Title: SHUTTER FOR SATELLITE TRACKING ANTENNA

Abstract: This invention provides a controllable e-m beam tracking shutter (20), and an arrangement for tracking LEO Satellites. A Luneberg lens (30) is used to project the locus of a LEO onto the tracking shutter formed of an array of controllable cells (31) controlled by controller (21) to pass wanted signals and to occlude unwanted signals. The controller may be programmed with the orbit information of constellation of LEOs. A collimating lens (84, 85) is also disclosed to improve the effectiveness of the shutter.
SHUTTER FOR SATELLITE TRACKING ANTENNA

Technical Field

This invention relates to a device for selectively blocking or passing electromagnetic radiation. In particular, the device may be used to form a matrix of cells which can be activated individually or in groups. A specific application of the invention is the selective opening of the cells of such an array to form the tracking mechanism for a LEO satellite communication system.

Background Art

The invention will be described in the context of an antenna arrangement for tracking LEO satellites.

To maintain continuous communication using a LEO satellite system, a pair of independently controllable mechanical tracking dish antennas are used so that, while a first antenna is tracking a first satellite within the communication window, the second antenna can lock on to a second satellite in preparation for a hand-over.

Typically a tracking antenna may have a beam width of the order of a few degrees, often one degree or less. Thus the mechanical tracking system must be fairly precise. A LEO satellite may be “in view” for only a few minutes and continuous use causes wear of precision components, making accurate tracking difficult.

To extend the life of these components, in some systems the tracking mechanism is switched off during “quiescent” traffic periods, or the antenna may be turned on only when the user wishes to transit or receive. However, increasingly there is a demand for “off-line” data push services where an agency needs to supply data to a subscriber. This can be done in a cost effective manner by transmitting the data during quiescent periods.

A particular problem which affects some LEO satellite systems is that they may use the same band as geo-stationary satellite. Thus it is necessary to prevent interference between the two systems which may occur when a LEO passes between a ground based transceiver and a geo-stationary satellite.
Disclosure of the Invention

This specification discloses an e-m beam shutter including a controllable element having a first state and a second state and control means to selectively switch the shutter between the first state and the second state,

- wherein in the first state, the shutter deflects incident radiation along a first path, and in the second state, the shutter permits or causes incident radiation to follow a second path.

The specification also discloses an array of shutters as claimed in any one of claims 1 to 4, the array including a programmable controller programmed with the locus of one or more moving sources of e-m radiation;

- e-m focussing means to focus e-m radiation from a moving source in a focal plane to produce a corresponding locus;

- the array being located at or near to the focal plane to block or pass the e-m radiation;

- the shutters of the array in the locus being opened sequentially by the controller to permit the passage of radiation as the focal point approaches the shutter.

The specification also discloses a paralleling lens adapted to convert input radiation into substantially parallel output radiation, the lens having a refractive index increasing from input to output.

Brief Description of the Drawings

Figure 1 shows a prior art arrangement of a pair of dish antennas using mechanical tracking.

Figure 2 shows an array of cells making up a tracking shutter embodying the invention.

Figure 3 to 6 show various embodiments of tracking antennas utilising a tracking shutter.

Figure 7 shows the function of a paralleling lens.

Figure 8 shows an analysis of the beam path through the paralleling plate;

Figure 9 is a graph showing the angle of refraction for differing values of relative refractive index of the paralleling plate.
Figure 10 shows an implementation of a LEO tracking antenna including a paralleling plate embodying the invention.

Figure 11 shows a section through a modified paralleling plate adapted to receive radiation over a wide input range.

Figure 12 shows a further development of the embodiment of figure 11 which can be used to produce a concentration of the input radiation on to a target area.

**Best mode of carrying out the Invention**

Figure 1 illustrates the dual mechanical tracking antenna arrangement of the prior art.

A pair of dish antennas, 1 and 2, are mounted on universal mountings 3 and 4, with independent drive controls 5 and 6. The antennas 1 and 2 are electrically connected to a transceiver 9 by connections 7 and 8. The antennas 1 and 2 are programmed and controlled to track different satellites, one antenna locking on to a satellite newly arrived in the window while the other antenna tracks an earlier satellite. A hand-over of the communication is arranged as the earlier satellite moves out of range, e.g. as it approaches 10° above the horizon.

Figure 2 illustrates an array of cells, 20, which are individually controllable to block or enable the passage of the e-m beam, such as the microwave band used by LEO systems. The array is shown as circular because the tracking antenna may have to track satellites within a spherical field of view of ±160°. However the shape of the array may be chosen to suit the particular application. For example, the array may be rectangular if a narrow scanning zone is required.

A controller 21 is connected to the array to open or close cells as required. The controller 21 may be programmed to open a sequence of adjacent cells, to mirror the path of a LEO satellite. Two or more satellites may be tracked simultaneously. The cells are opened in sequence on an “open-before-close” basis so that a newly opened cell is opened before the preceding cell is closed.

The cells may be miniaturized flip-disc type cells, being a scaled shown vision of the flip-disc public display systems, the discs being made of a material which reflects the e-m beam when the cell is closed, the disc being rotated to be substantially parallel to the e-m beam when the cell is open.
In a second mechanical movement embodiment the discs may be of a material which has a refractive index such that when the angle of incidence of the e-m beam is greater than a critical angle, the beam is reflected, and when the angle is less than the critical angle, the beam passes through the disc. The disc is thus controlled to tilt it mechanically to pass the beam to a target, or reflect or refract the beam away from the target.

In an alternative embodiment the cells may be composed of material whose refractive index or other optical or quasi-optical properties can be changed, e.g. by the application of light, or an electric field, or heat, or a magnetic field.

By changing the refractive index of the cell, the e-m beam can be deflected towards or away from a path which leads to or away from an antenna.

Photonic Spectra August 1997 discusses non-linear optical materials whose properties, including refractive index, can be changed by electrical or optical energy (see abstract at www.laurin.com/content/aug97/techhybrid.html).

Alternatively, a magnetic field may be used to alter characteristics of the material, such as optical transparency (Photonics Spectra, December 1997, www.laurin.com.dec97/techmag.html).

Figure 3 shows a first arrangement for a tracking antenna utilizing a shutter embodying the invention. The arrangement includes a first e-m lens such as a Luneberg Lens 30, a tracking array 31, a second e-m lens means 32 (e.g. a Fresnel lens), and an antenna 33. The first lens 31 focuses the incident beams onto a focal plane. The shutter array 31 is located at or near the focal lane. Thus the beam 34a, 34b is focused onto cell 35 of the shutter array. As the satellite moves across the field of view, the lens traces its locus on the focal plane so that a sequence of cells are illuminated, mirroring the passage of the satellite. A satellite moving from right to left will illuminate a locus moving a left to right.

The controller may be programmed with the orbit information of the constellation of satellites to enable it to track the projected locus.

To reduce the processing demands on the controller, the controller may only be programmed to track those satellites in the constellation which are within the window of the tracking system.
The information on the satellite orbits may be updated periodically to maintain the accuracy of the tracking.

As an example, Figure 3B shows the locus 100 of a satellite illuminating cells 101 to 110 in sequence.

The controller 21 (not shown in Figure 3B) opens the cells 101 to 110 in sequence, each cell being opened as the locus of the satellite approaches the cell, and being closed after the satellite locus has passed over the cell.

The second lens is used to focus the beams to (received beam) or from (transmitted beam) the antenna 33.

In this way, only beams to or from satellites within the aperture of the open cells can be transmitted or received via the antenna 33.

As the first locus 100 approaches the edge of the array, e.g. at cell 108, the controller 21 begins tracking a second satellite e.g. locus 111. Thus cell 120 or one of the subsequent cells (121 to 127) is activated before communication is lost with the first satellite, and a hand-over to the new satellite is initiated.

Figure 4 shows an arrangement similar to Figure 3, in which the lens 32 is replaced by a series of concentric annular reflectors 36 which deflect the beams to the antenna 33. The reflectors are arranged to collect beams from the corresponding cells and direct the beams to the antenna 33.

The embodiment shown in Figure 5 is similar to the embodiment shown in figures 3 and 4, but the second "quasi-optical" device, 37, is a selfoc lens having a radially graded index to focus the beams on the antenna 33.

The embodiment of Figure 6 has an additional element, paralleling lens 38.

The paralleling lens has the characteristic that, whatever the angle of incidence of the beam entering the lens, the output beam has a decreased divergence and is bent towards the normal to the refractive index gradient, (assuming transmission from less to greater refractive index) independent of where the incident beam strikes the lens. This differs from a normal convex lens where beams from any specific point on the focal plane exit in parallel to a line between the centre of the lens and the specific point on the focal plane.
A paralleling lens may be flat rather than lenticular and have a stepped or progressively increasing refractive index from the input to the output. This may be manufactured simply by laminating two or more layers having progressively increasing refractive indices. The increasing refractive index causes the incident beams to be deflected towards the normal. Thus whatever the incidence angle, all beams can be made to exit with a decreased divergence.

The use of the paralleling lens in conjunction with the shutter array simplifies the operation of the shutter array and the subsequent handling of the output beam, because all the beams incident on the array arrive at substantially the same angle. This averts or reduces the need to make significant geometric or refractive index adjustments for the cells in accordance with the location of the cells in the array. Thus the cells may not need to be inclined at significantly different angles within the array, and the same refractive index materials can be used in all cells. Depending on the configuration and operating conditions, the use of the paralleling lens means that little or no adjustment to these characteristics is necessary.

The paralleling lens located in the focal plane of a normal lens has the effect of transforming the groups of intersecting rays focussed on a specific focal point into a cohesive group of substantially parallel rays rather than continuing to diverge after passing through the focal point. The groups of rays corresponding to different focal points retain the relative geometric relationships with each other corresponding to the relative geometric relationship between the focal points. In other words the relative positions of the input points map across to the output.

Because all the groups of rays are substantially parallel, this standardizes and simplifies the design of the cells of the array.

Preferably, the paralleling lens should be located close to the array and/or have a matching refractive index material.

Figure 7 shows the transformation of non-parallel rays intersecting at a point, 71, on the input surface of a paralleling lens 70, to a first group of substantially parallel rays, 72, at the output of the lens. The inset depth (d) / refractive index (n) graph, 77, indicates that refractive index increases with depth.
A second group of rays, 73, intersect at a second point, 74, and are transformed into a second group of substantially parallel rays, 75.

The first and second groups of substantially parallel rays are shown projected onto a plane, 76, which represents the shutter array.

The intersecting rays on the incident face of the lens represent the focussed rays from a satellite at different points on its orbit, after the rays have been focussed by a focussing lens.

As can be seen, the relative geometric positions of the rays are maintained after passing through the paralleling lens. This means that the rays strike the cells of the array at substantially the same angle, simplifying the construction and operation of the cells, as it reduces or avoids the necessity to correct for the non-parallel nature of the rays emerging from the focussing lens.

It should be noted that the paralleling lens can be used to deflect the angle of the existing rays simply by tilting the paralleling lens, because the rays leaving the lens are deflected towards the normal to the refractive index contour of the lens. In a mechanically tilted array, the paralleling lens may be used as the array element, as tilting the element deflects the rays.

In an alternative embodiment, the array may have all its elements “open” except for the elements directed to the geo-stationary satellite or, if there is more than one geo-stationary satellite, the cells directed to the geo-stationary satellites are occluded. In this way, the array can transmit and receive in all directions except in the direction of the geo-stationary satellites, so that interference between the ground based terminal and the geo-stationary satellites is prevented.

Because the cells pointed at a geo-stationary satellite are always closed, a hand-over to a second LEO satellite is necessary before the first LEO satellite enters the “field of view” of the occluded cells. Thus the control system monitors the locus of the LEOs in relation to the position of the known geo-stationary satellites, and initiates a hand-over when the LEO locus approaches intersection with an occluded cell.

Due to the fact that the angle of incidence can vary between $+10^\circ$ to $+170^\circ$ above the horizon, the paralleling lens may be modified to function better over the
160° range. Allowing for the fact that the extreme incident angles will strike nearer the periphery, the parapelling effect can be reinforced in a concentric fashion to better maintain the parallel nature of the output, while also reducing the reflection of energy due to the low angle of incidence, i.e., the nearer the incident beam is to being parallel to the surface, the more energy is reflected. Thus, by having the edges of the parapelling lens raised to present a concave surface to the incident beam, more of the incident energy can be captured.

Accordingly, the parapelling plate has a radial graduation of its refractive index whereby incident radiation beams at large angles of incidence strike the plate near its periphery and are refracted more than the beams striking nearer the centre.

In a further modification of this embodiment, the radial graduation is achieved by laminating a series of concentric annuli having progressively increasing refractive indices and increasing inner radii. Preferably, the interface surfaces between the rings are sloped to optimize the refraction of the beams, so that, for example, the output beams all travel in substantially the same direction. Alternatively the sloping of the interface surfaces may be used to focus the beams to a target area.

Figure 8 shows an optical or quasi-optical arrangement including a lens 83, conceptually illustrated as a straight line and a parapelling plate 86. The parapelling plate has a first layer 84 having a refractive index $N_A$ at the wavelength of interest, and a second layer 85 having a refractive index $N_B$, where:

$$N_B > N_A \quad \text{and} \quad \frac{N_B}{N_A} = N$$

Lens 83 focuses incoming parallel rays 81 and 82 at the interface between layers 84 and 85. Ray 81, after passing through lens 83, strikes the interface at an angle $\theta_1$ to the normal to the interface and is refracted into layer 85 at an angle $\phi_1$. Because $N_B > N_A$, the refracted angle $\phi_1$ is less than $\theta_1$. Similarly for ray 82, $\phi_2 < \theta_2$. However according to Snell’s law, $N = \frac{\sin \theta_1}{\sin \phi_1}$ so that the sine of the angle of refraction is proportional to the sine of the angle of incidence. As the graph in Figure 9 shows, the consequence of this is that the deflection is proportionally greater than the angle of incidence, due to the flattening of the sinusoid curve.
The graph of Figure 9 has a Y axis representing the sine of an angle and an X axis graduated in degree of angle and shows a first curve, Sin A, representing the sine of the incident angle, and four other curves representing the sines of the corresponding angles of refraction for values of N equal to 1.1, 1.2, 1.4, and 1.8, the curves being progressively lower as N increases.

If a vertical line is drawn on the graph from an angle chosen as an incident angle, the vertical line will intersect the refraction curves at the corresponding value of the sine of the angle of refraction appropriate for the corresponding value of N.

Thus the graph can be used to determine the sine of the angle of refraction for a given angle of incidence and a given value of N.

In Table 1, the first column represents angles in degrees and column 2 represents the sine of these angles. Columns 3 to 9 represent the sines of the corresponding angles of refraction for the values of N ranging from 1.1 for 1.8 appearing at the head of the corresponding columns. Using this table the sine an angle of refraction can be determined for a known value of N for a given angle of incidence. Hence the angle of refraction can be determined from its sine.

The graph of Figure 9 or Table 1 can be used to determine the angle of refraction. For instance, referring to figure 9 and Table 1, suppose that:

\[ N = 1.2 \quad \& \quad \theta_1 = 50^\circ \quad \& \quad \theta_2 = 80^\circ \]

Then Sin \( \phi_1 = 0.63833 \) & Sin \( \phi_2 = 0.82067 \)

Thus \( \phi_1 \approx 44^\circ \) & \( \phi_2 \approx 65^\circ \)

Thus ray 1 has been refracted by an angle \( \theta_1 - \phi_1 = 50^\circ - 44^\circ = 6^\circ \), and ray 2 has been refracted by an angle \( \theta_2 - \phi_2 = 80^\circ - 65^\circ = 15^\circ \)

The beam divergence angle for the beam bounded by ray 81 and ray 82 has thus been reduced from \( \theta_2 - \theta_1 \) to \( \phi_2 - \phi_1 \), i.e. from 30° to 21°. This narrowing of the beam divergence increases with the value of N.

Hence for \( N = 1.4 \), retaining \( \theta_1 = 50^\circ \) & \( \theta_2 = 80^\circ \),

\( \phi_1 \approx 37^\circ \) & \( \phi_2 \approx 51^\circ \), giving an output beamwidth of \( 14^\circ \).

Similarly for \( N = 1.8 \), the beam width is reduced to \( 36^\circ - 28^\circ = 8^\circ \).
Figure 10 shows an implementation of a LEO tracking antenna using the quasi-optical characteristics of microwaves. A focussing lens 83, eg. a Luneberg lens, conceptually shown as a straight line, focuses microwave radiation (rays 81 & 82) onto a paralleling plate 86, also shown as a straight line. A controllable array of microwave gates 110 is located under the paralleling plate. The gate array may be controlled by control means 103 to track the locus of a LEO as it transits the field of view. Cells of the array are opened in sequence to permit the signals to pass while cells pointing (via lens 83) to unwanted sources of radiation remain closed.

The paralleling plate 86 narrows the beam and facilitates its passage through the cells of the array, which may be sensitive to the incident angle of the radiation. In addition the narrowing of the beam facilitates the focussing of the radiation onto the target area (antenna 112) by the collecting lens 111, also shown conceptually as a line.

Figure 11 shows a cross-section through a paralleling plate made up of two or more annular elements 121, 122, 123.

Annulus 122 has a triangular shape and its major sides are designed to interface with annulus (in this example, disc) 121, and annulus 123 which also has a triangular section. The refractive index of 123 is less than the refractive index of 122, which is less than the refractive index of 121.

As shown in Figure 11, the interfaces between at least some of the rings are sloped, to accentuate the angle of incidence.

The advantage of this arrangement is that, for example in the embodiment of figure 10, when the elevation of the LEO is low in the sky, the radiation would strike the paralleling plate at a skimming angle, and much of the radiation may be reflected rather than refracted. The low elevation radiation strikes the plate near its periphery. Thus by tilting the outer edges up in the Figure 11 embodiment, more of this radiation is refracted and less is reflected.

By judicious selection of the refractive indexes of the different receiving zones of the plate, the radiation output may be kept substantially parallel irrespective of the elevation of the LEO.
While it may be possible to build up a single plate having the appropriate RI profile, e.g. using CVD, this would be a complex operation, but is still within the scope of this invention. However, the manufacture of such a plate is simplified by the use of the triangular sectioned annulus technique illustrated in Figure 11.

The plate of figure 11 may also be extended to produce a focussing lens by having a further stack of such rings on the lower side of disc 21, with the refractive indices continuing to increase in the same direction.

This is illustrated in Figure 12, in which a further annulus 22' is applied under 21, and then another annulus 23' is applied under 22', the refractive index of 23' being greater than that of 122', which in turn is greater than the RI of 121. By appropriate choice of the angle of interface and RIs, a reasonable focus may be achieved.

Thus the triangular sectioned rings can be used to achieve both a narrowing of the beam and a change of direction, because the change of angle of the interface between the rings effectively increases the angle of incidence and hence produces a greater change in the angle of refraction.
The claims defining the invention are as follows:

1. An e-m beam shutter including a controllable element having a first state and a second state and control means to selectively switch the shutter between the first state and the second state,

   wherein in the first state, the shutter deflects incident radiation along a first path, and in the second state, the shutter permits or causes incident radiation to follow a second path.

2. A shutter as claimed in claim 1, wherein the controllable element is a rotatable mechanical disc.

3. A shutter as claimed in claim 1, wherein the controllable element is a tiltable refraction element adapted to reflect the incident radiation in a first position and to transmit the incident radiation in a second position.

4. A shutter as claimed in claim 1, wherein the controllable element is a cell having a controllable refractive index to selectively switch the radiation between the first and second paths.

5. A paralleling lens adapted to convert input radiation into substantially parallel output radiation, the lens having a refractive index increasing from input to output.

6. A lens as claimed in claim 5, wherein the refractive index is stepped or graded.

7. A lens as claimed in claim 5 or 6, having a planar input surface and the planar output surface, the output surface being parallel with the input surface.

8. An array of shutters as claimed in any one of claims 1 to 4, the array including a programmable controller programmed with the locus of one or more moving sources of e-m radiation;

   - e-m focussing means to focus e-m radiation from a moving source in a focal plane to produce a corresponding locus;
   - the array being located at or near to the focal plane to block or pass the e-m radiation;
the shutters of the array in the locus being opened sequentially by the controller to permit the passage of radiation as the focal point passes over the shutter.

9. An array as claimed in claim 8, wherein a paralleling lens as claimed in any one of claims 5 to 7 is located in the focal plane between the focusing lens and the shutters of the array.

10. A tracking array substantially as herein described with reference to the accompanying drawings.

11. A paralleling lens substantially as herein described with reference to the accompanying drawings.

12. A shutter substantially as herein described with reference to the accompanying drawings.

13. A wave transmission modifying element including at least a first region having a first refractive index, the first region interfacing with a second region having a second refractive index, the second refractive index being greater than the first refractive index, whereby waves passing from the first region to the second region are bent towards the normal to the interface between the first and second regions.

14. A wave transmission modifying element having a first refractive index at a first surface side and a second refractive index at a second surface, the refractive index changing in a step-wise or graded fashion from the first surface to the second surface.

15. An element as claimed in claim 13 or claim 14 wherein, at the low RI surface, the RI decreases from the centre to the periphery.

16. An element as claimed in any one of claims 13 to 15 wherein the low refractive index surface is concave.

17. An element as claimed in any one of claims 13 to 16 wherein the refractive index on the high RI surface increases from the centre to the periphery.

18. An element as claimed in any one of claims 13 to 17 wherein the high RI surface is concave.

19. An element claimed in any one of claims 13 to 18 wherein the interface between the low RI and high RI zones is dome shaped.
20. An element as claimed in claim 16 or claim 18 wherein the concave surfaces are built up by layers of triangular or tapered sectioned rings whose metering faces are substantially parallel, the inner diameter of the rings decreasing progressively towards the inner layer to expose a portion of each successive underlying ring.

21. A wave transmission modifying element substantially as herein described with reference to the accompanying drawings.

22. A LEO satellite tracking antenna system including a quasi-optical e-m wave path including:
   - a first lens, to direct em signal waves to or from a LEO satellite;
   - a wave transmission modifying element as claimed in any one of claims 13 to 21; and
   - an e-m wave gate array blocking e-m waves from unwanted sources.

23. A system as claimed in claim 22 wherein the wave path is bi-directional.

24. A system as claimed in claim 22 or claim 23 wherein the element and the gate array located near the focal plane of the first lens.

25. A system as claimed in claim 24 including a controller controlling the gate array to track the projected locus of the satellite.

DATED THIS TWENTY SIXTH DAY OF OCTOBER 2000

ALCATEL
\[
\text{Na} \times \sin \text{A} = \text{Nb} \times \sin \text{B} \\
\text{Nb}/\text{Na} = N \quad \text{Refractive index of output/R.I. of input = Relative R.I.} \\
^*\text{A}^* \text{ is the incident angle measured from the NORMAL} \\
^*\text{B}^* \text{ is the angle of refraction measured from the NORMAL}
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<th>Sin &quot;B&quot; (Angle of Refraction)</th>
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**TABLE 1**
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl.?: G02F 1/29, G02B 26/08, H04B 10/105, H01Q 19/06, G02B 3/00, H01Q 15/02, 15/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G02F 1/29, 1/31, 1/315, 1/33, G02B 3/-, 9/02, 26/08, 26/10, 27/30, G03B 9/-, H04B 10/-, 9/-, H01Q 15/-, 19/-, 21/-, C03B 23/22, F21V 5/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI, JAPIO, IFIPAT: IPC as above with keywords:- electromagnetic radiation, light, infrared, microwave, shutter, switch, deflect, reflect, refract, pass, transmit, open, path, direct, rotat, tilt, pivot, angle, refractive index, lens, quasi-optical, increase, decrease, vary, step, stepped, grade, change, first, second, greater, larger, smaller, parallel, converg, collimat, condens

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>X</td>
<td>US 5949594 A (IGLSEDER et al) 7 September 1999 Col 3 lines 30-37, col 6 lines 33-49; fig 2</td>
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<tr>
<td>X</td>
<td>US 5579149 A (MORET et al) 26 November 1996 Abstract</td>
<td>1, 2</td>
</tr>
<tr>
<td>X</td>
<td>US 5299054 A (GEIGER) 29 March 1994 Col 2 line 20 - col 3 line 6, col 4 line 3 - col 5 line 31; figs 3, 4</td>
<td>1, 4</td>
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X Further documents are listed in the continuation of Box C  X See patent family annex

Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means "W" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search 12 January 2001

Date of mailing of the international search report 16 January 2001

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<td>X</td>
<td>EP 207725 A (THE GENERAL ELECTRIC COMPANY) 7 January 1987 Whole document</td>
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<td>X</td>
<td>FR 2601786 A (TELECOMMUNICATIONS RADIOELECTRIQUES ET TELEPHONIQUES, T.R.T.) 22 January 1998 figs</td>
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<td>X</td>
<td>Derwent Abstract Accession No. 97-158236/15, Class V07, JP 08-271811 A (HITACHI CABLE LTD) 18 October 1996 abstract</td>
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<td>US 4836629 A (HUGNARD et al) 6 June 1989 Whole document</td>
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<td>US 5617252 A (MANHART et al) 1 April 1997 Figs 1, 11, 13, 14</td>
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Form PCT/ISA/210 (continuation of Box C (2)) (July 1998)
**INTERNATIONAL SEARCH REPORT**

**Box I**  Observations where certain claims were found un searchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. □ Claims Nos:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☑ Claims Nos:  **10-12, 21**
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
   These claims rely on references to description and drawings (Rule 6.2(a))

3. □ Claims Nos:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

**Box II**  Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. Claims 1-4, 8, 9 directed to an e-m beam shutter having control means to selectively switch a controllable element of the shutter between a first state and a second state, wherein in the first state the shutter deflects incident radiation along a first path, and in the second state the shutter permits or causes incident radiation to follow a second path. It is considered that the combination of control means and controllable element having the defined first and second states comprises a first "special technical feature".

2. Claims 5-7, 13-20, 22-25 directed to a lens or wave transmission modifying element having regions of different refractive index, which is considered to comprise a second separate "special technical feature".

   1. ☑ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims
   2. □ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
   3. □ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. □ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  

**Remark on Protest** □ The additional search fees were accompanied by the applicant's protest.

☑ No protest accompanied the payment of additional search fees.
This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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