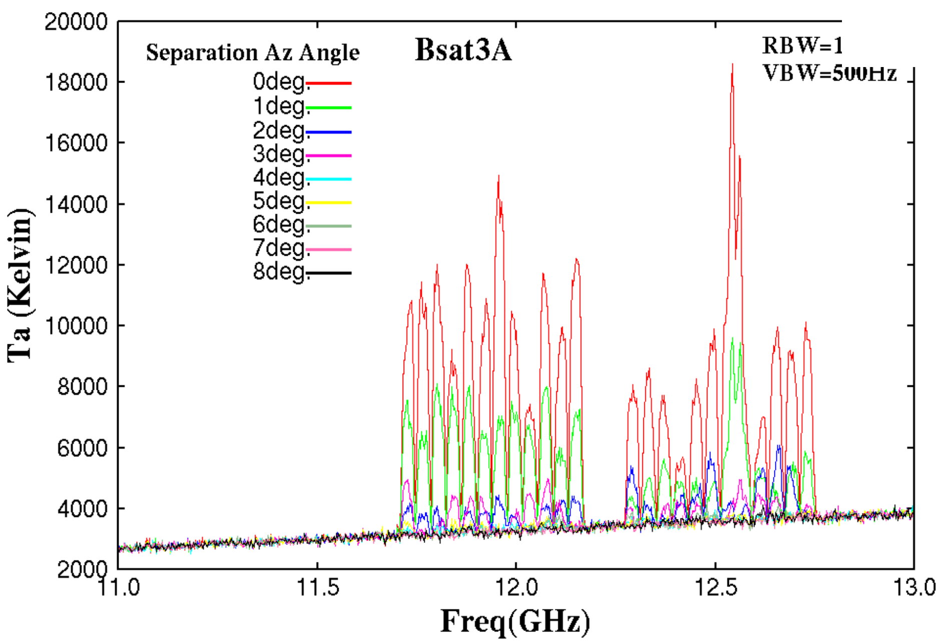
$$G = \frac{4\pi}{\lambda^2} A\eta$$

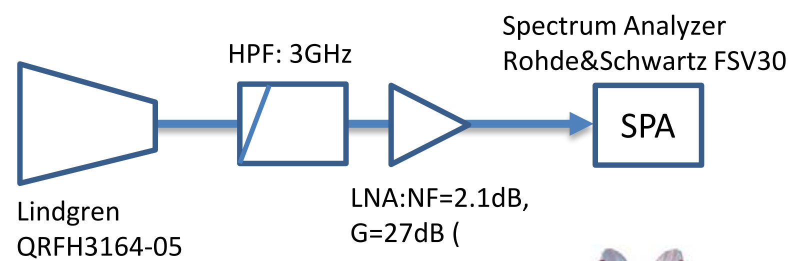
Beam Width=$\frac{\lambda}{D}$

Beam width~ 2 deg.

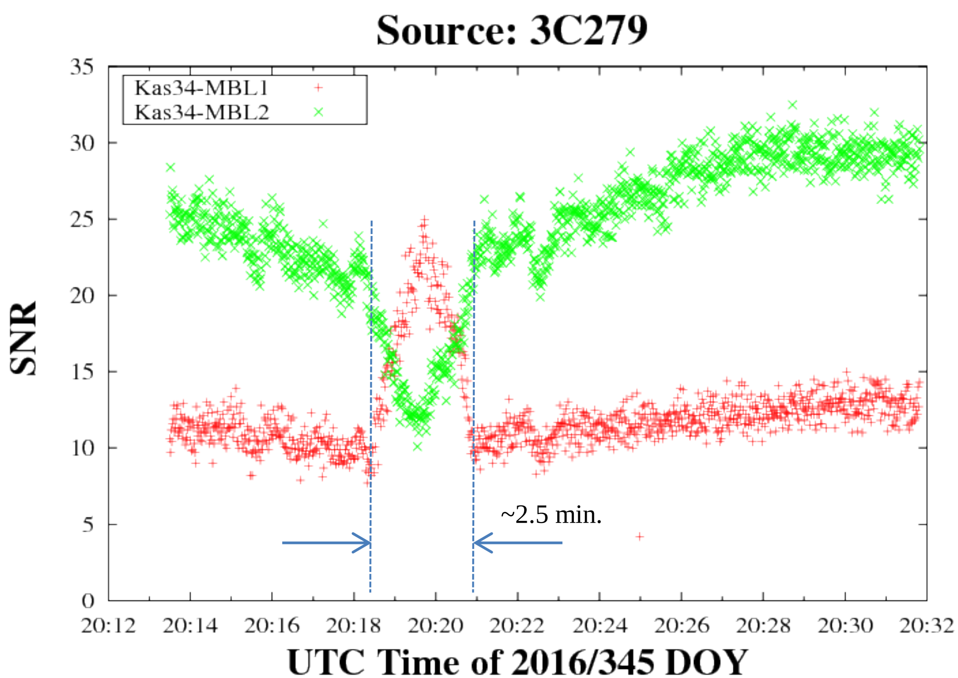


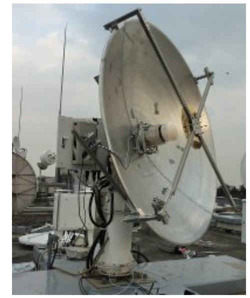






The probability is low but it might have happened!! Pointing to Stellate.



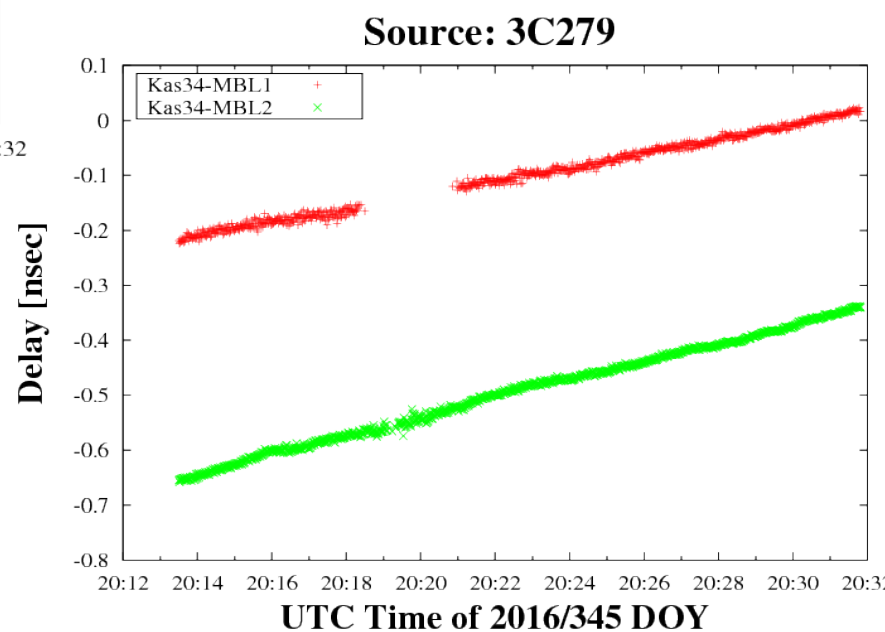


Marble2(2.4m)

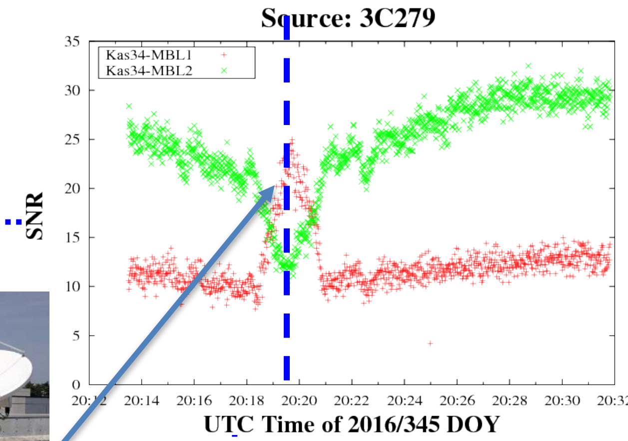
Kashima34m

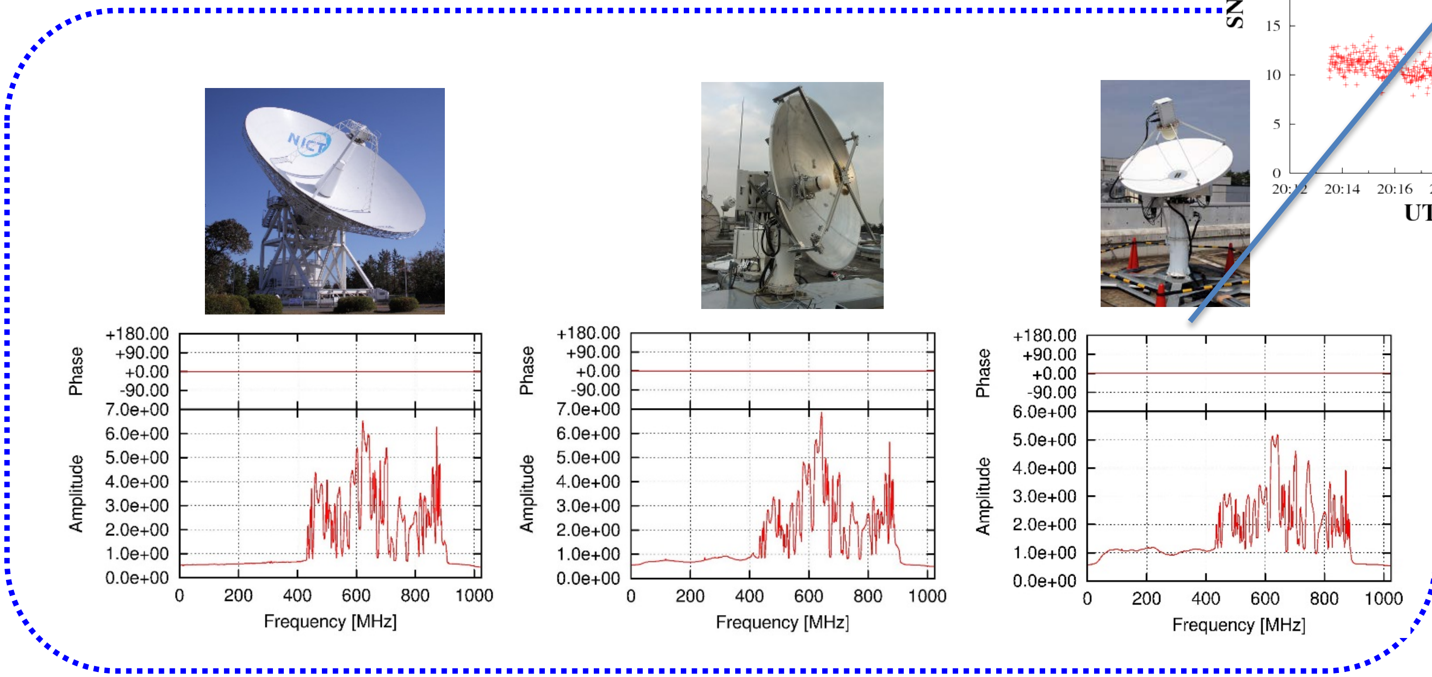
Marble1(1.6m)

There were abnormal data for a few minutes in output of bandwidth synthesis(3.3-11GHz). Each data points represent observed data with 1 sec. integration.



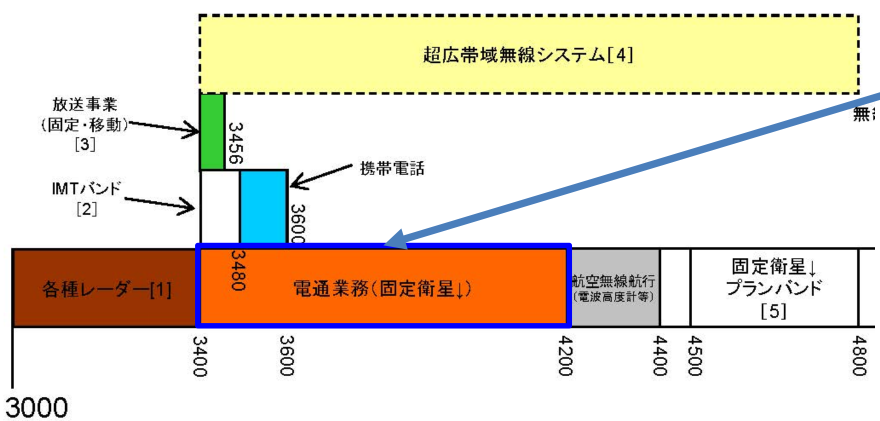
RFI from Satellite





Lo=3288MHz

Downlink from Stationary Satellite



Current Frequency Allocation Table by Ministry of General Affairs.

Validation of Measurement
Comparison of Receiving Power between Theory and Practice

Emission Power of BS Sat.

EIRP=59 dBW for BS
Prop. Loss= -205.8 dB
Power on the Earth:-116.8dBm

Beam width~ 1-2 deg.

Expected Rec. Power

D=1.6m
$\eta = 0.4$
G=42.1 dB

$$G = \frac{4\pi}{\lambda^2} A\eta$$

Power=-74.7dBm

Actual Rec. Power

T=1.e4 K(-187dBK)
BW= 400MHz(86dBHz)
Power=-71.8dBm

Expected Rec. Power with VGOS station

D=13m
$\eta = 0.6$
G=62 dB

$$G = \frac{4\pi}{\lambda^2} A\eta$$

Power= -54.8dBm

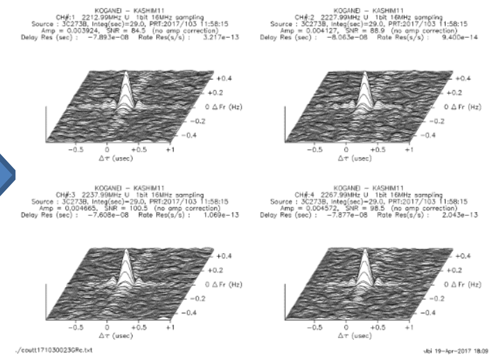
Expected full receiving power is significant, but beam coupling probability will be much less due to narrow beam width(0.1 deg.)

A Quiz on Saturation

```
******************************************************************
*                                                                *
*  MONIT (signal level monitor for K5/VSSP | K5/VSSP32 | VSSP64) *
*              by T.Kondo/NICT  (Ver. 2016-12-14)                *
*                 Target Board is K5/VSSP32                      *
*                                                                *
*                     CTRL C   for STOP                          *
*                                                                *
*******T*************************************************KONDO********

                                     2017/04/13 (103) 11:36:38

2017/04/13 (103) 11:21:32  CH 2          CH 3          CH 4
  *
   + FULL   |*            |**           |*            |*
            |***          |****         |***          |***
            |*******      |*******      |******       |******
            |**********   |**********   |*********    |**********
            |*********    |*********    |**********   |*********
            |******       |*******      |******       |******
            |***          |****         |***          |***
   - FULL   |*            |**           |*            |*
  DC OFFSET    0.8/256      0.3/256      0.5/256      1.0/256
  ONE SIGMA   53.0/256     57.7/256     50.9/256     50.9/256
```

X

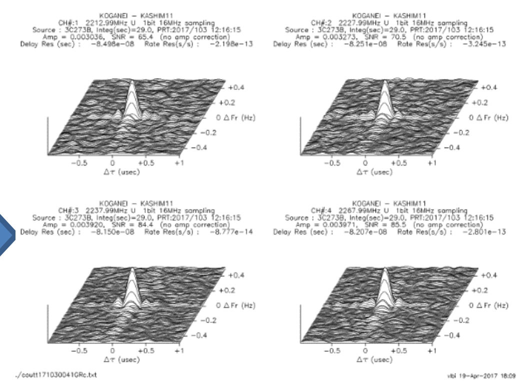
```
******************************************************************
*                                                                *
*  MONIT (signal level monitor for K5/VSSP | K5/VSSP32 | VSSP64) *
*              by T.Kondo/NICT  (Ver. 2016-12-14)                *
*                 Target Board is K5/VSSP32                      *
*                                                                *
*                     CTRL C   for STOP                          *
*                                                                *
*******T*************************************************KONDO********

                                     2017/04/13 (103) 11:33:54
^C
2017/04/13 (103) 11:21:41  CH 2          CH 3          CH 4
  *
   + FULL   |**           |*            |*            |*
            |***          |***          |**           |***
            |*******      |******       |******       |*******
            |**********   |**********   |**********   |*********
            |*********    |*********    |*********    |**********
            |******       |******       |******       |*******
            |***          |***          |**           |***
   - FULL   |*            |*            |*            |**
  DC OFFSET    1.7/256      0.3/256      0.0/256     -1.2/256
  ONE SIGMA   55.1/256     51.1/256     49.0/256     54.8/256
```



```
******************************************************************
*                                                                *
*  MONIT (signal level monitor for K5/VSSP | K5/VSSP32 | VSSP64) *
*              by T.Kondo/NICT  (Ver. 2016-12-14)                *
*                 Target Board is K5/VSSP32                      *
*                                                                *
*                     CTRL C   for STOP                          *
*                                                                *
*******T*************************************************KONDO********

                                     2017/04/13 (103) 12:03:03
^C
2017/04/13 (103) 12:00:42  CH 2          CH 3          CH 4
  *
   + FULL   |*********    |*******      |*******      |********
            |******       |******       |******       |******
            |********     |********     |********     |********
            |**********   |*********    |*********    |**********
            |*********    |**********   |**********   |*********
            |********     |********     |********     |********
            |******       |******       |******       |******
   - FULL   |*********    |*******      |********     |********
  DC OFFSET   -0.5/256     -0.7/256     -0.8/256     -0.2/256
  ONE SIGMA   76.3/256     72.3/256     73.4/256     73.7/256
```

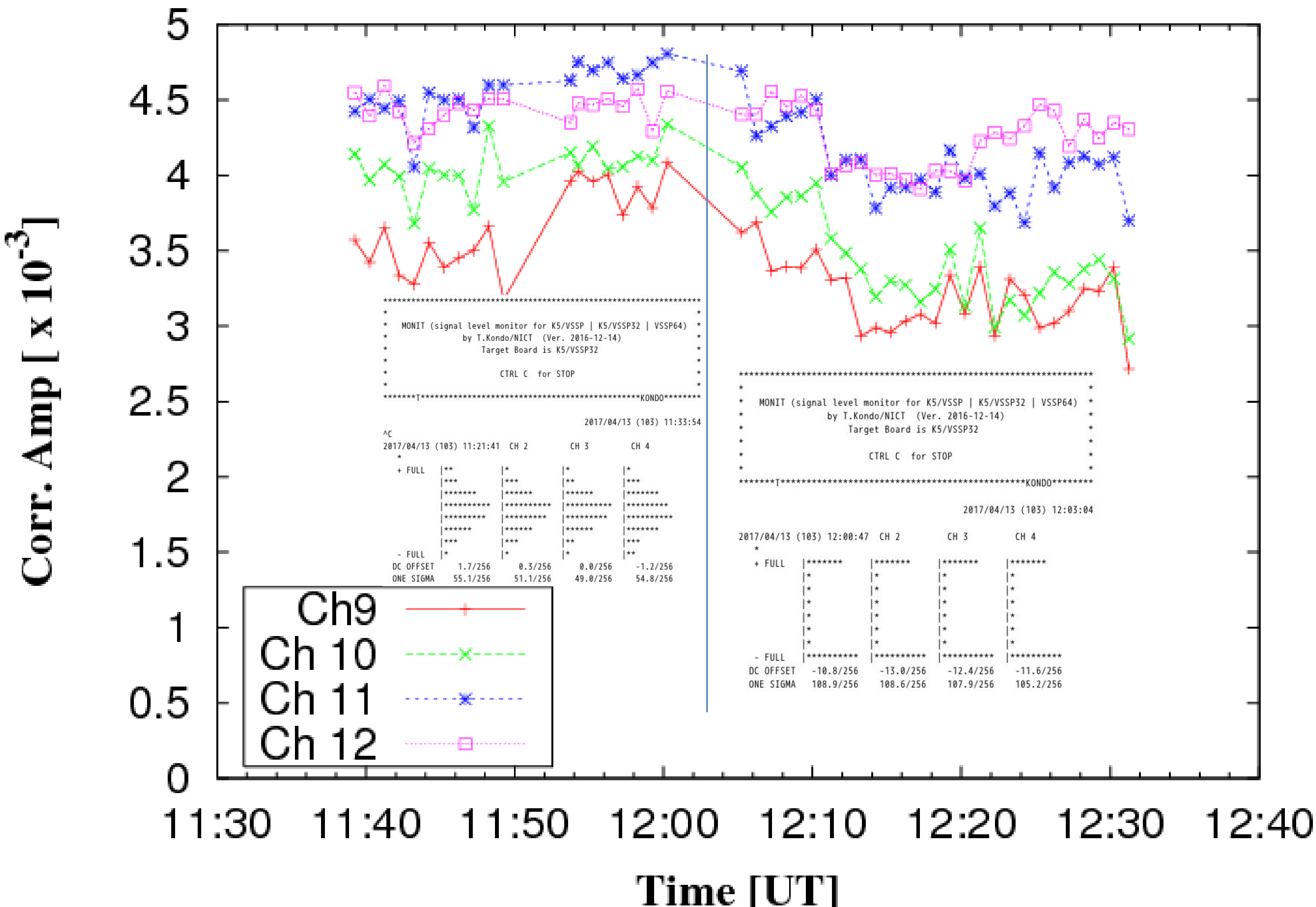
X

```
******************************************************************
*                                                                *
*  MONIT (signal level monitor for K5/VSSP | K5/VSSP32 | VSSP64) *
*              by T.Kondo/NICT  (Ver. 2016-12-14)                *
*                 Target Board is K5/VSSP32                      *
*                                                                *
*                     CTRL C   for STOP                          *
*                                                                *
*******T*************************************************KONDO********

                                     2017/04/13 (103) 12:03:04

2017/04/13 (103) 12:00:47  CH 2          CH 3          CH 4
  *
   + FULL   |*******      |*******      |*******      |*******
            |*            |*            |*            |*
            |*            |*            |*            |*
            |*            |*            |*            |*
            |*            |*            |*            |*
            |*            |*            |*            |*
            |*            |*            |*            |*
   - FULL   |**********   |**********   |**********   |**********
  DC OFFSET  -10.8/256    -13.0/256    -12.4/256    -11.6/256
  ONE SIGMA  108.9/256    108.6/256    107.9/256    105.2/256
```

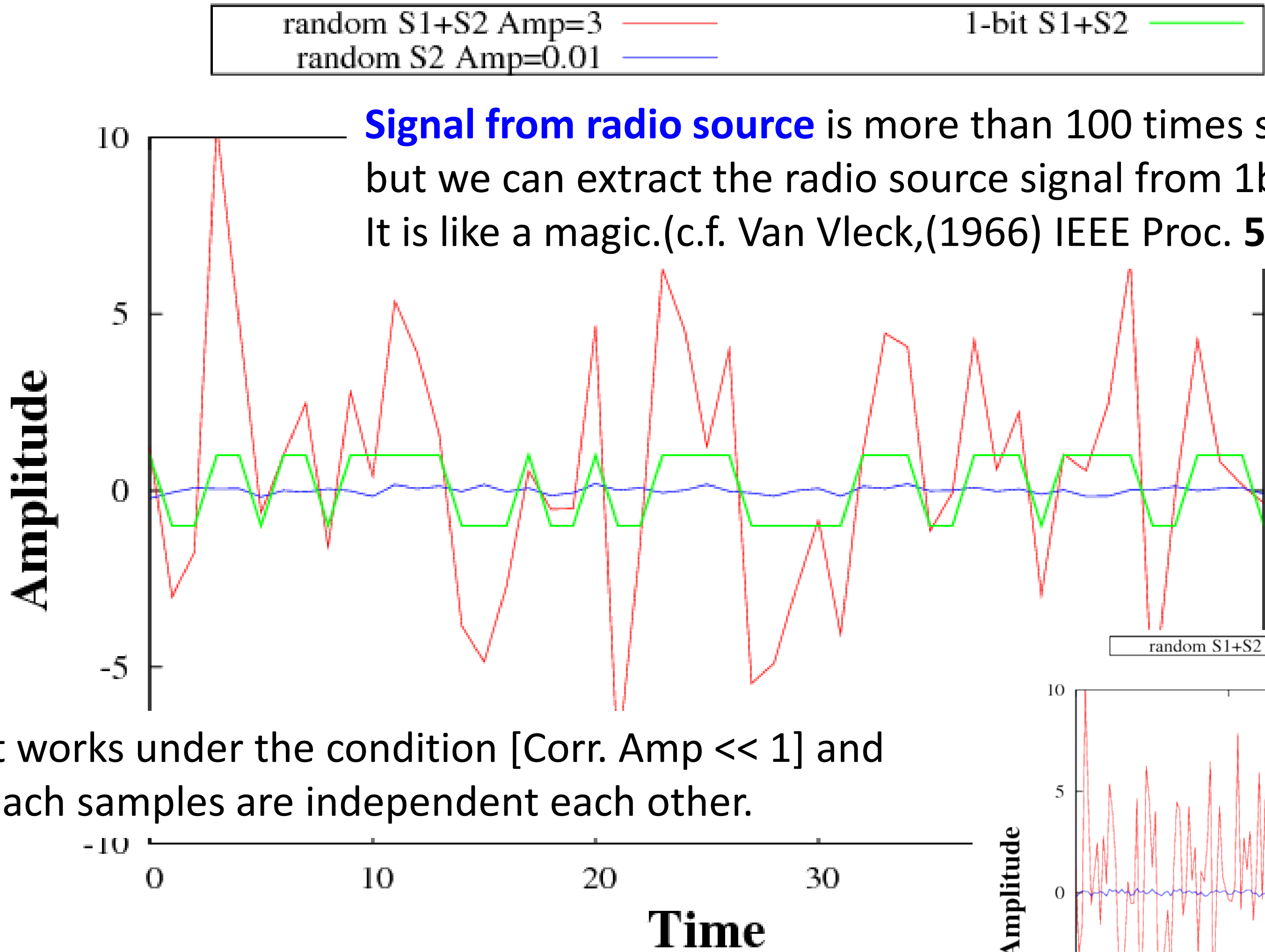


Saturation is not problem for 1bit sampling

Decrease of Corr. Amp is due to Loss of Info caused by DC-bias, but not saturation.



1bit sampling Simulation [noise(3)]

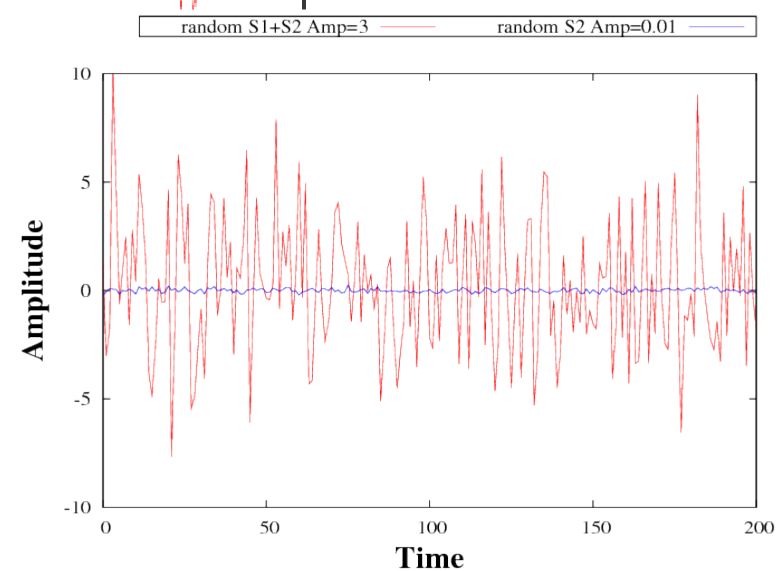


Signal from radio source is more than 100 times smaller than **noise,** but we can extract the radio source signal from 1bit sampling data. It is like a magic.(c.f. Van Vleck,(1966) IEEE Proc. **54**,1,2-19)

S1:System noise
S2: Radio source

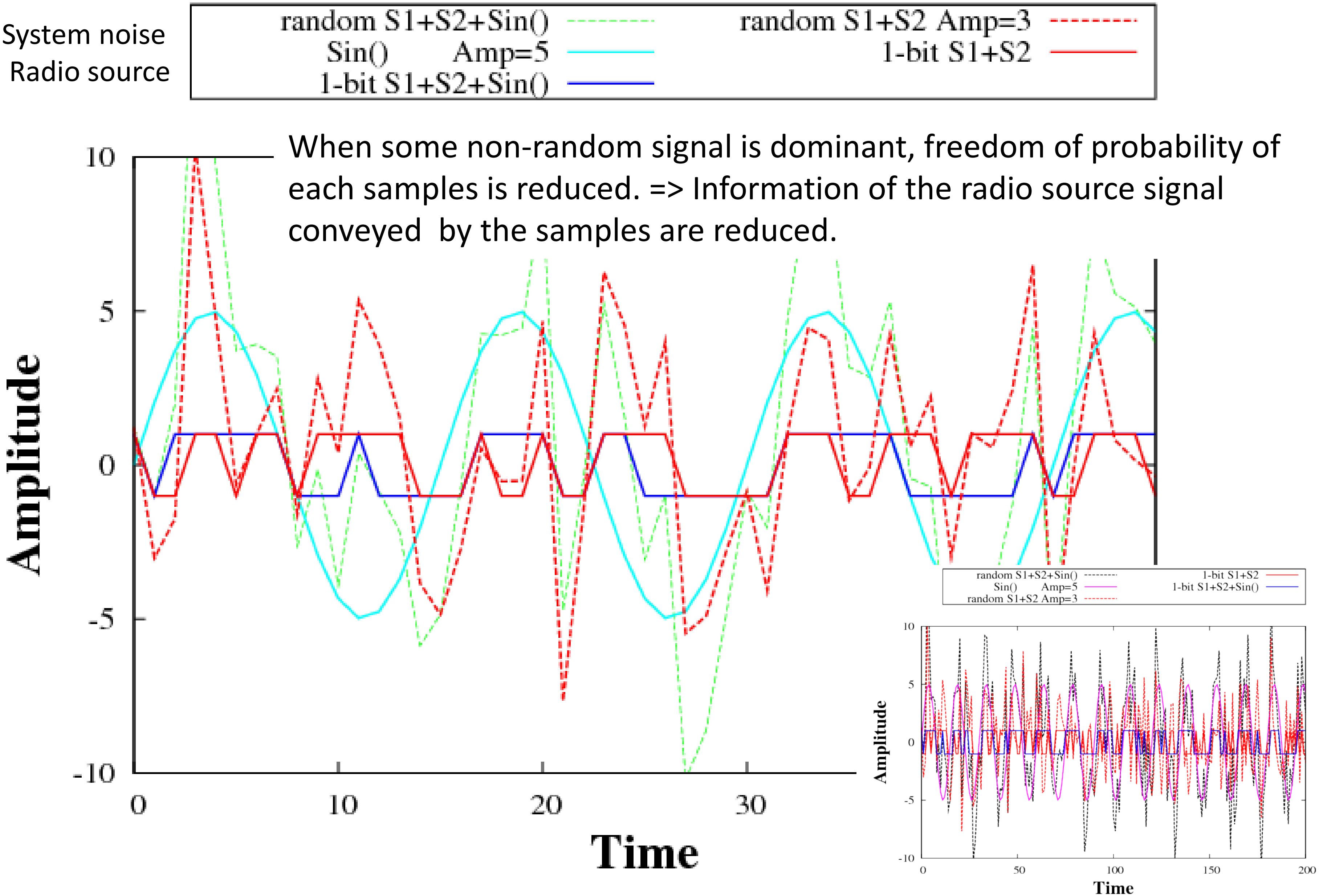
It works under the condition [Corr. Amp << 1] and each samples are independent each other.

VLBI(1bit) is sampling the probability distribution of the signal.



1bit sampling Simulation [noise(3)+sin(5)]

S1:System noise
S2: Radio source

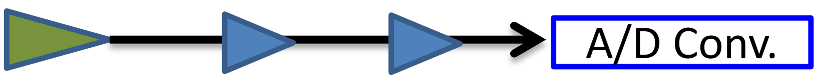


When some non-random signal is dominant, freedom of probability of each samples is reduced. => Information of the radio source signal conveyed by the samples are reduced.

Advantage of RF-Direct Sampling
- Robustness to RFI -

Broadband (~ 10GHz) Case:

T=200K= **-176dBm/Hz = -101dBm/32MHz = -76dBm/10GHz**



40dB **36dB**

Feed

Gain: +76dB

Total: +0dBm@10GHz

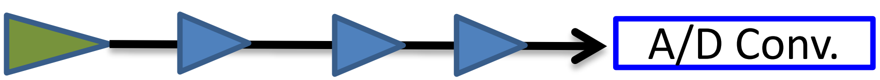
Power density: -36dBm/MHz

Case Study:

In the case RFI of +20dB up from noise floor with 1 MHz width (=-96dBm).

Total Power of RFI		Total Power of Signal
-20dBm	<	**0dBm**

Narrow Band (~ 32MHz) Case:



30dB **30dB** **40dB**

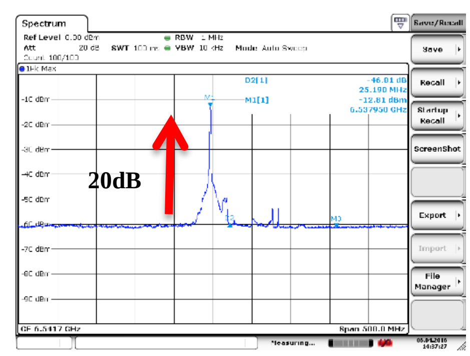
Feed

Gain:+100dB

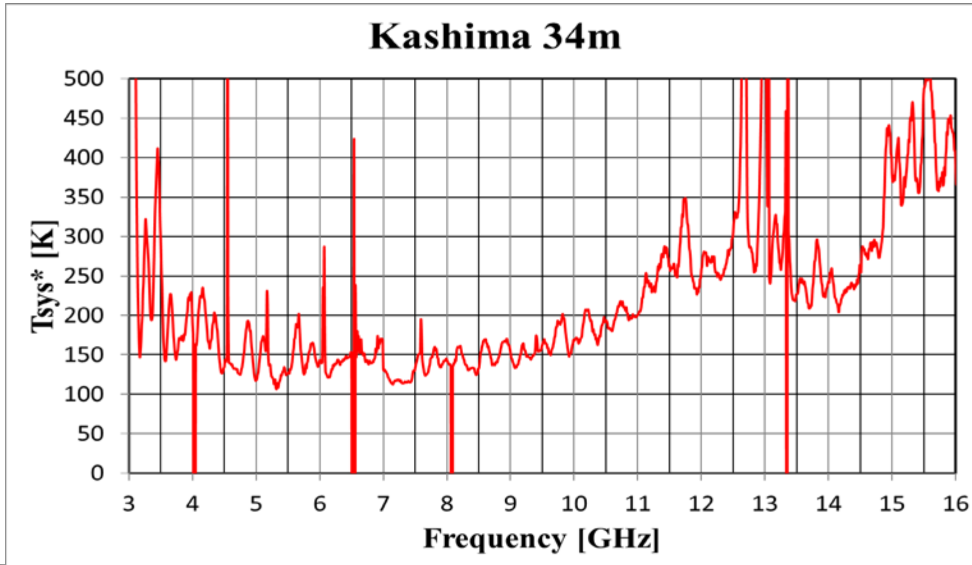
Total: +0dBm 32MHz

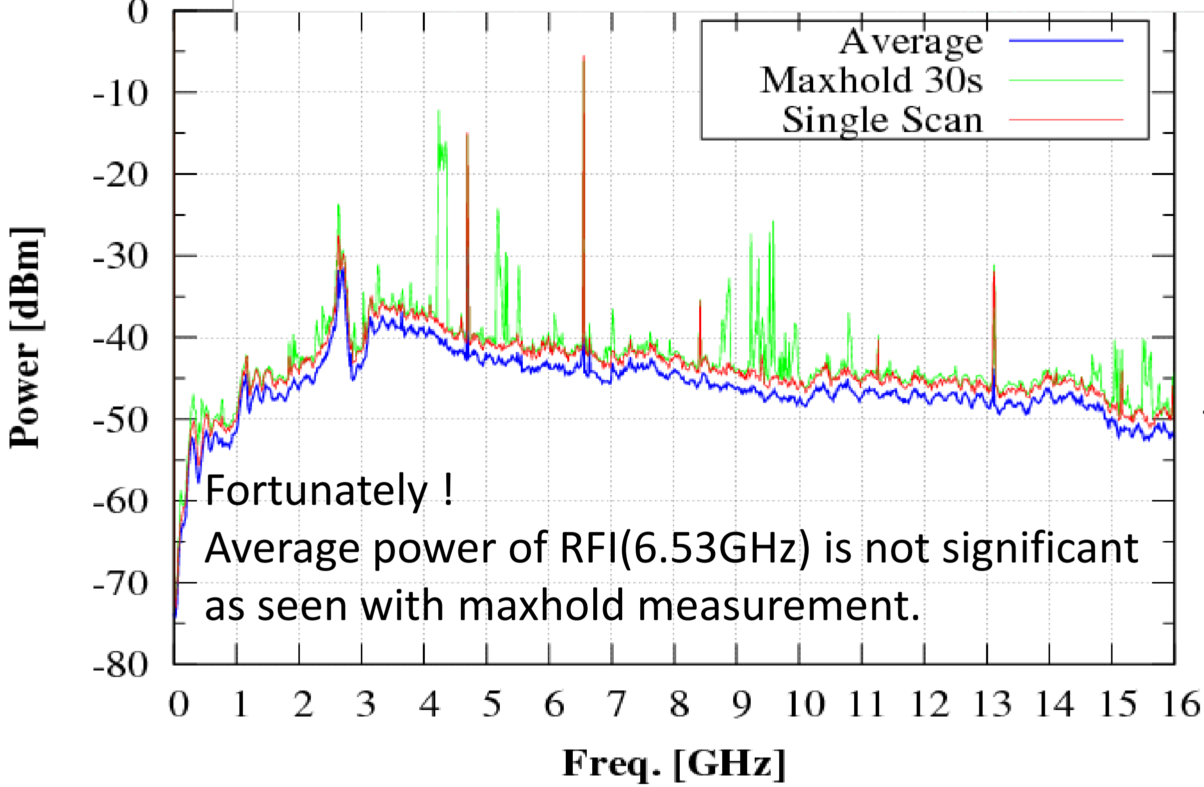
Power density: -16dBm/MHz

Total Power of RFI		Total Power of Signal
+5dBm	>	**0dBm**



Current 34m





Fortunately !
Average power of RFI(6.53GHz) is not significant as seen with maxhold measurement.

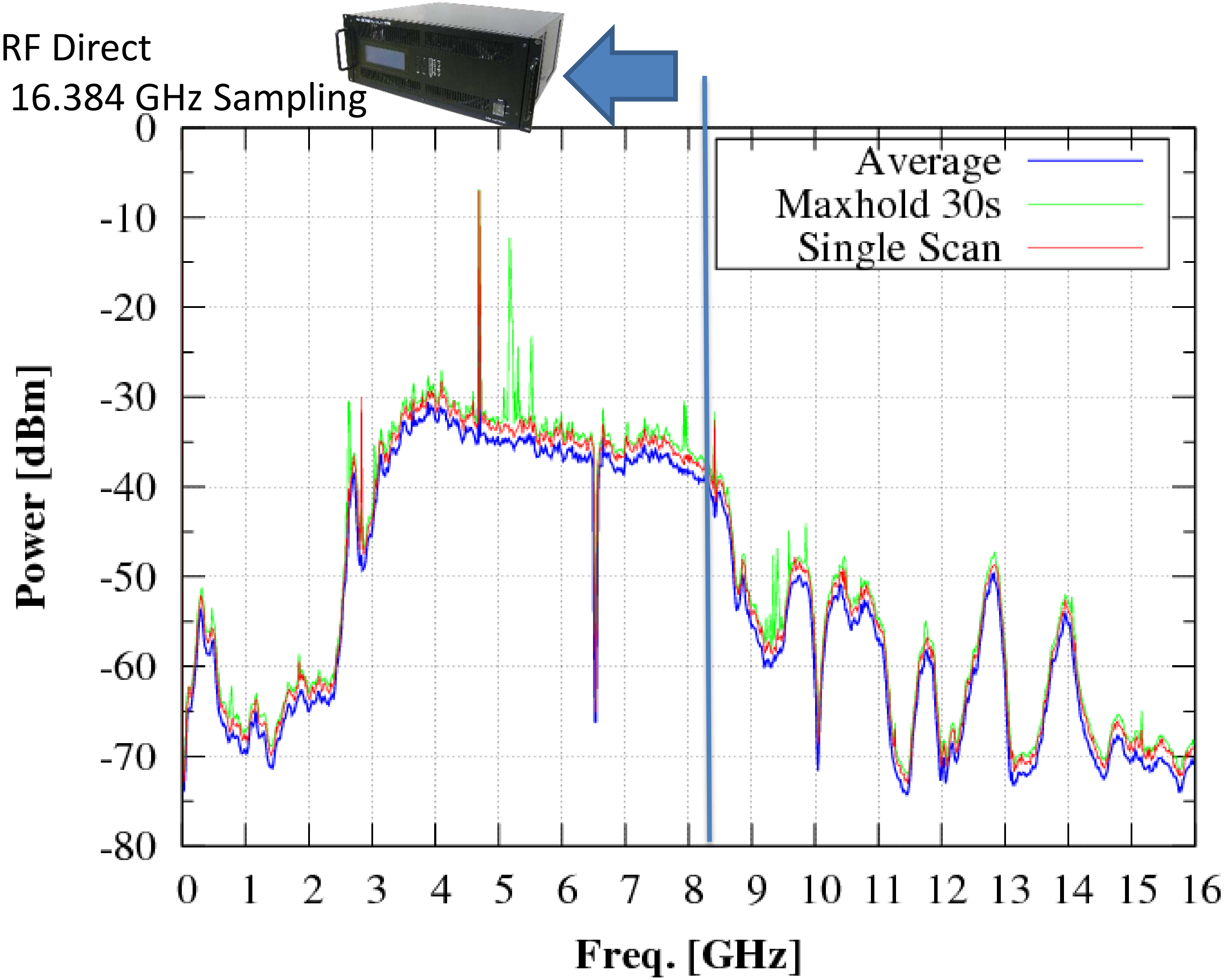
RBW=3MHz
Whole BW~12GHz

N=12GHz/3MHz
=36dB

Total Powe~-45+36
=-9dBm
< -5dBm (RFI)

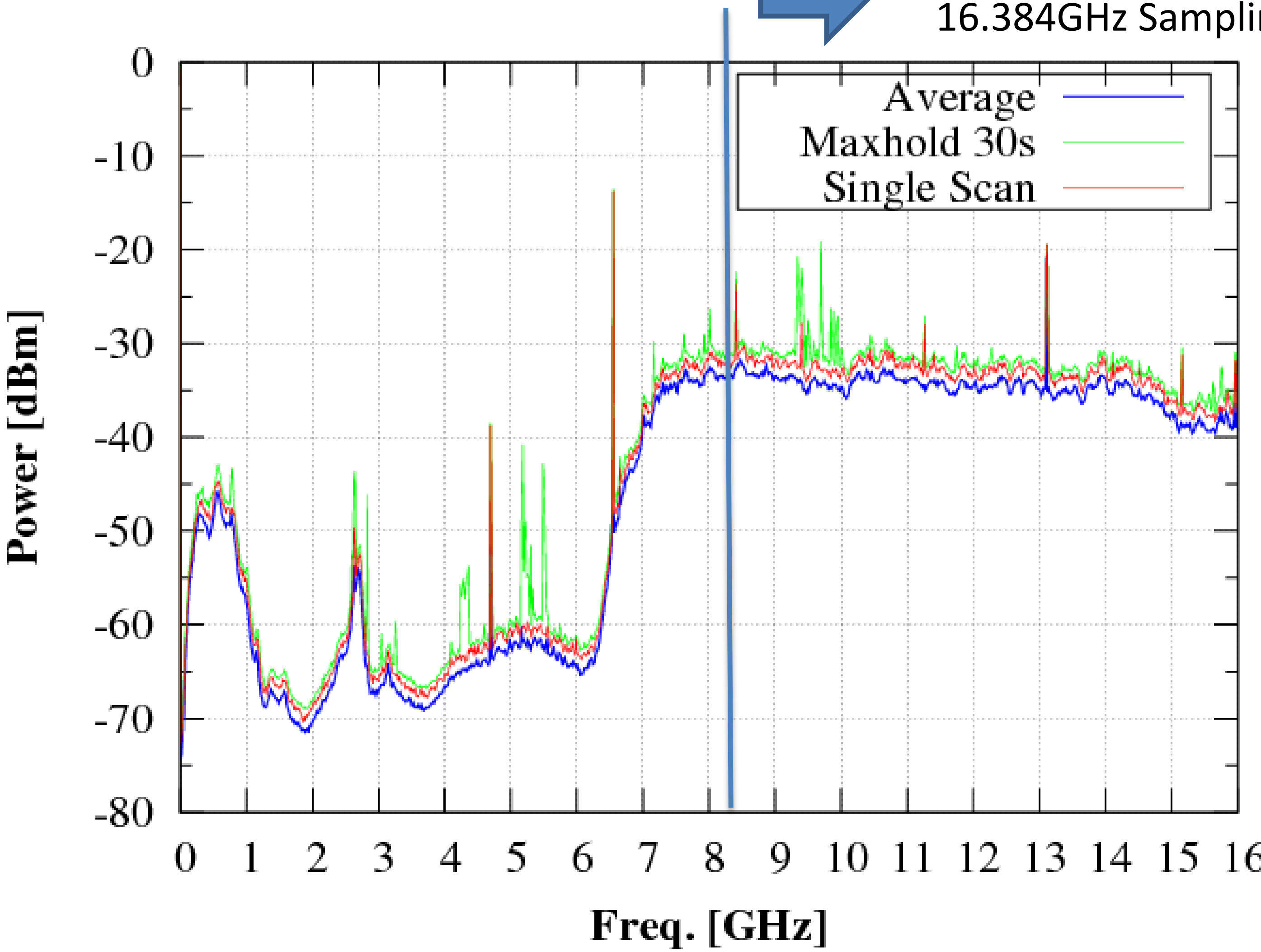
Real Input to A/D at Kashima 34m Broadband Signal(Lower Band<8.2GHz)

RF Direct
16.384 GHz Sampling



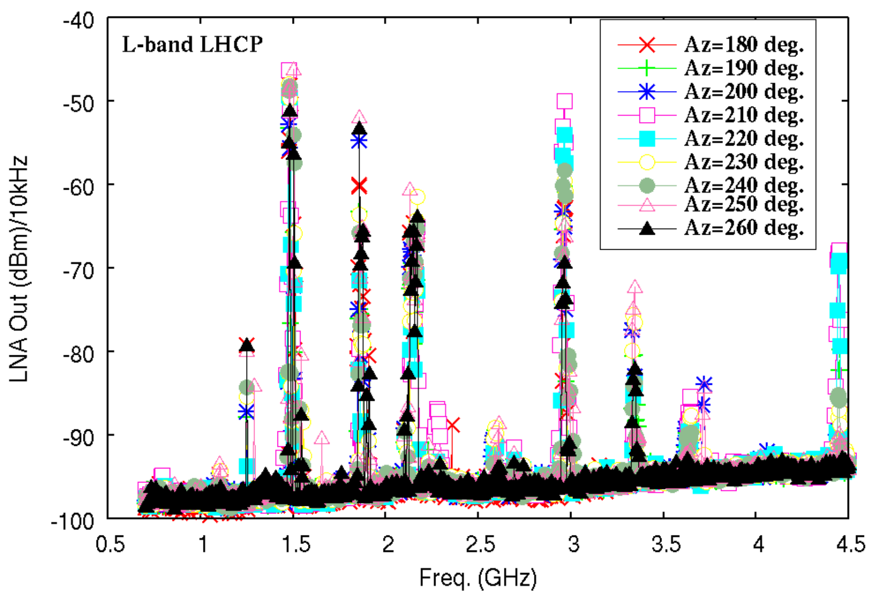
Real Input to A/D at Kashima 34m Broadband Signal(Upper Band>8.2GHz)

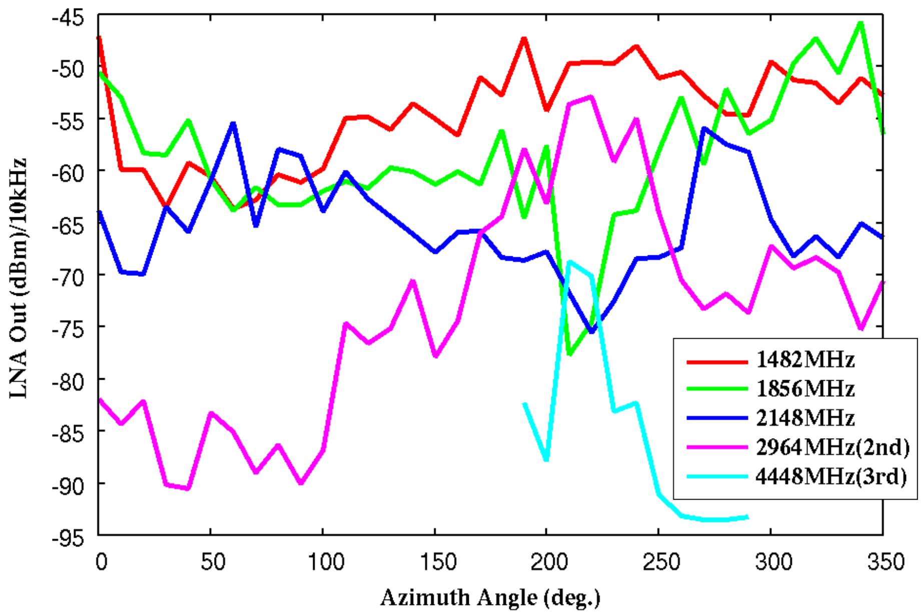
RF Direct
16.384GHz Sampling



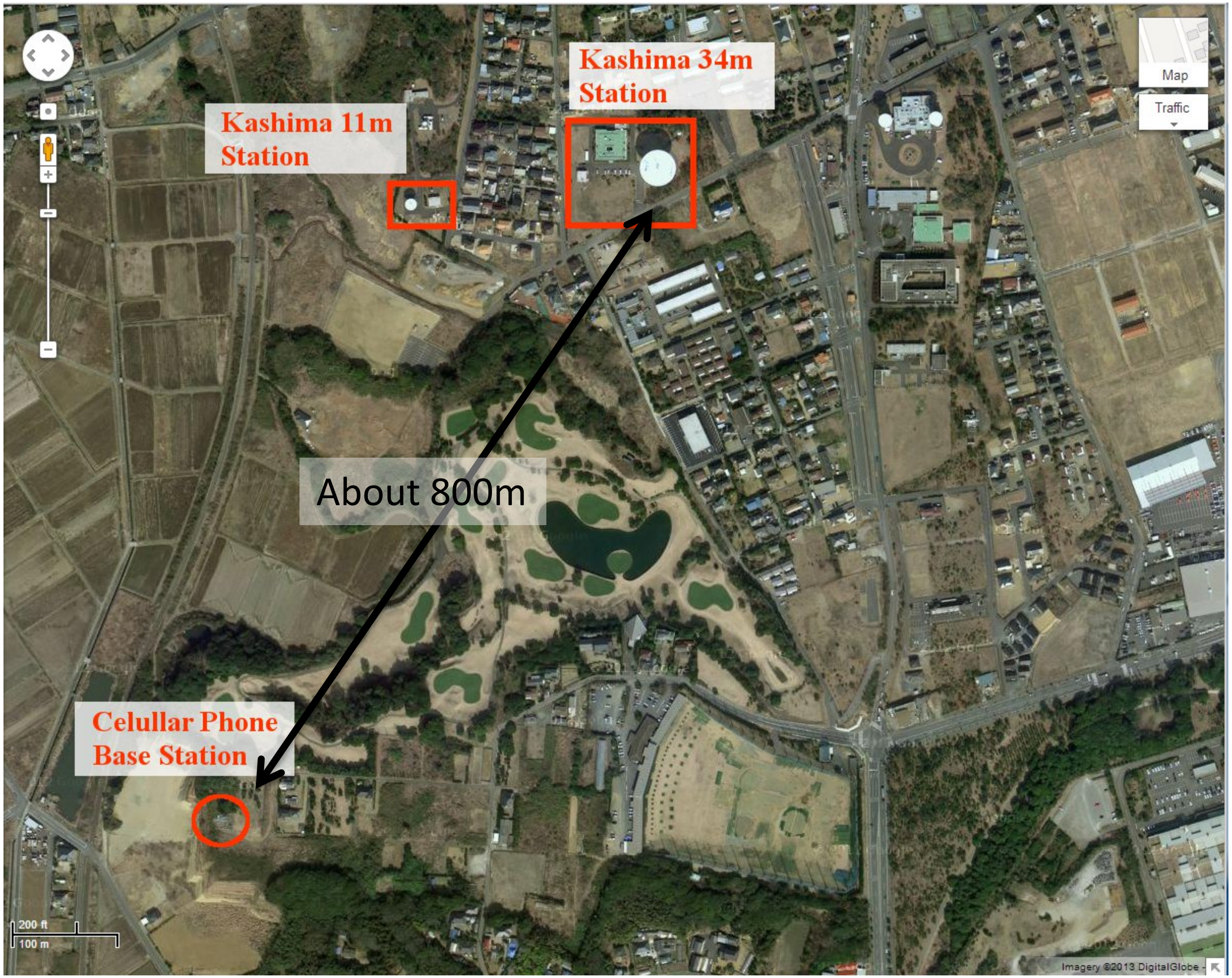
Example of a LNA saturation due to strong RFI

- L-band receiver of Kashima 34m Radio Telescope was affected





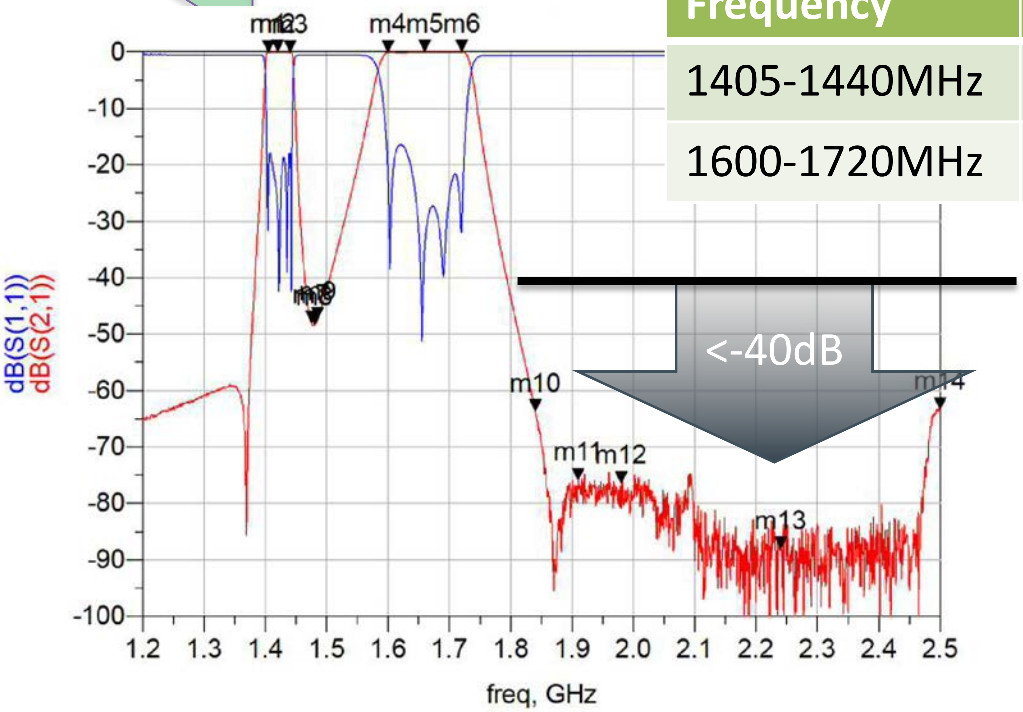
Source of RFI (Cell Phone Base Station)



We could solve the problem

- Super Conductor Filter(Toshiba Co. Ltd) in front of LNA.
- By negotiation with Cell Phone carrier Company, they paid for the filter cost(~87k USD).

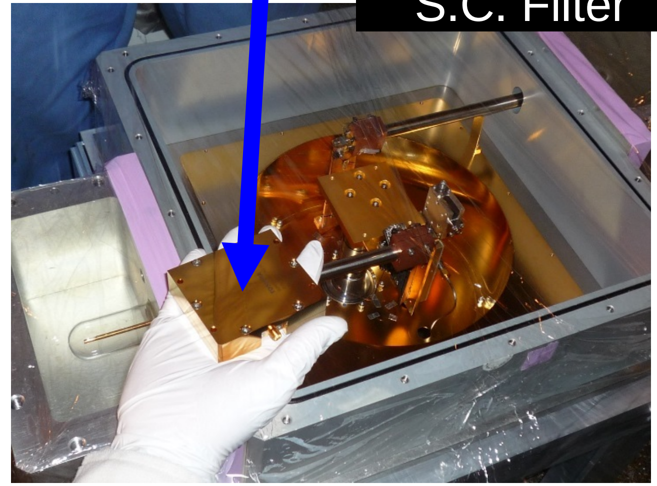
Insertion Loss < 0.5dB



<-40dB

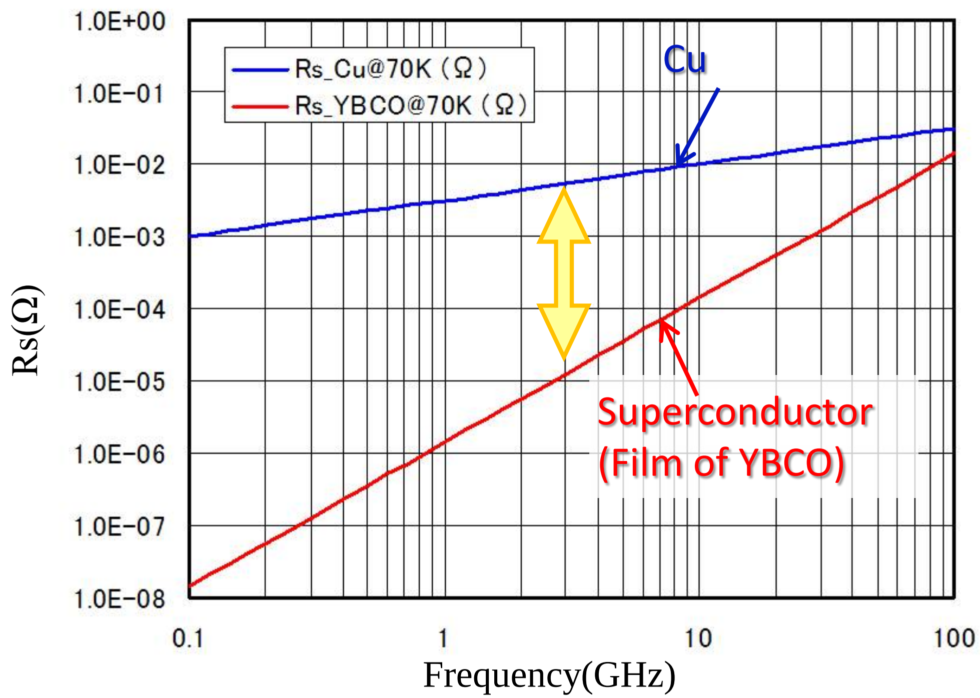
Pass band Frequency	Insertion Loss@20K	Additive Noise [K]
1405-1440MHz	<0.12dB	<0.6 K
1600-1720MHz	<0.08 dB	<0.4K

S.C. Filter



Background

- Superconducting materials have low surface resistance characteristic.



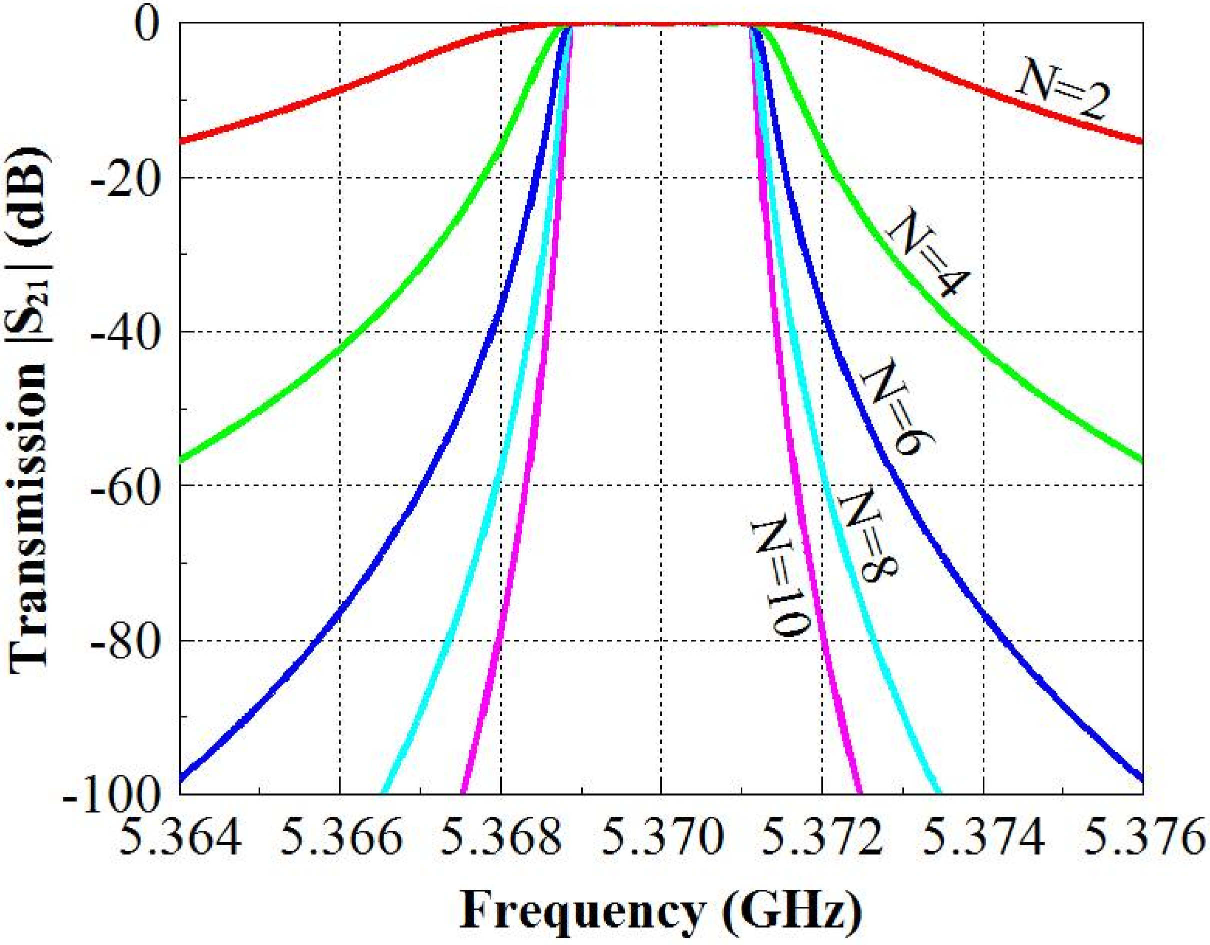
Superconductor is three orders of lower Rs as compared to copper

＊1 YBCO：$YBa_2Cu_3O_{7-x}$

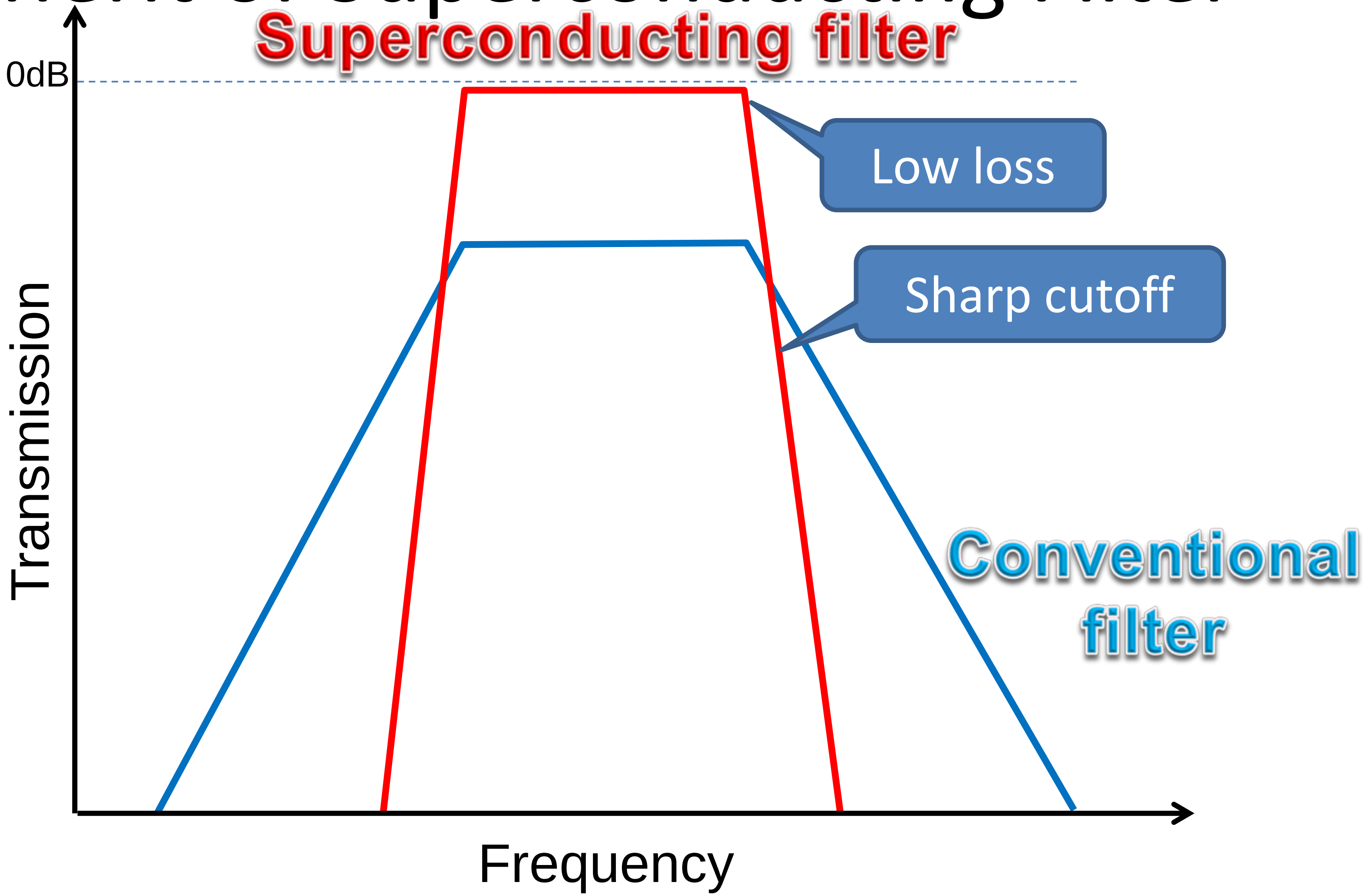
<u>Surface resistance characteristic of Superconducting film（YBCO＊1）</u>

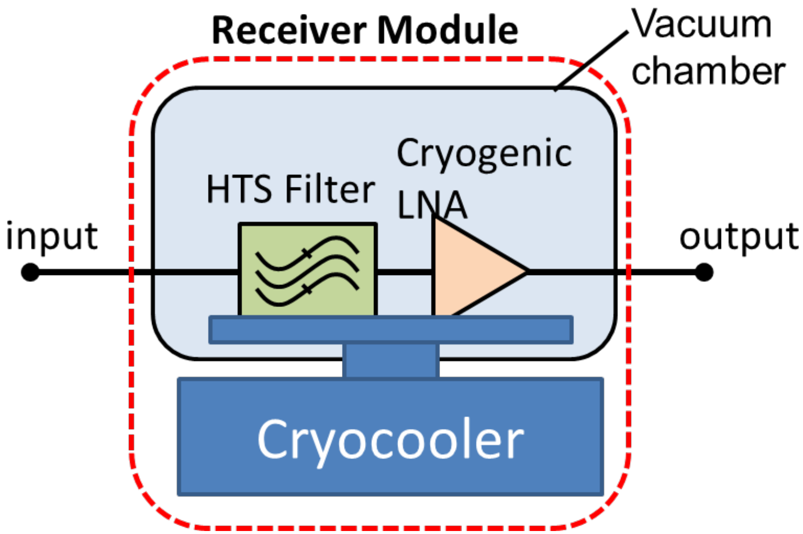
T.Hashimoto, et al., IEICE Trans. Electron., vol. E86-C, No. 8, pp. 1721-1728, Aug. 2003.

Dependence of Resonator Number

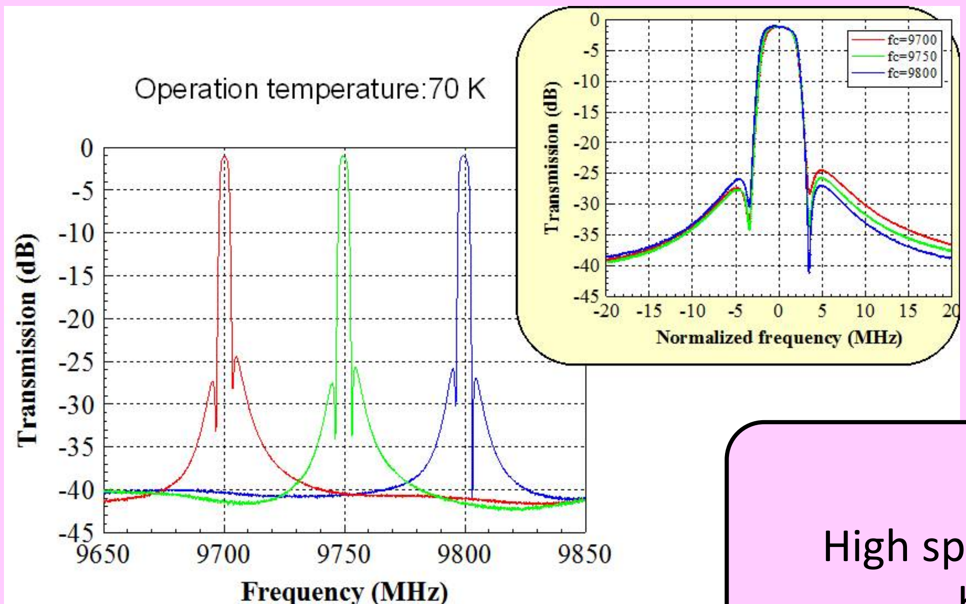


Merit of Superconducting Filter





2L size receiver unit at 77 K cooled by Starling cycle cryogenic system.



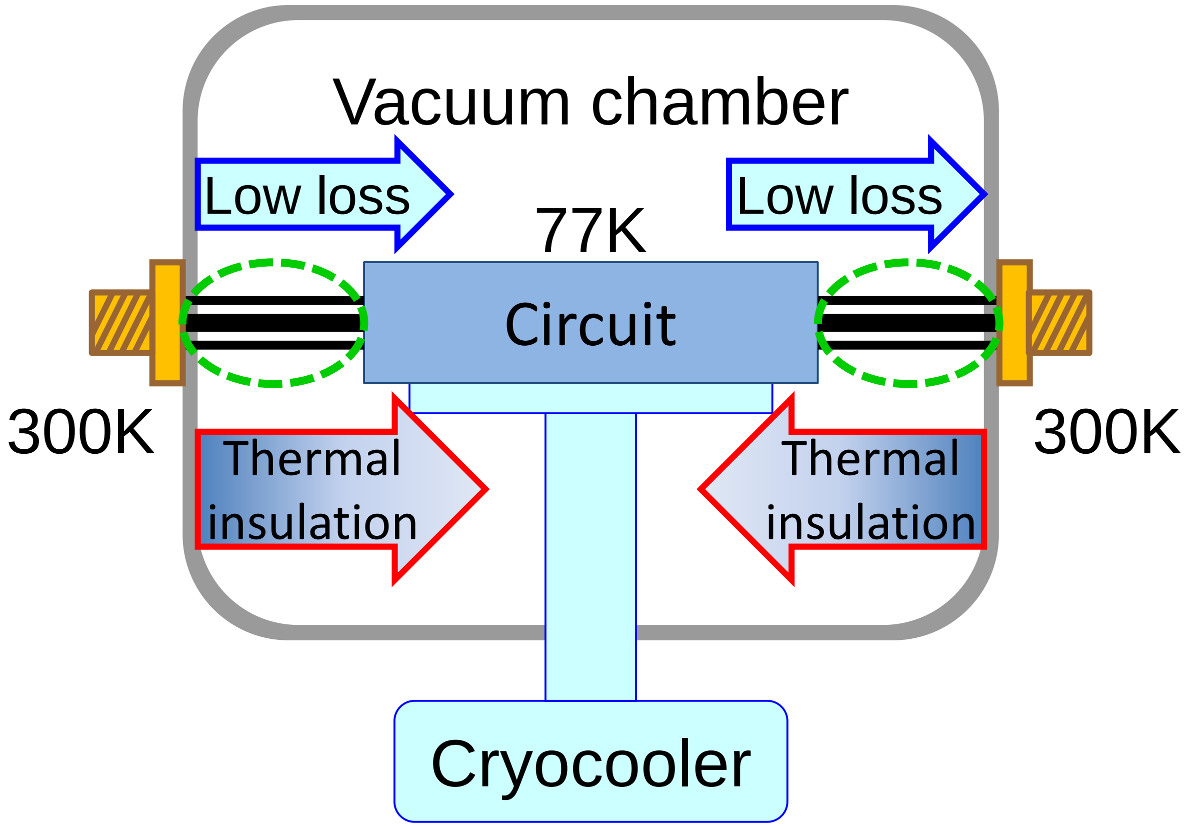
Tunable

High speed and constant bandwidth

H. Ikeuchi, T. Kawaguchi, N. Shiokawa, and H. Kayano, "L-band Small High-Sensitivity Microwave Receiver Module using Superconducting Filter," 2015 Asia-Pacific Microwave Conf. Dig., WE1C-5, Dec. 2015.

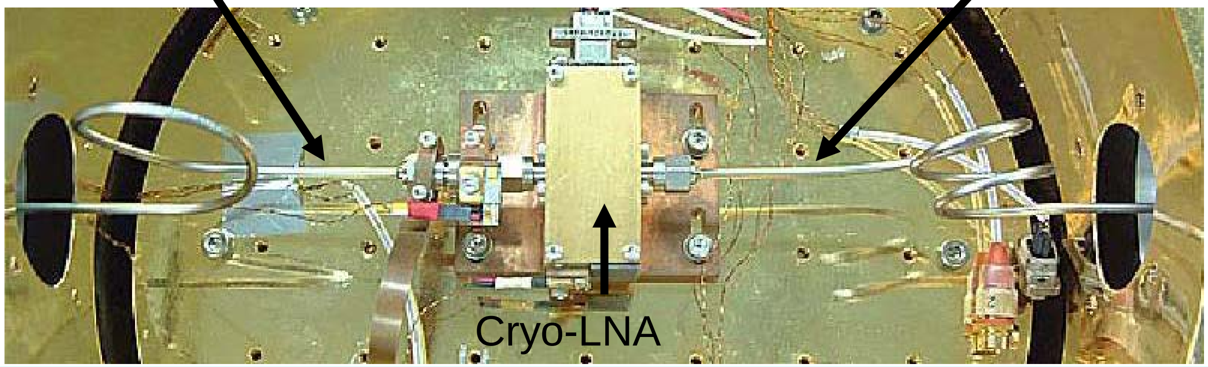
APMC 2015 Fig. 6

Thermal Insulating RF interface



Compatibility of both low loss and thermal insulation

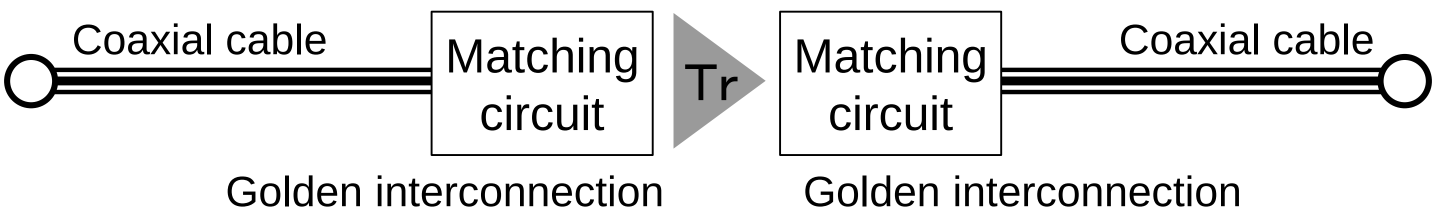
RF interface Comparison



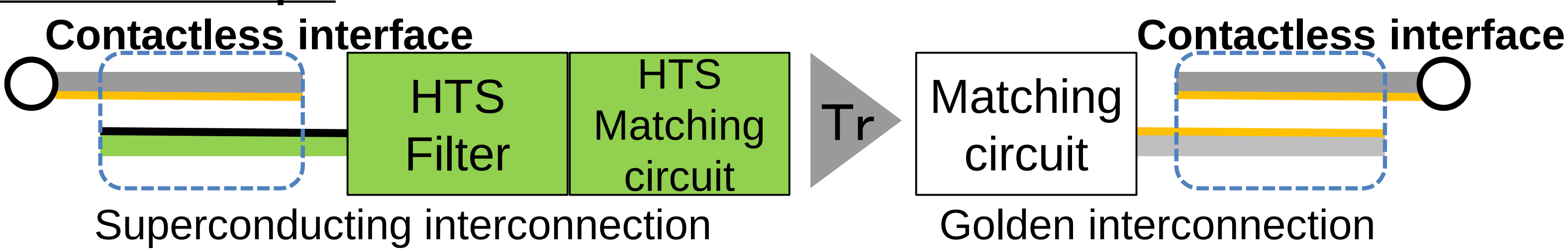
Chau-Ching Chiong, et. al, "Design and Measurements of Cryogenic MHEMT IF Low Noise Amplifier for Radio Astronomical Receivers," 4th European Microwave Integrated Circuits Conference, Sept. 2009.

Require the large cryocooler for large thermal conduction

●Conventional technique



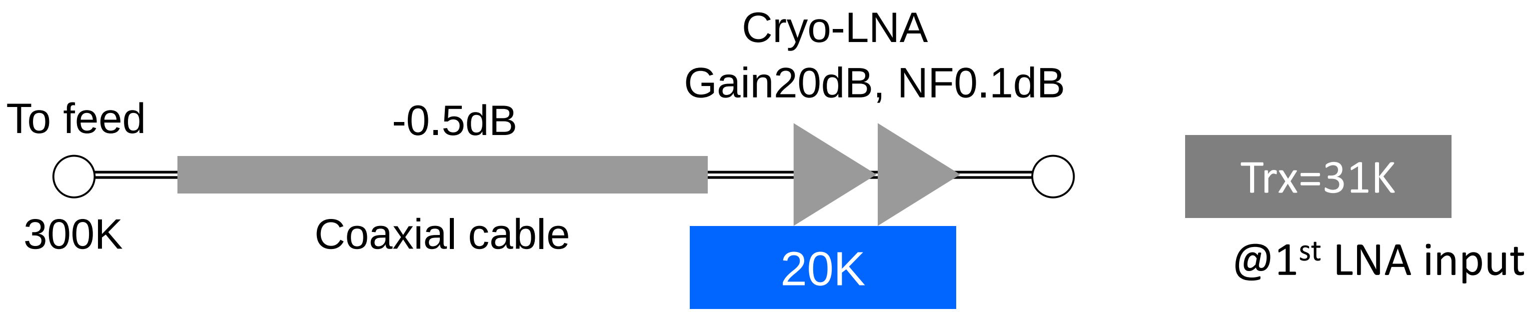
●New technique



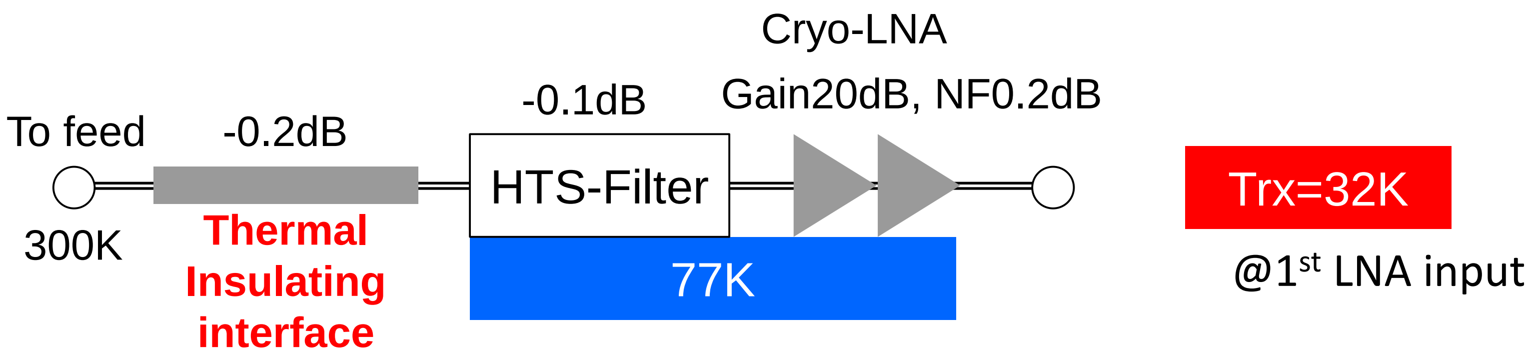
Example of installation to Usuda 64 m radio telescope

Comparison of Receiver Noise Temperature

●Conventional Cryo-receiver



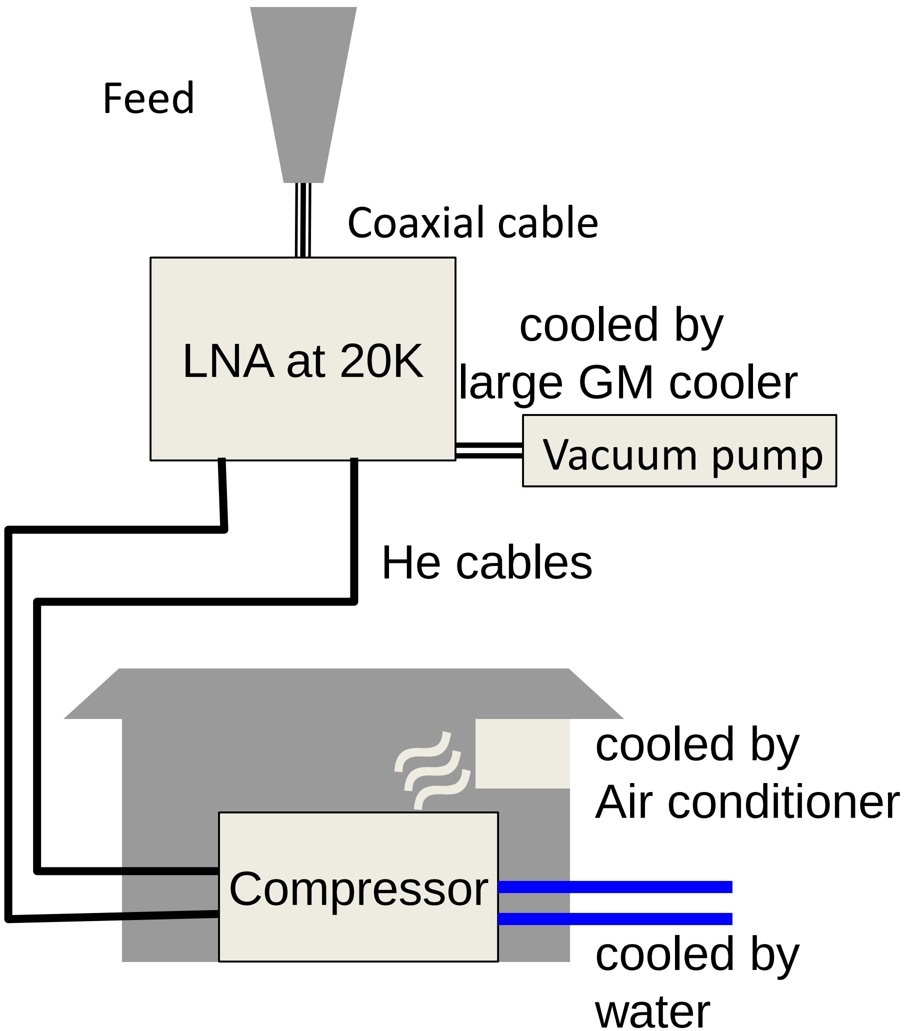
●Cryo-receiver with thermal insulating interface technique



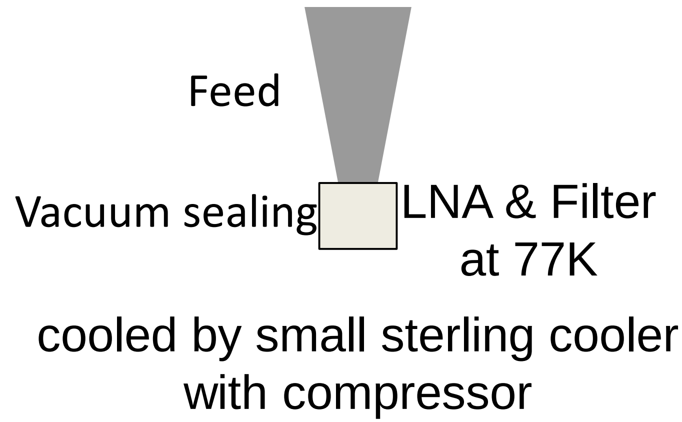
※at L-band

Constitution of Cryo-receiver

Conventional Cryo-receiver



TOSHIBA's Cryo-receiver



- Simple constitution
- Low cost

Compare of Receivers

Item	Conventional receiver	TOSHIBA's receiver
Power consumption	3000W	80W
Noise temperature	31K	32K
Operation temperature	20K	77K
Volume	Over 100 liters	2 liters
Weight	Over 100Kg	2Kg
Life time	About 1 year	Over 5 years
Ambient temperature	0～30 degrees	-40～55 degrees
Cooling water	necessity	unnecessary
Pipe arrangement of He	necessity	unnecessary

Energy saving, low cost,
long life time, and high reliability

Measurement in Usuda 64m Radio Telescope

Actual cryo-receiver

Tsys=96K @1.4GHz

Tsys=85K @1.6GHz

-25% to -40%

Toshiba's cryo-receiver

Tsys=56K @1.4GHz band

Tsys=65K @1.6GHz band