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Aperture Efficiency Calculation of Multi-beam Axisymmetric Dual-reflector Antenna of Cassegrain Type

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Next-generation radio telescopes with large reflectors are planned in the field of millimeter-wave to THz astronomy. A new radio telescope is desired to have imaging survey capabilities like a wide field-of-view (FoV) for radio cameras with a large-format detector array. The design of a multi-beam radio telescope is a new challenge since the design of traditional radio telescopes is based on the methods to treat a single pencil beam. The antenna efficiency of aperture type, known as aperture efficiency in the field of radio astronomy, is one of the important figure-of-merits of such radio telescopes. When the incident plane wave perfectly couples with a receiver beam of the fundamental Gaussian mode at a circular aperture, the aperture efficiency becomes the product of the taper efficiency and the spillover efficiency. This result is generalized to an axisymmetric system with blockage by the sub-reflector [1]. Though this is a well-known result of a single-beam system, the corresponding formalism of a multi-beam system was not clear, even for the center beam of an axisymmetric system.

Recently, we developed a theory that factorizes the aperture efficiency of a general dual-reflector antenna into three factors: the beam coupling efficiency, the exit pupil spillover efficiency, and the entrance pupil spillover efficiency [2]. The entrance pupil spillover efficiency is a new factor essential for a multi-beam system. We applied this theory to a multi-beam axisymmetric dual-reflector antenna modeled as shown in Fig. 1. We obtained an analytical expression of the aperture efficiency of the center beam while the aperture efficiencies of off-center beams can be calculated using numerical integrations. The calculation assumes an ideal coupling in polarization and phase which are affected by aberrations [3] but takes Gaussian illumination by the feed and the blocking by the sub-reflector into account, and thus gives an ideal efficiency for the given setup. We established a procedure to optimize the configuration under constraints on main reflector diameter D_1, FoV radius φ_{FoV}, main reflector focal length f_1, and distance between the sub-reflector and the focal plane l_{f}. Since the calculation is similar for the Cassegrain type and the Gregorian type, we restrict our explanation to the former in this contribution.

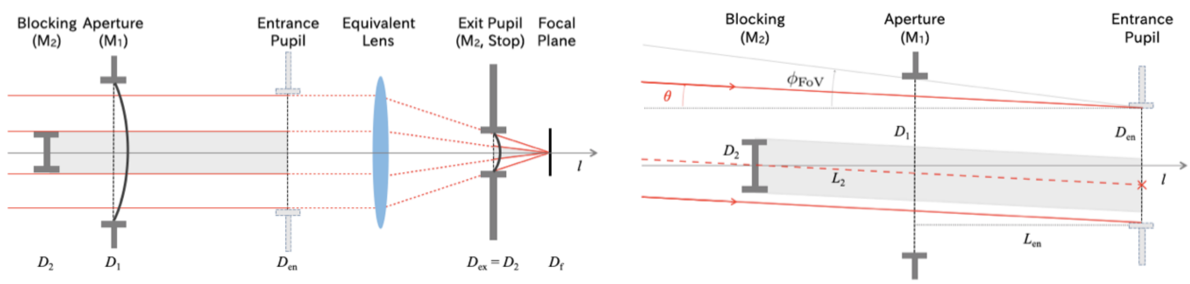

Figure 1. Schematic of beam path. (Left) Path of the center beam, entering the entrance pupil, focused on the focal plane. (Right) Path of an off-center beam of angle θ, entering the entrance pupil. Rays are drawn based on geometrical optics. The shadow made by the blockage of the sub-reflector is shaded in gray.

References

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