A CONCEPTIONAL STUDY OF OPTICAL EARTH OBSERVATION FROM GEOSYNCHRONOUS ORBIT

Hajime Koshiishi, Kohzo Homma
National Aerospace Laboratory
7-44-1, Jindaijihigashi-machi, Chofu, Tokyo 182
Japan
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Summary

At first we assumed that requisitions of earth observation from geosynchronous orbit are 100 m spatial resolution at 1.1 μm wave length. Then design of telescope system had done with the Schmidt type telescope. The optical parameters of resulted design are 5 m focal length and 1 m aperture. Then we had introduced new scanning scheme: conical scan on image plane. Analytical calculation by wave optics had been done and it became clear that the 100 m spatial resolution can be get with very high OTF with this conical scheme.

Introduction

For various fields of earth observation, an observation from geosynchronous orbit is desired. For example, observation of climate condition and warning, ocean observation and forestry need geosynchronous earth observation satellite. Especially, the Japan islands are covered by clouds steadily and only for 80 days a year can be observed from remote sensing satellites. Therefore the observation from geosynchronous orbit will be particularly useful for the Japanese remote sensing users, nevertheless such a system is usually excluded because of the long distance and the imagined enormousness required for high resolution. If we use some catadioptoric telescope and conical scan scheme on the image plane, can get 100 m resolution with a comparatively small telescope system, and it is realizable even by existing technologies. We have done the conceptual design of the earth observing system from geosynchronous orbit applying a catadioptoric telescope design. This paper presents the outline of the design studies.

1. To observe the Japan islands from the geosynchronous orbit

There are three schemes of FOV (Field of View) for observation the Japan islands from the geosynchronous orbit. The three schemes are shown in Fig. 1, (a), (b) and (c). In the scheme of (a), a usual small circular FOV and scan are used to observe the total area of the Japan islands. That is, some slewing motion of satellite is needed. When the diameter of the FOV and mean distance between the geosynchronous orbit and the Japan islands are assumed to be 600 km and 38,000 km respectively, the angular FOV becomes to 0.9 degree. To utilize the Cassegranian telescope with parabolic primary mirror for this angular FOV may not be good design scheme because of various aberrations at the edge of FOV. This angular FOV may require the Ritchey-Chretien scheme. In the scheme (b) all of the Japan islands is put into one FOV and staring mode observation is possible and there is no need of slewing of satellite. Nevertheless the diameter of FOV may be 2,000 km and the angular FOV will be 3 degree. Assuming the aperture dimension of CCD element and the required ground resolution are 14 μm and 100 m respectively, then the focal length of telescope must be 5.32 m. The aperture will be 1.32 m for F-number 5. It is very easy to get 3 degree of FOV by refractive system, but to do it with the focal length and the aperture diameter is not conceivable. On the other hand, this 3 degree of FOV imposes difficulty on Cassegranian reflective scheme. The Makstov type or Schmidt type catadioptoric schemes are only solutions for this telescope. The scheme (c) is a rather exotic scheme which uses the conical scanning on the focal plane. In this scheme the total Japan islands are imaged in some circular arc area of the focal plane as shown in Fig. 1 (c). The optical axis of telescope points to somewhere of Chinese continent. To image islands from Hokkaido to Kyusyu, about 3.2 degree of FOV is required, and to image total islands including Okinawa island about 4 degree of FOV is required. According to similar consideration as scheme (b), the pertinent telescope is the Makstov or Schmidt type catadioptoric system. On the focal plane the image of Japan islands are formed along with concentric strips, on which all image points are focused best and have same optical performances.

2. Design of Schmidt telescope to observe the Japan islands with conical scan from geosynchronous orbit

2.1 The principle of Schmidt telescope

Fig. 2 shows the basic principle of Schmidt telescope. S is a primary mirror with spherical surface, and C is an aspheric lens which called the correcting plate and positioned on the center of curvature of the primary mirror. The central part of this correcting plate is forming a convex lens, but the peripheral part is forming a concave lens and there is no power part between these two parts, which does not refract ray. The spherical aberration is removed completely by this correcting plate. Oblique light beam is symmetrical about the principal ray OA. Due to this symmetry there is no coma and astigmatism. The focal plane is spherical surface with 1/2 length radius of curvature compared to the primary mirror. That is, on the spherical focal plane we can get complete image without any aberration.

2.2 Calculation of optical parameters of the Schmidt telescope

We adopt the scheme (c) and put the image of Japan islands in the concentric strips on the spherical focal plane of Schmidt telescope. Then the projection of telescope FOV on the Earth's surface is a circle, which comes in contact with parallels of latitude 29 degree and 61.5 degree, and the center of FOV is projected on the parallel 45 degree and the distance from satellite on the geosynchronous orbit to the projected image center is 38,140 km (cf. Fig. 3). The focal length f, the distance between satellite and the center of FOV on the ground D, the spatial resolution on the ground Δx and the aperture of sensor element d are related in formula:

Fig. 1 (a) FOV for observation from geosynchronous orbit

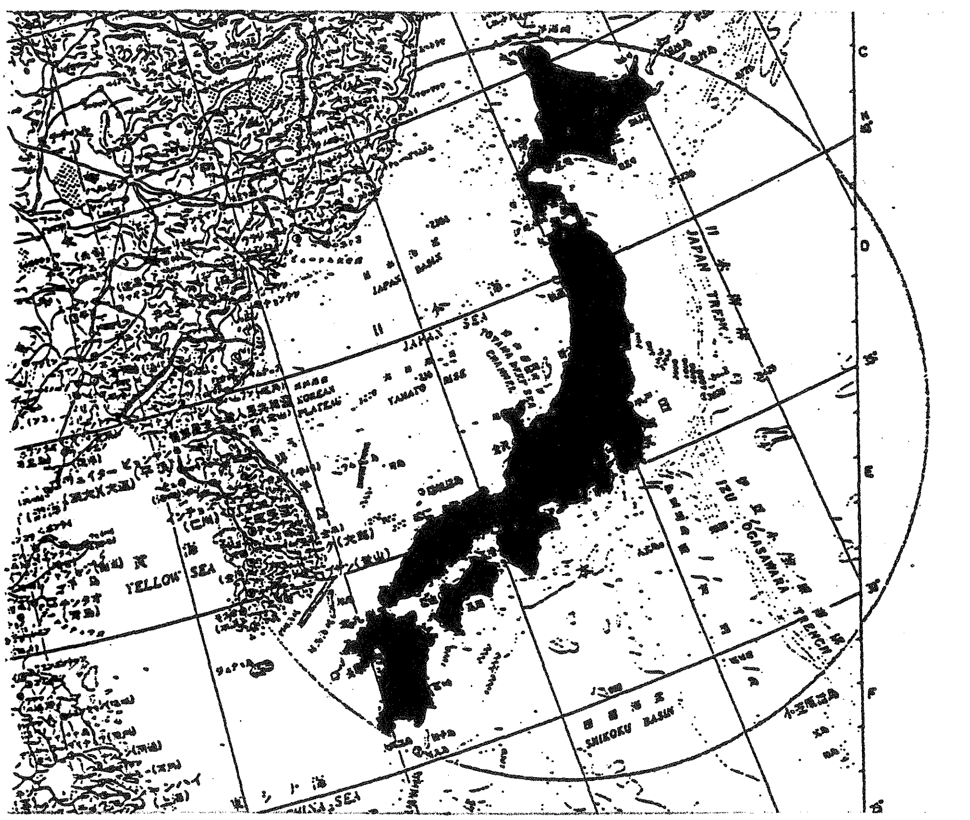

Fig. 1 (b) FOV for observation from geosynchronous orbit

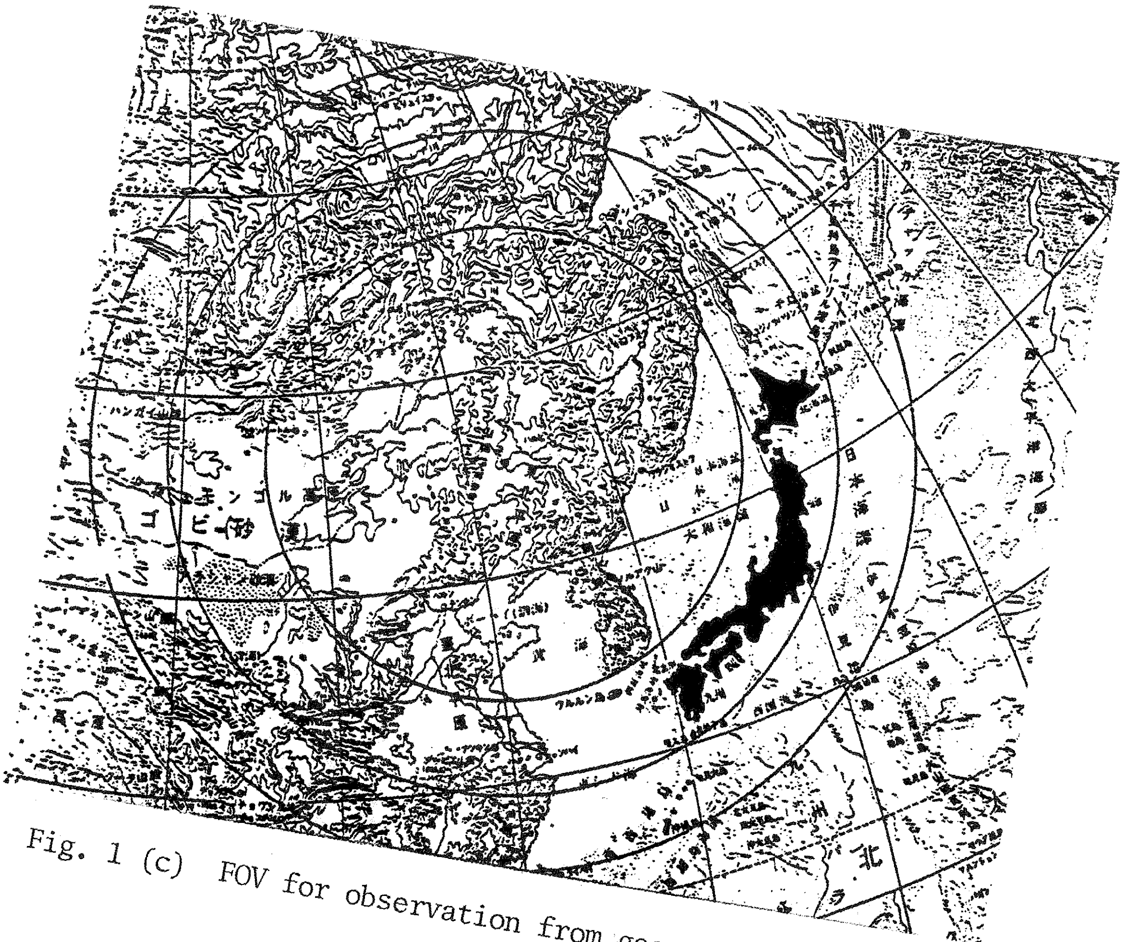

Fig. 1 (c) FOV for observation from geosynchronous orbit

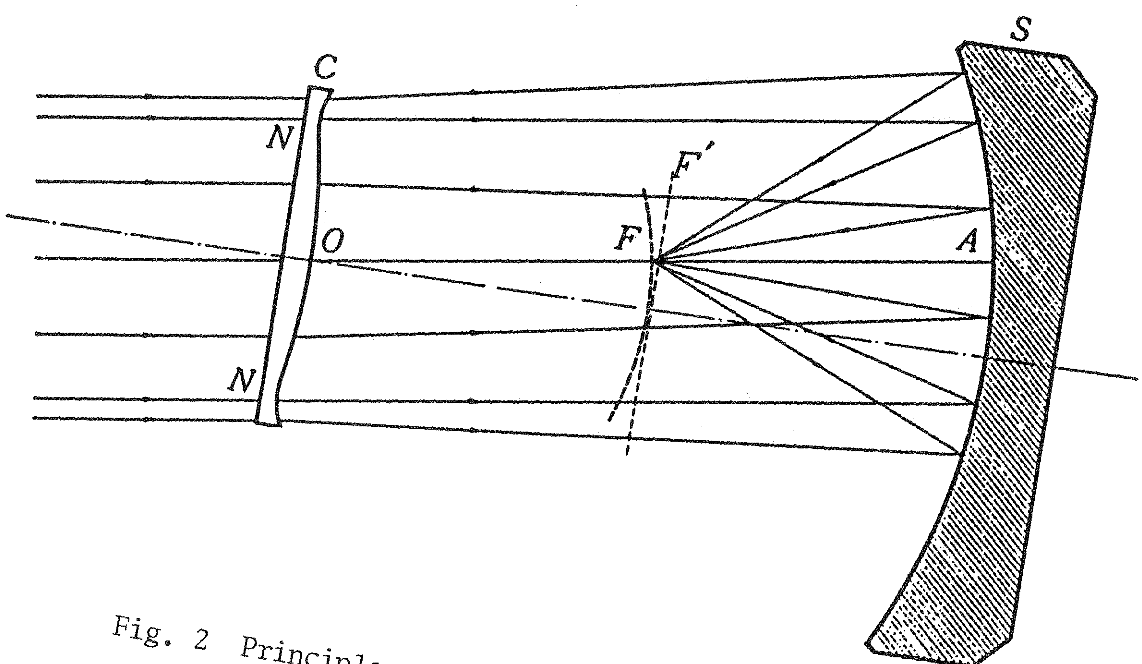

Fig. 2 Principle of Schmidt telescope

$$f = D \cdot d/\Delta x \qquad (1)$$

Fig. 4 shows this relation with the parameter d. The most small photodiode size is about 7 μm and usually 14 μm size photodiode elements are arranged in a linear array. So, two lines for 7 μm and 14 μm are shown in the figure. Spatial resolution of telescope is limited by diffraction. The aperture of telescope ϕ, wave length λ, and an angular resolution Δw are connected as follows:

$$\Delta w = 1.22\ \lambda/\phi$$

The limited ground resolution Δx_L is $D \cdot \Delta w$, then, we have,

$$\phi = 1.22\ \lambda D/\Delta x_L \qquad (2)$$

Fig. 5 shows this relation provided that D is 38,140 km and λ is 1.1 μm.

If 100 m ground resolution is required for the observing wave length 1.1 μm and photodiode aperture 14 μm, then we can say from Fig. 4 and Fig. 5 that the focal length must be 5.35 m and the aperture of telescope 0.5 m at least.

If 50 m ground resolution is required for the same wave length and photodiode aperture, then 10.7 m focal length and 1 m minimum aperture are needed.

2.3 Shape of correcting plate

The shape of correcting plate of Schmidt telescope is given by following equations:

$$Z = \beta y^4 - \alpha y^2$$

$$\alpha = \frac{k}{128(n-1)f-(F_{NO})^2}$$

$$\beta = K_O\left[1 - \frac{2k}{64(F_{NO})^2}\right]^2 \qquad (3)$$

$$K_O = \frac{1}{32(n-1)f^3}$$

Here, k is a parameter which determine the radius of neutral zone (no power part between the convex and concave parts), and n is an index of glass (cf. Fig. 6). The radius of curvature of the primary mirror R is given by the equation:

$$R = f + \sqrt{f^2 + \frac{k\phi^2}{16}} \qquad (4)$$

As above mentioned the minimum aperture of telescope for 100 m ground resolution is 0.5 m, however this diameter is required

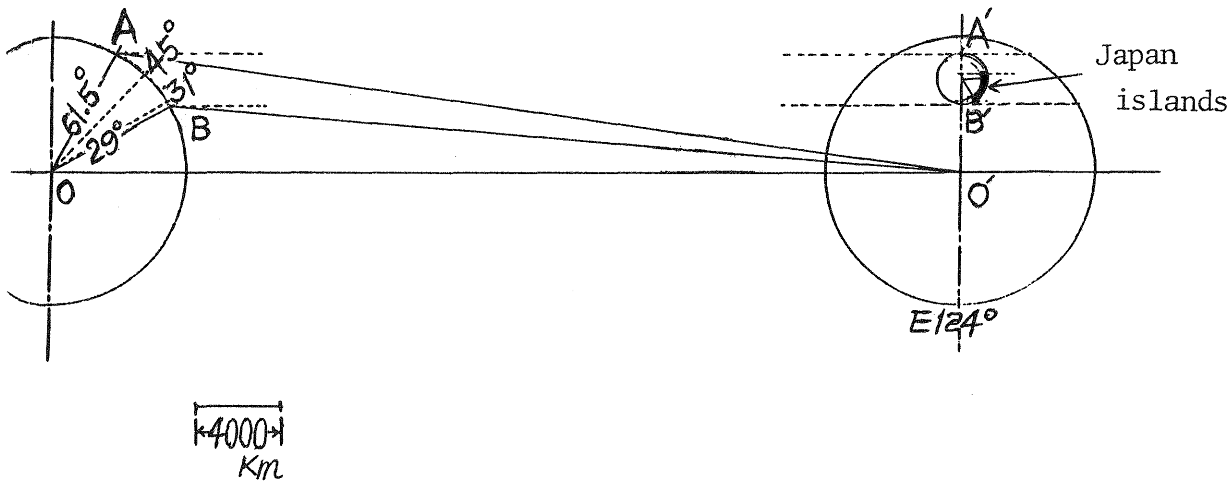

Fig. 3 Telescope on geosynchronous orbit and Japan islands

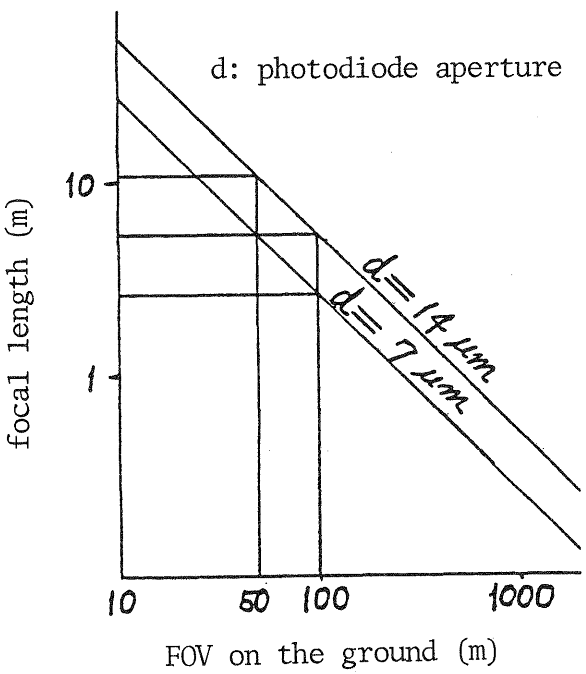

Fig. 4 Relation of focal length and ground resolution

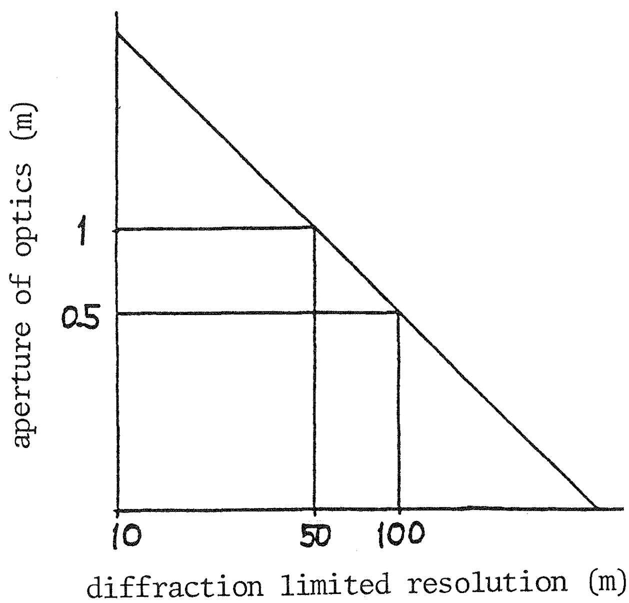

Fig. 5 Aperture and diffraction limited resolution

for diffraction limited resolution. If we take into consideration various degradation factors, for example the effect of atmosphere, imcompleteness of hardware system, we must extend the aperture a little more. Therefore, we assumed 1 m aperture as an actually required diameter of telescope. Another assumptions are the glass material BK-7 for correcting plate and 1.5 for parameter k which determines the radius of neutral zone. Then, utilizing equation (3), we can fix the parameters α , β and R as follows:

$$\alpha = 3.68616 \times 10^{-8}$$

$$\beta = 3.92868 \times 10^{-13}$$

$$R = 1.06825 \times 10^{4} \text{ mm}$$

From these parameters, non-spherical coefficients of correcting plate are determined, and ray trace, aberrations, spot diagram and OTF are calculated.

3. Calculation of optical performances

Calculations of aberrations and OTF are performed by wave optics, so the calculated results will give physical insight of the system performances. Incidentally geometrical optics sometimes gives too superior results for such a reflecting system. The focal plane of Schmidt telescope is spherical as shown in Fig. 2, F. The spot diagrams of on axis and semi-field angle 1.65 degree on this curved focal plane are shown in Fig. 7, (a), (b) and the spot diagram at 1.65 degree on flat plane F' is shown in Fig. 7, (c) for comparison. The former two spot diagrams are smaller than the assumed photodiode aperture 14 μm, but the latter spot diagram on flat plane is large extraordinarily. Fig. 8 is the OTF for Fig. 7 (b). It is clear that the OTF value at the cut off frequency of photodiode aperture 14 μm is about 0.67 for both tangential and sagital directions. This means that the conical scan utilizes the curved focal plane itself gives sufficient performance for 100 m spatial resolution from geosynchronous orbit.

4. Conclusion

100 m spatial resolution at 1.1 μm wave length can be realized with good performance utilizing conical scan on the curved focal plane of Schmidt telescope. The diameter of the telescope is 1 m and the focal length is about 5 m. This dimension is rather small compared to the space telescope and it's realization is not so difficult. The observation from geosynchronous orbit is a staring type and sufficient integration time for signal will be obtained. By focal plane construction we can extend the image to surrounding sea area of the Japan islands and to other area, for example, the Chinese continent area.

Reference

1. Handbook of Optics, Optical Society of America, 1978, McGraw-Hill.

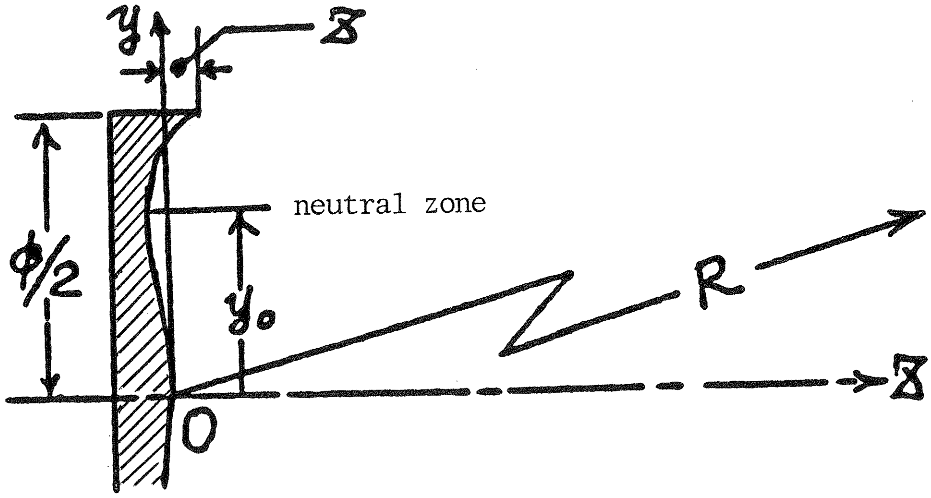

Fig. 6 Difinition of parameters on correcting plate

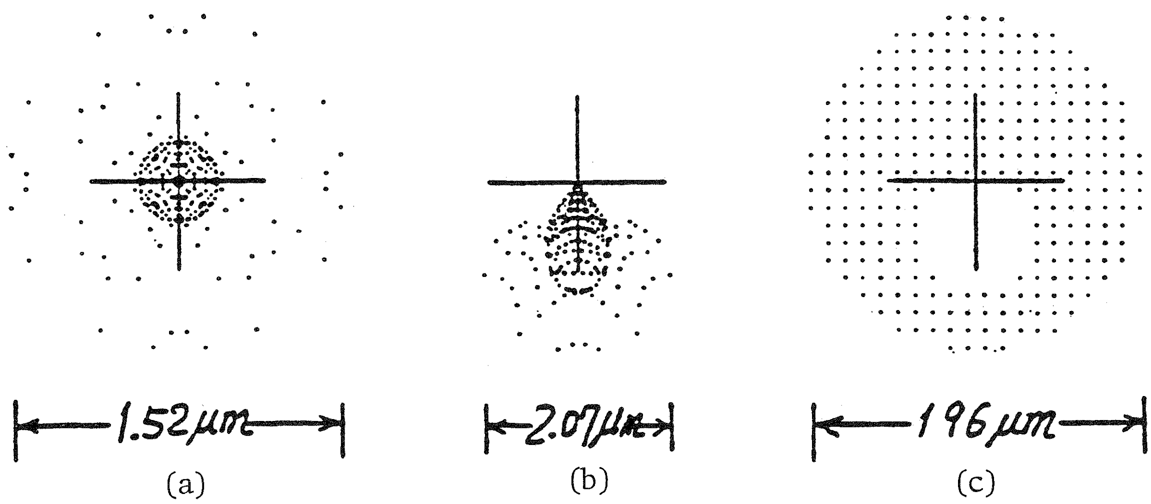

Fig. 7 Spot diagrams of Schmidt telescope

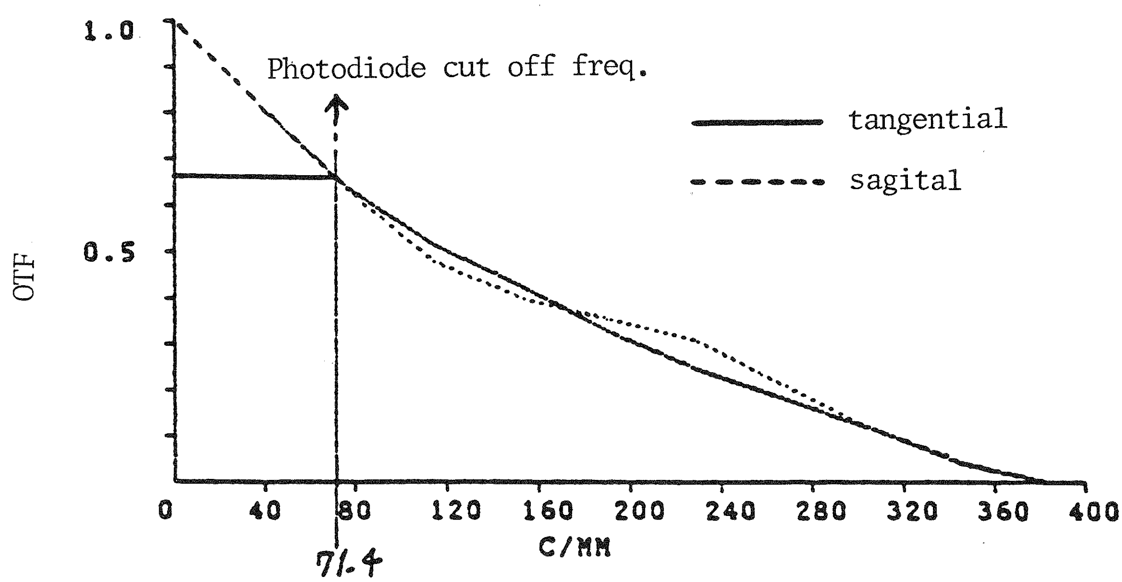

Fig. 8 OTF of Schmidt telescope

Fig. 1 (a) FOV for observation from geosynchronous orbit

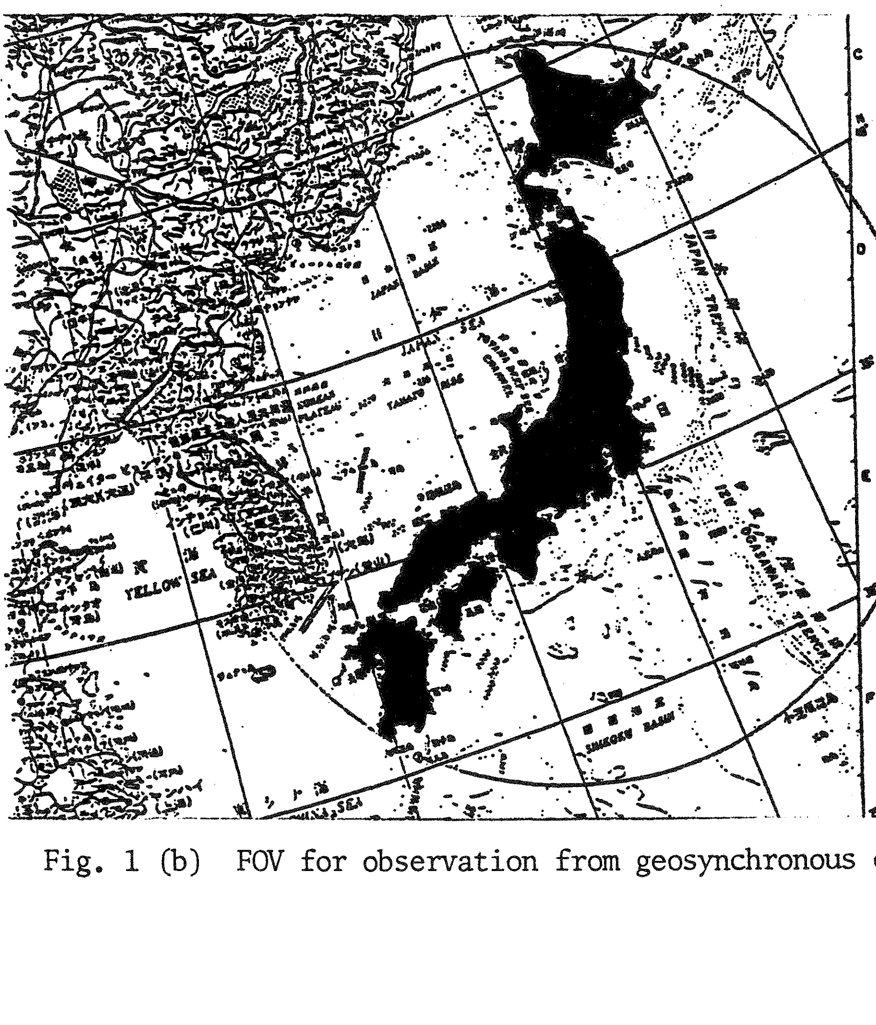

Fig. 1 (b) FOV for observation from geosynchronous orbit