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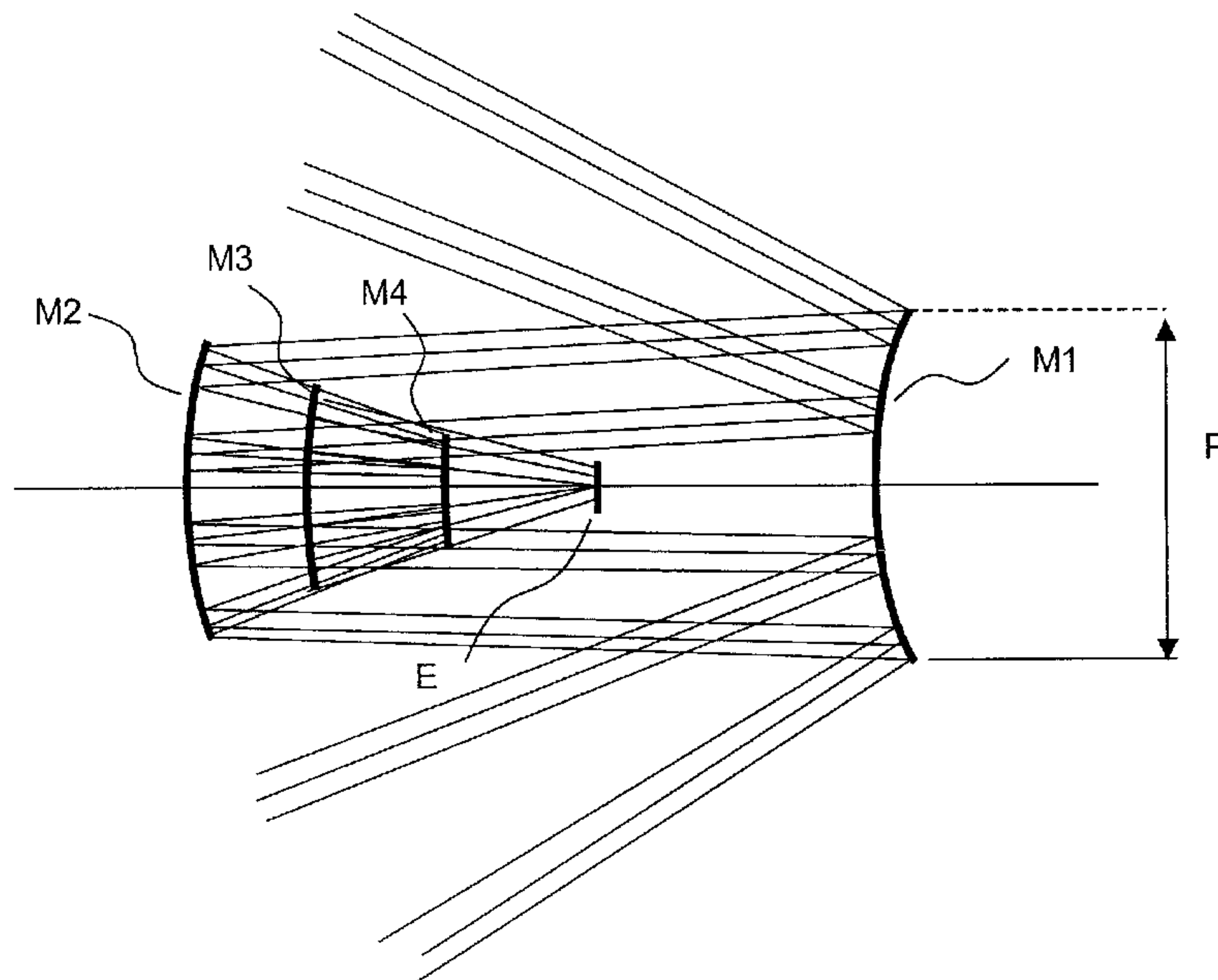
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(54) **Titre : SYSTEME CATOPTRIQUE GRAND ANGULAIRE**

(54) **Title: WIDE-ANGLE CATOPTRIC SYSTEM**



(57) **Abrégé/Abstract:**

The wide-angle catoptric system with linear field for astronomical or space observation, comprising a first mirror (M1), a second mirror (M2), a third mirror (M3) and a fourth mirror (M4).

It is characterized in that the first mirror is convex, the second mirror is concave and that the radii of curvature of the first (M1) and second (M2) mirrors are substantially equal.



ABSTRACT

The wide-angle catoptric system with linear field for astronomical or space observation, comprising a first mirror (M1), a second mirror (M2), a third mirror (M3) and a fourth mirror (M4).

It is characterized in that the first mirror is convex, the second mirror is concave and that the radii of curvature of the first (M1) and second (M2) mirrors are substantially equal.

FIG.4

WIDE-ANGLE CATOPTRIC SYSTEM

TECHNICAL FIELD

The present invention relates to the realm of telescopes and more particularly observation telescopes on board satellites. More precisely, the invention relates to the realm of wide-angle catoptric systems, notably for a wide spectral range.

BACKGROUND OF THE INVENTION

Currently, a conventional solution for observation, notably of the earth, is the use of anastigmatic telescopes comprising 3 mirrors, also called "TMA telescopes", standing for "Three Mirrors Anastigmat". TMA telescopes offer fields generally lying between 25° and 30° of angle while correcting 3rd-order aberrations. But beyond this field, the image degradations become significant.

This field limitation is not suited to advances in earth observation missions which require ever wider linear fields so as to increase the instantaneous field covered by the instrument revolving around the earth. The importance of these missions is to take photographs at regular intervals over a wide field.

In this context, telescopes of the TMA type are no longer sufficient to cater for missions that require wide fields to be photographed.

A solution making it possible to magnify the width of the field is the use of anastigmatic telescopes comprising four mirrors, also referred to in the technical terminology as FMA for "Four Mirrors Anastigmat". Notably, the Sagem Patent with French publication No FR 2 764 081 A1 (or United States Patent 6,356,388 B1) details a telescope comprising four mirrors whose field possesses a maximum width of 70° of angle. This field remains a limitation when the image is processed at the conditions at the limits typically at $\pm 35^\circ$.

A solution for magnifying the field can be to increase the slit which diaphragms the field. In this latter case, the aberrations of the image, and particularly the distortion of the image produced, very quickly become significant and do not allow an image of good quality to be obtained over the whole width of the limited field at the level of the aperture diaphragm.

SUMMARY OF THE INVENTION

An aim of the invention is to remedy these drawbacks and notably makes it possible to exceed the current field width limitations for observation telescopes. The invention proposes to employ four mirrors in such a way that
 5 the first mirror M1 is convex and the second mirror M2 is concave and that the two mirrors M1, M2 possess substantially the same radius of curvature.

Advantageously, the wide-angle catoptric system with rectangular field for astronomy or Earth observation, comprises a first mirror M1, a second mirror M2, a third mirror M3 and a fourth mirror M4.

10 Advantageously, the first mirror is convex, the second mirror is concave and the radii of curvature of the first M1 and of the second M2 are substantially equal.

Advantageously, the ratio between:

- 15
- the distance calculated from the mirror M2 to the focus of the system formed of the first M1 and of the second M2 mirrors, and ;
 - the distance calculated from the mirror M2 and the focus of the M1 lies in the range [0, 1].
- 20

Advantageously, the focal length of the system formed by the first mirror M1 and the second mirror M2 multiplied by $2\sqrt{2}$ is substantially equal to the radius of curvature of the mirror M1 or M2.

25 Advantageously, the mirror M3 is convex and/or the mirror M4 is concave.

Advantageously, the mirrors M1, M2, M3 and M4 are axisymmetric, such that:

- 30
- M1 is aspherical to order 6;
 - M2 is an ellipsoid;
 - M3 and M4 are flattened spheroids.

Advantageously, the pupil of the telescope is on M3.

Advantageously, the aperture number is greater than or equal to
 35 3.8.

Advantageously, the inter-mirror gaps are substantially equal to the following values:

- $d(M1-M2) = 154\text{mm};$
- $d(M2-M3) = 80\text{mm};$
- 5 • $d(M3-M4) = 55\text{mm};$
- $d(M4\text{-image}) = 75\text{mm}.$

Advantageously, the linear field is $2^\circ \times 85^\circ$.

Advantageously, the telescope possesses a length substantially
10 equal to 170mm.

Advantageously, the telescope possesses a height substantially
equal to 45mm.

Advantageously, the telescope possesses a width of 110mm.

15 **BRIEF DESCRIPTION OF THE DRAWINGS**

Other characteristics and advantages of the invention will become apparent with the aid of the description which follows, given in relation to the appended drawings which represent:

- Figure 1 represents the diagram of the general principle of an
20 imaging telescope providing the image of an object to a Spectrometer;
- Figure 2 represents an embodiment of the arrangement of the mirrors M1 and M2;
- Figure 3 represents an embodiment of a four-mirror telescope
25 according to the invention.
- Figure 4 represents the system according to the invention seen from above.

DETAILED DESCRIPTION OF THE INVENTION

30 In the present invention, the system comprises four mirrors, the first two M1 and M2 of which have substantially the same radius of curvature. M1 is convex and M2 is concave.

An exemplary case of a case of embodiment described hereinafter is taken for a radius of curvature of M1 equal to 197 mm and a radius of
35 curvature of M2 equal to 203 mm. In the latter case, the two radii of curvature

are considered to be substantially equal apart from their sign, the mismatch between the two radii of curvature being 3%.

Among the various possible configurations of arrangement between M1 and M2, the system according to the invention makes it possible to arrange the mirrors M1 and M2 in such a way that the ratio between the algebraic distance between the image produced by M2 and the mirror M2 and the algebraic distance between the image produced by M1 and the mirror M2 lies in the range $[-1, 0]$.

In the present invention, the system comprises a mirror M1 of which a 6th-order shape distortion term makes it possible to correct certain aberrations. This term renders the mirror slightly aspherical.

Figure 1 represents the general principle of an imaging telescope TI generally associated with a slit spectrometer, notably in observation missions. The image 100' of an object 100 is formed from light rays 101 entering the telescope TI and convergent on exit from the telescope at the focus. The image 100' can then be the source of a slit spectrometer making it possible to disperse the light so as to spread the spectrum.

The system according to the invention is an imaging telescope of catoptric type comprising 4 mirrors, denoted M1, M2, M3 and M4 in the subsequent description.

An embodiment according to the invention proposes a telescope whose mirrors are slightly tilted with respect to one another. The field angle between the mirror M1 and the incoming light rays is close to 30° of angle.

An embodiment according to the invention proposes a telescope having reduced proportions. The overall proportions, for a focal length of 45mm, are: length 170mm, height 45mm and width 110mm.

In order to obtain a wide field, the catoptric system possesses a reduced number aperture, the latter is defined by the ratio F/D , "F" denoting the focal length and "D" the diameter of the entrance pupil denoting the aperture of the telescope, one then speaks of a "compact" telescope. An exemplary case of embodiment is taken for an aperture number equal to 3.8.

Such a ratio of focal length to aperture diameter makes it possible to obtain a wide field of the imaged object, the latter may be of the order of 85°x2° of rectangular shape.

Under these conditions the field admissible through the telescope

is +/- 42.5°.

In order not to degrade the image obtained by the four mirrors M1, M2, M3 and M4, forming a telescope of FMA type, the system according to the invention proposes to employ a convex first mirror M1 and a concave second mirror M2.

The mirrors are axisymmetric surfaces. The description of these surfaces is carried out on a meridian which is defined by the equation of the sag Z as a function of the distance h from the optical axis by the following formula:

$$Z = \frac{\frac{h^2}{R}}{1 + \sqrt{1 - (1+k)\frac{h^2}{R^2}}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10}$$

with the coefficients defined as follows:

- R: Radius of curvature at the vertex of the surface
- K: conicity constant of the surface
- A: shape distortion constant of order 4
- B: shape distortion constant of order 6
- C: shape distortion constant of order 8
- D: shape distortion constant of order 10

This distortion makes it possible to define the shape of the mirrors employed in the optical combination of the system.

The terms A, B, C, D are "asphericity" terms also called shape distortion terms, specific to the shape of the mirror.

In an embodiment, the invention proposes to employ four mirrors M1, M2, M3, M4 such that:

- the shape of M1 is aspherical to 6th order, the terms A, C and D are zero and B is nonzero.
- the shape of M2 is an ellipsoid, A, B, C, and D are zero and k lies between -1 and 0;
- the shape of M3 is a flattened spheroid, A, B, C, and D are zero and k is nonzero;
- the shape of M4 is flattened spheroid, A, B, C, and D are

zero and k is nonzero.

An embodiment makes it possible to arrange the mirrors in such a way that

- 5 • the distance D_{12} between M1 and M2 is substantially close to 155mm;
- the distance D_{23} between M2 and M3 is substantially close to 80mm;
- 10 • the distance D_{34} between M3 and M4 is substantially close to 55mm;
- the distance $D_{4\text{image}}$ between M4 and the image is substantially close to 75mm, this distance being called the "extension".

15 In an embodiment the ratio of the focal length to the inter-mirror gap is substantially close to 0.5. It may be of the order of 0.4 in a close case.

For an 85° linear field such as this, the system according to the invention reduces spherical aberrations, coma, astigmatism and field curvature to 3rd order.

20 Figure 2 represents a telescope formed of the centred mirrors M1 and M2.

The parallel light rays 1 and 1' are reflected by M1, convex type mirror, onto M2, the point 3 being considered to be the virtual object of M2, the source of the rays 4, 4' reflecting on M2. The final image being formed at
25 the focus 6 of the telescope.

In this example, the distance S_2 is the algebraic distance between the mirror M2 and the focus of M1, and on the other hand the distance S_2' is the algebraic distance between the mirror M2 and the focus of the telescope. The system according to the invention comprises two mirrors M1 and M2
30 whose ratio $\frac{S_2'}{S_2}$ lies in the interval [0,1].

The system formed of the mirrors M1 and M2 is aplanatic, it corrects the spherical aberrations and the coma to third order.

The system formed of the mirrors M1 and M2, in an embodiment, is combined with a mirror M3 of convex type which limits the aperture

diaphragm. In this case, the pupil of the telescope is situated on M3.

A case of embodiment makes it possible to employ a concave fourth mirror M4 which makes it possible to obtain a good quality image of the object of the catoptric system in an 85° field.

5 Figure 3 represents the association of the four mirrors M1, M2, M3 and M4 arranged in such a way that they are all substantially on one and the same axis, the drawing not being to scale. The light rays 200 arriving on M1 at an angle of close to 30° are reflected onto M2 then onto M3 and finally onto M4, the latter reconstructing the image at a point of the focal plane E of
10 the mirror M4.

Figure 4 represents a view from above of the system according to the invention where the width P corresponds to the width of the mirror M1.

The overall proportions L/H/P of the four mirrors arranged according to the system of the invention occupy a small space, a case of
15 embodiment having the following dimensions: 170mm/45mm/110mm. Such a dimension is similar to telescopes of FMA or TMA type.

The image quality is superior at the diffraction limit at 587nm on average in the field.

This type of linear field offers advantages in terms of
20 instantaneous field covered by the telescope.

The material used is preferably glass for the mirrors and carbon for the structure.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Wide-angle catoptric system with rectangular field for astronomy or Earth observation, comprising a first mirror, a second mirror, a third mirror and a fourth mirror, wherein the first mirror is convex, the second mirror is concave and that the radii of curvature of the first mirror and second mirror are substantially equal, the ratio between:

- the distance calculated from the second mirror to a focus of a system formed of the first and of the second mirrors ;
 - the distance calculated from the second mirror to a focus of the first mirror
- lying in the range $[0, 1]$.

2. Catoptric system according to Claim 1, wherein a focal length of the system formed by the first mirror and the second mirror multiplied by $2\sqrt{2}$ is substantially equal to the radius of curvature of the first mirror or the second mirror.

3. Catoptric system according to Claim 2, wherein the third mirror is convex.

4. Catoptric system according to Claim 3, wherein the fourth mirror is concave.

5. Catoptric system according to Claim 4, wherein the first, second, third and fourth mirrors are axisymmetric, such that:

- the first mirror is aspherical to order 6;
- the second mirror is an ellipsoid;
- the third mirror and the fourth mirror are flattened spheroids.

6. Catoptric system according to Claim 5, wherein a pupil of a telescope is on the third mirror.

7. Catoptric system according to Claim 6, having a numerical aperture that is greater than or equal to 3.8.
8. Catoptric system according to Claim 7, wherein the distance between the first mirror and the second mirror, the distance between the second mirror and the third mirror, the distance between the third mirror and the fourth mirror, the distance between the fourth mirror and an image are respectively and substantially equal to the following values:
 - 154mm;
 - 80mm;
 - 55mm;
 - 75mm.
9. Catoptric system according to Claim 8, wherein a linear field is $2^{\circ} \times 85^{\circ}$.
10. Catoptric system according to Claim 9, wherein the telescope possesses a length substantially equal to 170mm.
11. Catoptric system according to Claim 10, wherein the telescope possesses a height substantially equal to 45mm.
12. Catoptric system according to Claim 11, wherein the telescope possesses a width of 110mm.

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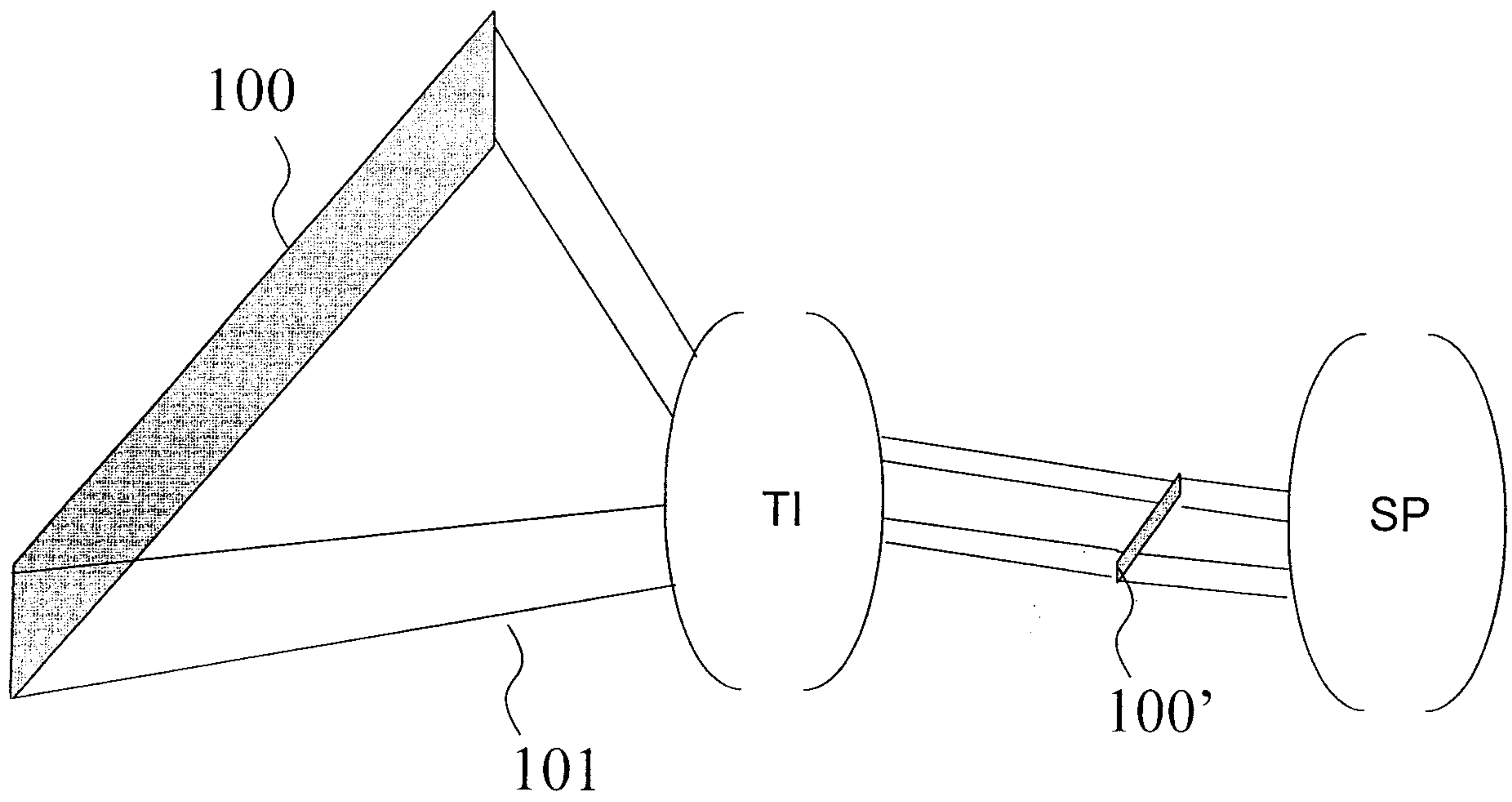


FIG.1

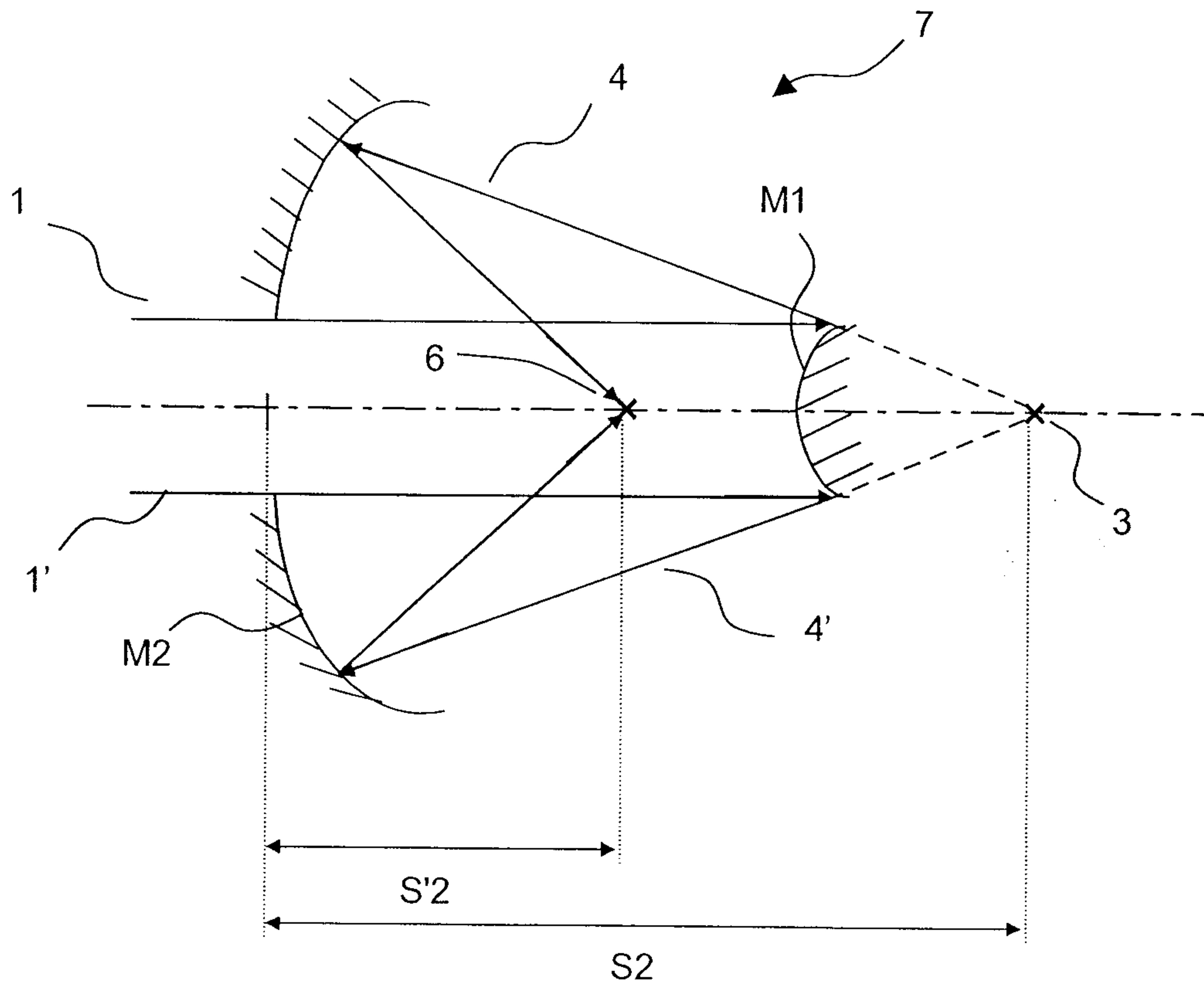


FIG.2

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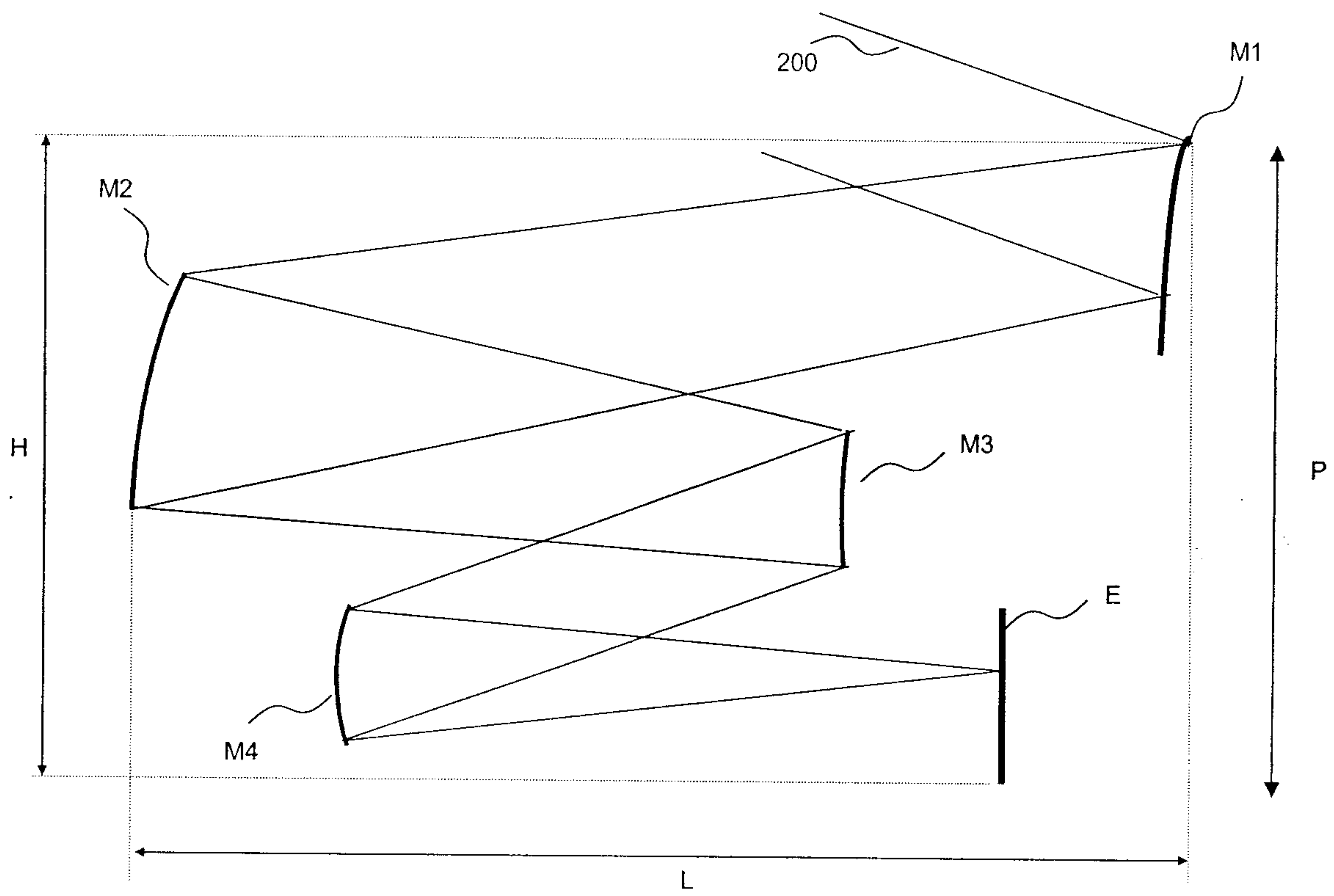


FIG.3

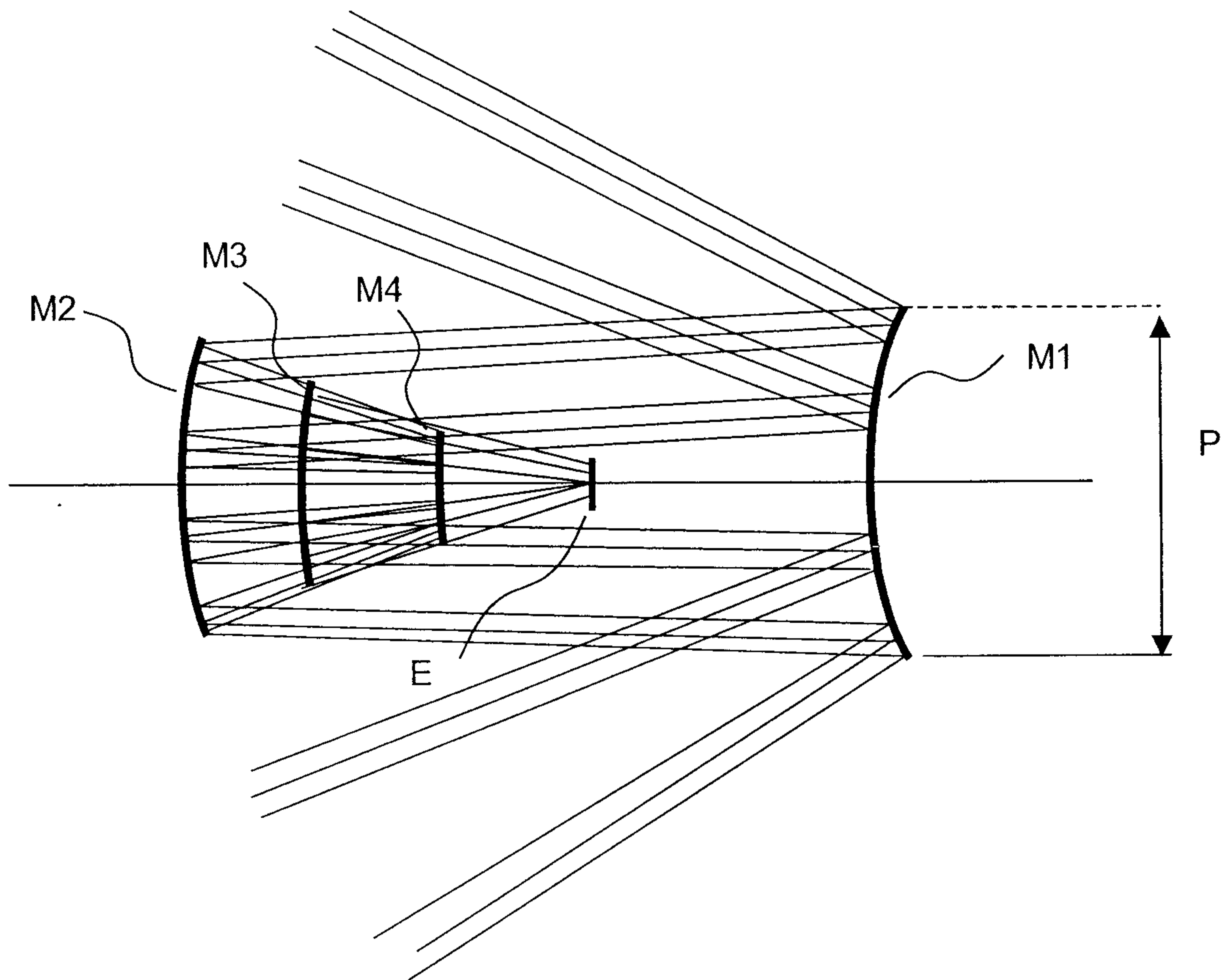


FIG.4

