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

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Abstract

We report a preliminary Quasi-optics design of the simultaneous K-Q-W band receiver system for the 40m Thai Nation Radio Telescope (TNRT) by National Astronomical Research Institute of Thailand (NARIT) under the scope of "Radio Astronomy Network and Geodesy for Development (RANGD)" project. The antenna's specifications allow the observing frequency from 0.3 GHz to 115 GHz. The receivers can be installed on both primary and secondary focus. The position and beam waist of all reflectors or mirrors and receiver feeds are calculated with quasi-optic and Gaussian beam principles to determine the beam waist to find optimal alignment of the optical components. We obtain preliminary calculations of the beam waist for feed design of K, Q, and W band receivers which are 29.81 mm, 22.20 mm and 7.10 mm, respectively. Further investigations of the efficiency of the designed will be done with specialized simulation software.

1 Introduction

A calibration technique for Very Long Baseline Interferometry (VLBI), known as "Frequency Phase Transfer (FPT)", has become widely adapted for several VLBI stations around the world. The fact that the conditions of the Earth's Troposphere vary rapidly shortens coherency for VLBI observation. Requiring multiple frequency bands observed simultaneously, FPT technique has been developed to apply the measured phase information obtained from the lowest frequency band to calibrate the phase of higher frequency bands ([1] and reference therein). Korean VLBI network (KVN) has pioneered the simultaneous-frequency receiver systems covering 22, 34, 86 and 129GHz [2,[3], which are being implemented in several VLBI arrays to provide a new perspective in mm-VLBI science (e.g. [4]). A new compact Triple-Band receiver system is being developed for KVN to achieve a more compact size of K, Q, W band receivers, while maintaining the performance total aperture efficiency of the feed design almost constant within 1% [5].

Under the framework of the Radio Astronomy Network and Geodesy for Development Project by the National Astronomical Research Institute of Thailand (NARIT), the 40m Thai Nation Radio Telescope (TNRT) is being constructed in Chiang Mai, Thailand. The antenna employs a similar optics as found in the 40m IGN Yebes Telescope in Spain [9]. However, a lower observing frequency is achieved with TNRT's primary focus receivers capability. In addition to its key mission to facilitate astronomy research and education in Thailand, this project has aimed to accelerate state-of-the-art engineering development, such as high-precision machining, low-temperature active and passive RF components, optical design and Digital Signal Processing, which is necessary for a self-sustain path to operate and develop next generation instruments for astronomy.

The multi-frequency K-Q-W band receiver system has been planned as one of the key features in single-dish and VLBI science applications. The receivers of K(18-26.5GHz), Q(35-50GHz) and W(85-115GHz) band will be designed and installed on the optical bench implementing quasi optical technique to evaluate the beam waist, position and optical alignment. TNRT commissioning stage is expected to begin in late 2020 with L-band and K-band as the first two scientific receivers.

2 Design Theory

2.1 A Quasi-optical circuit principle in case of frequency dependent

The beam transforms [6] on one focusing element is shown on Figure 1. 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.

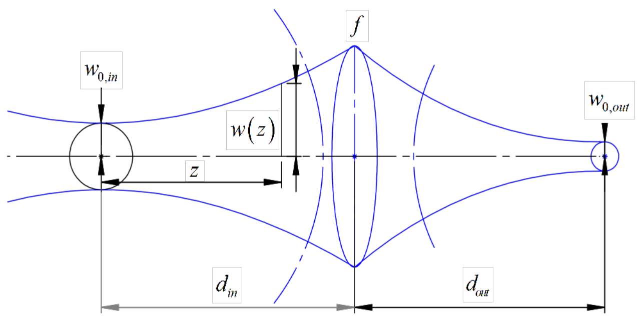

Figure 1. The Gaussian beam transform on one focusing element.

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

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

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

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).

2.2 A Quasi-optical circuit principle in case of a Gaussian Beam Telescope (GBT)

The Gaussian Bean Telescope (GBT) [6, [7] 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 2, 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. Gaussian Beam Telescope Method is therefore best suitable for optical designs for wide bandwidth receiver systems [8].

$$w_{0,out} = \frac{f_2}{f_1} w_{0,in} \quad (4)$$

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

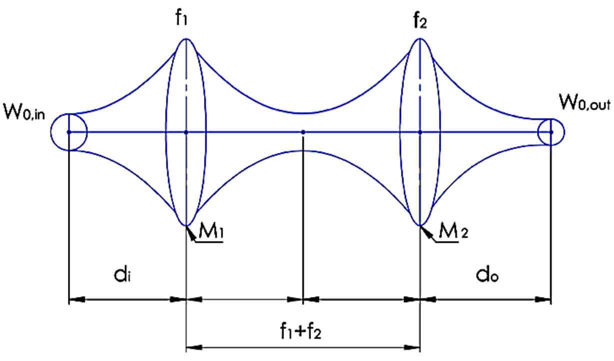

Figure 2. The configuration of the Gaussian Beam Telescope.

3 Quasi-optical design of K, Q, W-band receivers for 40-m Radio Telescope

3.1 Antenna optical system of 40m-TNRT

The 40m TNRT has a Nasmyth-Cassegrain optical design that consists of a main paraboloid reflector of 15m focal length and the secondary hyperboloid mirror of 3.28m diameter with 26.6m focal length. At the primary focus cabin, called the "Tetrapod Head Unit (THU)", a rotating mechanism is implemented to switch between Primary-Focus (PF) mode and Secondary-Focus (SF) operation with the secondary mirror. The PF operation requires the feed design to coverage an angle of 134.76 degrees with F/D of 0.375. The low frequency band and phase array receivers are most suitable and will be installed at the PF. The SF operation focuses on higher frequency bands, several receivers can be installed inside the receiver room with a high magnification of 21.09 with F/D of 7.909. The feed design at the secondary focus sustains a narrower angle of 7.24 degrees. The illuminate edge taper of -12 dB is used on the sub-reflector to acquire the maximum efficiency.
For further calculations the beam waist based on Gaussian Beam Principle, the beam waist at the sub reflector edge is $w_s = 1395mm$ .The curvature radius is $R_s = 25396mm$. The K, Q, W band receivers are located on an optical table with optical elements, such as parabolic mirrors, elliptical mirrors, flat mirrors and low pass and high pass filters configured to implement simultaneous frequency observing system.

3.2 Optical circuit design of K-band receiver

The K-band receiver has the observing frequency range between 18 to 26.5GHz. It will be the first receiver to install on the optical table as shown in Figure 3 . The optical equivalent circuited design is shown in Figure 4. This circuit is determined with the illuminated edge taper of -12 dB on the sub-reflector. The gaussian beam is considered to evaluate the quasi-optical circuit. At the center frequency at 22 GHz is demonstrated to get the beam waist $(w_0@22GHz)$ is 78.82 mm located at the geometrical focus 78.95mm by Equation (1). The offset parabolic mirror (Mp) is implemented to make the output beam parallel to horizon. The output beam waist and output distance are calculated using Equation (2) and (3) obtaining 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.

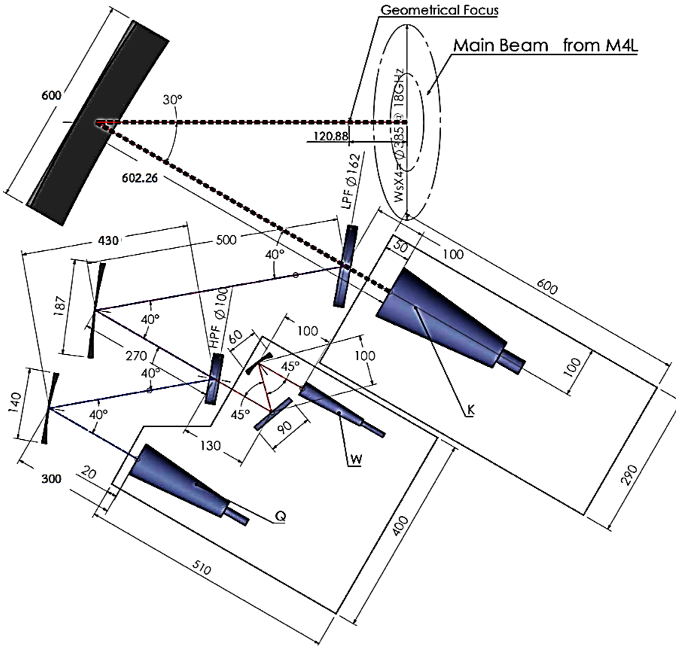

Figure 3. Layout of the Q, K, W-band receivers for simultaneous-frequency observing system (unit in mm).

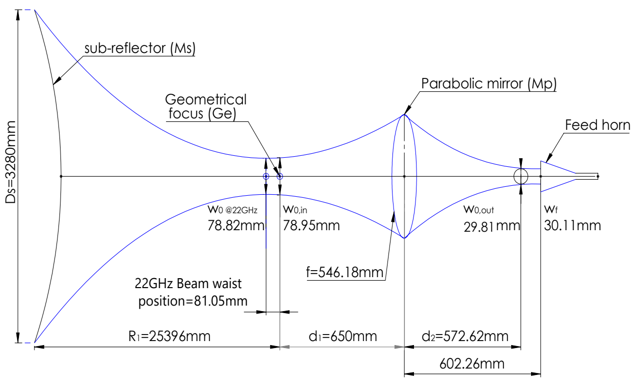

Figure 4. The optical circuited design of the K-band receiver.

3.3 Optical circuit design of Q-band and W-band receivers

Similarly, the Q-band and W-band design consist of one focusing mirror in the GBT configurations as shown in Figure 5. 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 [5]. 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. 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 calculated results are shown in Table 1. 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.

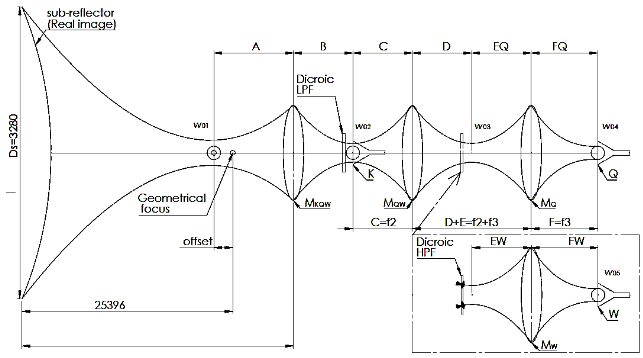

Figure 5. The optical circuited design of the Q-band and W-band receivers.

Table 1. The parameters of Q, W band optical circuit (∴ when x represents of Q or W band)

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

3.4 The layout of simultaneous K, Q W-band receiver

The Figure 3 shows the K, Q, W band receiver alignment. The K-band receiver is design in one cryostat that separates from another receiver. For the Q, W-band receivers, those will be built in one cryostat. Those receivers will be alimented on the optical table with size of 1400mmx 2000mm.

4 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. Moreover, those receivers are alimented on the horizontal by using the offset parabola that is easily to adjustment, installation and fine tuning.

5 Acknowledgements

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