Vignetting Analysis of GOCI Optical System

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Abstract: GOCI(Geostationary Ocean Color Imager) is the core paryload of the geostationary satellite COMS(Communication, Ocean and Meteological Satellite) for ocean monitoring. It is scheduled to be launched at the end of 2008. GOCI observes ocean color around the Korean Peninsula over 2500km×2500km area. Whole field of view is divided into 16 solts and scan mechanism enables to point each slot position. Tilted two-axis scan method is used to observe entire field of view with great pointing stability. Vignetting of the optical system appears when the partial obscuration by intermediate optical components occurs. It leads to the variation of the illumination in the image and gradual fading near the edge of the field. It should be prohibited for the stable radiometric performances. In this work, vignetting analysis of GOCI optical system is performed. For the systematic approach, GOCI optical system is divided into scan mechanism part and telescope part. Vignetting analysis of each part is performed and each result is combined for the overall vignetting performances. The analyzed results can be applied to the selection of slot acquisition angle of scan mechanism to minimize vignetting effects.

Keywords: Vignetting, Scan Mechanism, COMS, GOCI.

1. Introduction

The Communication, Ocean, and Meteorological Satellite(COMS), to be launched at the end of 2008, is the geostationary satellite which has three missions of satellite communication, ocean monitoring and meteorological service[1]. GOCI(Geostationary Ocean Color Imager) is the core instrument of the COMS system for ocean monitoring. It acquires data in 8 visible wavebands with a spatial resolution of about 500m over the Korean sees. The ocean data products that can be derived the measurements are mainly the chlorophyll concentration, the optical diffuse attenuation coefficient, the concentration of dissolved organic material or yellow substance, and the concentration of suspended particulates in the near-surface zone of the sea. In operational oceanography, satellite derived data products are used in conjunction with numerical models and in situ measurements to provide forecasting and now casting of the ocean state. Such information is of genuine interest for many categories of users.

Vignetting of the optical system appears when the partial obscuration by intermediate optical components occurs. It leads to the variation of the illumination in the image and gradual fading near the edge of the field[2]. It should be prohibited for the stable radiometric performances.

In this work, vignetting analysis of GOCI optical system is performed. For the systematic approach, GOCI optical system is divided into scan mechanism part and telescope part. Vignetting analysis of each part is performed and each result is combined for the overall vignetting performances. This paper is organized as follows. In the next section, GOCI optical system is described. Vignetting analysis of telescope part and scan mechanism part are discribed in Section 3 and 4. A summary and some concluding remarks are provided in the last section

2. GOCI Optical System

GOCI observes ocean color around the Korean Peninsula over 2500km×2500km area. The operating principle consists in imaging a portion of the specified image frame, termed slot. A pointing mirror provides a bidimensional circular scanning on the Earth. By successively pointing 16 pre-defined directions, the array is moved in the field of view to cover the complete image area as illustrated in Figure 1. Each slot is imaged over the 8 spectral channels. The image is acquired for two gain levels corresponding to sea and cloud radiance levels, respectively. The image data are sent in real-time to the satellite.

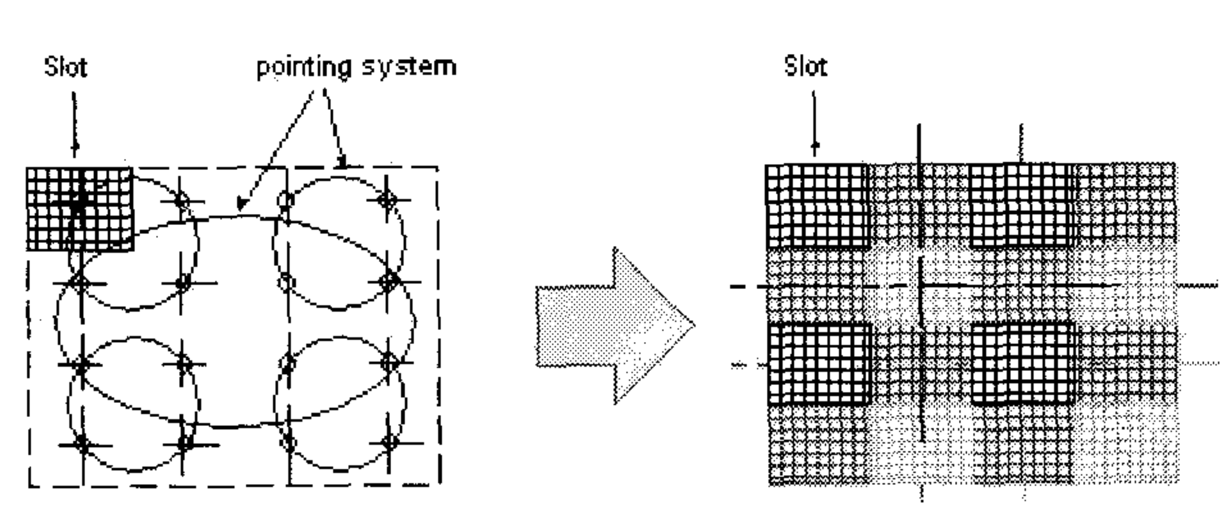

Fig. 1 Pointing princile

GOCI optical system consists in a Three Mirrors Anastigmat (TMA) telescope and a folding mirror, associated with a pointing mirror, located at the entrance of the telescope. The pointing mirror reflects the incident light to the primary mirror (M1). It is then reflected, in turn, by secondary mirror (M2), the tertiary mirror (M3) and the folding mirror before it reaches to the filter assembly. Once passed the filter, it goes to the detector surface. The schematic diagram of optical system can be seen in Figure 2.

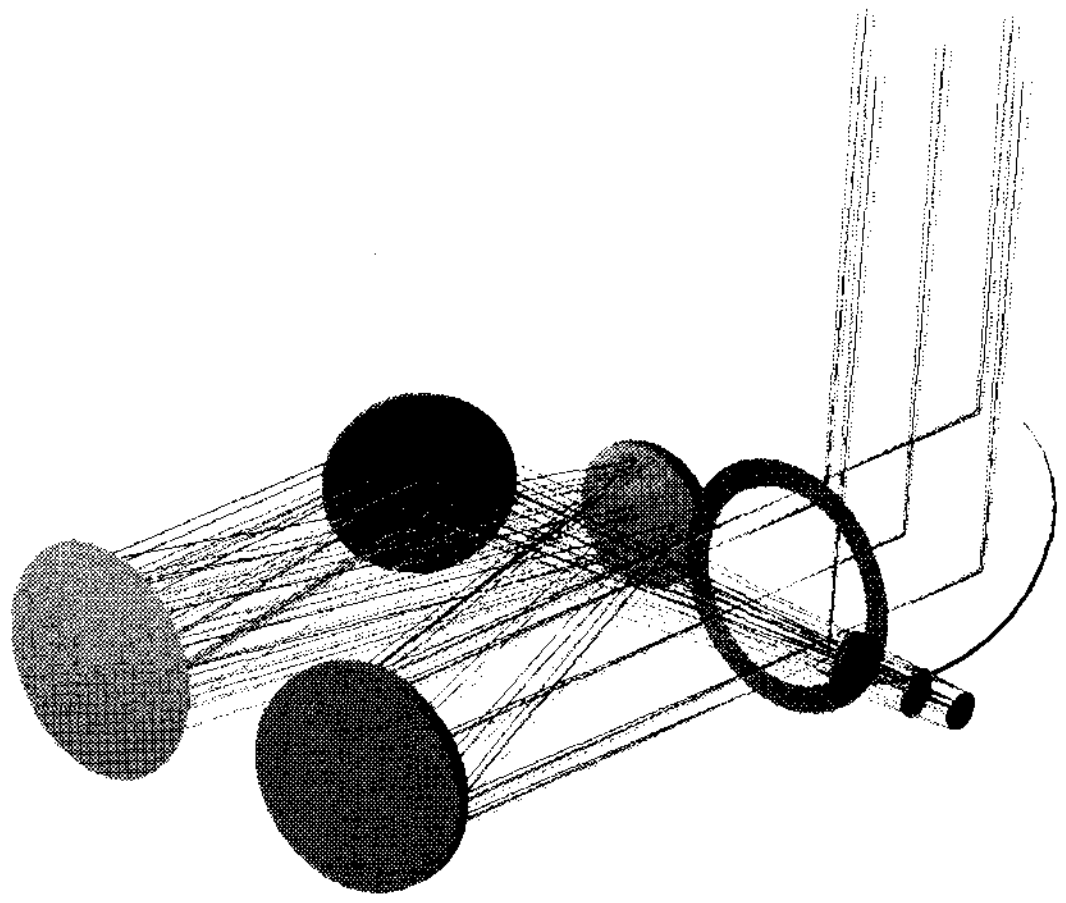

Fig. 2 Schematic view of GOCI optical system

For the systematic approach of vignetting analysis, GOCI optical system is considered as a combination of telescope part and scan mechanism part. Telescope part is consists of TMA mirrors, folding mirror, filter assembly and detector. It is the optical part after pupil stop. Scan mechanism part is consists of pointing mirror and scan mechanism. It is the optical part before pupil stop.

3. Vignetting of Telescope Part

TMA optical configuration is off-axis but there is no central obscuration that generally appears in the reflective system such as Cassegrain configuration.

The optical system has the instantaneous field of view of β_{EW} degree in East-West direction and β_{NS} degree in North-South direction[3]. It is determined by the detector size, focal length and aperture size.

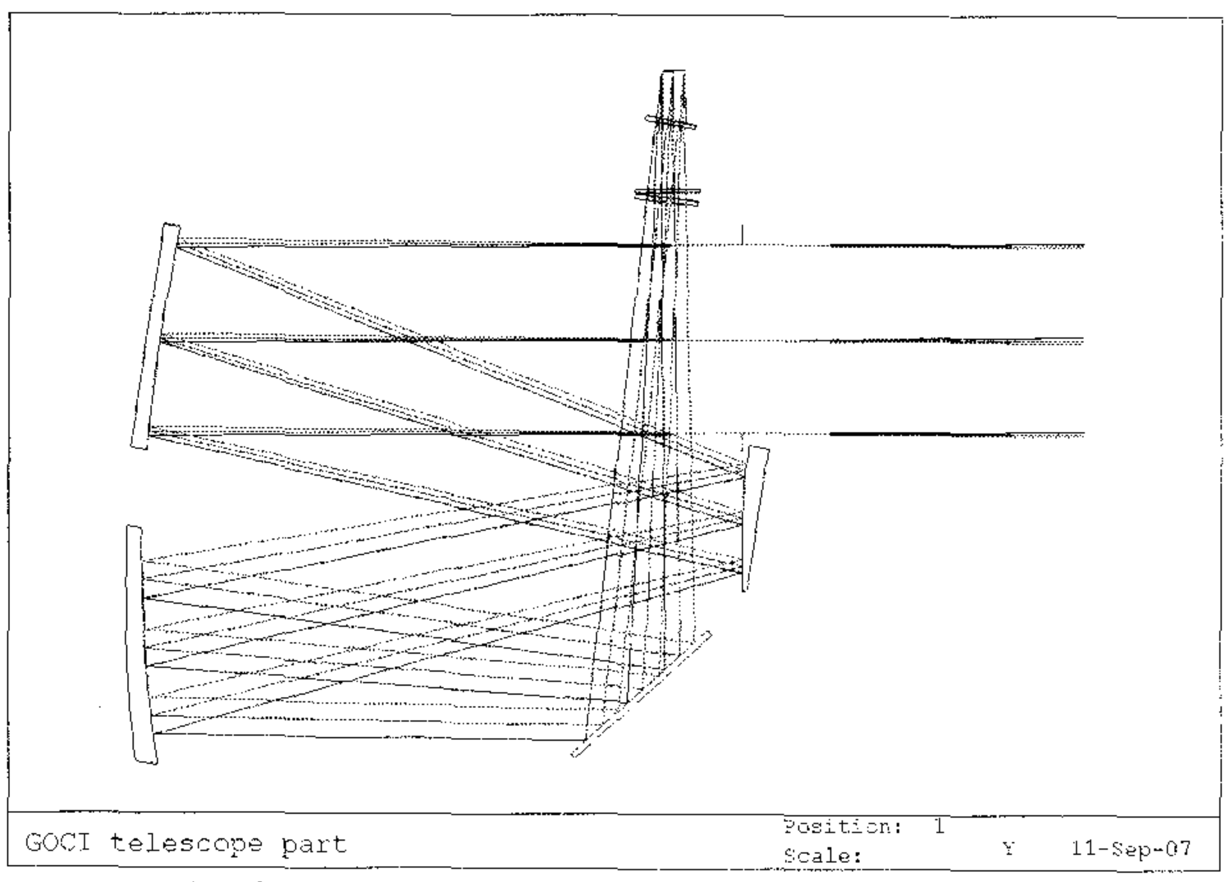

Fig. 3 Telescope part ray tracing for all fields

For the all field angles, ray tracings are performed in the telescope part to check the vignetting. Figure 3 shows the results. No obscuration is observed for all fields. It means that there is no vignetting for telescope part.

4. Vignetting of Scan Mechanism Part

GOCI scan mechanism uses tilted two-axis scheme. Its schematic view can be seen in Figure 4. Driving unit 1 is fixed to the base plate and driving unit 2 is joined to the driving unit 1 with small tilt angle θ_1. Pointing mirror is joined to the driving unit 2 with small tilt angle θ_2. Each driving unit is composed of rotor and stator. Successive rotation of driving unit 1 and 2 changes the pointing vector N with the help of tilt angle θ_1 and θ_2. Figure 5 shows the entrance baffle and optical system in another viewpoint. As shown in the figure, entrance baffle ensures φ_{BF} field of view. Incident rays that exceeds field angle φ_{BF} can be blocked by the entrance baffle.

Let the rotation of pointing vector N with respect to EW direction as φ_{EW} and NS direction as φ_{NS}. The rotation of pointing vector magnifies the rotation of reflected ray two times. Therefore, for the following condition vignetting occurs:

$$\varphi_{BF} - 2\varphi_{EW} < \beta_{EW}/2 \quad (1)$$

$$\varphi_{BF} - 2\varphi_{NS} < \beta_{NS}/2 \quad (2)$$

For the coordinate system as in Figure 4, pointing vector N is tilted θ_2 with respect to the rotation axis (z) of rotor 2 coordinate R_{rotor2}. Therefore, pointing vector can be expressed as follows:

$$N^{rotor2} = \begin{bmatrix} \cos\theta_2 & 0 & -\sin\theta_2 \\ 0 & 1 & 0 \\ \sin\theta_2 & 0 & \cos\theta_2 \end{bmatrix} \begin{Bmatrix} 0 \\ 0 \\ 1 \end{Bmatrix} = \begin{Bmatrix} -\sin\theta_2 \\ 0 \\ \cos\theta_2 \end{Bmatrix}. \quad (3)$$

On the other hand, stator 2 coordinate $R_{stator2}$ can be chosen to have the same z axis as R_{rotor2} and rotation angle a_2 with respect to x-y plane.

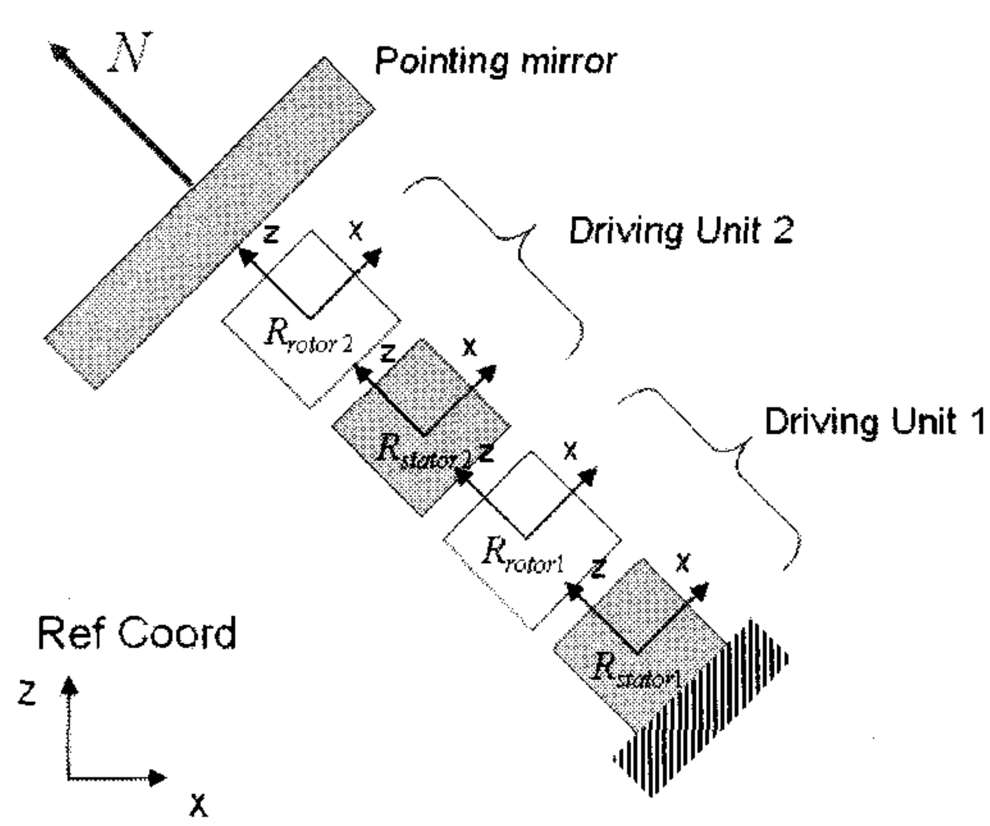

Fig. 4 GOCI scan mechanism

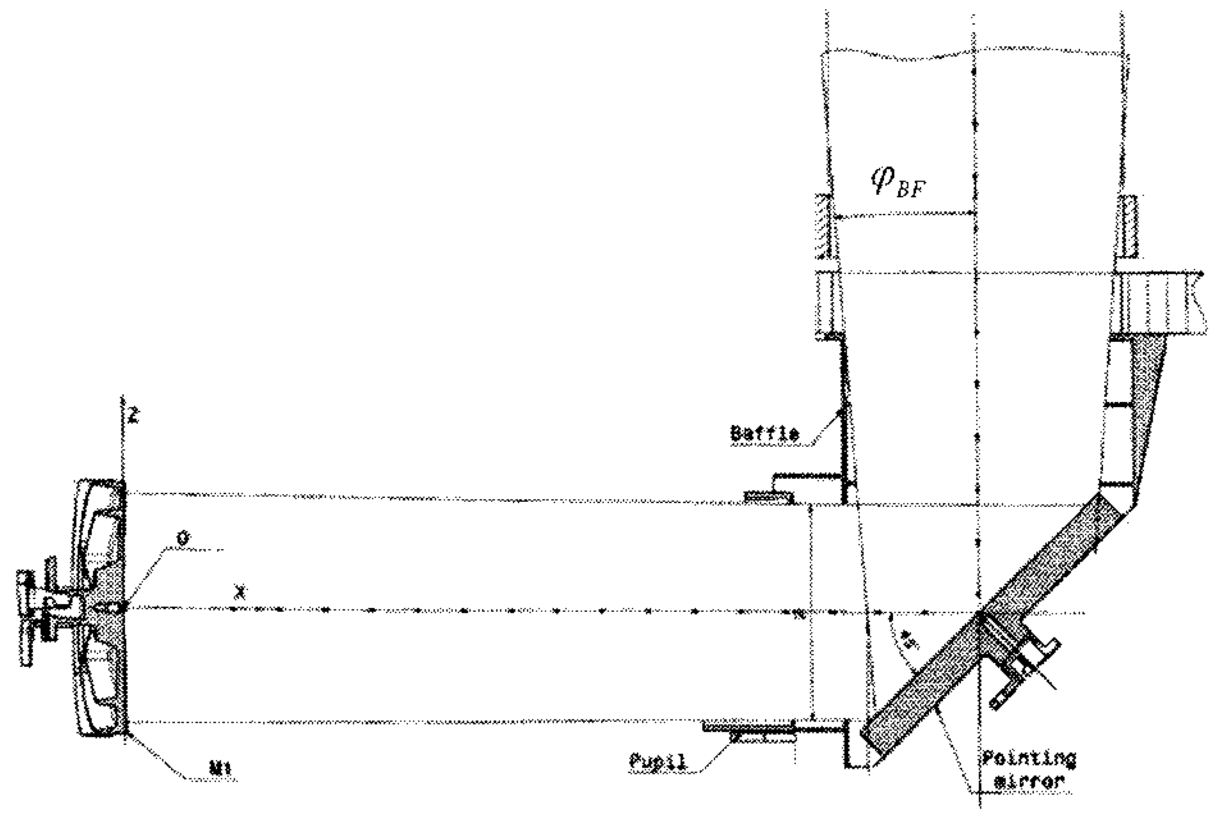

Fig. 5 Entrance baffle and field of view

Therefore, the transformation matrix from R_{rotor2} to $R_{stator2}$ can be written as

$$^{stator2}C^{rotor2} = \begin{bmatrix} \cos a_2 & \sin a_2 & 0 \\ -\sin a_2 & \cos a_2 & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{4}$$

Stator 2 is tilted θ_1 with respect to rotor 1. we can choose the rotor 1 coordinate R_{rotor1} to have the θ_1 tilted z axis with respect to $R_{stator2}$. Then, the transformation matrix from $R_{stator2}$ to R_{rotor1} can be written as

$$^{rotor1}C^{stator2} = \begin{bmatrix} \cos\theta_1 & 0 & -\sin\theta_1 \\ 0 & 1 & 0 \\ \sin\theta_1 & 0 & \cos\theta_1 \end{bmatrix}. \tag{5}$$

Also, stator 1 coordinate $R_{stator1}$ can be chosen to have the same z axis as R_{rotor1} and rotation angle a_1 with respect to x-y plane. The transformation matrix from R_{rotor1} to $R_{stator1}$ can be written as

$$^{stator1}C^{rotor1} = \begin{bmatrix} \cos a_1 & \sin a_1 & 0 \\ -\sin a_1 & \cos a_1 & 0 \\ 0 & 0 & 1 \end{bmatrix}. \tag{6}$$

Finally, the pointing vector can be represented in the coordinate fixed to the base plate.

$$N^{stator1} = {}^{stator1}C^{rotor1} \cdot {}^{rotor1}C^{stator2} \cdot {}^{stator2}C^{rotor2} \cdot N^{rotor2} \tag{7}$$

The explicit form is as follows

$$N^{stator1} = \begin{Bmatrix} -Ca_1C\theta_1Ca_2S\theta_2 - Ca_1S\theta_1C\theta_2 + Sa_1Sa_2S\theta_2 \\ Sa_1C\theta_1Ca_2S\theta_2 + Sa_1S\theta_1C\theta_2 + Ca_1Sa_2S\theta_2 \\ -S\theta_1Ca_2S\theta_2 + C\theta_1C\theta_2 \end{Bmatrix} \equiv \begin{Bmatrix} N_x \\ N_y \\ N_z \end{Bmatrix} \tag{8}$$

where, $C(\bullet) = \cos(\bullet)$ and $S(\bullet) = \sin(\bullet)$.

The rotation of pointing vector with respect to EW direction and NS direction can be calculated to the following formula.

$$\cos\varphi_{EW} = \frac{N_z}{\sqrt{N_x^2 + N_z^2}} \tag{9}$$

$$\cos\varphi_{NS} = \frac{N_z}{\sqrt{N_y^2 + N_z^2}} \tag{10}$$

The vignetting condition (1) and (2) can be calculated according to the rotation angle of each driving unit a_1 and a_2.

For the EW condition (1), the result is represented in Figure 6. At the 6 corner areas vignetting occurs. For the NS condition (2), the results is represented in Figure 7. Vignetting only occurs in the limited area where a_1 is around 90° and 270° and a_2 is around 0° or 360°. It is due to the NS field of view of detector is smaller than the EW field of view.

Figure 8 shows the both vignetting conditions. The results show that vignetting occurs only small area among the whole possible working range of mechanism.

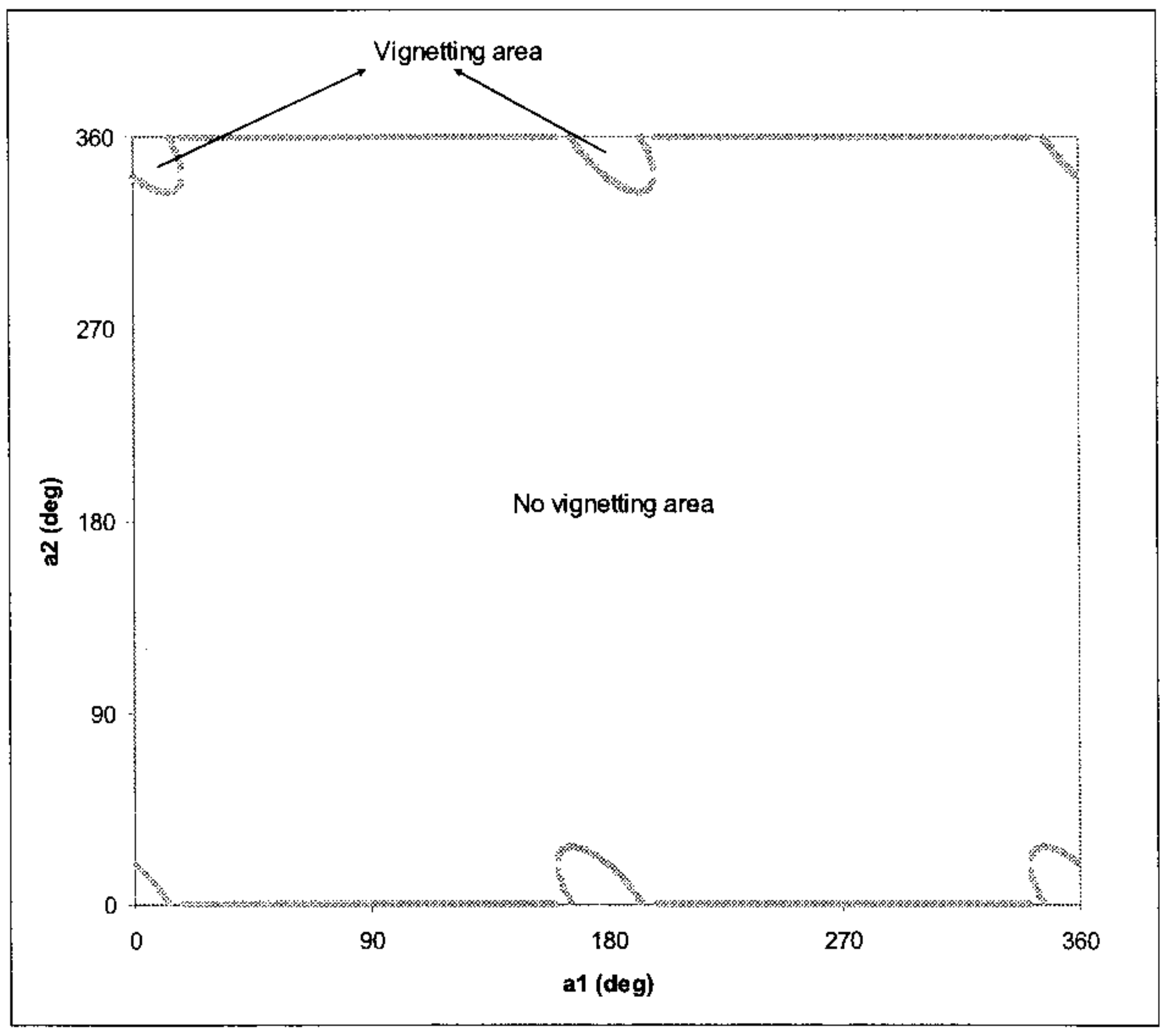

Fig. 6 EW vignetting condition

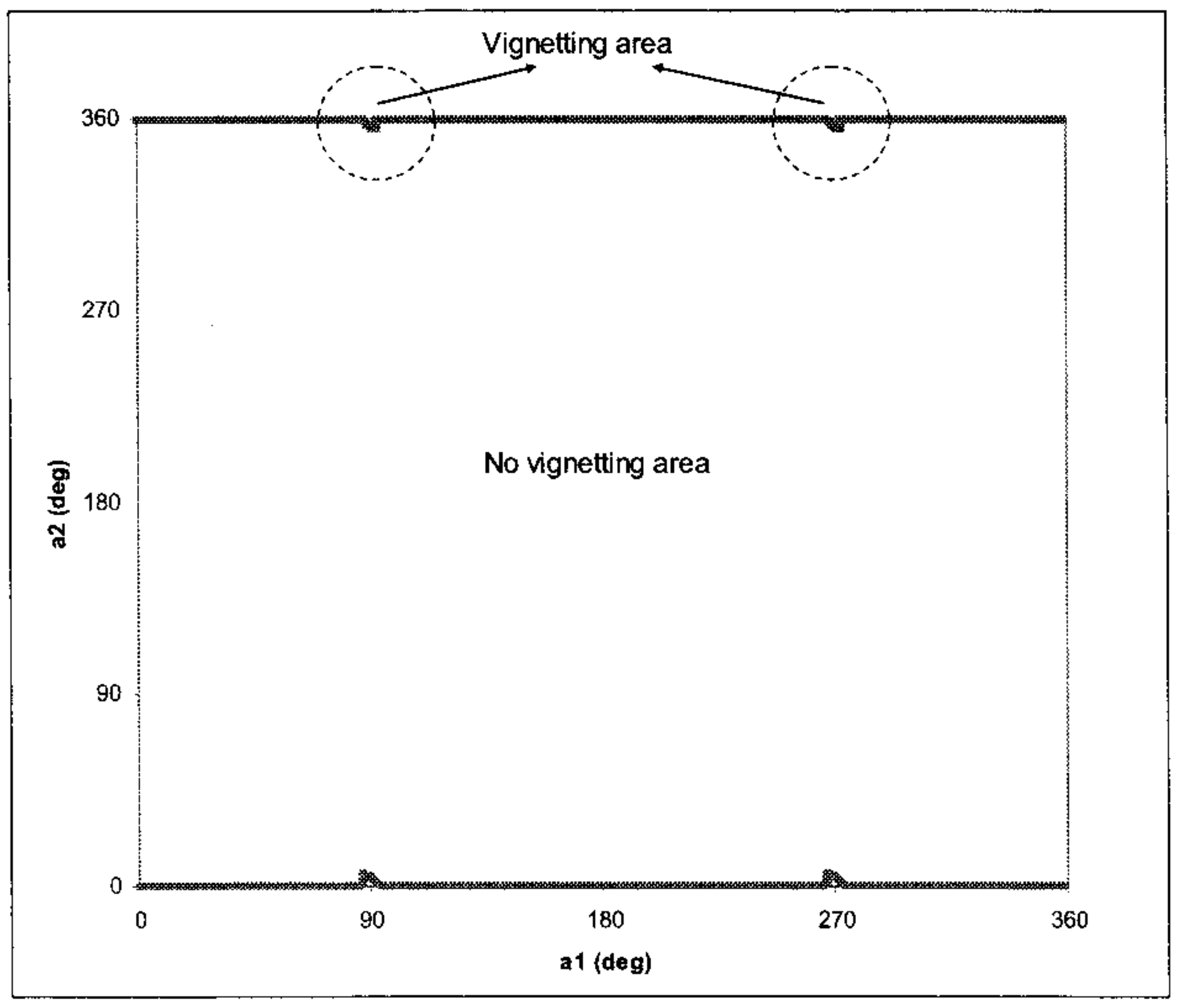

Fig. 7 NS vignetting condition

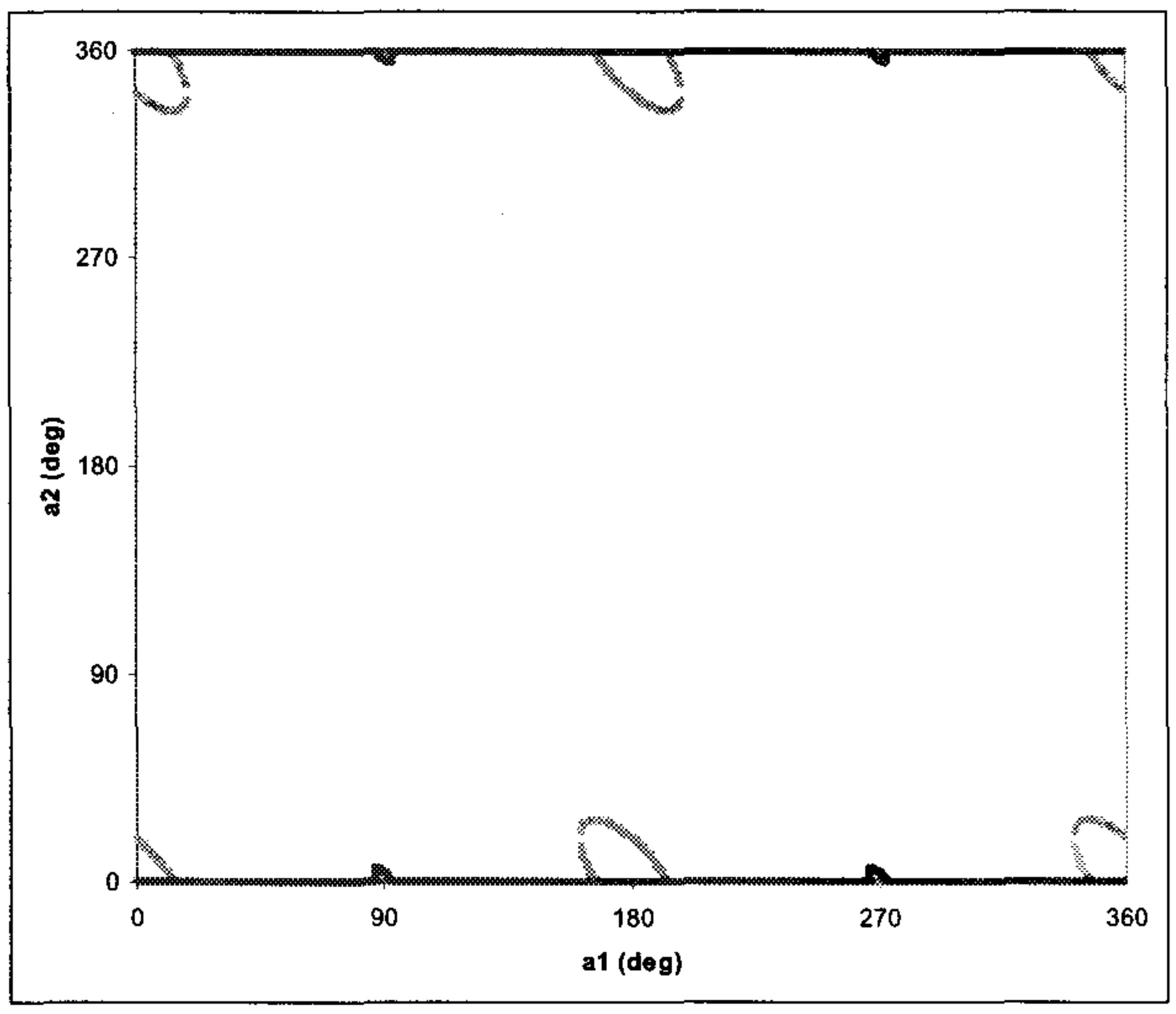

Fig. 8 Vignetting condition due to scan mechanism

The orbital position of COMS in the geostationary orbit is not yet determined. The working rotation angle of each driving unit a_1 and a_2 will be selected for the proper slot acquisition according to the orbital position. The slot acquisition angles should be selected to minimize the vignetting effects.

4. Concluding Remarks

In this work, vignetting analysis of GOCI optical system is performed. GOCI optical system is composed of telescope part and scan mechanism part. Vignetting analysis of each part is performed and each result is combined for the overall vignetting performance.

In the telescope part, ray tracings for all fields show that there is no obscuration and no vignetting. In the scan mechanism part, pointing model of scan mechanism introduced and vignetting condition is calculated. Large variation angle of pointing vector can lead to vignetting because of the limited field angle of entrance baffle. However, the results show that vignetting occurs only small area.

The calculated vignetting condition should be considered for the selection of slot acquisition angle to minimize vignetting effect.

References

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