Compact, Wide-Angle Catadioptric Telescope Design for MWIR Imaging: Optical Performance Analysis Using Zemax®

Sami D Alaruri, Independent Researcher, Mill Creek, USA

ABSTRACT

In this work, the optical design of a compact diffraction-limited F/3.0 MWIR (3-5 µm) catadioptric telescope which consists of an aspheric primary mirror, a spherical secondary mirror, a ZnSe-ZnSe-Ge triplet lens and an air-spaced Si-Ge-Si corrector triplet lens placed before the focus is given. The calculated effective focal length, full field of view (FFOV) and angular magnification values for the designed telescope are 600 mm, 2.6° and -9.2, respectively. Zemax® calculations for the telescope MTF (modulation transfer function), PSF (point spread function), RMS (root-mean-square) wavefront error (WFE), optical path difference (OPD), Seidel aberrations, encircled energy, distortion and field curvature are discussed. The telescope performance analysis indicates that the telescope can achieve diffraction-limited image quality performance within the 2.6° full field-of-view. Additionally, the designed telescope can resolve at 50% contrast spatial frequency equal to 18.5 cycles/mm (at the on-axis FOV). Finally, a detailed tolerance analysis for the telescope design employing Monte Carlo and sensitivity analysis simulation features in Zemax® is provided.

KEYWORDS

Mid-Wave Infrared (MWIR), Modulation Transfer Function (MTF), Monte Carlo Analysis, Seidel Aberrations, Sensitivity Analysis

INTRODUCTION

A catadioptric optical system is a system which consists of reflective (mirrors) and refractive (glass lenses) optical components. Catadioptric optical systems are commonly used in constructing imaging systems, such as optical telescopes and microscopes, and illumination optical systems, such as headlamps (Wikipedia, 2019).

In a catadioptric telescope the distance between the dioptric components (i.e., the primary mirror and the secondary mirror) and the catoptic lens assembly is optimized for the formation of a sharp image at the image plane (Bentley, 2012; Greivenkamp, 2004; Wolfe, 1996; Laakin, 2007; Kingslake & Johnson, 2010).

In this paper, a description for the design of a catadioptric telescope which incorporates ZnSe-ZnSe-Ge and Si-Ge-Si triplet lenses (Alaruri, 2016; Sharma, 1992) for imaging targets in the MWIR

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(3-5 μm) region of the spectrum is given. The telescope two triplet lenses, which are used to correct for the optical system aberrations, were selected from standard IR (Infrared) materials such as Si, Ge and ZnSe. Calculations performed using Zemax® (Zemax, 2013; Geary, 2002) lens design software for the telescope MTF (modulation transfer function), PSF (point spread function), RMS (root-mean-square) wavefront error (WFE), optical path difference (OPD), Seidel aberrations, encircled energy, distortion and field curvature are discussed. Employing the Monte Carlo and sensitivity analysis features in Zemax® a simulation for the impact of the catadioptric telescope tolerances (i.e., tilt, decenter, thickness and surface radius) on image quality is provided.

Lastly, this paper provides a full analysis for the optical design of a MWIR catadioptric telescope and a detailed tolerance analysis for the telescope design with Zemax® which is rarely treated in scientific literature dealing with catadioptric telescopes design (Fjeldsted, 1984; Kreitzer, 1985; Norrie, 1986; Palmer, 1987; Mercado, 1989; Mercado, 1990; Sigler, 1992; Sigler, 1992; Sinclair, 1999; Bahrami & Goncharov, 2010; Kai, Si-zhong, Jing, Yan-bin, & Heng-jin, 2011). The telescope can be coupled to mercury cadmium telluride (HgCdTe or MCT), antimonide-based (InGaAsSb) or chalcogenide-based (PbS, PbTe, PbSe) imager (Razeghi & Nguyen, 2014; Rogalski, 2017) for imaging applications in the MWIR.

Finally, other applications for catadioptric lenses include high-resolution microscopy objectives, fluorescence imaging and optical coherence tomography (Shafer, Chuang, & Armstrong, 2014).

THE CATADIOPTRIC TELESCOPE LENS DESIGN FILE AND SPECIFICATIONS

Figure 1 depicts the catadioptric telescope optical layout, which consists of a primary mirror with conic constant $=-3.283$ (hyperboloid), a secondary spherical mirror, spherical ZnSe-ZnSe-Ge triplet lens and an air-spaced spherical Si-Ge-Si triplet corrector lens.

Figure 1. Schematic illustrating the MWIR catadioptric telescope 3D optical layout