Invited Paper

Tri-reflector Compact Antenna Test Range Design at High Frequency

Xiaoming Liu [1], Yuan Mai [2], Hansheng Su [1], Daohui Li [1], Xiaodong Chen [1], Rob Donnan [1], Clive Parini [1], Shaohua Liu [2], and Junsheng Yu [2]
[1] School of Electronic Engineering and Computer Science, Mile End Road, London UK, E1 4NS
Email: xiaoming.liu@elec.qmul.ac.uk
[2] School of Electronic Engineering, Beijing University of Posts and Telecommunications, 279Box, 10 Xi Tu Cheng Road, Haidian District, 100876, Beijing, China
Email:gtuitri@163.com

(Received 11 November 2010)

Abstract: The Compact Antenna Test Range (CATR), which generates a pseudo-plane wave in a very short distance, is commonly employed to measure electrically large aperture antennas. This paper presents the designs of two tri-reflector CATRs operating at 200 GHz: a Cassegrain-Gregorian (CG) configuration and a Double Gregorian (DG) one. Both of the two designs utilise two shaped sub-reflectors and a spherical main reflector. The characteristics of the two designs were verified using a commercial package GRASP9.

Keywords: Compact Antenna Test Range, Tri-reflector, millimeter/sub-millimeter wave

doi: 10.11906/TST.020-025.2011.03.03

1. Introduction

The reflector antennas operating in the millimetre-wave and submillimetre-wave range have been widely used in radio astronomy and remote sensing. The increase of operating frequencies, which can go up to several Terahertz [1], has posed a challenge to the antenna/antenna system measurement. The conventional far field method requires a minimal separating distance of $d = 2D^2/\lambda$ between the antenna under test and the radiating unit, where D denotes the diameter of the aperture, and λ is the wavelength. A distance of 6.67 *km* will be needed for an aperture antenna with 1 m diameter working at 1 *THz*. In the near field method, the amplitude and phase of a field over a plane, a sphere, or a cylinder chosen to represent the antenna aperture are recorded. The far field is obtained by taking a Fourier transform of the measured field. The scanning step usually needs to be small enough to safeguard far field convergence. However, the near field measurements at high frequency suffer a number of difficulties, including phase errors, long scanning time and so forth. A CATR collimates the field distribution from a feed in the purpose of producing pseudo-plane wave in a relative short distance. The most common CATR is using a single parabolic reflector in an offset arrangement. The drawback of a single reflector CATR is often referred to as its low quiet zone usage, typically 30%. This is mainly due to that the fixed shape of the reflector does not allow the designer to tailor the magnitude of the aperture field, producing non-uniform aperture field distribution. There exists also shaped dual-reflector CATR, which means both the sub-reflector and main reflector are shaped, can provide 60% quiet zone usage. As in general, manufacture of the main reflector is the most expensive item in the construction of a CATR due to the fact that the main reflector has to be large enough to provide a sufficiently extensive quiet zone. The cost of a shaped dual-reflector CATR may increase sharply in comparison with single reflector one. It is well known that most optical telescopes have spherical main reflectors so considerable knowledge exists as how to produce accurate spherical surfaces. This paper presents two tri-reflector CATR designs with two shaped sub-reflectors and a spherical main reflector. The sub-reflectors can be made considerably smaller than the main reflector resulting in cost reduction compared with a shaped dual-reflector CATR and without compromising the quiet zone usage. As a matter of fact, the quiet zone usage can be expected to more than 70%. The two designs have been demonstrated to work at 200 GHz in the simulation using GRASP9.

2. Design Methods

The design of the two tri-reflector CATRs followed the method given by Kildal [2] in a dynamic ray tracing manner, which is also referred to as synthesis-by-ray-tracing (SRT). In the frame of SRT, Geometrical Optics (GO) is employed due to its wide band feature. The SRT method treats reflectors and wavefronts in terms of surface curvature parameters, and the corresponding local bi-parabolic expansion of these surfaces. Also, in the SRT method, the differential ray strip is defined as a flat bundle of rays tracing out a ribbon in space. The features of a differential ray strip are very much the same as a ray described in GO [3]. The surface curvature parameters description in cooperation with differential ray strip, lays the foundation of SRT in conform to the basic GO properties. Both the surface curvature parameters and differential ray strip are pictorially demonstrated in Fig. 1.

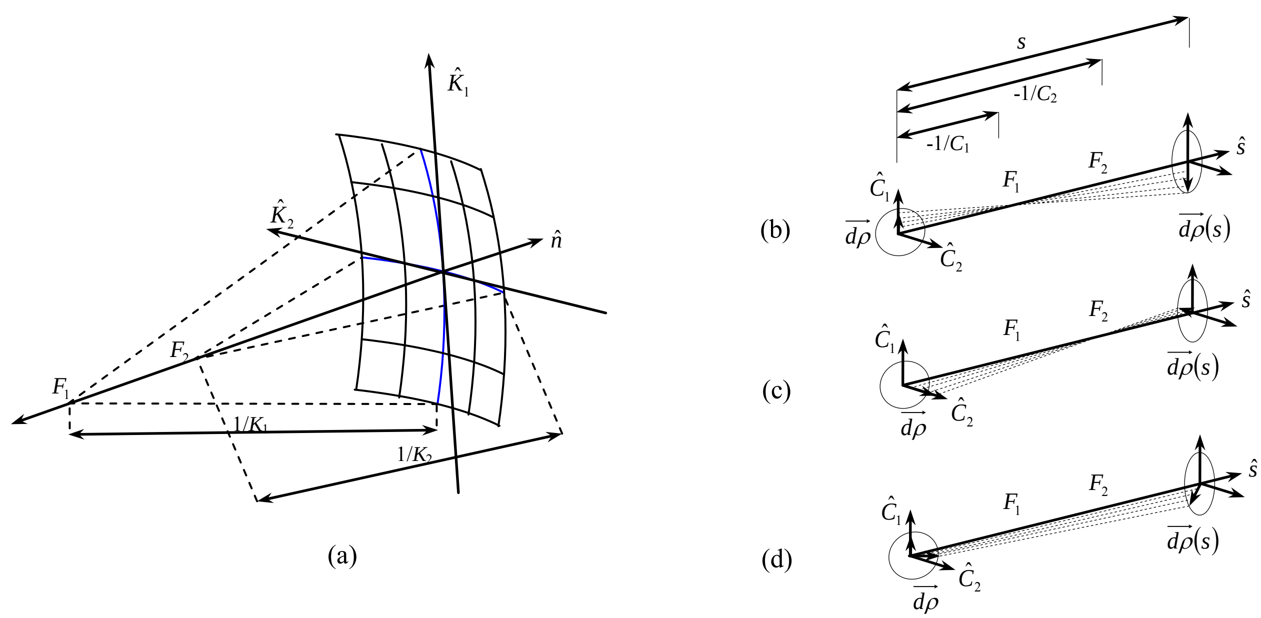


Fig. 1 (a) The treatment of surfaces using surface curvature parameters, and local bi-parabolic expansion. F_1 and F_2 are the two centres of the curvature; $\hat{n}$, local surface normal; K_1 and K_2, principal curvatures corresponding to the principal directions of curvature $\hat{K}_1$ and $\hat{K}_2$, respectively. (b), (c), (d) differential ray strip $\overrightarrow{d\rho}$ passing through two caustics F_1 and F_2. C_1 and C_2, principal curvatures corresponding to the principal directions of curvature $\hat{C}_1$ and $\hat{C}_2$, respectively [2].

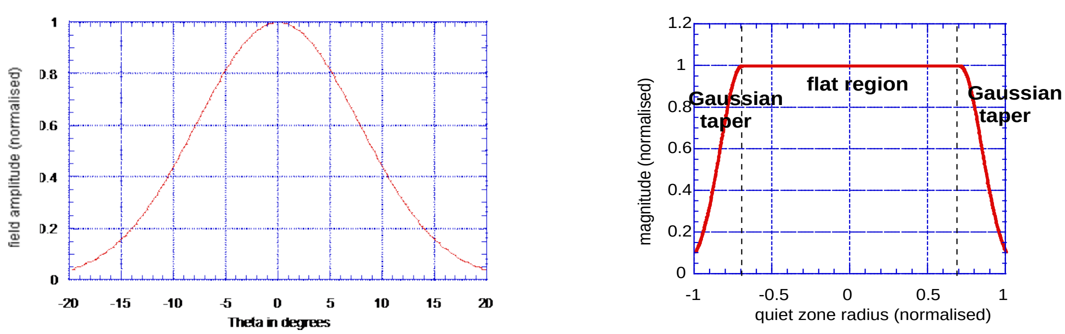
The basic requirements on a CATR are its amplitude ripples and phase ripples. In addition, the cross-polar isolation is also considered in a CATR design. There are two basic strategies in the SRT method to achieve the requirements, the mapping function and dynamic ray tracing. Mapping function is in essence to redistribute the field from a feed to a required field over the aperture plane after several collimating components. In a CATR design, the feed might be a corrugated horn as used in our designs, producing Gaussian distribution, which can be expressed as

$$G(\theta) = G_0 10^{\left(\frac{EL}{20}\left(\frac{\theta}{\theta_0}\right)^2\right)}, \tag{1}$$

where EL is the edge taper in dB at θ_0. The field over the aperture plane can be described ideally as

$$E(\rho) = E_0 \begin{cases} 1 & ,0 \le \rho_E \\ 10^{\left(\frac{EI}{20}\left(\frac{\rho-\rho_E}{\rho_{\max}-\rho_E}\right)^2\right)} & ,\rho_E \le \rho \le \rho_{\max} \end{cases}, \tag{2}$$

in which, ρ_E is an edge radius describing the desired size of the quiet zone, $\rho_{\max}$ is the radius of the main reflector, and EI denotes the edge illumination of the main reflector in dB. Both the patterns of a corrugated horn and the desired aperture field are illustrated in Fig. 2. The mapping is done by ensuring that $P(\rho)/P(\rho_M) = p(\theta)/p(\theta_M)$, where ρ_M is the radius of the main reflector, θ_M defines the rim of the first reflector, and $P(\rho) = a\int_0^{\rho}|E(\rho)|^2 2\pi\rho d\rho$, $p(\rho) = \int_0^{\theta}|G(\theta)|^2 2\pi \sin\theta d\theta$. Ideally, the mapping function can ensure the quiet zone to a desired size. The phase ripple is suppressed by making every single ray has the same optic distance. This is done firstly fixing each optic centre (OC), then the optic distance is calculated as the sum of 1) from the feed to OC of Sub-reflector 1 (SR), (2) OC of SR1 to OC of SR2, (3) OC of SR2 to OC of the main reflector. And this value serves as a benchmark for a next ray, the intersection points of which with all the three reflectors have to be determined by an iterative procedure of changing the surface parameters at the OCs Fig. 3 (a). The whole SR is hence defined numerically and iteratively. More detailed formalism will be referred to [2]. Based on this method, two CATRs are synthesed, one is of a Cassegrain-Gregorian, and the other one being Double Gregorian configuration. Both of them are illustrated in Fig. 3 (b), (c).



(a) (b)

Fig. 2 (a) Typical Gaussian feed far field pattern as used by the synthesis algorithm; (b) a typical aperture field distribution.

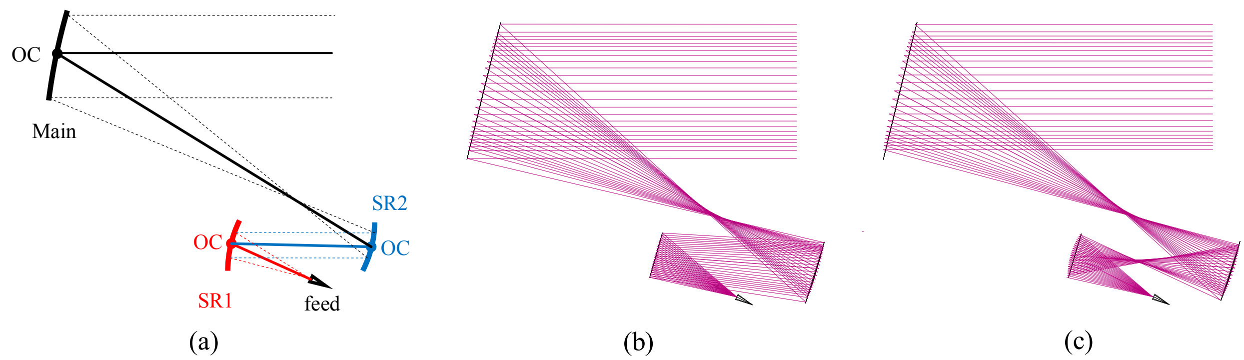


Fig.3 (a) Dynamic ray tracing procedures. SR stands for sub-reflector, OC denotes Optical centre; (b) Cassegrain-Gregorian configuration; (c) Double Gregorian configuration.

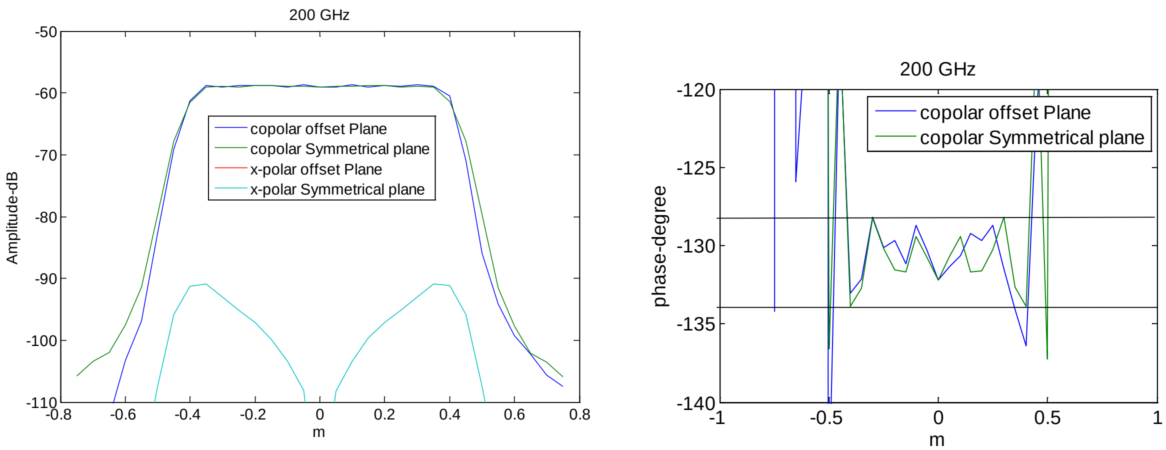
3. Two Tri-reflector CATR Designs

A CG configuration CATR was previously designed in Queen Mary University of London [4] operating at 90 GHz with a predicted amplitude ripple within ±0.5 *dB*, and phase ripple within ±5˚. In this follow on design, the CG CATR gives an amplitude ripple within ±0.28 *dB*, and the phase ripple is less than ±3˚, shown in Fig.4. Feed is so chosen that the edge taper is -14 *dB* at 14˚. In the previous study in Queen Mary University of London, the DG did not meet the specifications. In this design, however, the performance of DG also satisfies all the specifications at 200 *GHz* (Fig. 5), which is higher than that of the 90 *GHz* design. Feed has a -20 *dB* edge taper at 15˚. It is also worth mentioning that the cross-polarisation isolation of the DG is 10 *dB* better than that of the CG.

Tab. 1 Comparison between the two CATRs

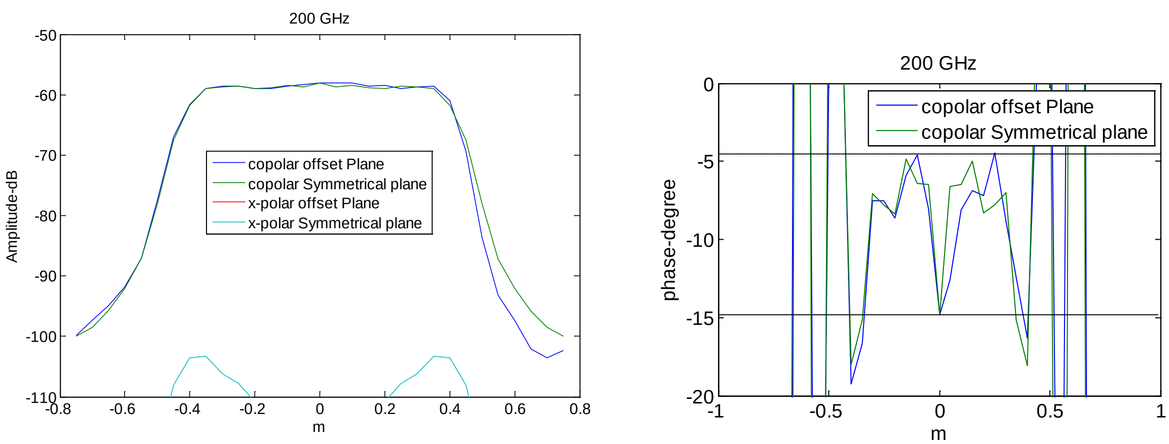
		Amplitude ripple	phase ripple	x-polar isolation	Quiet zone usage
Cassegrain Gregorian	100 GHz	±0.29 dB	±5˚	30 dB	70%
	200 GHz	±0.22 dB	±3˚	30 dB	70%
	300 GHz	±0.29 dB	±2˚	30 dB	70%
Double Gregorian	100 GHz	±0.67 dB	±13˚	40 dB	70%
	200 GHz	±0.49 dB	±5˚	40 dB	70%
	300 GHz	±0.7 dB	±4˚	40 dB	70%

Inspection of Tab. 1, it is clear that the CG configuration covers a wide frequency range. However, the best performance seems at 200 *GHz* as the ripple is increasing when the frequency goes either up or down 200 *GHz*. The phase ripple undergoes a monotonous decrease as the frequencies increase. The x-polarisation and quiet zone usage do not change too much. For the DG configuration, only 200 *GHz* satisfies all the specifications in this design. The trends of the specifications, however, have the same story as that of the CG configuration. Comparing the two configurations, it seems the DG configuration produce bigger ripple. On the other hand, the cross-polarisation isolation of the DG is much better than that of the CG configuration. In summary, both the designs meet all of the specifications at 200 *GHz*.



(a) (b)

Fig. 4 Simulation results of CG configuration. (a) The amplitude ripple is less than ±0.3 *dB*; (b) the phase ripple is around ±3˚.



(a) (b)

Fig. 5 Simulation results of DG configuration. (a) The amplitude ripple is less than ±0.5 *dB*; (b) the phase ripple is around ±5˚.

4. Conclusion

Two CATRs with two shaped sub-reflectors and a spherical main reflector were designed for high frequency operation. The prediction indicated that both designs met the specifications at 200 *GHz*. It was also shown that CG CATR gives lower ripples, while DG CATR has higher cross-polarisation isolation.

References

[1] A. J. Nozik, Spectroscopy and hot electron relaxation dynamics in semiconductor quantum wells and quantum dots, *Annu. Rev. Phys. Chem.*, 52, 193-231, (2001).

[2] Dominic Doyle, Göran Pilbratt, and Jan Tauber, The Herschel and Planck Space Telescopes, *Proceedings of the IEEE*, 97(8), 1-9, (2009).

[3] Per-Simon Kildal, Synthesis of Multireflector antennas by Kinematic and Dynamic Ray Tracing, *IEEE Trans. On Antennas and Propagations*, 38(10), 1587-1599, (1990).

[4] Georges A. Deschamps, Ray Techniques in Electromagnetics, *Proceedings of the IEEE*, 60(9), 1022-1035, (1972).

[5] http://www.elec.qmul.ac.uk/antennas/index.html