Quasi-Optical design of K, Q and W-band receiver system for 40-meter Thai National Radio Telescope (40m TNRT)

URSI GASS 2020

by

Dan Singwong

Radio Astronomy Operation Center (RAOC)

National Astronomical Research Institute of Thailand (Public Organization (NARIT)

NARIT

U.R.S.I.

Thai National Radio Astronomy Observatory

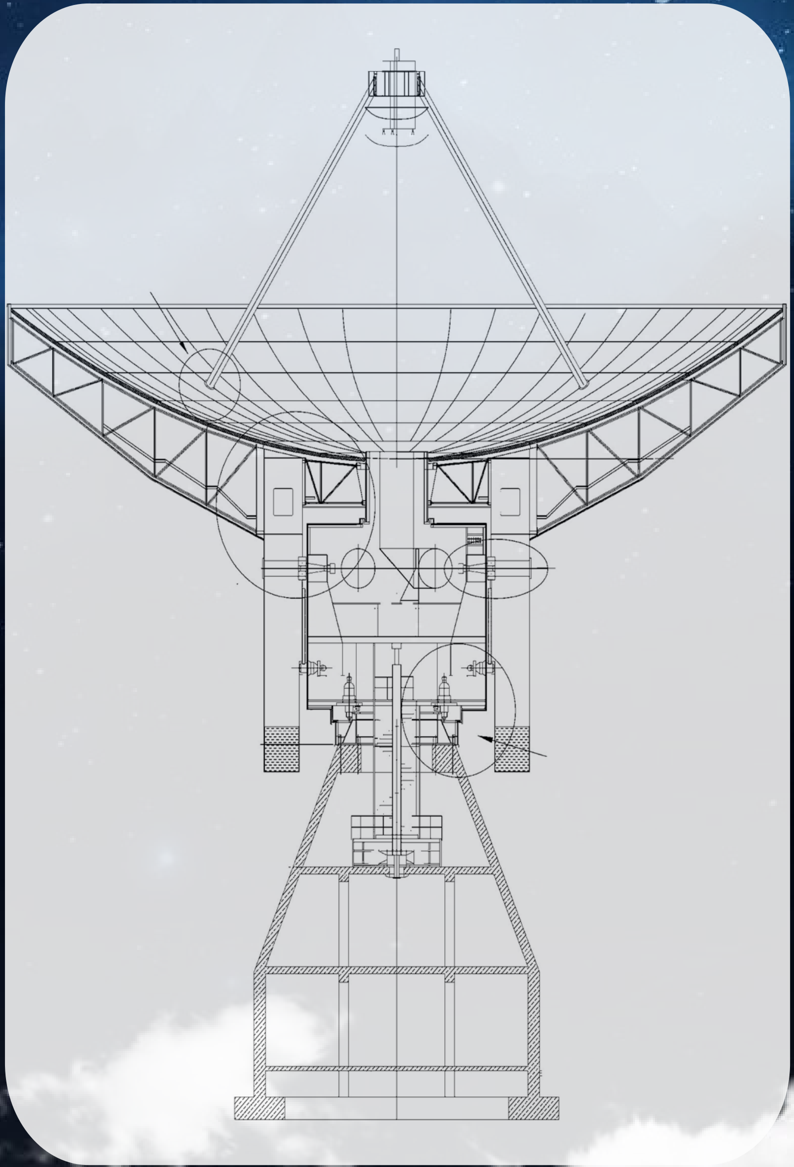
Outline

1. Overview of 40 meter Thai National RadioTelescope (40m-TNRT)
2. 40m-TNRT Optical parameters and Layout
3. Optical Design System
    - 3.1 One element mirror calculation
    - 3.2 GBT element mirror calculation
    - 3.3 Optical design for M4L path
    - 3.4 Optical design for M4R path
4. Calculation optical circuit of K and QW band receiver
5. Summary

1. Overview of 40 meter Thai National RadioTelescope (40m-TNRT)

The 40 meter Thai National RadioTelescope (40m-TNRT) is the biggest Radio Telescope in Southeast Asia. The objective is Astronomy observation and Geodesy observation. The optical design is Nasmyth-Cassegrain telescope. The receiver can be installed at the primary focus and secondary focus. At the primary focus, that has a special mechanic to flip the sub-reflector and has the Gravity sliding for install low band frequency receiver. It is called "Tetrapod Head Unit (THU)".

The structure of 40m-TNRT



The specification of the 40m-TNRT

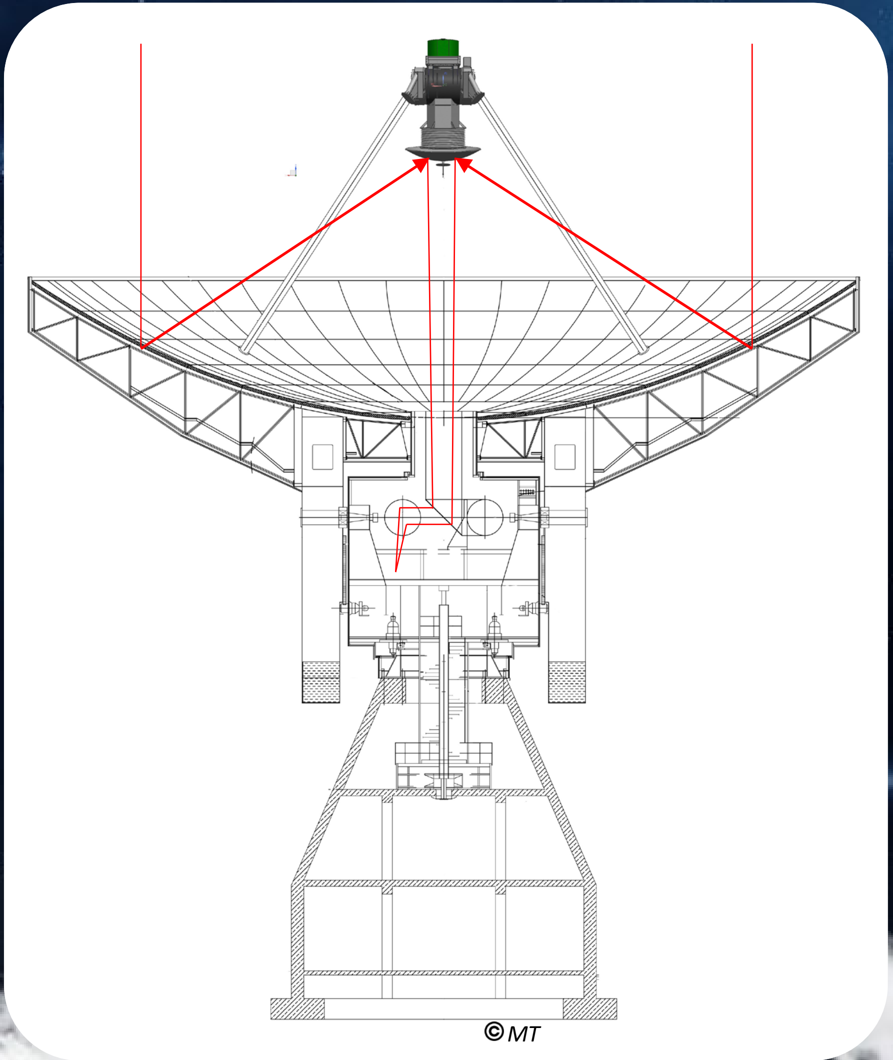
40m TNRT Specification		
Parameter	Value	Unit
Antenna Type	Paraboloid Antenna, Cassegrain-Nasmyth optics	
Antenna Diameter	40	meter
Surface accuracy	150	um (rms)
Frequency Response	0.3- 115	GHz
Slew Rate	Az 3 deg/s, EL 1 deg/s	
Pointing accuracy	2" (no wind)	
	6" (5 m/s wind)	
f/D ratio for Primary focus	0.375	
f/D ratio for Secondary focus	7.909	
Mechanical Switch Mode	THU (Tetrapod Head Unit)	
Low frequency mode	0.3-2	GHz
High frequency mode	2-115	GHz

Current status of structure building (Aug 2020)

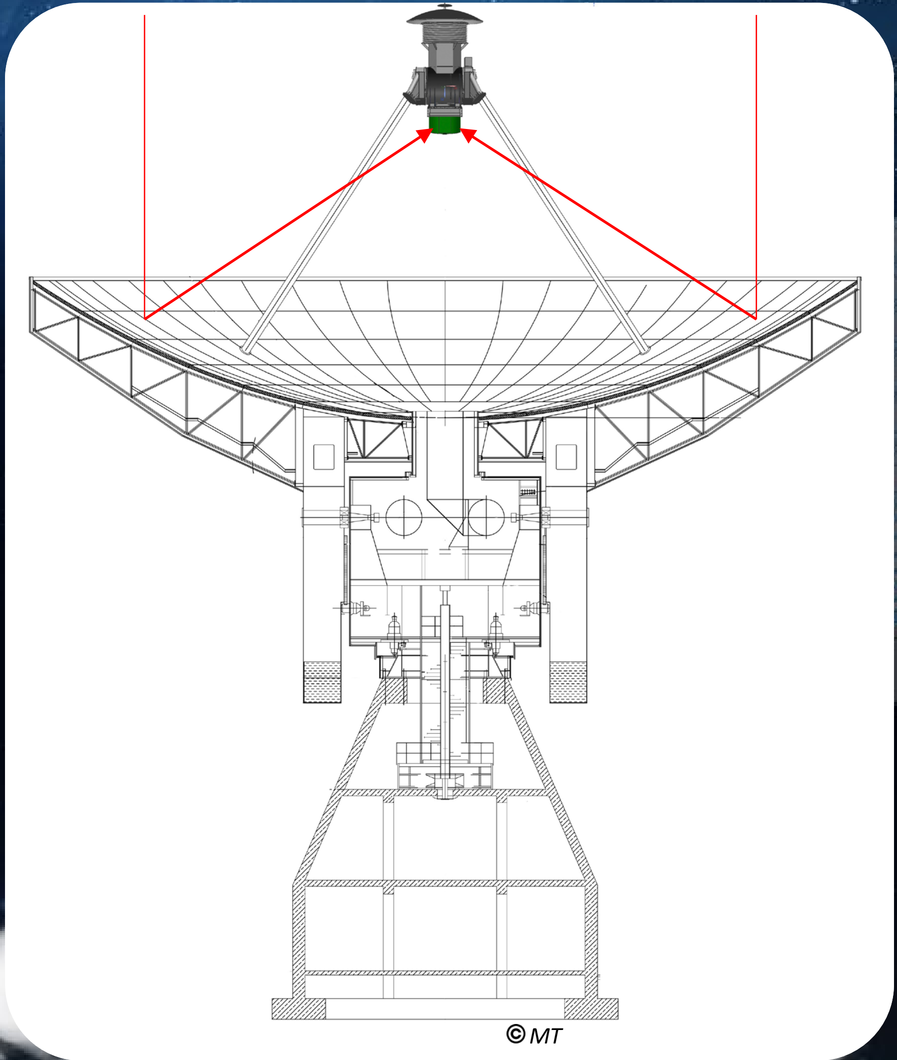
1. Overview of 40 meter Thai National RadioTelescope (40m-TNRT)

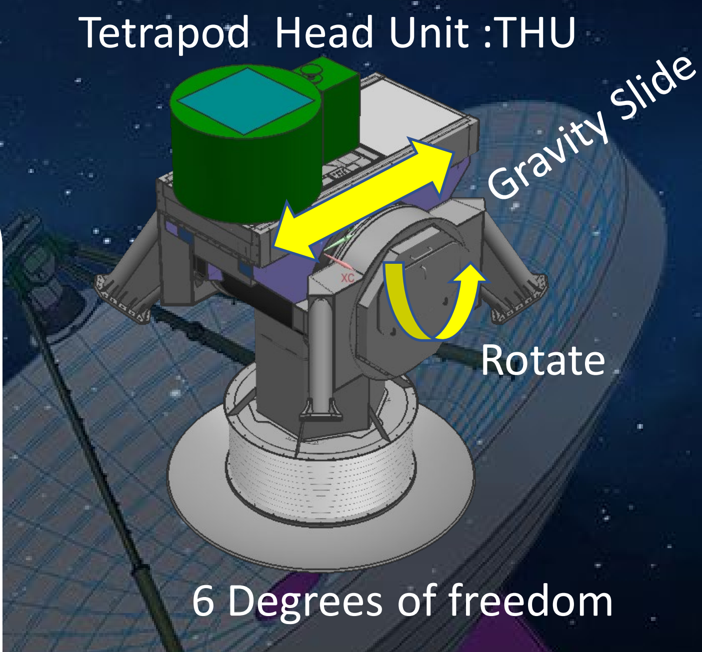
Mode Operation for the 40m TNRT

High frequency Mode



Low frequency mode

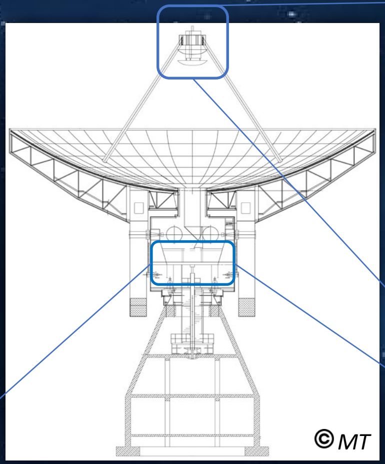


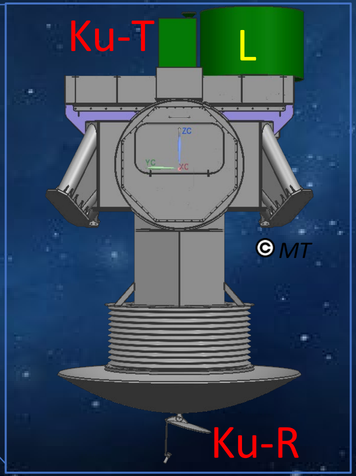


-The THU can be rotated: 0-180 degree
-The Gravity sliding has a linear movement in range of 100cm
-TNRT 40M Operation Mode are:
Low frequency mode:
<2 GHz
High frequency Mode:
2-115GHz

1. Overview of 40 meter Thai National RadioTelescope (40m-TNRT)

A Layout receiver of the 40m TNRT



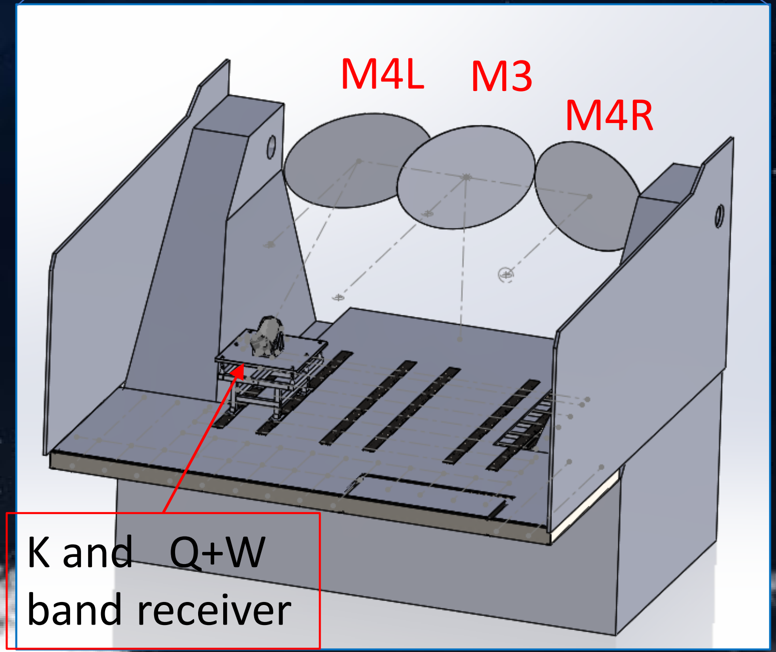


Primary Focus

-L-band receiver
-Ku Reference
-Ku Test

In next future

-L band phase array fees

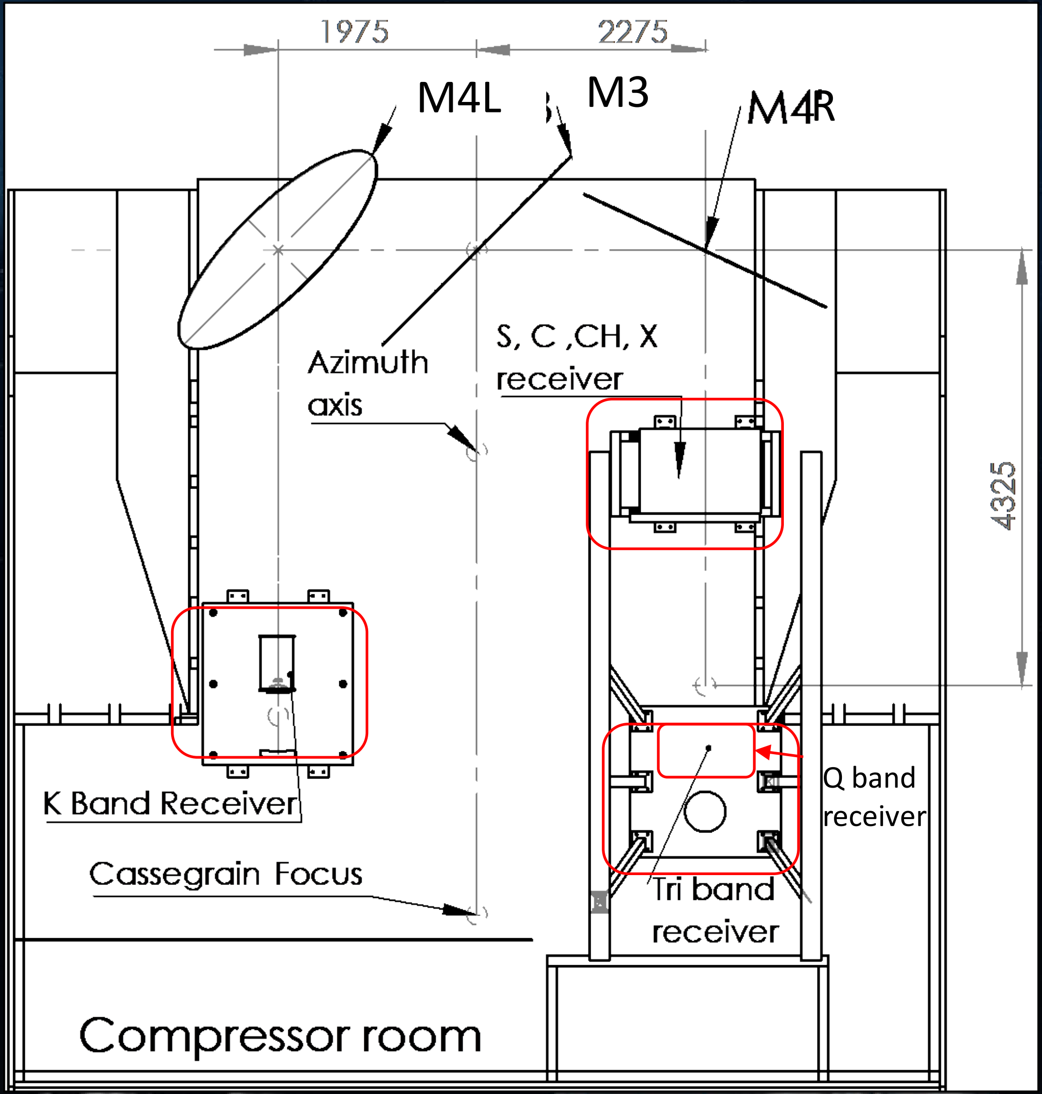


Receiver Room

-K Band receiver
-Q+W Band receiver

In next future

-C Band
-Tri band receiver
- S, CH, X band receiver



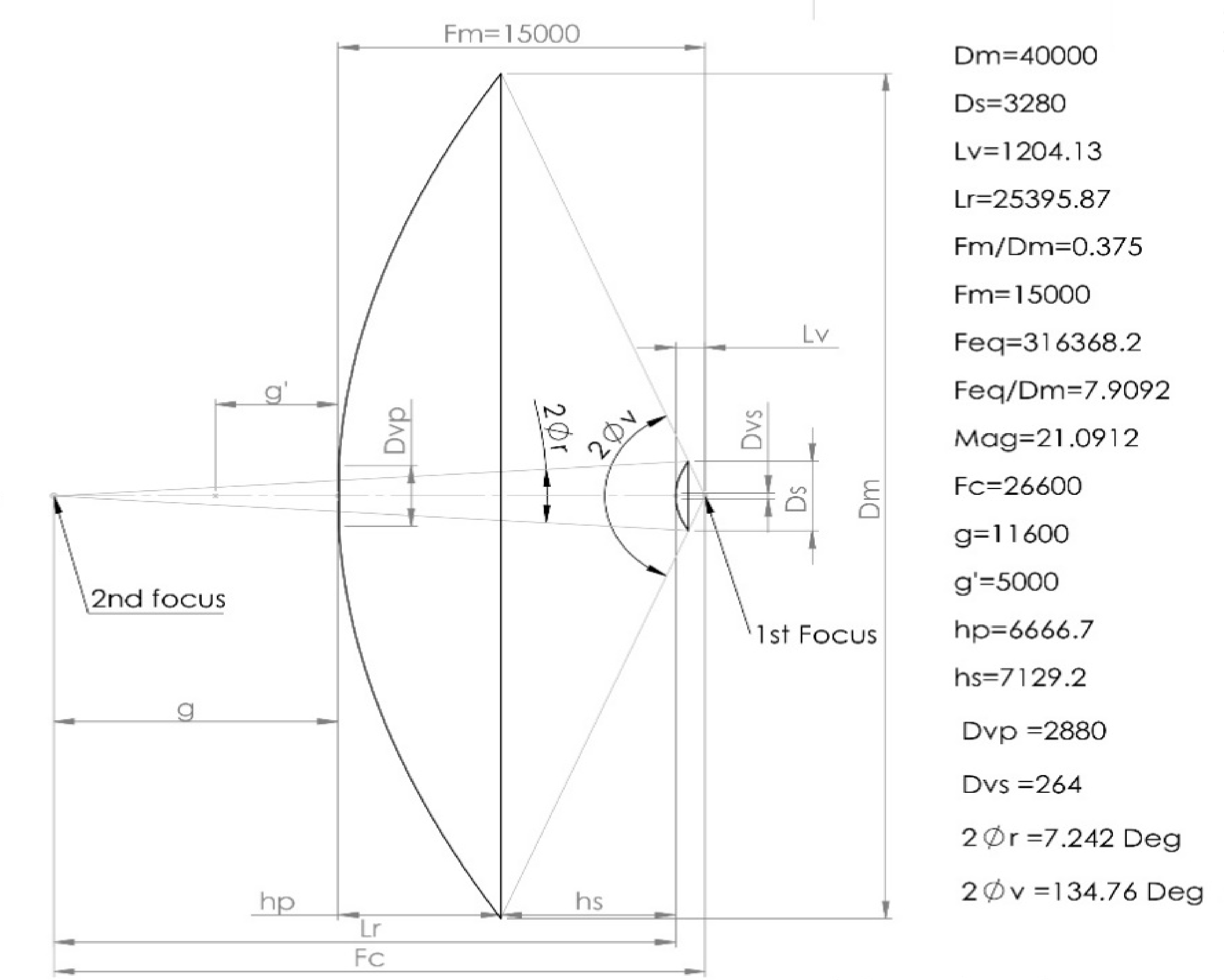
Receiver room top view

2. 40m-TNRT Optical parameter and Layout

The optical parameters of the 40m TNRT

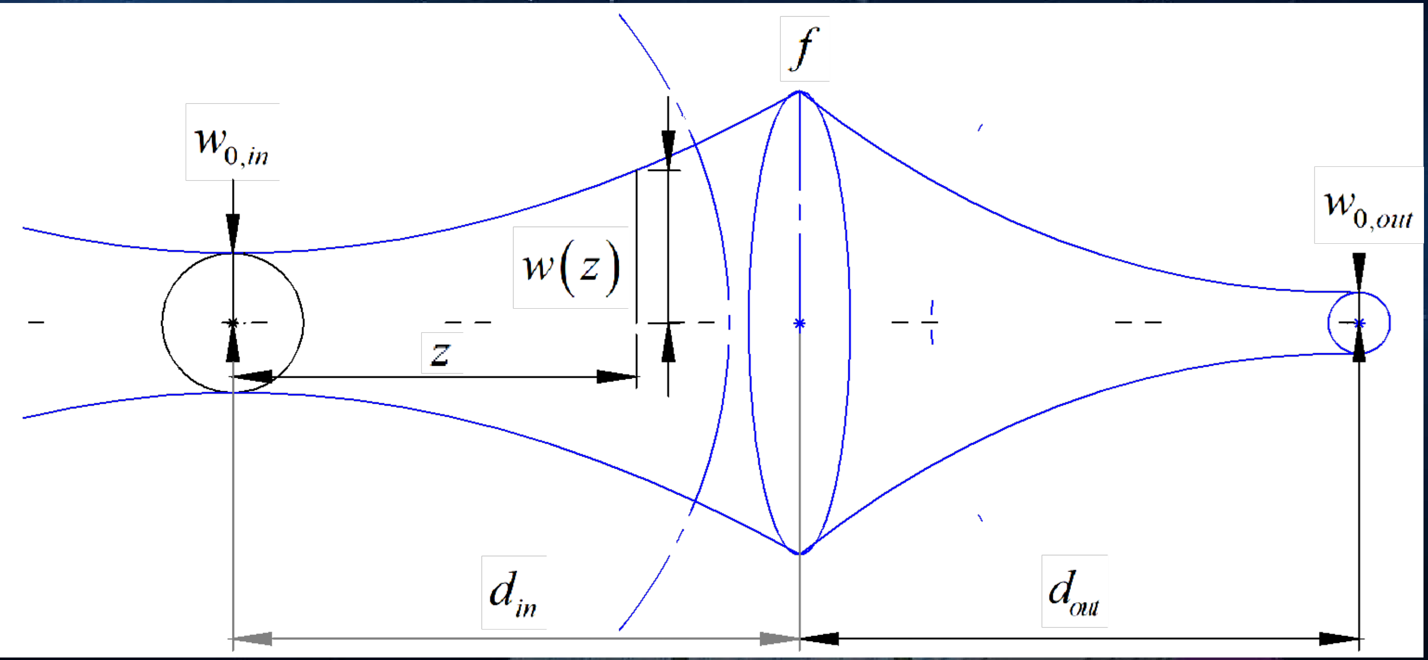
The picture at right side shows the optical parameters of the 40m TNRT. It has the dimeter size of 40 meter, the primary focus 15-meter, F/D is 0.375. The primary focus has the sub-reflector which is the hyperboloid with eccentricity 1.099548 then the Cassegrain parameters has equivalence focal length about 316.3 meter and the equivalence magnification about 21.09.

The 40meter reflector has the center hold about 2.88 meter and the angle at secondary focus is 7.242 degree.



3. Optical Design System

The beam transforms on one focusing element is shown in Figure right side. The waist size w(z) at distance (z) can be calculated by Equation (1). When the beam waist at the confocal (w_0), λ is the wavelength at center frequency.



$$w(z) = w_0 \left[1 + \left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]^{\frac{1}{2}} \quad (1)$$

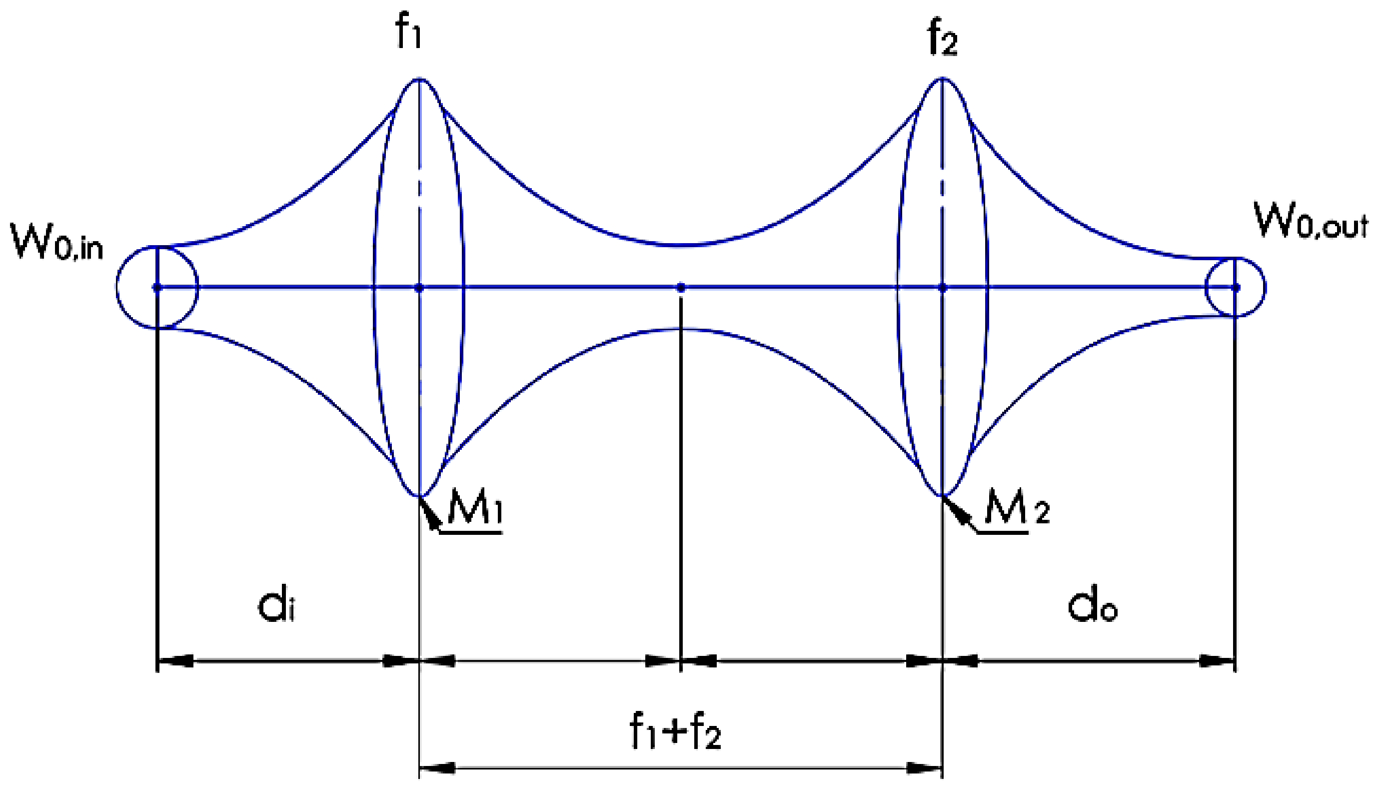
$$d_{out} = f + f\left[\frac{d_{in}/f - 1}{(\frac{d_{in}}{f} - 1)^2 + z_c^2/f^2}\right] \quad (2)$$

$$w_{0,out} = \left[\frac{w_{0,in}}{\left[(\frac{d_{in}}{f} - 1)^2 + z_c^2/f^2\right]^{\frac{1}{2}}}\right] \quad (3)$$

For a mirror or the thin lens, the output distance (d_{out}) can be derived as Equation (2). When f is the focal length of the element, z_c is confocal distance that can be calculated from $\pi w_0^2/\lambda$ and d_{in} is the input distance. The output beam waist ($w_{0,out}$) can be derived with Equation (3)

3. Optical Design System

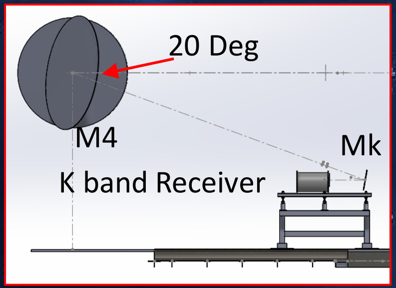
The Gaussian Bean Telescope (GBT) is a system consisting of two optical focusing elements which have focus points f_1 and f_2 are separated by $f_1 + f_2$ This configuration is illumined in Figure , where f_1 is the focal length of the mirror (M1), f_2 *is* the focal length of the mirror (M2), the $w_{0,in}$ is the input beam waist, the $w_{0,out}$ is the output beam waist and can be determined by Equation 4. The output distance (d_o) which is independent on frequency then the d_o depends only on input distance d_i . It can be calculated by in Equation 5.

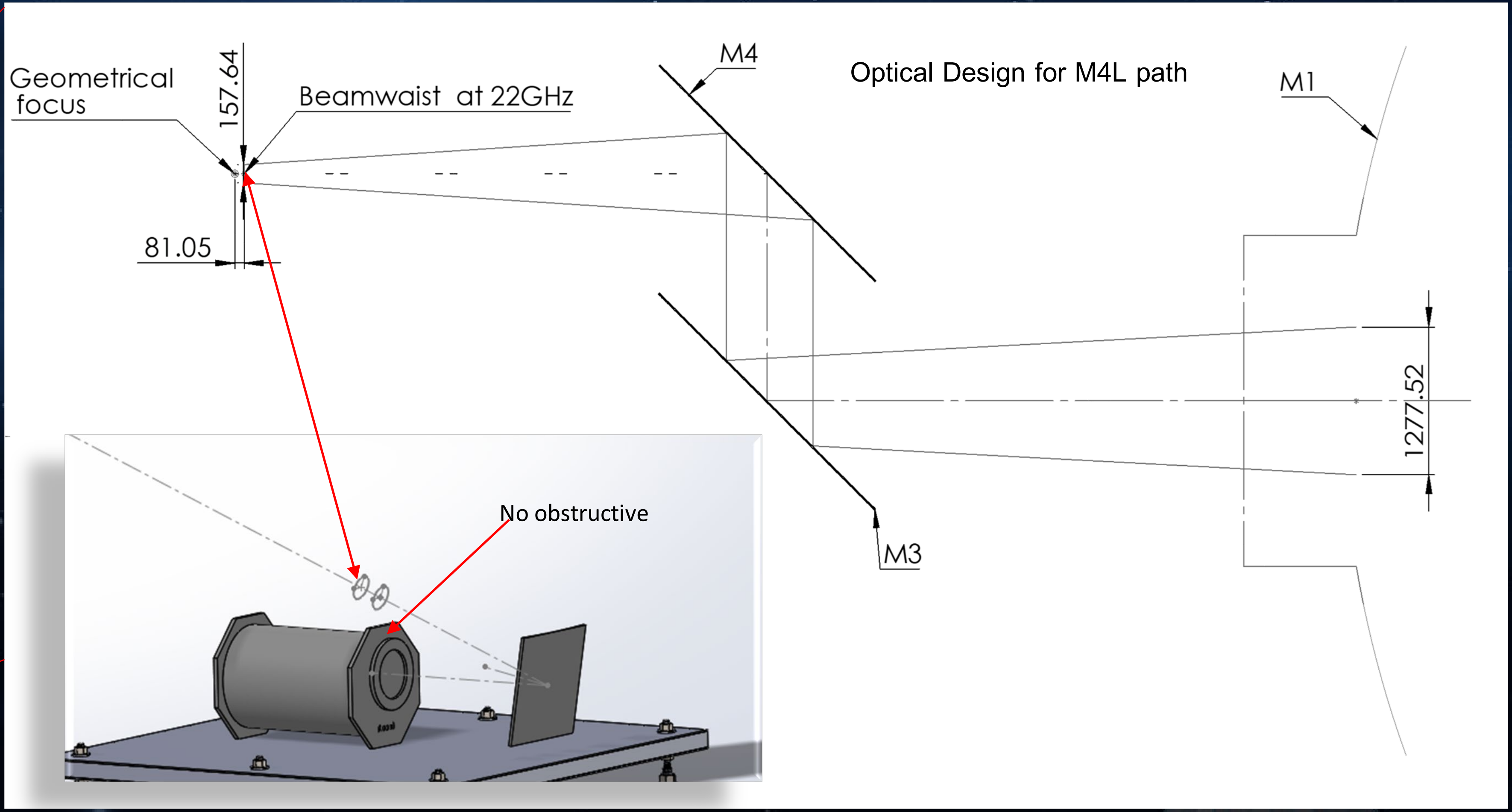


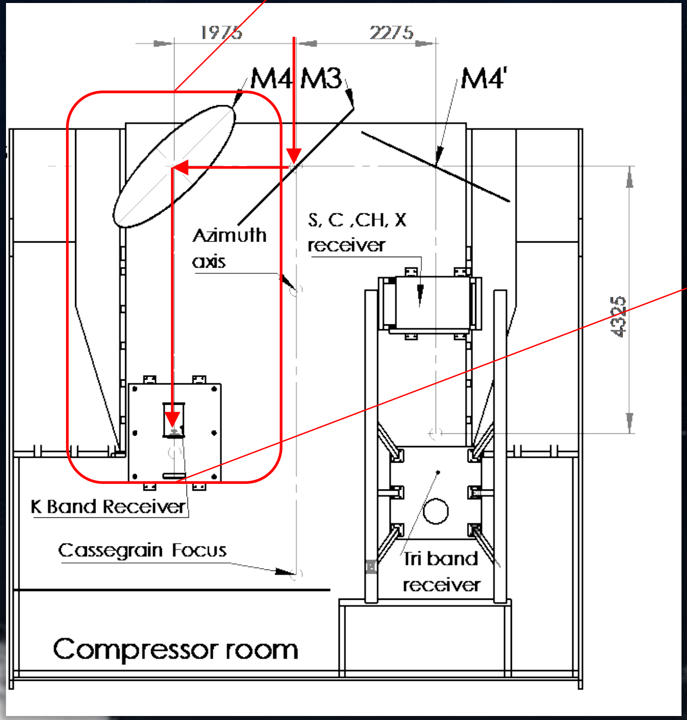
$$w_{0,out} = \frac{f_2}{f_1} w_{0,in} \tag{4}$$

$$d_o = \frac{f_2}{f_1}\left(f_2 + f_2 - \frac{f_2}{f_1} d_i\right) \tag{5}$$

3. Optical Design System: For 40m-TNRT on M4L part



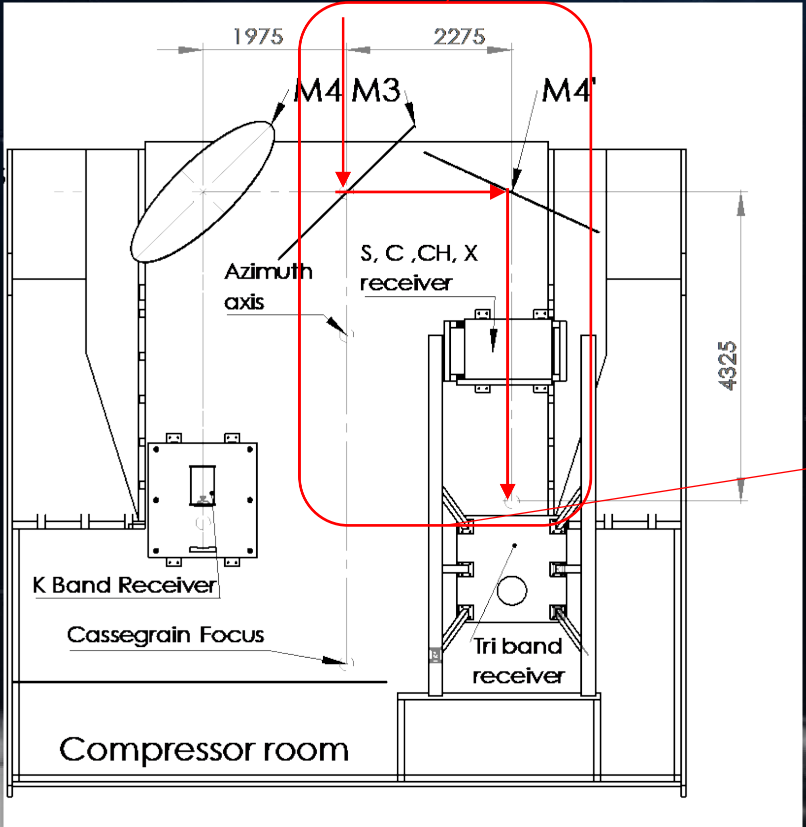


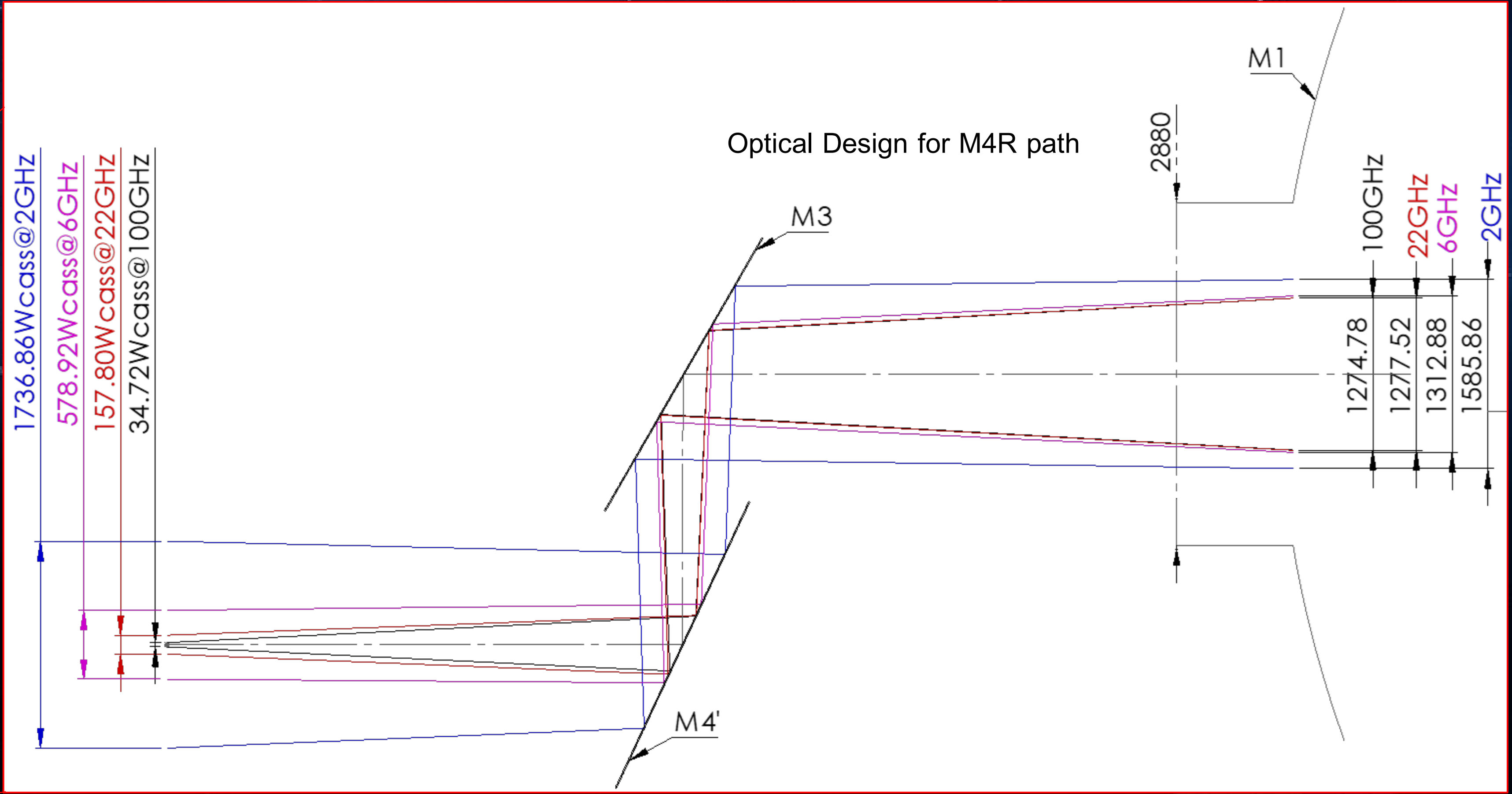


The optical design of M4L path for demonstration of 22GHz is shown above. The mirror M4L can be rotated in range of 0-20 degree.
The beam waist diameter at the hole of primary reflector (M1) of 22GHz have 1277.52mm. It has the output beam waist dimeter at the Nasmyth focus of 81.05mm.

3. Optical Design System : For 40m-TNRT on M4R part

Optical design of M4R path. For low band receiver and High band receiver for simultaneous observation

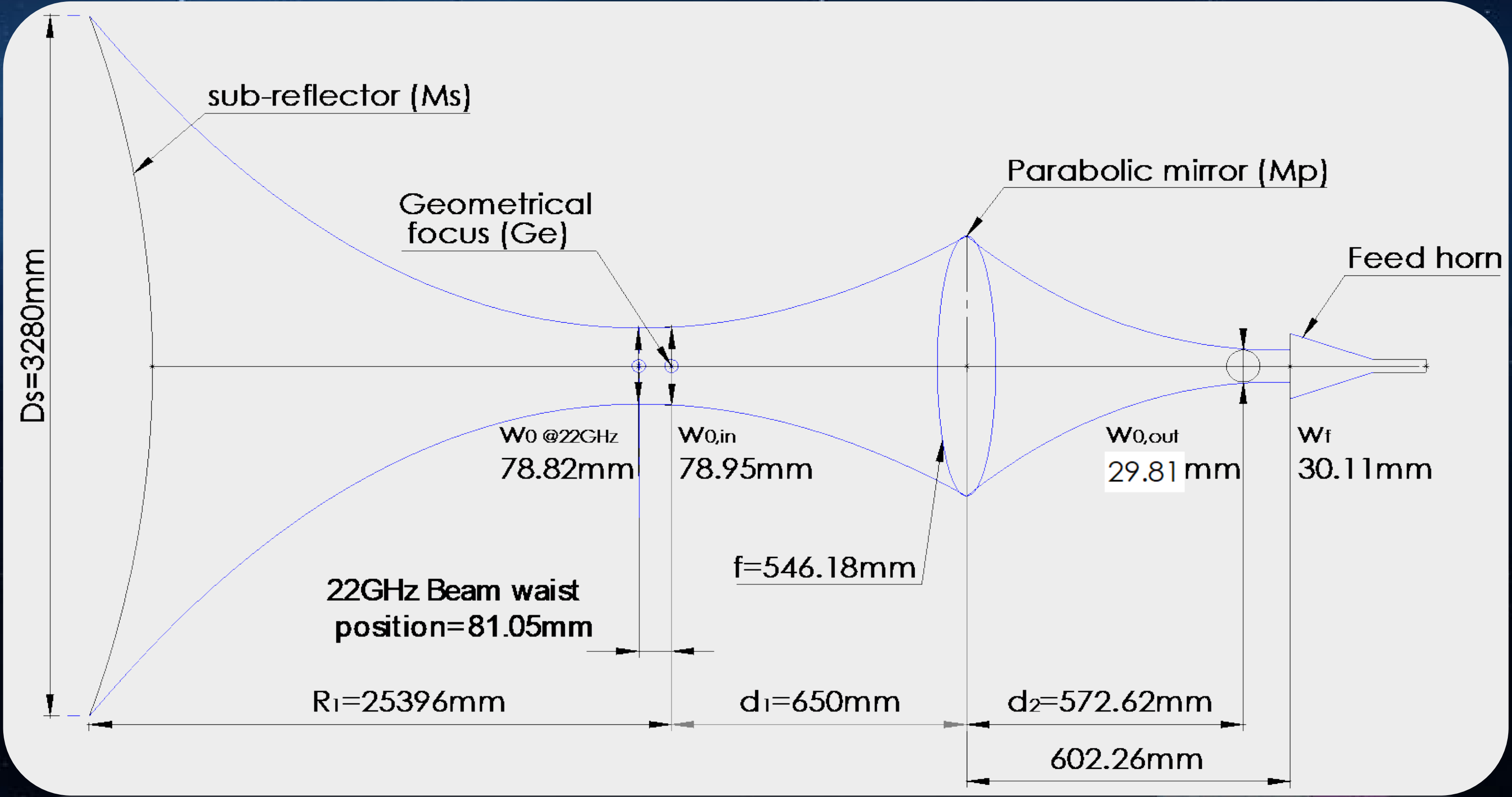




For M4R path, The beam waist diameter at the hold of primary reflector (M1) of each frequency 2GHz, 6GHz 22GHz and 100GHz have 1585.86mm, 1312.88mm,1277.52mm and 1274.88mm respectively. They have the output beam waist dimeter at the Nasmyth focus of 1736.86mm, 578.92mm, 157.80mm, and 34.72mm respectively.

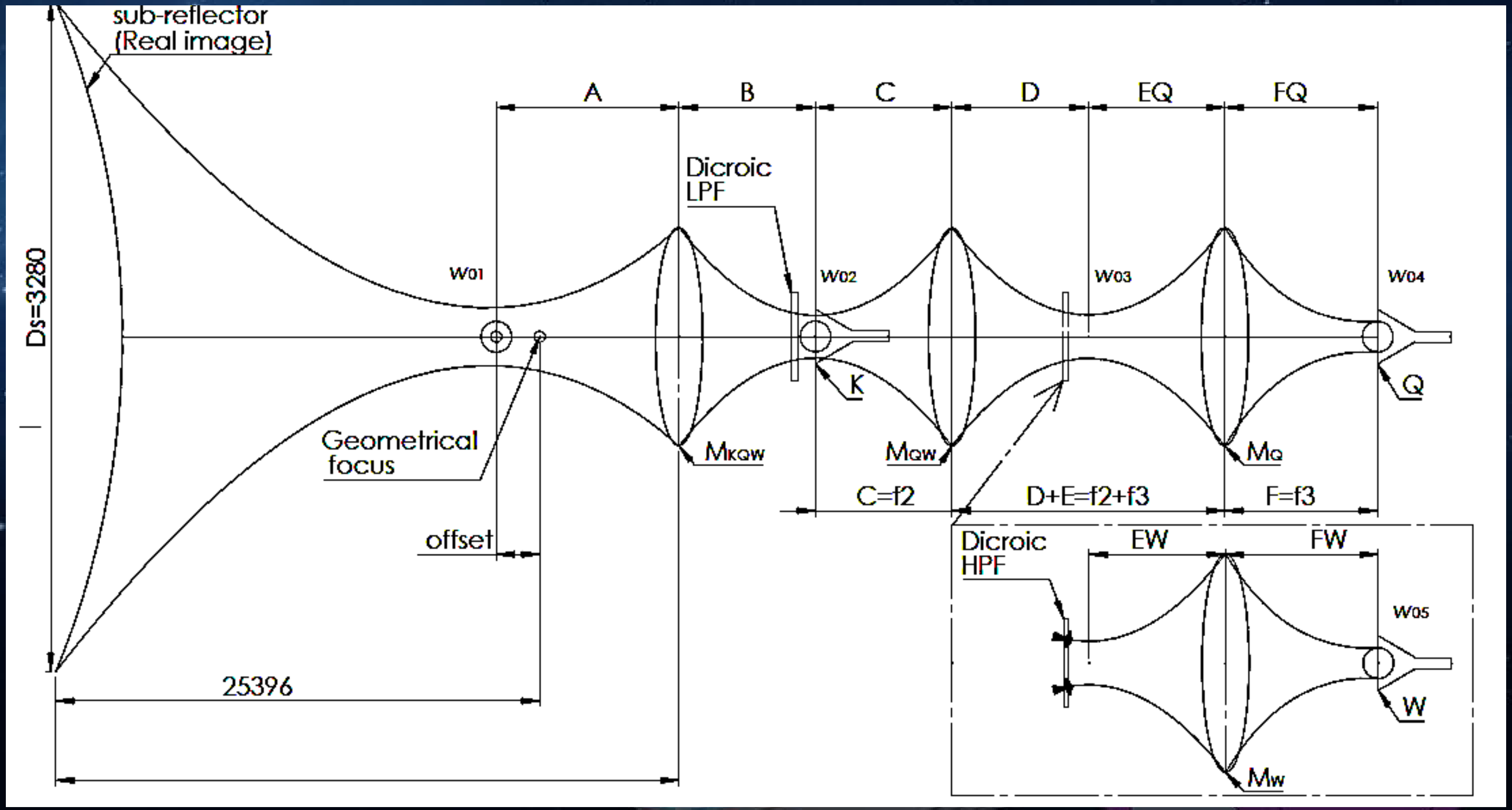
4. Calculation : K-band optical circuit

The K-band receiver has the observing frequency range between 18 to 26.5GHz. This circuit is determined with the illuminated edge taper of -12dB. The center frequency of 22 GHz is demonstrated to get the beam waist (w_0@22GHz) is 78.82mm and the geometrical focus of 78.95mm. The offset parabolic mirror (Mp) is implemented to make the output beam parallel to horizon. The output beam waist and output distance are calculated to obtain 29.81mm and 572.62mm respectively. The optimized position of the feed is located at 602.26 mm from the center of the mirror. And the beam waist of 30.11mm is used to design the feed of the K band receiver.



4. Calculation: Q+W band optical circuit

The Q-band and W-band design consist of one focusing mirror in the GBT configurations. The center frequency of the Q-band and W-band are 43GHz and 100GHz are demonstrated. The output beam waist from the first mirror will be the input image to the beam waist of the GBT circuit. Dichroic filters are important components of the simultaneous design system . The final beam waists of Q, W-band are 22.2mm and 7.10mm respectively. These parameters are used to design the -band and W-band feeds.

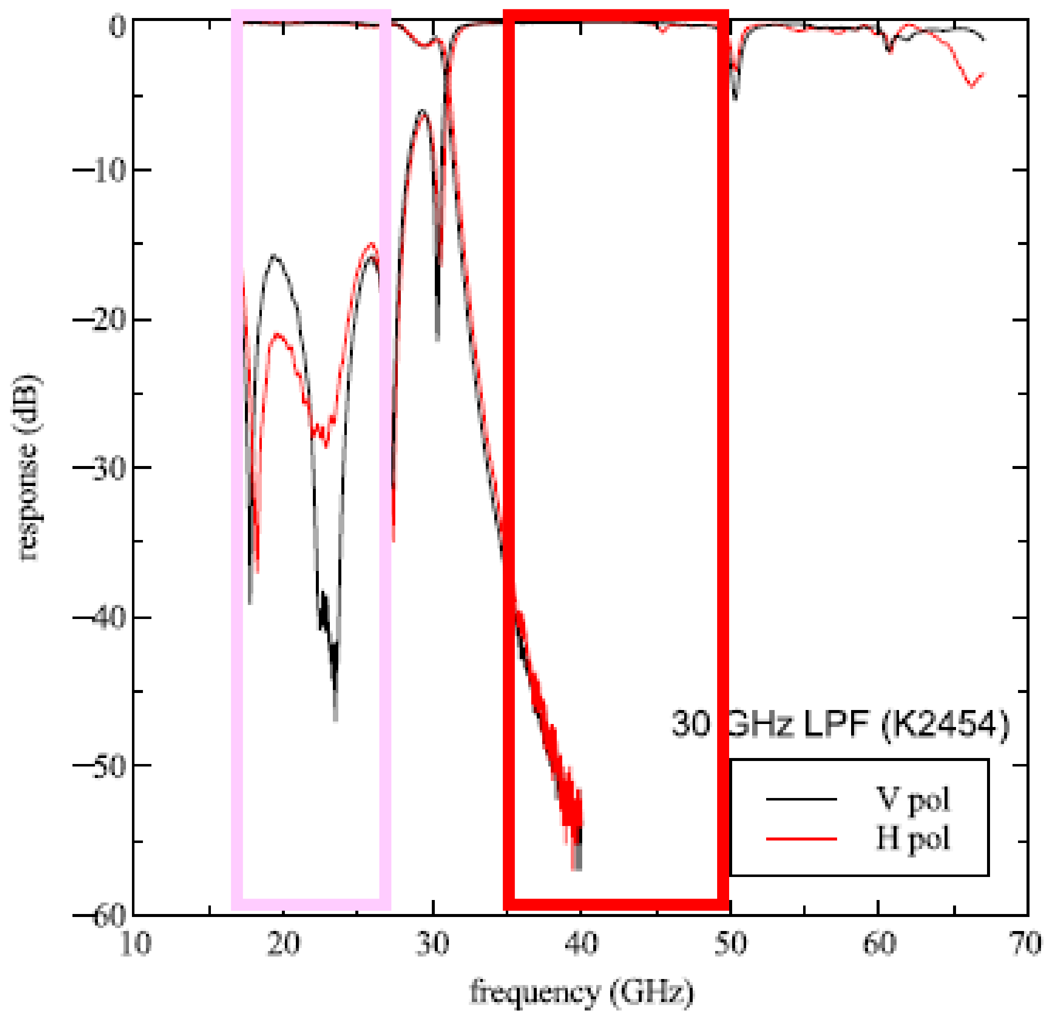


Freq. (GHz)	Fc (GHz)	Length (mm)										
		W01	A	f1	B	W02	C	f2	D+Ex	f3	Fx	W04
Q	35	49.6	682.1	546.2	594.9	29.7	407.4	400	700	300	295.9	22.27
35-50	43	40.4	671.3	546.2	613.4	29.5	388.9	400	700	300	306.3	22.20
	50	34.7	665.7	546.2	632.4	29.5	369.8	400	700	300	317.0	22.12
W	85	20.4	655.5	546.2	763.2	28.8	239.1	400	500	100	110.1	7.20
85-115	100	17.4	653.9	546.2	834.4	28.4	167.8	400	500	100	114.5	7.10
	115	15.1	652.9	546.2	912.6	28.0	89.7	400	500	100	119.4	6.99

4. Calculation: Dichroic filter- Low pass filter

Dichroic filters are important components of the simultaneous design system . They have different propagation properties as transmission or reflection for high and low frequency waves and therefore are used to split the frequency bands. The first dichroic Low Pass Filter (LPF) is placed in front of the K-band receiver permitting the low frequency, while reflecting higher Q/W frequency wave.

Developed by QMC, Wales, recommend from Dr. Han



(b) LPF (low pass filter)

Transmission
18-26GHz

Reflection
35-50 GHz

4. Calculation: Dichroic filter- High pass filter

The second dichroic High Pass Filter (HPF) is placed in front of the W-band feed to reflect the Q-band signal to the Q-band feed. The W-band signal can be passed to the W-band feed.

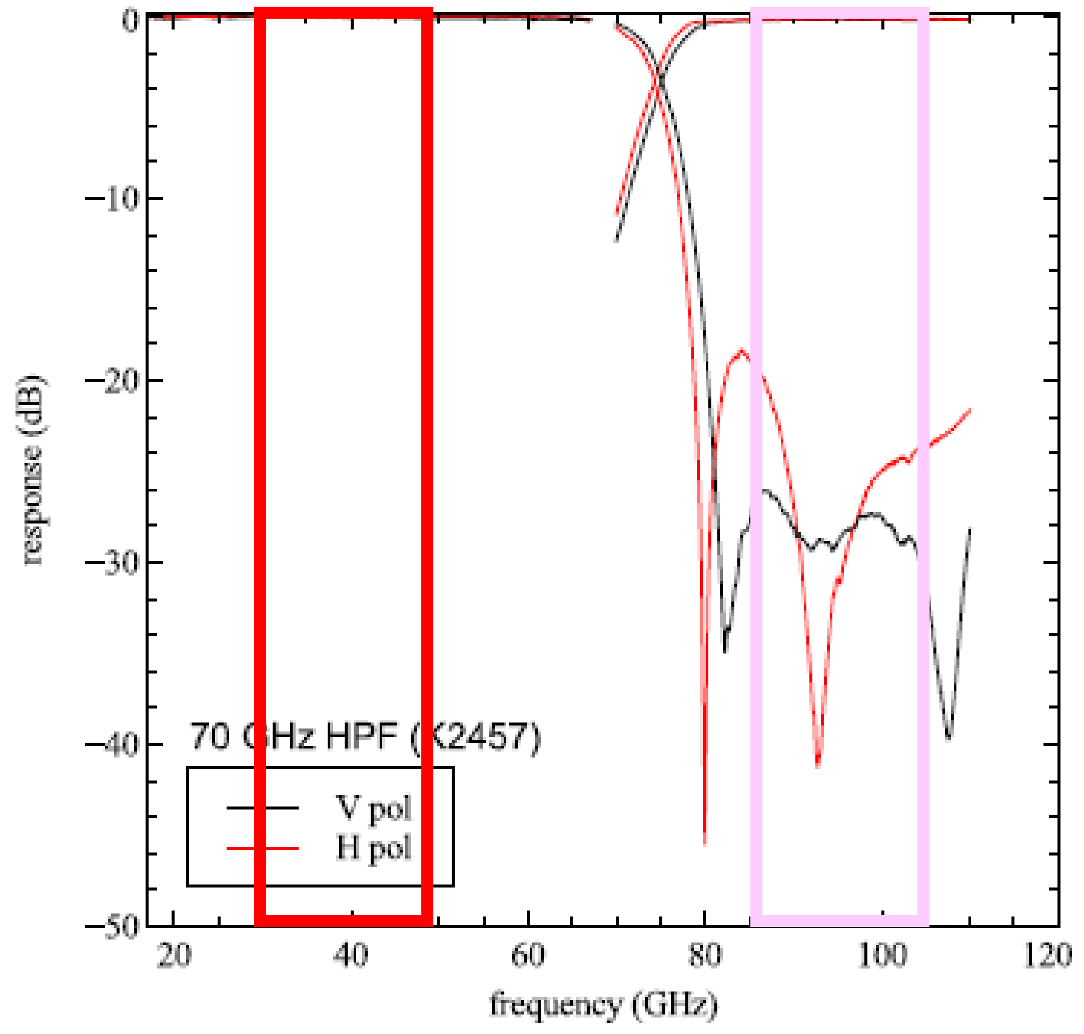
Transmission

80-115GHz

Reflection

33-50 GHz

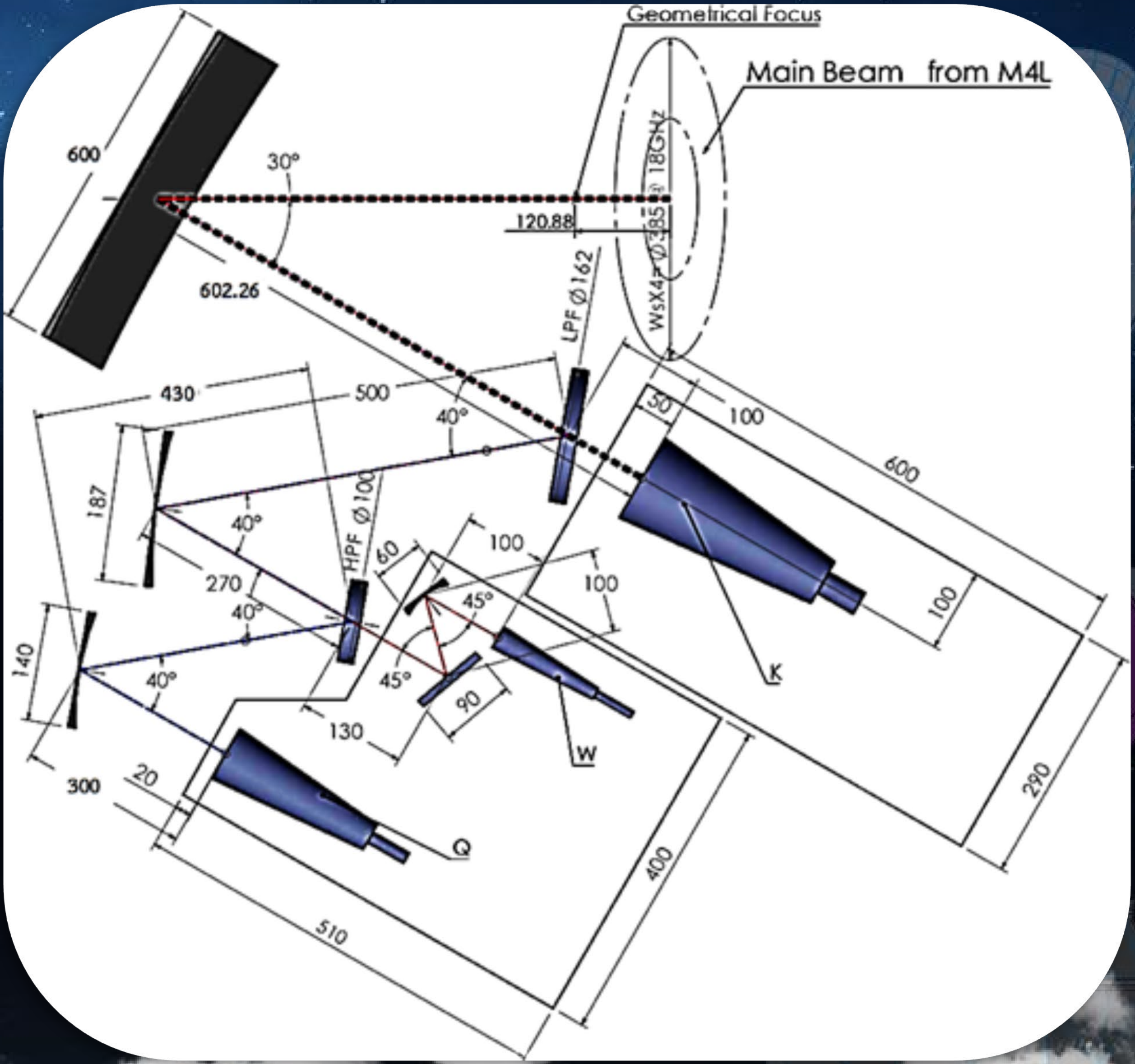
Developed by QMC, Wales, recommend from Dr. Han



(a) HPF (high pass filter)

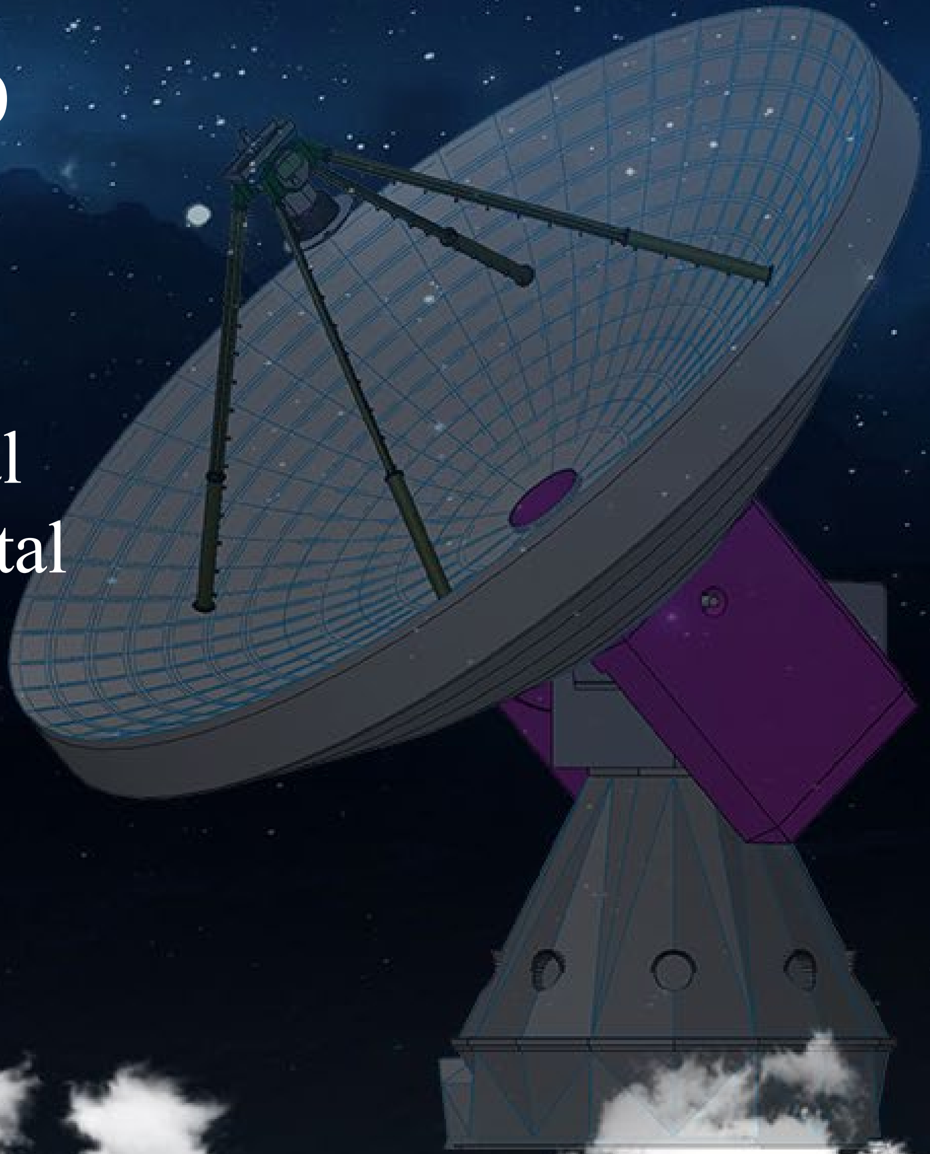
4. Calculation : K and Q+W band Layout

The picture shows a layout of K and Q+W band alignment. The K-band receiver will be built and installed at first time. It will be used for commission test to confirm the performance of 40-meter radio telescope. After that the Q+W band receiver will be built in single cryostat. The reflector elliptical mirror will be aligned on the optical table to make a beam matching follow on the layout.



5. Summary

- The calculation of beam waist of K, Q, and W band receivers are 29.81mm, 22.20mm and 7.10 mm, respectively.
- That are used to determine the aperture of K, Q and W band feeds.
- The alignment of receivers is fitted to the optical table. those receivers are aligned on the horizontal by using the offset parabola that is easily to adjustment, installation and fine tuning.
- The Dichroic filters of LPF and HPF are implemented for simultaneous receiver design.



Thank You for Your attention

NARIT

U.R.S.I.

Thai National Radio Astronomy Observatory