Millimetron Workshop, Paris France

A quasi-optical circuit design for simultaneous millimeter and submillimeter wave observations

Seog-Tae Han and KVN receiver group
Korea Astronomy and Space Science Institute (KASI)

Sept. 9~11, 2019

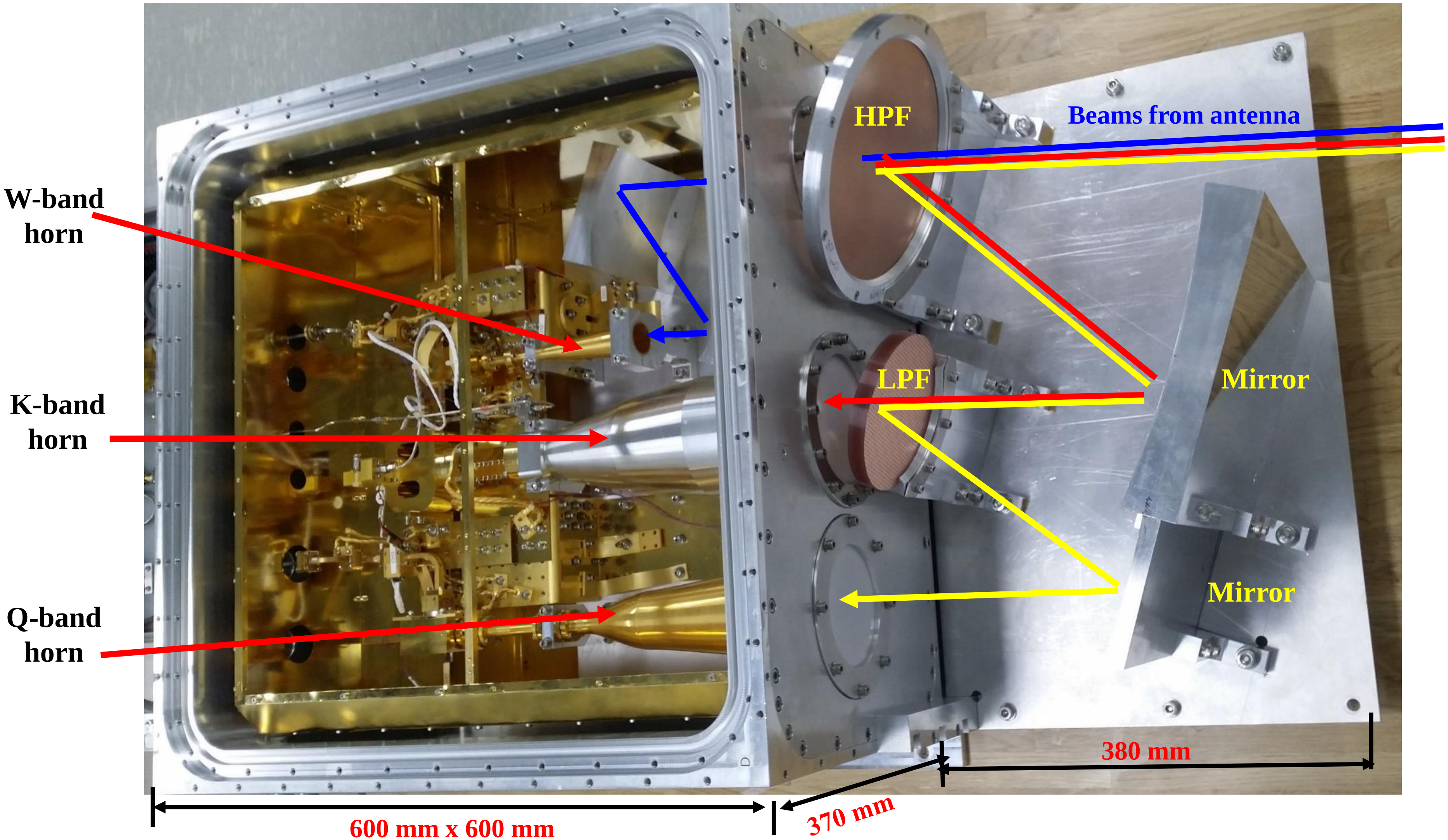
Outline

I. Development of CTR Receiver

II. What I have done for Millimtron receiver

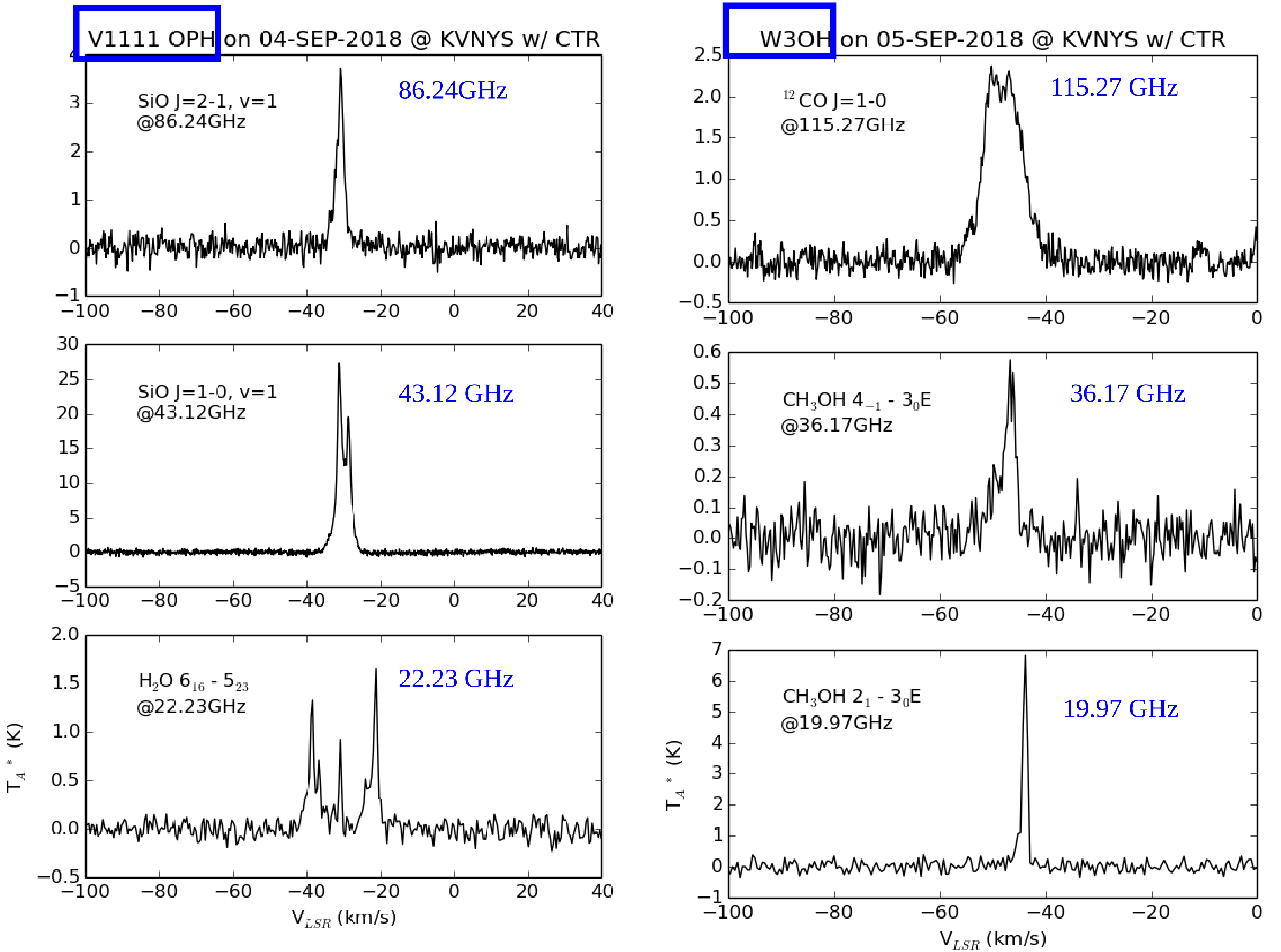
I. Development of the compact triple band receiver

Development of Compact Triple band Receiver (May 2015~ Sept. 2018)



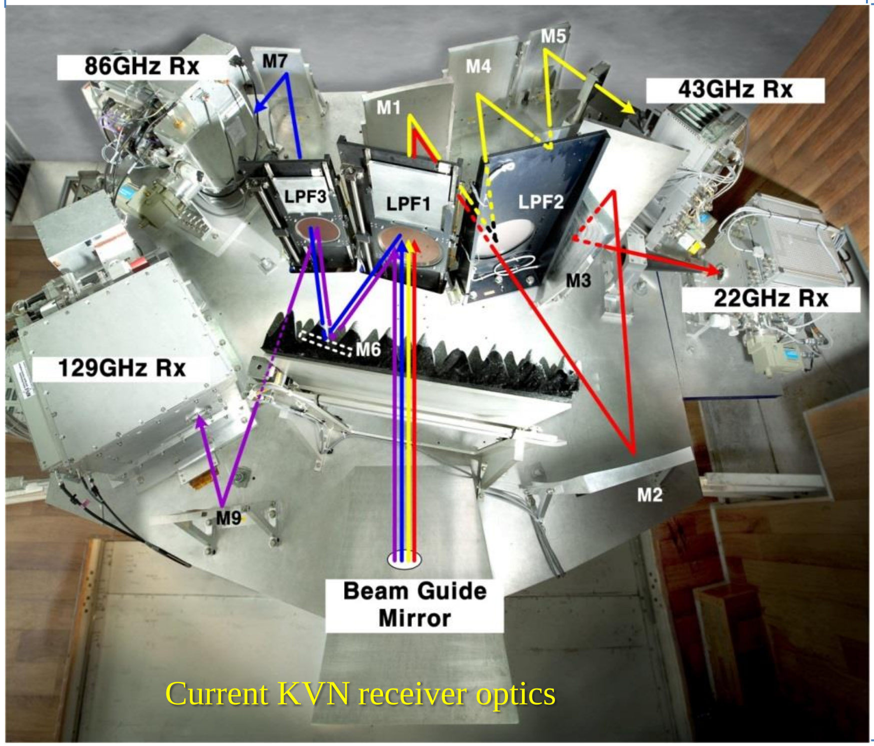
Observing bandwidths	IF bandwidths	Polarization	Receiver noise temperature	Operation Mode
K-band : 18~26GHz	8~16GHz(full band)	RHCP	30 K	SSB
Q-band : 34~50GHz	2~18GHz(full band)	LHCP	40 K	
W-band : 84~116GHz	2~34 GHz(full band)		70 K	

Simultaneous observation results



Summary

2300 mm



2600 mm

600 x 980 x 370 mm

- Pointing offset among 3 channels : less than 3 arcsec to conduct simultaneous observations
- Aperture efficiencies : Obtained as much as we could (K- : 68 %, Q-: 66 %, W-band : 50%)
- Receiver noise temperatures : Not bad, but have to be improved (OMT, Polarizer and LNA)

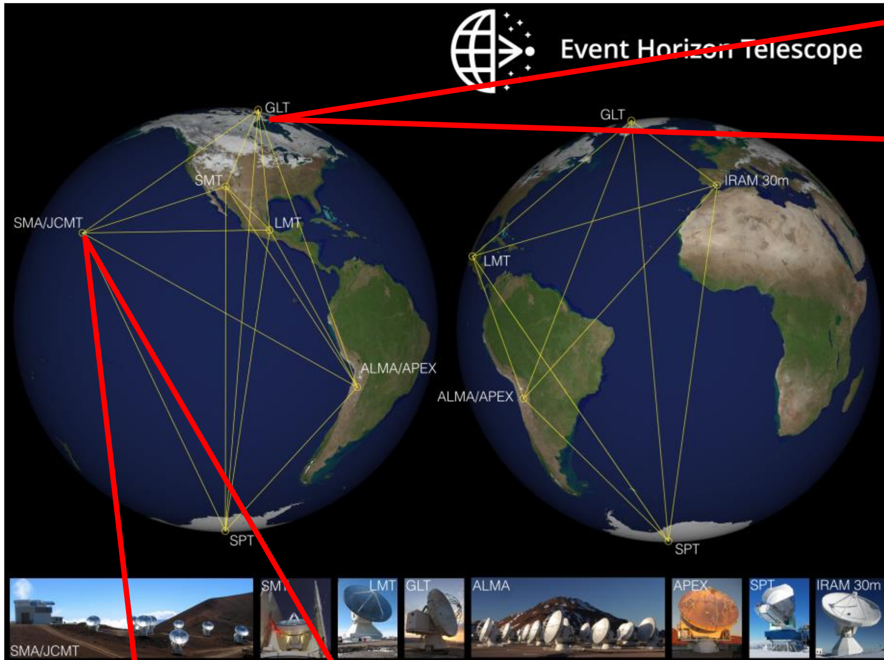
❖ CTR is tailorable for use in any telescopes with a small receiver cabin.

❖ Ultimately this concept may lead to development of much more compact multi-frequency receiver systems for mm-wave and sub-mm radio telescopes

What I have done for the future Millimetron Space VLBI receiver so far

- **Ground station for Millimetron, especially EHT station**
- **Key components such HPF and LPF**

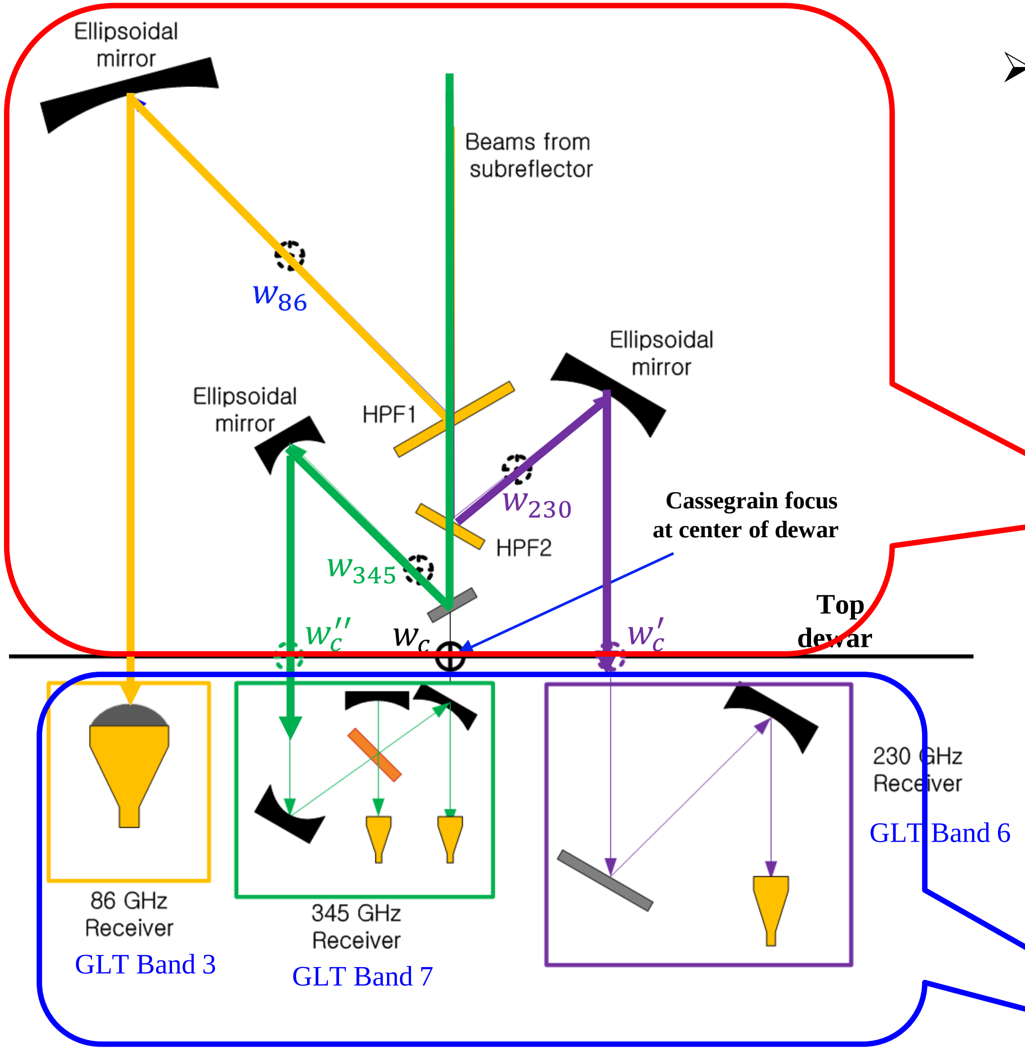
1. GLT(Green Land Telescope) for EHT, Taiwan



- **We are considering to make optics of 100/230/345 GHz for JCMT, Hawaii in near future**

3. Conceptual design of quasi-optical circuit for simultaneous observations

- **Simultaneous 100/230/345 GHz band Observations with their own receivers**
- **Only the optical circuit will be installed on top of dewar**



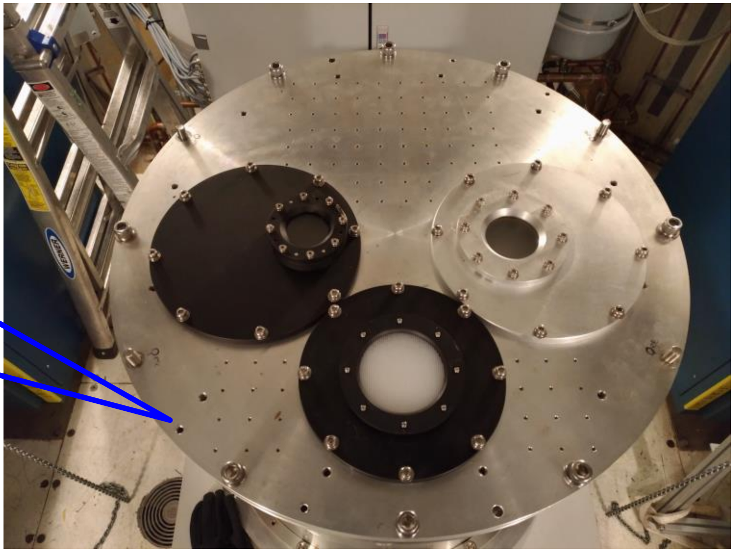
- **Optical beam waist is equal to original beam beast at Cassegrain focus**

$w_{86} = w_c$(original beam waist)

$w_{345} = w_c'' = w_c$ (original beam waist)

$w_{230} = w_c' = w_c$(original beam waist)

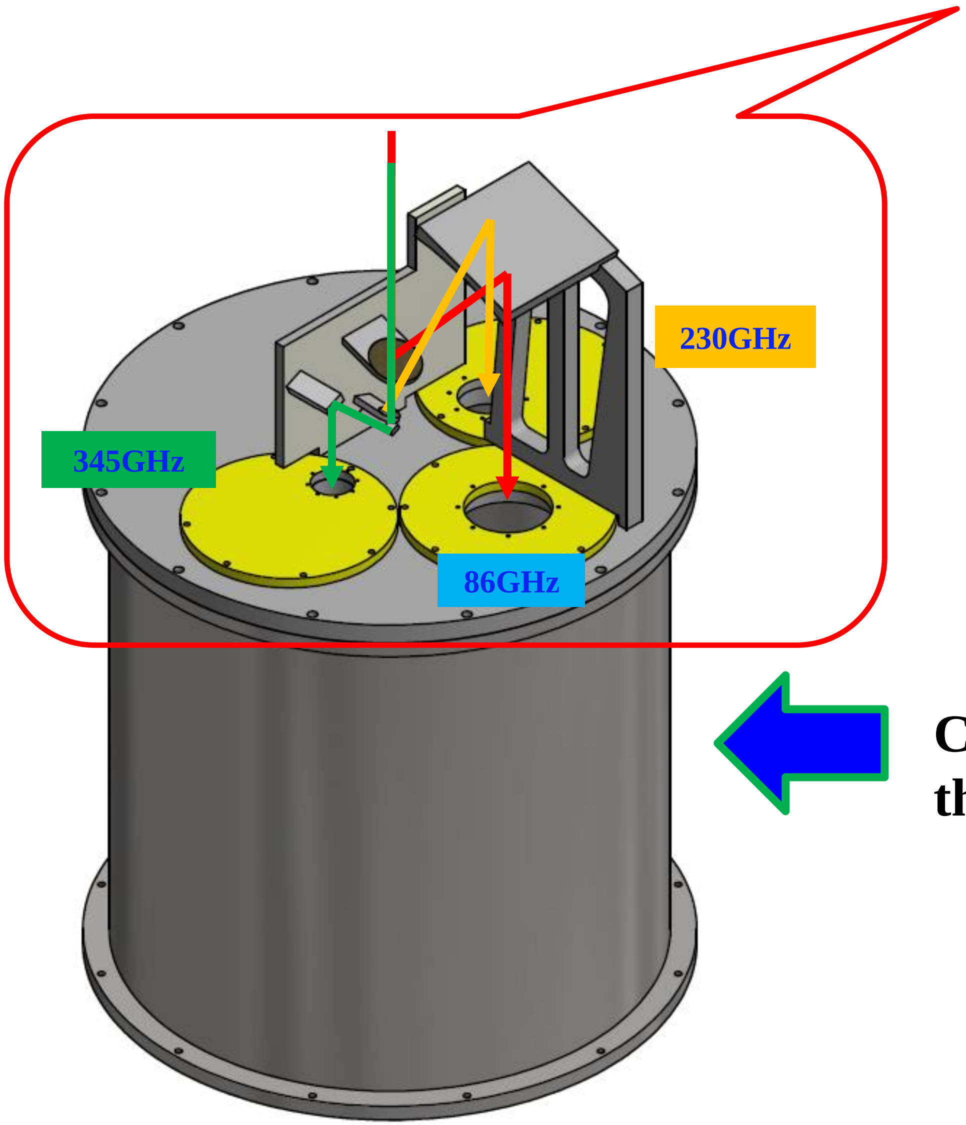
New design optical circuit to make simultaneous observations



- **Current receivers will be used**

- **It will be one of experience to development of Millimetron quasi-opitcs**

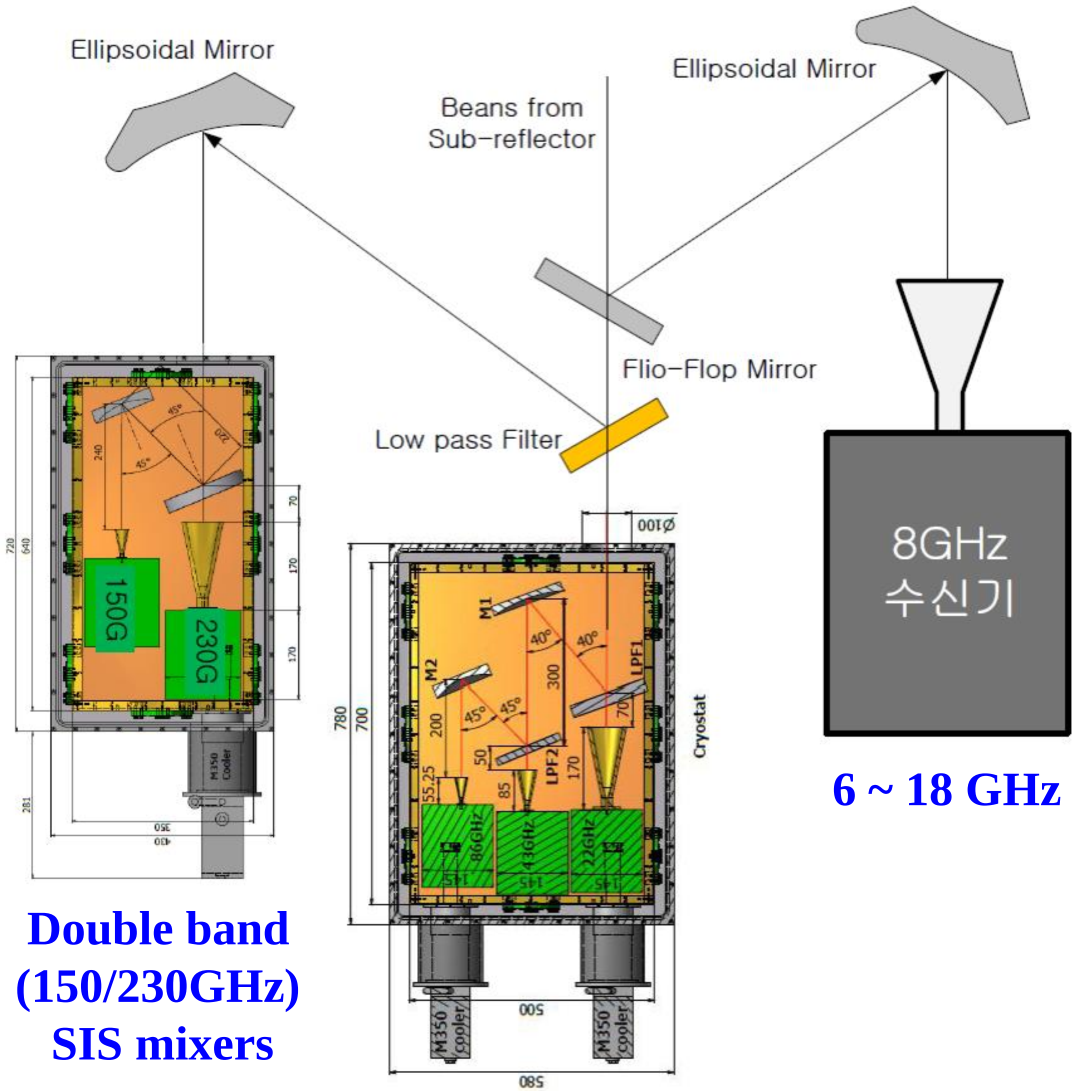
New design optical circuit
to make simultaneous observations



Current receiver chamber which is the same as GLT receivers

4. Conceptual design of E-KVN receiver system

- **Period : 2020 ~ 2022(3 years)**
- **Quintuple band (Double + Triple) simultaneous observation 18 GHz to 230 GHz**
- **6 GHz to 18 GHz receiver**



Double band (150/230GHz) SIS mixers

6 ~ 18 GHz

- **Triple band(K/Q/W)**

A review of quasi-optical circuit for Millimetron space VLBI receivers

1. Space-Earth VLBI receivers Specifications for Millimetron

- **Optical circuit design of the simultaneous observation for 100 GHz, 230 GHz and 345 GHz**
- **Have to consider for ground station such EHT stations to make sure of the space VLBI observations**

Space-Earth VLBI receivers

In red, high priority (EHT) bands;

In grey TBC; depending on science cases and implementation feasibility

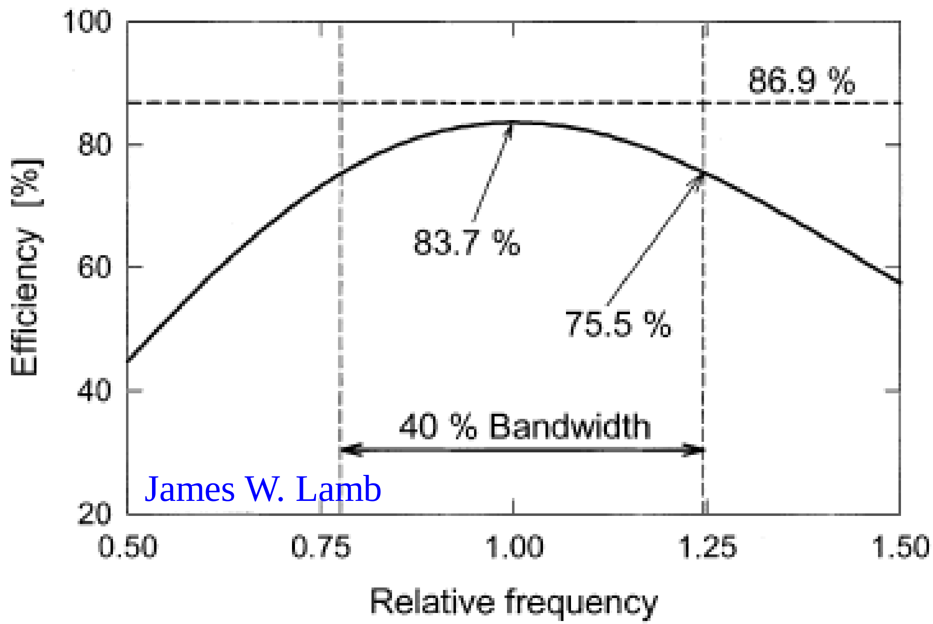
Band	Frequency (GHz)	IFBW (GHz)	Instantaneous bandwidth (GHz)	Polarization	T_{noise} (K)	Comments
1	33 – 50 ALMA Band 1	4-12 (HEMT)	4 (max)	Circular	<17	Post cryo capable
2	84 – 116 ALMA Band 3	4-12 (HEMT)	4 (max)	Circular	<37	Post cryo capable
3	211 – 275 ALMA Band 6	4-12 (SIS)	4 (max)	Circular	<80	Dedicated SIS receiver
4	275 - 373 ALMA Band 7	4-12 (SIS)	4 (max)	Circular	<80	Dedicated SIS receiver
5	*490-650* *HIFI band 1*	*4-12* *(SIS)*	*4 (max)*	*circular*	*< 80*	*Dedicated SIS receiver*

Thijs de Graauw; (tdegraau@alma.cl)

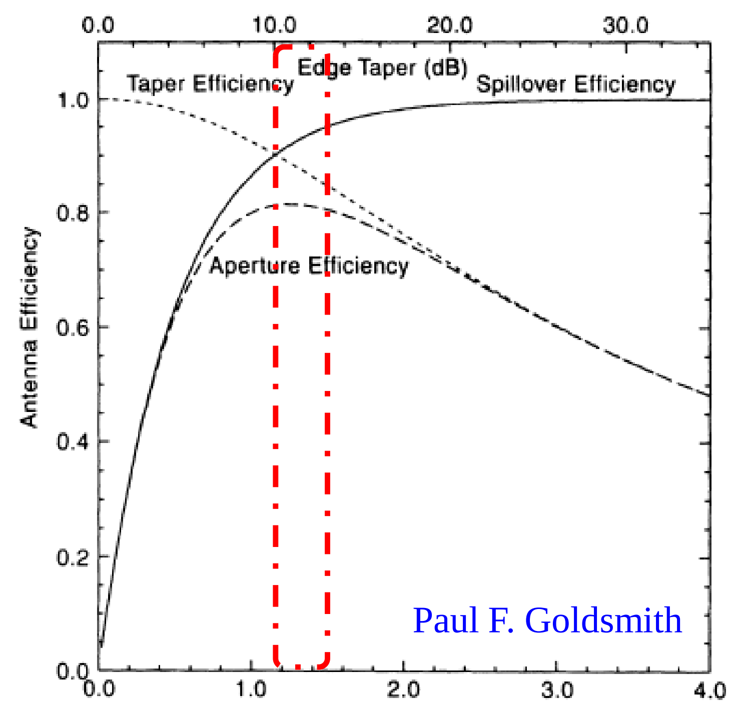
I. Overview of Quasi-optical circuit design

1. An aperture efficiency and quasi-optical circuit property

- **It aims to not only to obtain maximum aperture efficiency given operational bandwidth but also to desire more than 40 % operational RF bandwidth**



Antenna aperture efficiency

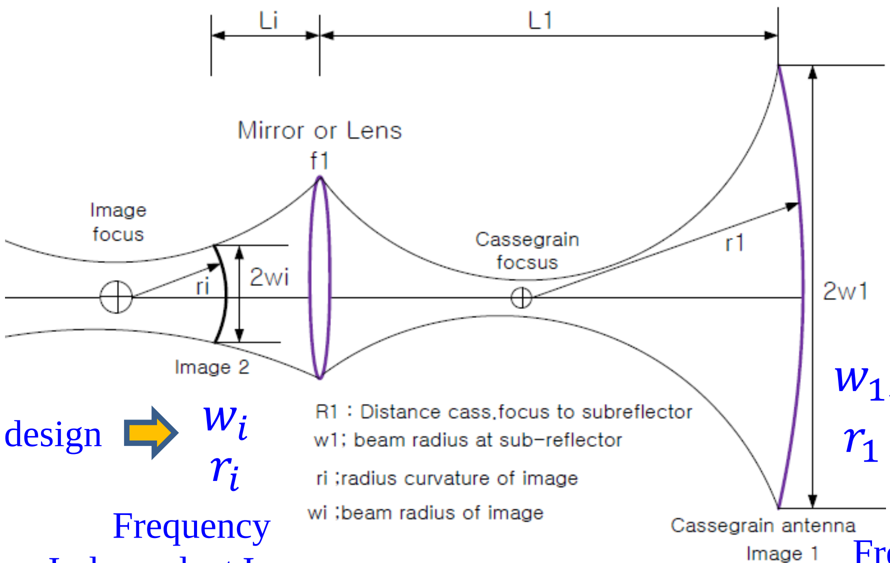


Antenna edge taper

- **Aperture efficiency for an ideal corrugated feed horn at the secondary focus : Solid Line**
- **Frequency independent quasi-optical circuit : Dashed Line**
- **Antenna edge taper : $12 \sim 14\ dB$ in terms of spillover and taper efficiencies**
- **My quasi-optical circuit always has been chosen "Frequency Independent Image technique"**

II. Gaussian beam transformation with frequency independent properties

1. Frequency Independent Image : KVN, ALMA, CTR



Feed horn design ⇨ w_i r_i

Frequency Independent Image

w_1, r_1

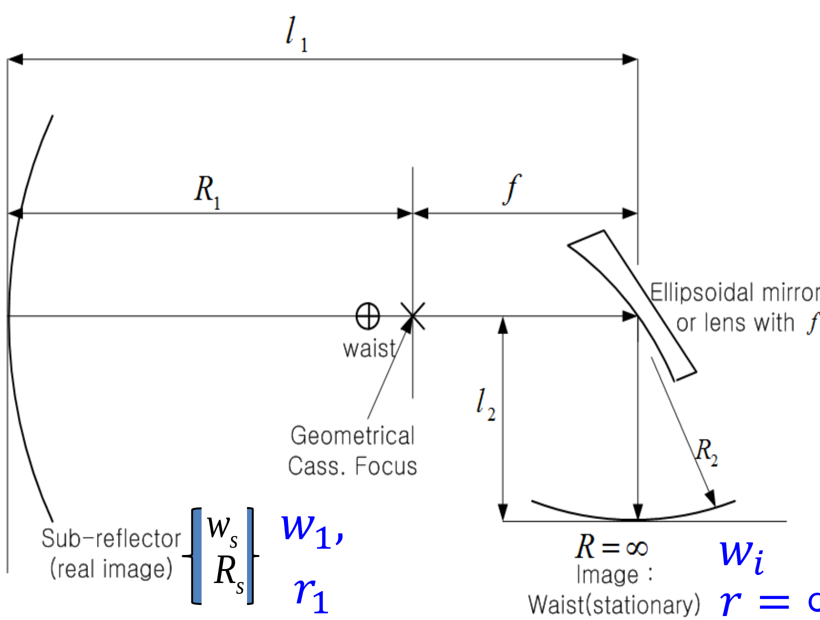
Frequency Independent Image

$$\frac{w_i}{w_1} = \frac{L_i}{L_1}$$

$$\frac{1}{L_i} + \frac{1}{L_1} = \frac{1}{f_1}$$

$$\frac{1}{r_1} = \frac{1}{L_1}\left[1 + \frac{L_i}{L_1}\left(1 + \frac{L_i}{r_i}\right)\right]$$

T.S. Chu
"An Image Beam Waveguide Feed"
1983. 7. IEEE AP, AP-31, No.4



w_1, r_1

w_i $r = \infty$ ⇦ Feed horn design

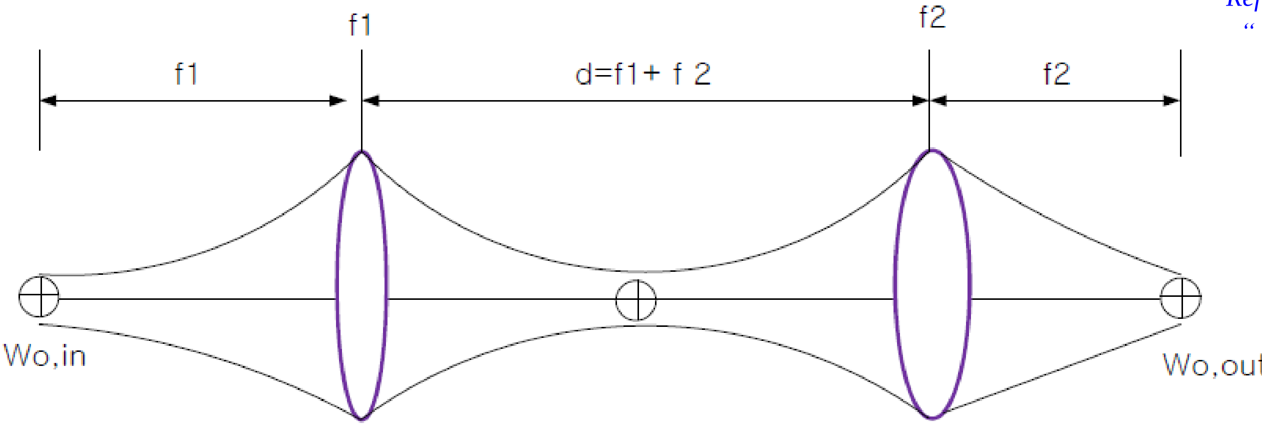
$$l_1 = f - R_1 \qquad l_2 = -\frac{l_1}{R_1} \cdot f$$

$$R_2 = \frac{l_2}{1 + \frac{l_1}{l_2} \cdot \frac{f}{R_1}} = \frac{l_2}{1 + \frac{l_1 - f}{R_1}} \Rightarrow \infty$$

Seog-Tae Han ,et al
"Millimeter-wave Receiver Optics for Korean VLBI Network"
2008. 1. JIMW, Vol. 28, No. 1, pp 69-78

2. Gaussian Beam Telescope: KVN

Reference : Gaussian Beam Theory
" Quasioptics system " Paul Goldsmith, IEEE Press



$$w_{o,out} = \frac{f_2}{f_1} w_{o,in}$$

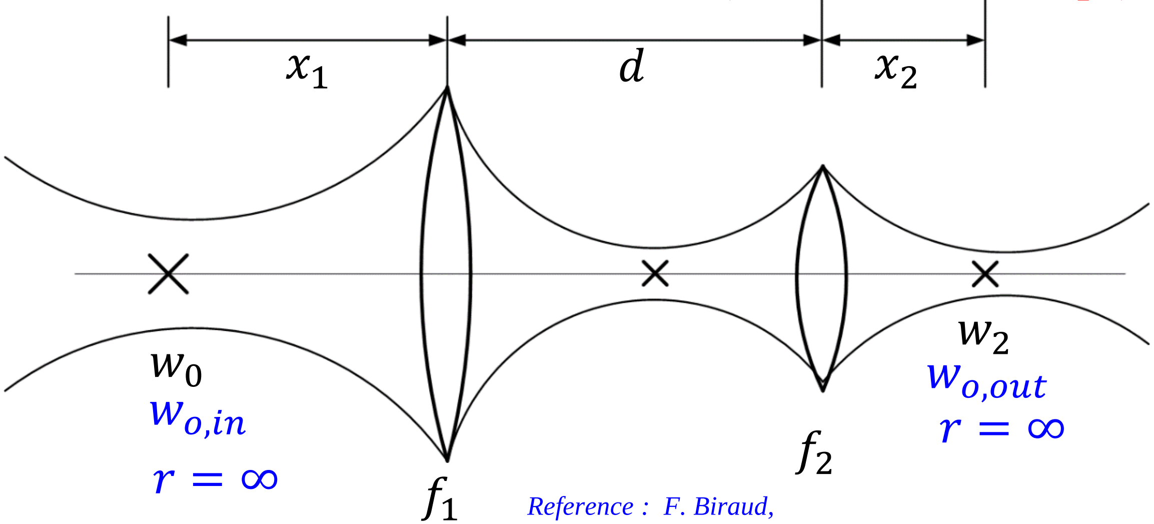
$$d_{out} = \frac{f_2}{f_1}\left(f_1 + f_2 - \frac{f_2}{f_1} d_{in} \right)$$

$$\text{if } d_{in} = f_1 , d_{out} = f_2$$

$w_{o,in}$
$r = \infty$
Frequency Independent Image

Feed horn design ⇒ $w_{o,out}$
$r = \infty$
Frequency Independent Image

3.Achromatic Doublets for Gaussian beam : Italian radio telescope, Effelsberg 100 m telescope, Finland(Metshahovi telescope)



$w_{o,in}$
$r = \infty$

$w_{o,out}$
$r = \infty$

$$w_2{}^2 \, w_0{}^2 = \frac{f_e{}^2}{\pi^2}$$

$$d = f_2 + \frac{x_1 f_1}{(x_1 - f_1)}$$

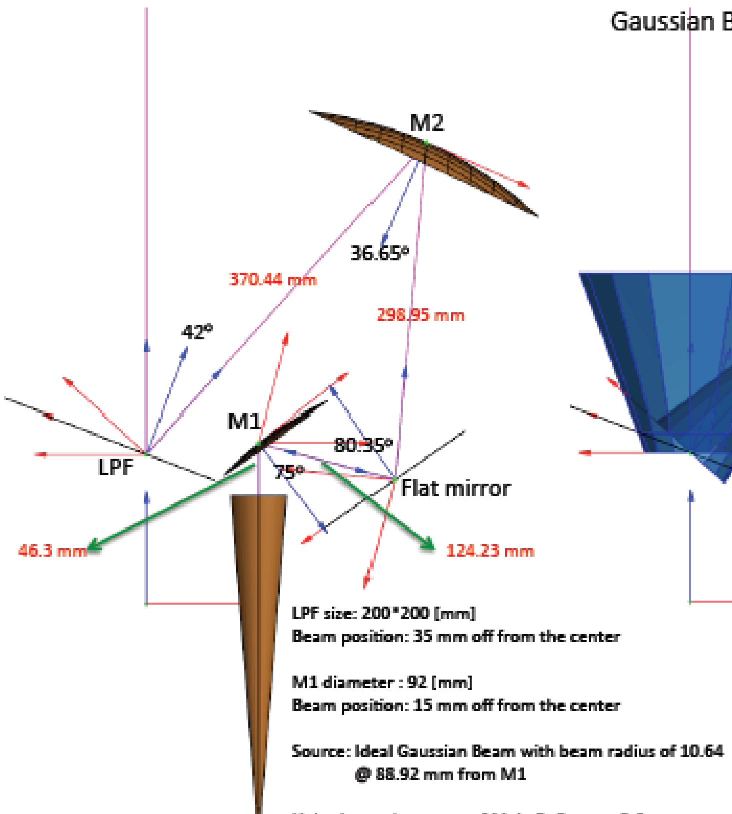
$$f_e = -\frac{f_2}{f_1}(x_1 - f_1)$$

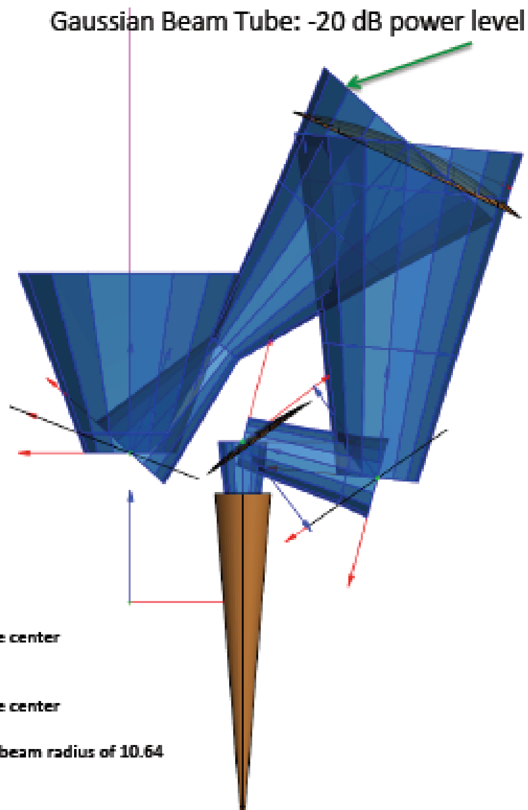
$$x_2 = x_1 \left(\frac{f_2}{f_1}\right)^2 + f_2 \left(1 - \frac{f_2}{f_1}\right)$$

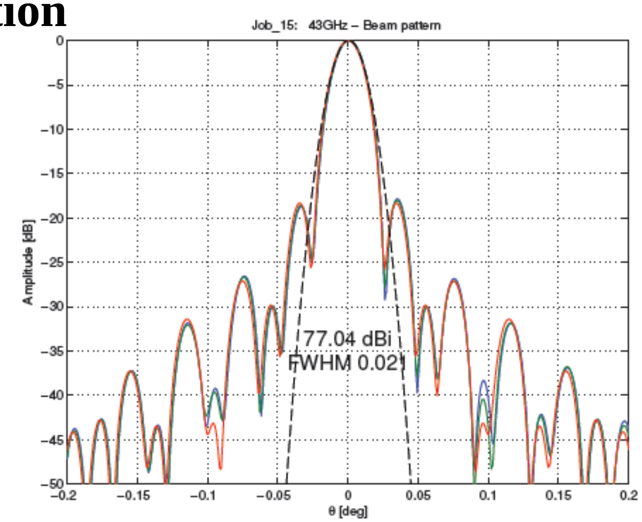
Reference : F. Biraud,
" Achromatic Doubelt for Gaussian beam " IEEE, AP, vol 39, No.4, Aprl, 1991

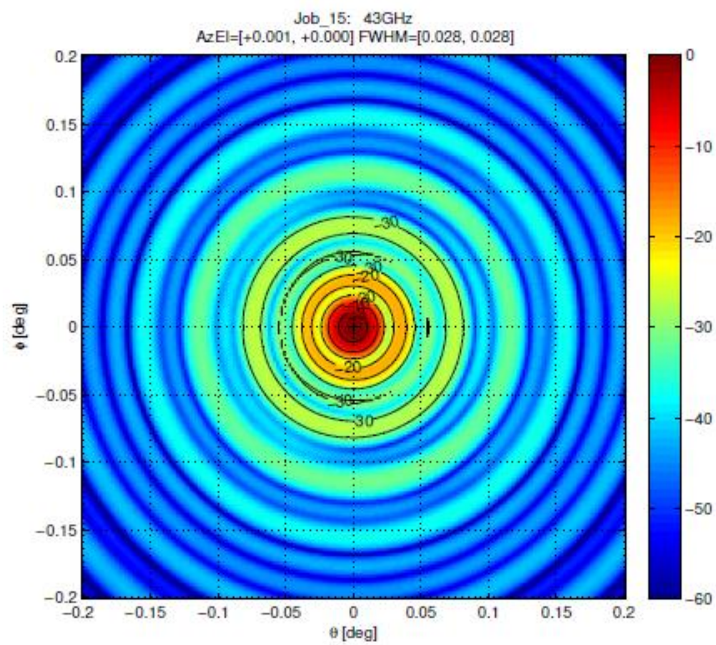
Theoretical evaluation for quasi-optical circuit by GRASP

- Aperture efficiency as function of frequency
- Radiation patterns for co- and cross polarization

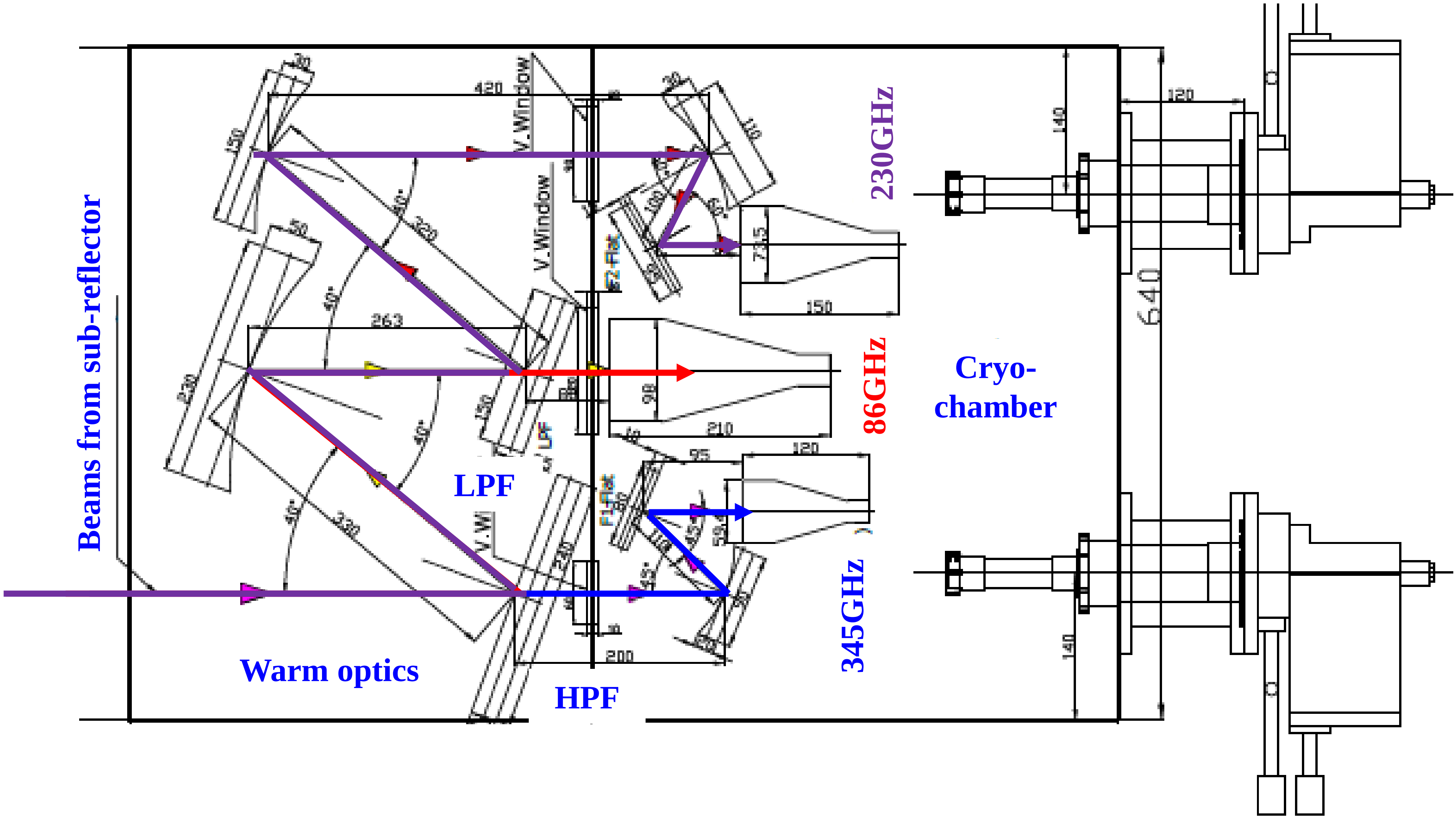




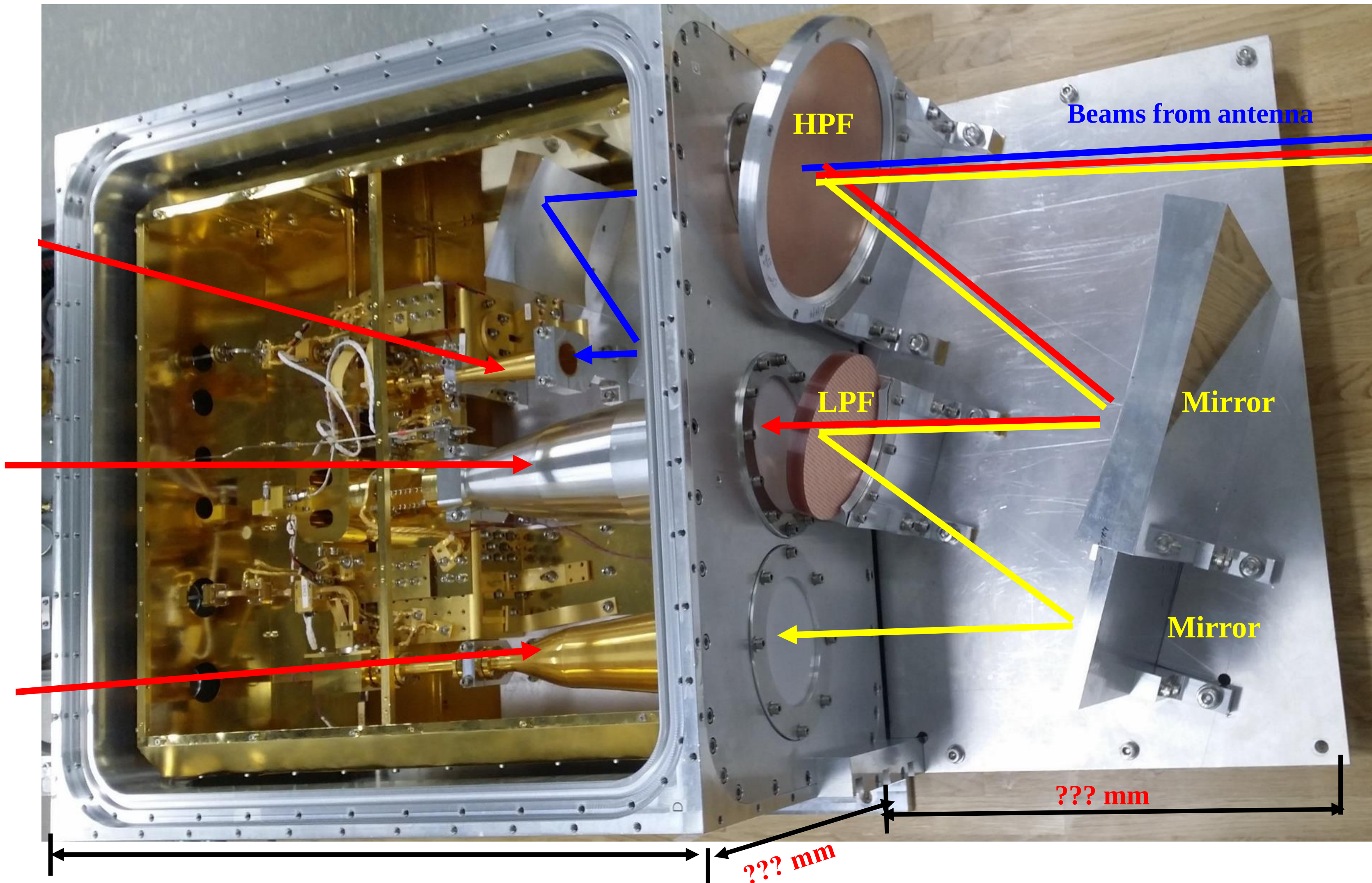




Conceptual design of Space VLBI receiver for Millimetron



Conceptual design of Space VLBI receiver for Millimetron



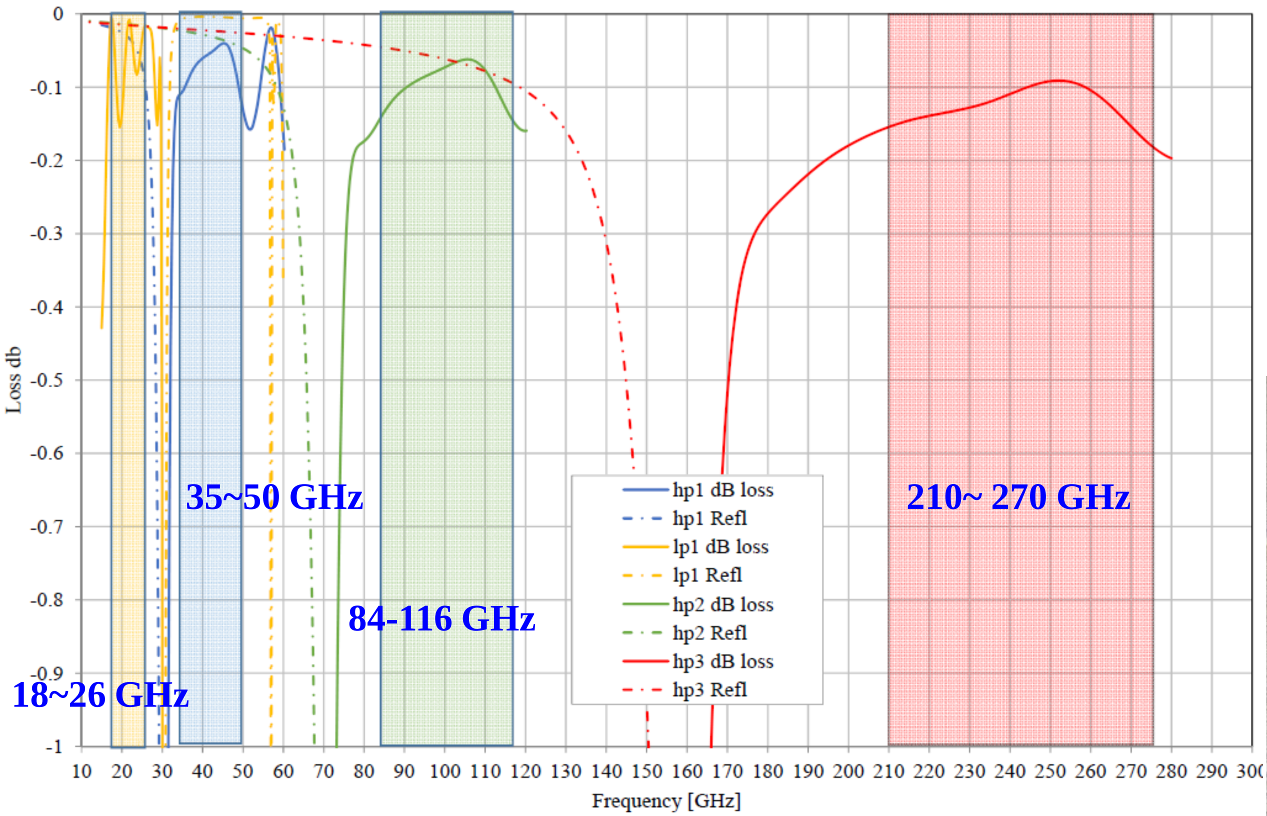
Much smaller than 600 x 600 mm due to 3 time shorter than wavelength

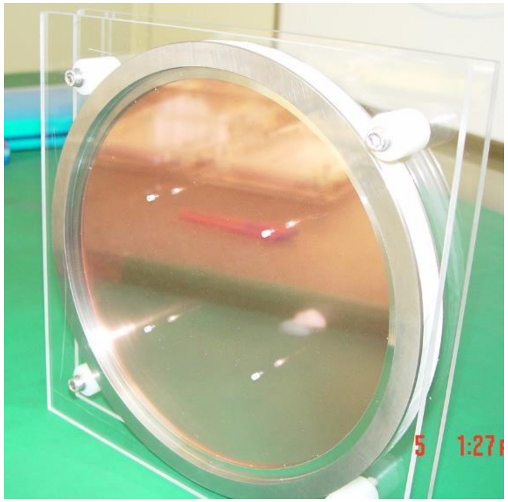
Observing bandwidths	IF bandwidths	Polarization	Receiver noise temperature	Comments
100 GHz : 84~116GHz	4~12GHz	Circular Polarization	< 40	HEMT
230 GHz : 211~276GHz			< 80	SIS Mixer (HEMT)
345 GHz : 275~373GHz			< 80	SIS

Quasi-optical High Pass Filter and Low Pass Filter

➢ **Made by QMC in Cardiff University, Wales**

- ➢ **Low transmission and reflection loss : lower than 0.2 dB**
- ➢ **Low cross polarization : less than 25 dB**
- ➢ **No beam deviation when it reflects or transmits at the filter**
- ➢ **Investigate 343~375 GHz in future**





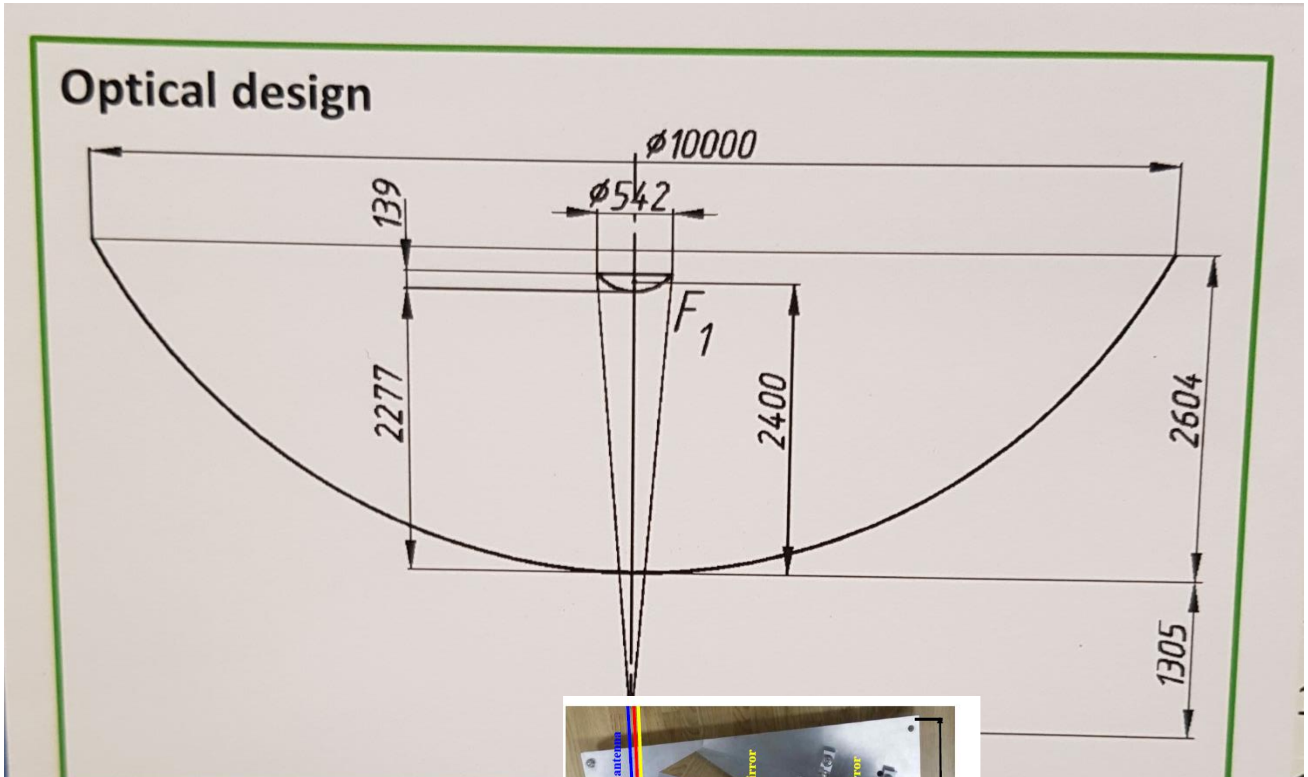
➢ **HPF**

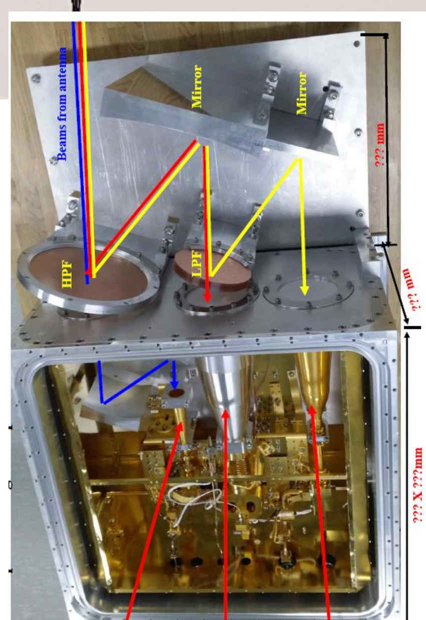
➢ **LPF**

Home works

1. Study on the Millimetron antenna properties
2. Quasi-optical circuit design
3. Investigation for the quasi-optical HPF and LPF
4. Development of the quasi-optical components
   - Feed horn, lens, Mirror
5. Evaluation the quasi-optical circuit by using GRASP
6. Proper materials to be used for space application quasi-optical components
7. Manufacture prototype of Millimetron quasi-optical circuit and test

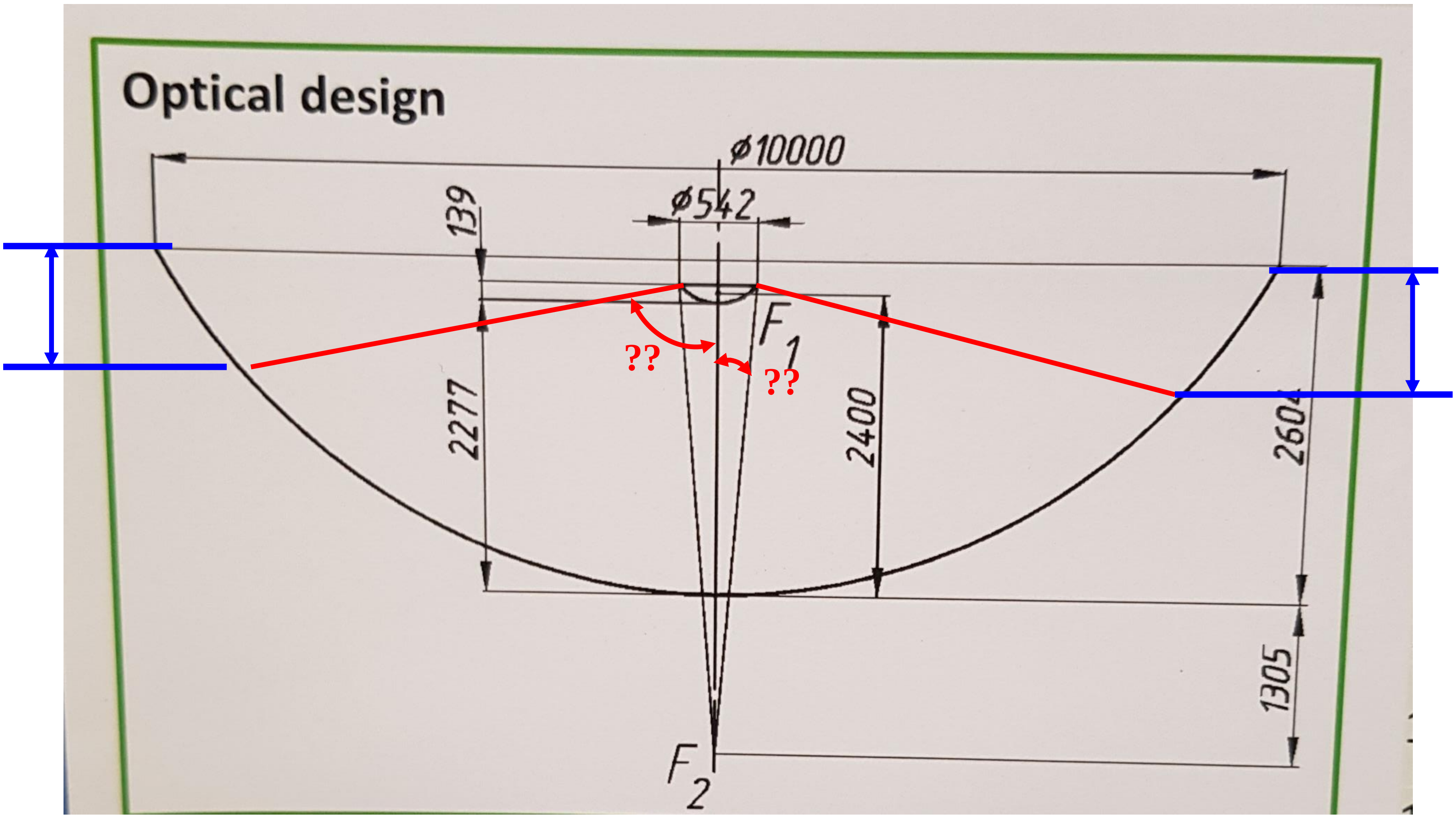
Dream comes true !!!!!!!!

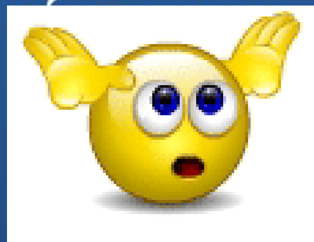


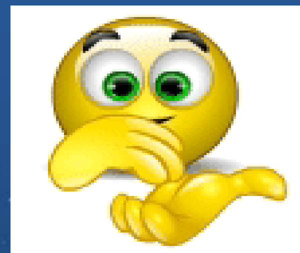


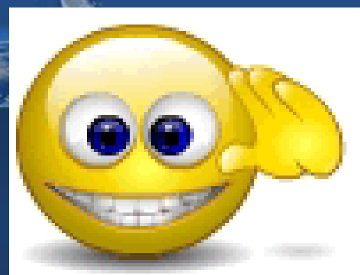
Confirmation

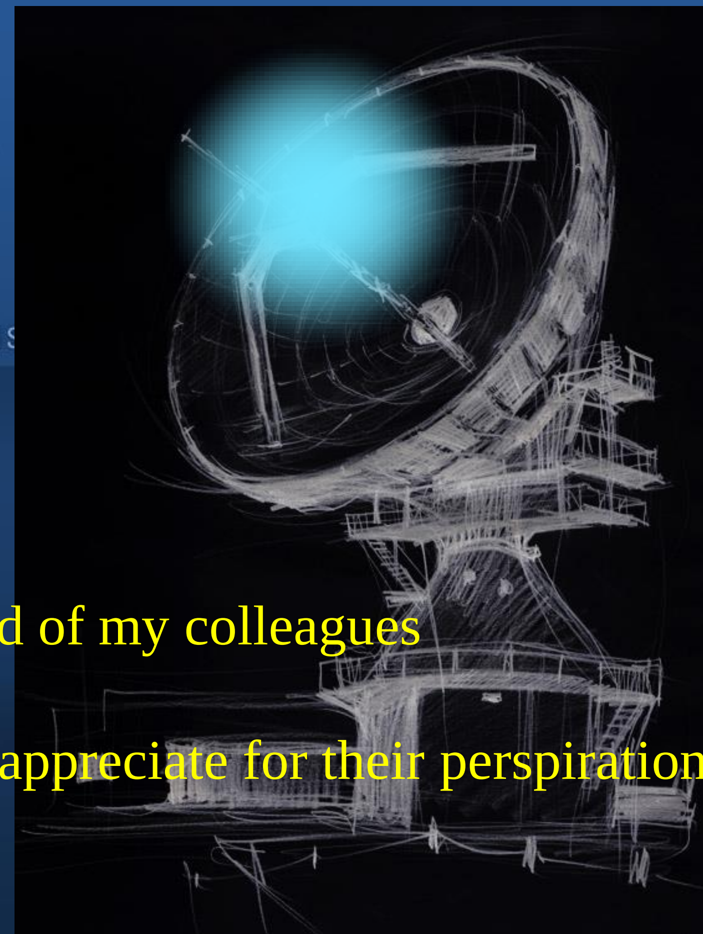
To start the quasi-optical design,
the antenna specification has to be clear absolutely,











Not only I am very much proud of my colleagues
and their achievements,
But also I would like to really appreciate for their perspiration
and enthusiasm for KVN

Thanks for your attention