MJFAS MALAYSIAN JOURNAL OF FUNDAMENTAL AND APPLIED SCIENCES
PRINT ISSN: 2289-5981 | ONLINE ISSN: 2289-599X

RESEARCH ARTICLE

Optimization of reflector antennas in radio telescopes

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Article history
Received 3 February 2017
Accepted 4 July 2017

Abstract

We present an analysis on the performance of Cassegrain reflector antennas. In our study, we have adopted the design parameters for the Cassegrain configuration used in the Atacama Large Millimeter Array (ALMA) project. We have adjusted the focal-length-to-diameter ratio *f*/*D* of the primary reflector to investigate the optimum performance of the antenna. In our study, signal frequency at the high edge of ALMA band 1, i.e. 45 GHz has been selected. The results obtained from the physical optics simulation show that the aperture efficiency of the antenna is at its optimum (i.e. 80.36%) when *f*/*D* ranges from 0.5 to 0.6. The radiation characteristics at this range of ratio are found to be similar. The radius of the secondary reflector and edge taper T_e which correspond to the optimum aperture efficiencies ranges from 371 mm to 372 mm and 10.64 dB to 10.75 dB, respectively.

Keywords: Cassegrain antenna, edge taper, spillover efficiency, taper efficiency, aperture efficiency, radiation characteristics

INTRODUCTION

In ground-based radio astronomy, radio telescopes are widely used to observe naturally occuring signal emission from celestial objects, such as stars and planets (Yeap et al., 2013; Phillips and Keene, 1992; Cheng et al., 1994; Wotten, 2008; Yeap et al., 2011). The typical radio telescope consists of four main parts, namely main reflector, subreflector, elevation wheel and azimuth bearing, as shown in Fig. 1. The performance of telescope can be enhanced with large aperture of the reflector to achieve high precision and sensitivity (Chen et al., 2016).

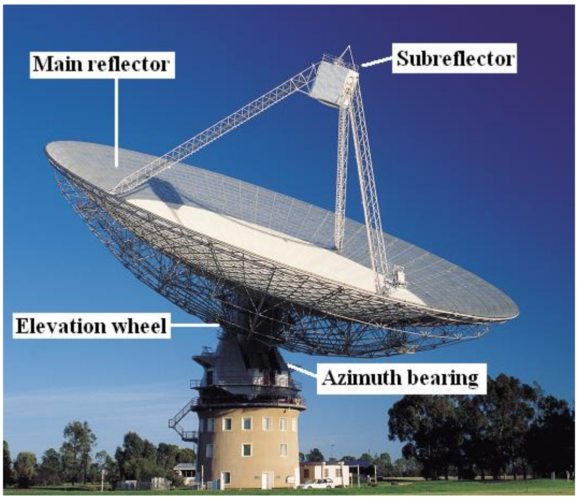

Fig. 1 Structure of radio telescope. (Photograph by CSIRO, distributed under a CC-BY 3.0 license.)

In radio telescopes, circular parabolic reflector antennas are used to obtain large collecting areas and high angular resolution over a wide range of frequencies. There are various geometrical configurations for the reflector antennas. One of the most commonly used configurations is the Cassegrain antenna. Examples of radio telescopes that implement the Cassegrain antenna are the Atacama Large Millimeter/submillimeter Array (ALMA) telescope (Gonzalez et al., 2011; Tham, Yassin and Carter, 2007; Candotti, Baryshev and Trappe, 2007) and the Crawford Hill telescope (Rusch, 1992; Courtney-Pratt, Hett and McLaughlin, 1963; Milligan, 2005). As shown in Fig. 2, a Cassegrain antenna consists of a primary and secondary reflectors. The size of the primary reflector is larger than its secondary counterpart. The secondary reflector has to be in hyperboloid form and is mounted below the focal point of the primary reflector.

In this paper, the aperture efficiency is numerically investigated where the design parameters for optimum performance for the Cassegrain antenna configuration is evaluated.

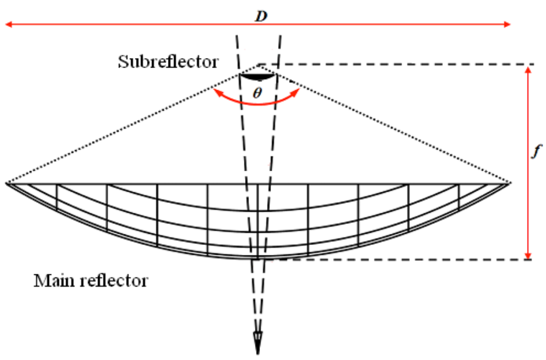

Fig. 2 A Cassegrain reflector antenna.

DESIGN

In our analysis, we have adopted the parameters used in the design of the Cassegrain antenna for the ALMA telescope. Table 1 summarizes the key parameters for the design. Here, we vary the focal length f to diameter D ratio of the primary reflector from 0.1 to 1.0 to investigate how it affects the performance of the antenna. We compute the spillover efficiency ε_s and plot the radiation patterns of the antennas using GRASP physical optics compiler. The edge taper T_e, aperture efficiency ε_a and taper efficiency ε_t are then determined using the following expressions (Yeap et al., 2016; Goldsmith, 1998):

Table 1 Parameters for the reflector antennas.

Description	Data
Primary reflector diameter, *D*	12 m
Distance between foci relative to primary reflector focal length	1.287 m
Secondary reflector eccentricity, *e*	1.105

Table 2 Performance of the Cassegrain antenna (focal-length-to-diameter ratio f/D, secondary reflector radius r_s, edge taper T_e, spillover efficiency ε_s, taper efficiency ε_t, aperture efficiency ε_a).

f/D	r_s (mm)	T_e (dB)	ε_s (%)	ε_t (%)	ε_a (%)
0.1	535	10.43	90.94	87.08	79.19
0.2	399	10.85	91.79	87.38	80.20
0.3	381	10.91	91.90	87.39	80.31
0.4	375	10.86	91.79	87.53	80.34
0.5	372	10.75	91.59	87.74	80.36
0.6	371	10.64	91.36	87.96	80.36
0.7	370	10.50	91.09	88.21	80.35
0.8	369	10.34	90.75	88.51	80.32
0.9	369	10.17	90.39	88.79	80.26
1.0	369	10.00	90.01	89.09	80.19

$$T_e = \frac{\ln(1-\varepsilon_s)}{-0.2303} \quad (1)$$

$$\varepsilon_a = \frac{-4\left\{\exp\left[0.5\left(\frac{r_s}{r_a}\right)^2 \ln(1-\varepsilon_s)\right] - \exp[0.5\ln(1-\varepsilon_s)]\right\}^2}{\ln(1-\varepsilon_s)} \quad (2)$$

$$\varepsilon_t = \frac{\varepsilon_a}{\varepsilon_s} \quad (3)$$

where r_a and r_s denote the primary and secondary reflector radius, respectively. It is to be noted that r_s is not fixed in this case and it varies in accordance to the f/D ratio.

RESULTS AND DISCUSSION

Table 2 tabulates the efficiencies and edge tapers of the design. Although variations exist at different f/D ratios, it can be observed from the table that the spillover, taper and aperture efficiencies are somewhat close to each other. Fig. 2 depicts the overall aperture efficiencies ε_a as f/D varies. As it can be seen from Table 2 and Fig. 3, ε_a reaches its peak at 80.36% when f/D is set between 0.5 and 0.6. It indicates that the performance of the antenna is at its optimum when the radius of the secondary reflector ranges from 371 mm to 372 mm whereas the edge taper T_e ranges from 10.64 dB to 10.75 dB. The radiation patterns for the antenna design with f/D = 0.5 and 0.6 are shown in Fig. 4. Upon close inspections on the radiation patterns, it can be observed that the magnitudes of the main and side lobes agree very closely with each other.

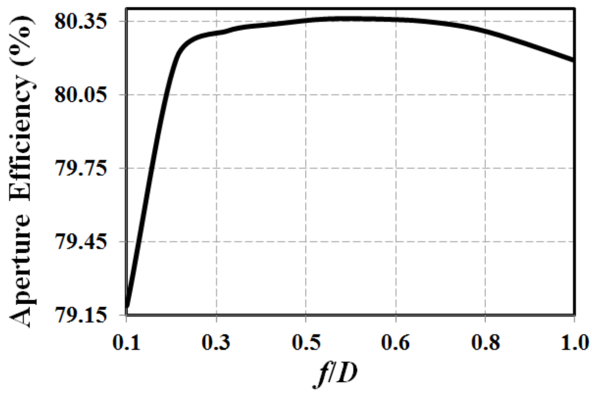

Fig. 3 Aperture efficiency at different primary reflector focal-length-to-diameter f/D ratio.

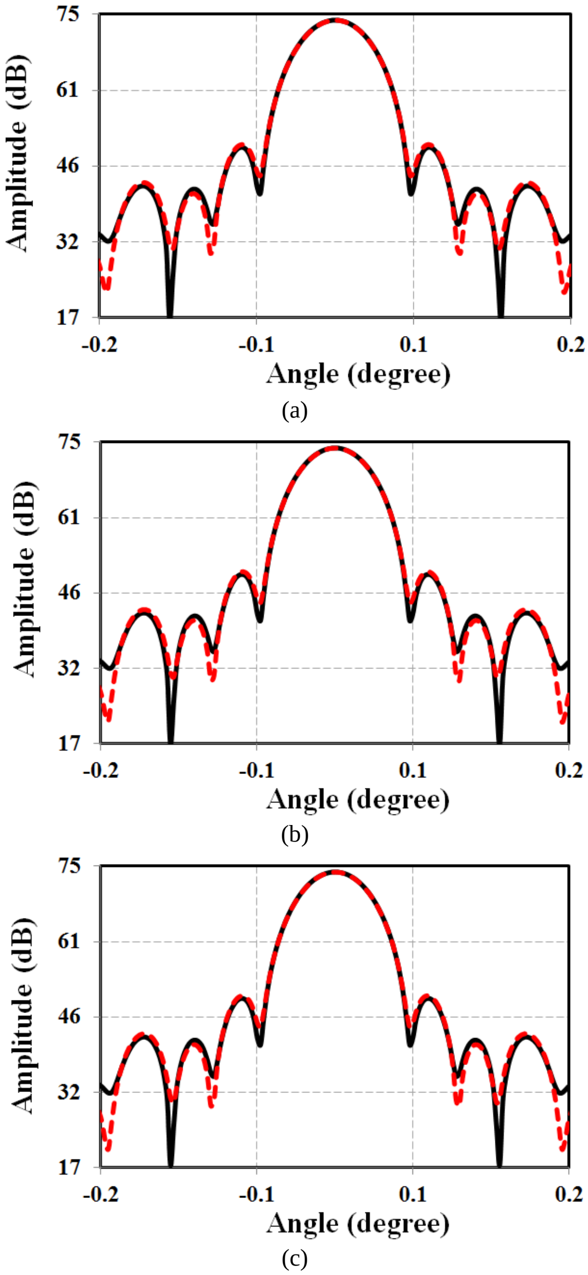

Fig. 4 The beam patterns of f/D = 0.5 (solid line) and 0.6 (dotted line) for a Cassegrain antenna, at f = 45 GHz for observations at φ = (a) 0°, (b) 45°, and (c) 90°.

CONCLUSION

We have compared and analyzed the performance of a Cassegrain antenna with different primary reflector focal-length-to-diameter *f*/*D* ratio. The results show that the antenna design obtains an optimum aperture efficiency of 80.36% when *f*/*D* = 0.5 to 0.6. This corresponds to the radius of the secondary reflector and edge taper which ranges respectively from 371 mm to 372 mm and 10.64 dB to 10.75dB.

ACKNOWLEDGEMENT

Part of this work has been supported by the Fundamental Research Grant Scheme FRGS funded by the Ministry of Education, Malaysia (FRGS/2/2013/SG02/UTAR/02/1) and Universiti Tunku Abdul Rahman research fund UTARRF (IPSR/RMC/UTARRF/2014-C1/Y03).

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