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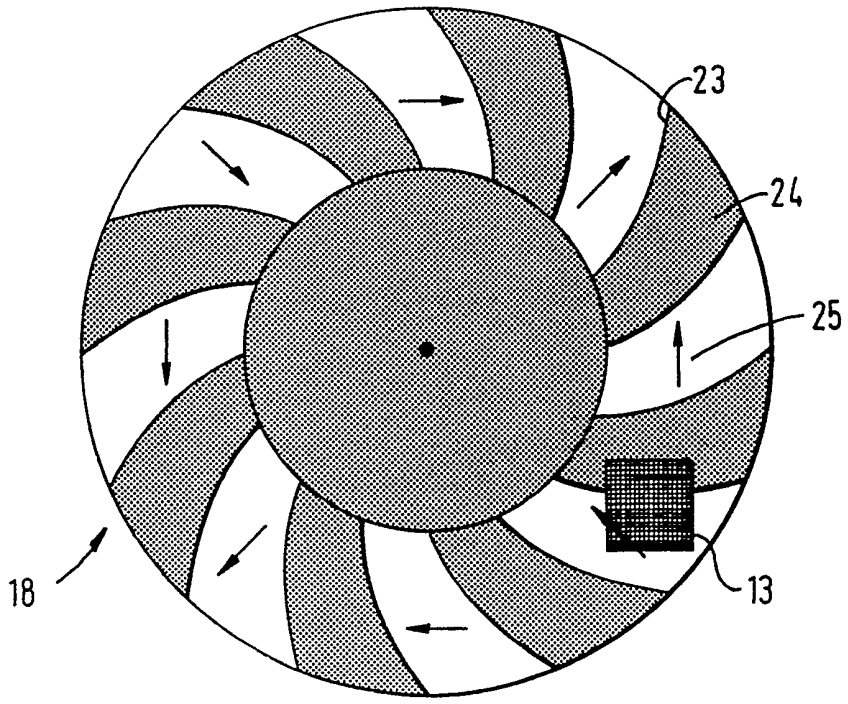
(56) Documents cited
GB 2204210 A GB 2152781 A EP 0133890 A2

(58) Field of search
UK CL (Edition K) H4F FCB FCC FCK FDX FJB FJC FJS
INT CL[5] H04N

(54) An imager with image microscanned over sensor array

(57) An IR imager in which an image is microscanned i.e. dithered, over a sensor array comprises a member 18 for interrupting radiation between a lens and the sensor array of imaging elements 13. The member 18 comprising alternate refractive transmissive regions 25 and non transmissive regions 24. The transmissive regions 25 refracting radiation transmitted through them in the direction shown by the arrows. As the disc rotates across the array 13 the image focused on it moves giving successive frames which are shifted relative to one another.

FIG.6



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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FIG.1A

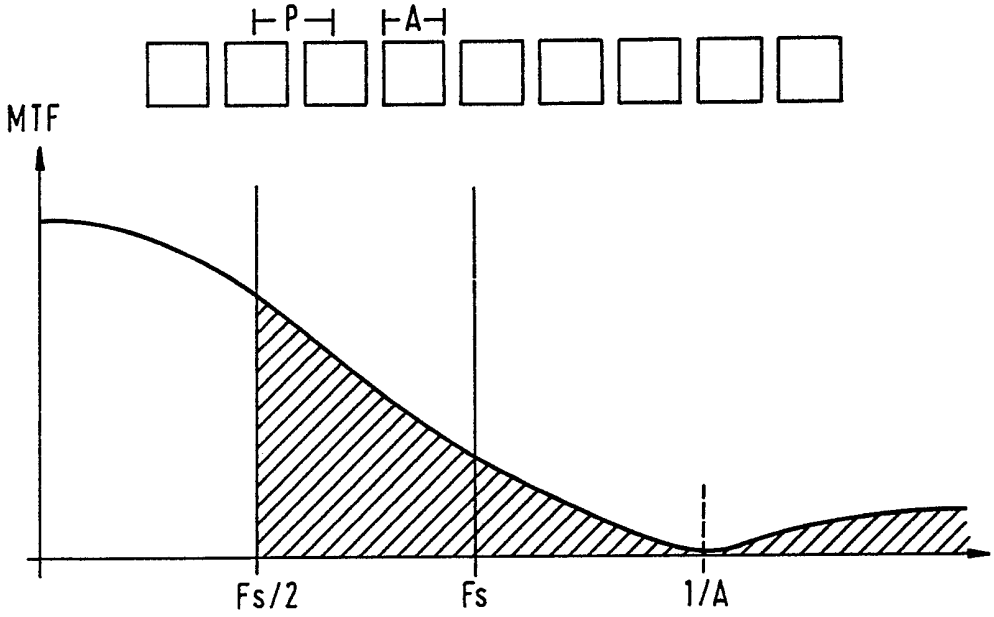


FIG.1B

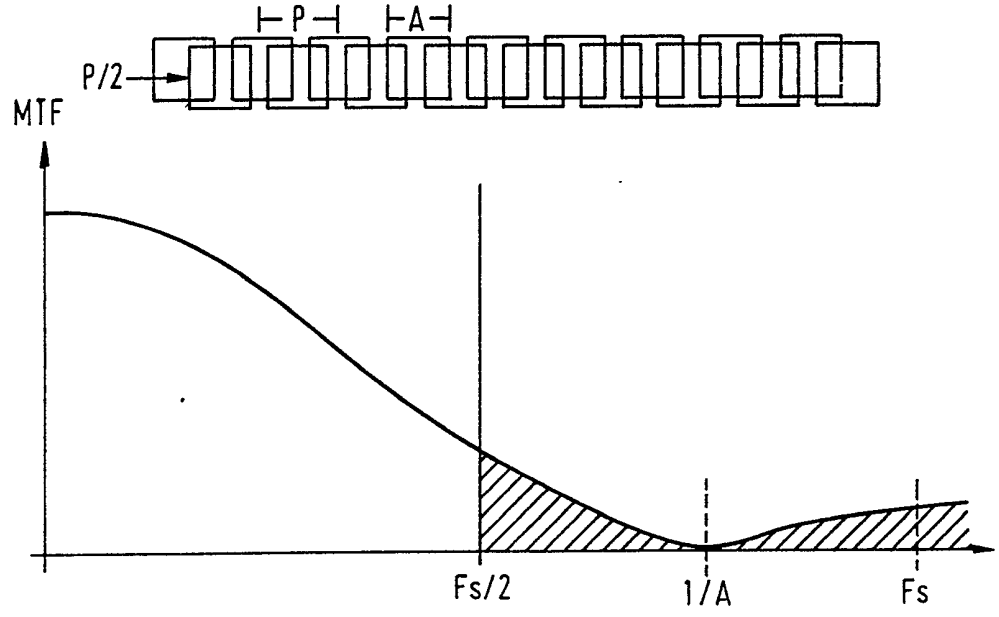


FIG. 2

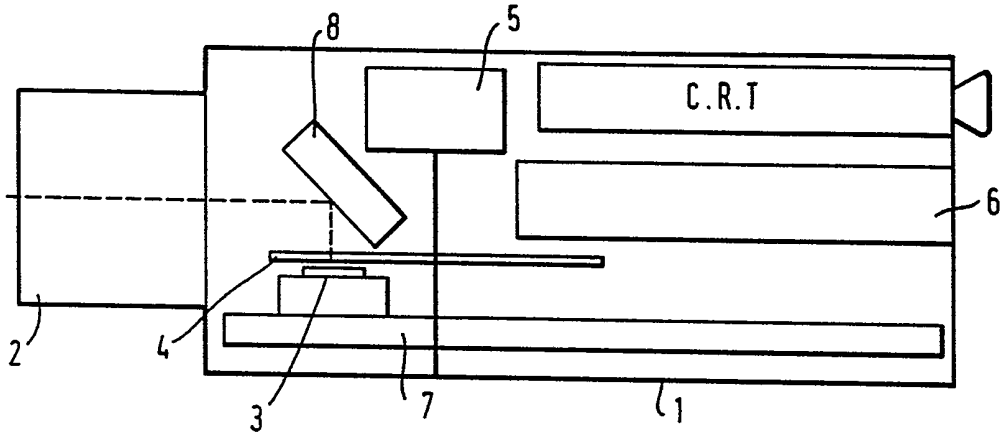


FIG. 3

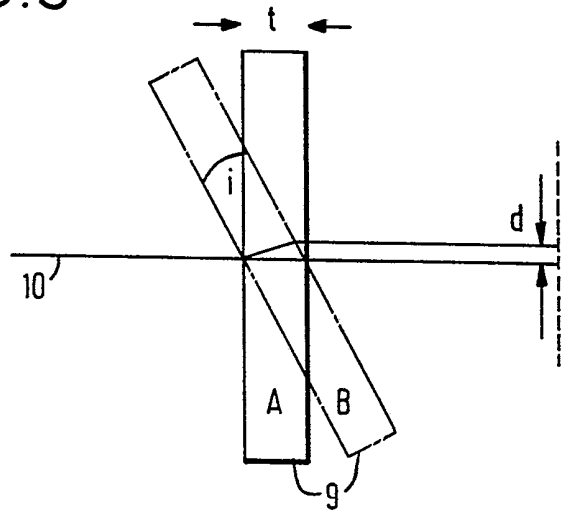


FIG.4

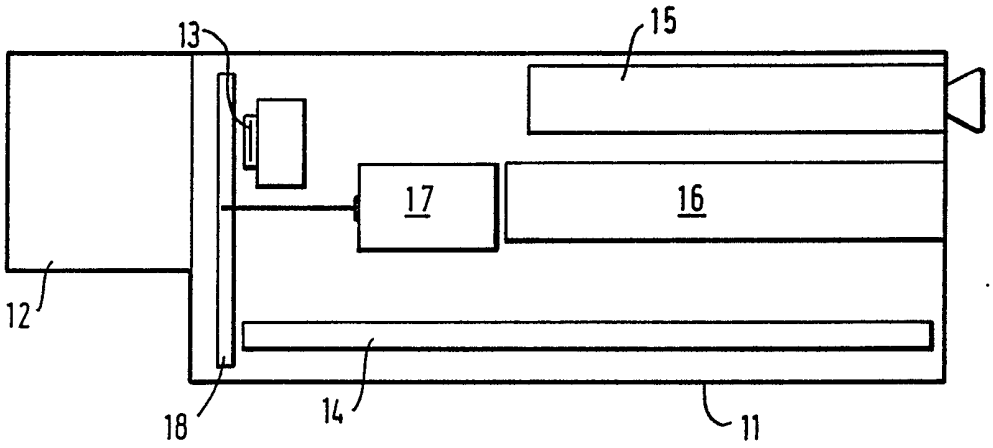


FIG.5

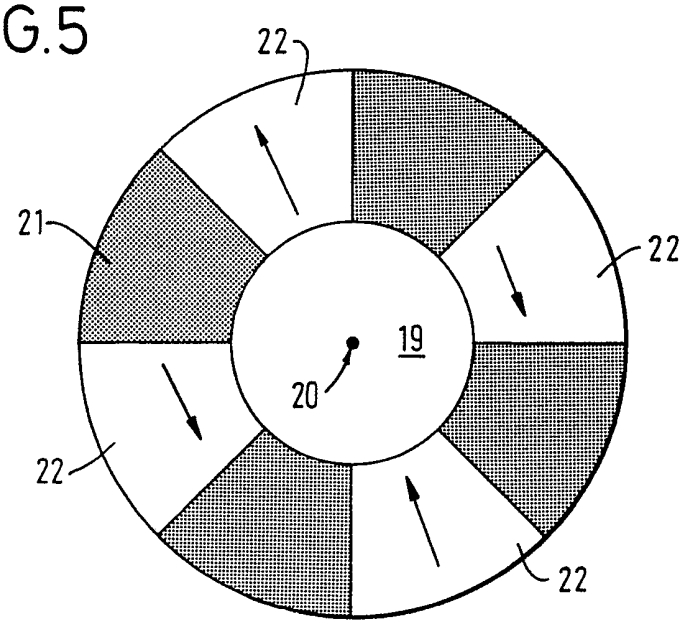


FIG.6

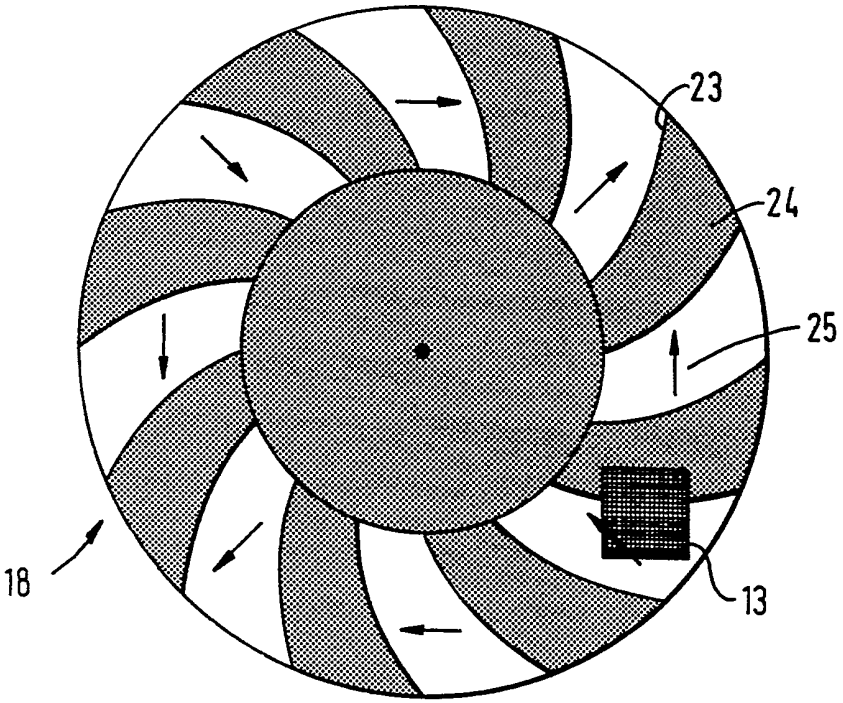
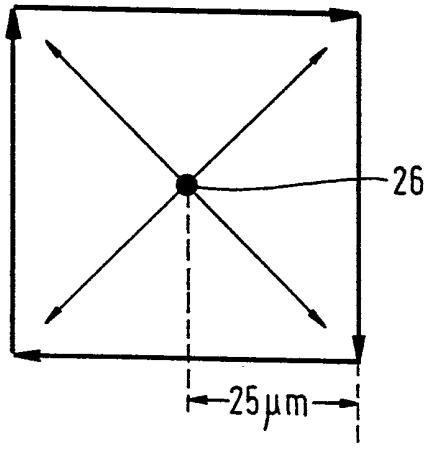


FIG.7



An Imager

This invention relates to an imager using Focal Plane Arrays (FPAs), and in particular but not exclusively to such imagers, imaging in the Infra Red (IR) wavebands.

IR imaging systems are becoming more important in many fields now, in particular military, security and search and rescue applications. Early IR imagers employed a small number of detector elements, across which was scanned an IR image of the scene via a system of mirrors and polygons. More recent developments include imagers based on 2 dimensional arrays of detector elements, so called staring arrays, which require no scanning to produce a useful image of the scene. The dwell time available for each detector element in such systems is considerably increased over earlier scanner systems resulting in significantly improved system performance being achievable from comparable detector materials. The IR system designer can choose whether to exploit this increase in performance or use a lower performance detector material to achieve a similar sensitivity as in the earlier scanner systems. High system performance is typified by imagers based on arrays of Cadmium Mercury Telluride cooled to liquid nitrogen

temperatures, whilst conventional levels of performance are achieved by imagers based on Schottky barrier arrays and pyroelectric ceramics. These latter systems offer significant advantages in terms of cost and or logistical support requirements (such as coolant supplies) over the high performance systems.

Unfortunately, several disadvantages of FPA imagers must be overcome to provide performance comparable with conventionally scanned imagers. Current FPAs are only available in limited pixel counts, typically 128x128 or 256x256 elements, which is insufficient to match the spatial resolution of the best scanned imager systems. Eventually, the development of suitable fabrication technologies will overcome this problem, resulting in large pixel densities.

A more fundamental problem, however, concerns the basic physics of imaging via a focal plane array. This is shown schematically in Figure 1a, where a single row of elements from the detector array is considered. For simplicity the elements are considered square in shape, of length given by A, and are fabricated with a pitch P. The modulation transfer function (MTF) of a single element in the array is given by the modulus of the sinc function, as shown in the figure, with the first zero occurring at a

spatial frequency of 1/A. Since an array of such elements is used, this MTF as shown in Figure 1a is convolved with a series of delta-functions separated by spatial frequencies of Fs(=1/P), the sampling frequency. As shown in the figure, this results in a folding of the MTF curve into the area between 0 and Fs/2. Spatial frequencies higher than Fs/2 which are present in the image are reproduced by the array as lower, alias frequencies in the range 0 to Fs/2. For 2 dimensional arrays the effect is much worse than Figure 1A shows, since aliasing occurs in both axes simultaneously. The effect is similar to conventional data sampling limitations, governed by Nyquist's Theorem, except that it occurs in the spatial domain rather than in the post detection electronics.

For staring systems, therefore, the MTF is limited by twice the detector pitch, and the full MTF available from the detector geometry cannot be exploited as it would in a scanning system. One technique which has been widely used to overcome this limitation is microscan, or mechanical interlace. In this technique, the image of the scene is moved across the detector array, when the device is not imaging, by a fraction of the inter element pitch, such that an integral number of steps fit into the pitch. The display of the subsequent field of data is shifted by a

corresponding amount to ensure the fidelity of the reconstructed image. The effect of microscan is shown in Figure 1b, which considers a first order microscan, in which the image is moved by 1/2P. The MTF of the individual elements remain unchanged, however the sampling frequency is multiplied by the microscan factor, in this case x2. As a result a much larger portion of the MTF can be utilised before aliasing is encountered.

Microscan therefore permits the MTF of scanning systems to be achieved in staring systems. Different orders of microscan are frequently adopted, such as 2x2 or 3x3, the numbers representing the number of steps in each axis per pixel pitch. The optimum choice of microscan order depends on the relative size of the element and sampling pitch and the effect of other factors such as the optical MTF.

Figure 2 shows a typical imager 1 for implementation of microscan. The imager 1 comprises a lens 2 focusing radiation on to an imaging array of pyroelectric detectors 3. Such detectors require the radiation incident on them to be modulated by a chopper 4, driven by motor 5 energised by battery 6, in order for the detection process to work. A leading edge of the chopper 4 scans across the array 3 synchronously with readout from the array by the electronic

circuit 7. Radiation from the scene is incident on the detector via a mirror 8. Microscan is achieved by tilting the mirror 8 while the entire detector is covered by the chopper 4. This implementation has the following disadvantages:-

1. The microscan mechanism can be quite complex, since the mirror is ideally required to tilt in two orthogonal axes at a relatively high speed;

2. For maximum efficiency, the detector would be operated in consecutive fields, with the gaps between the chopper blades being exactly the same size as the detector itself. This would result in the entire detector being closed to radiation only for an instant. For the microscan mirror to move without degrading the image quality, this must be extended to a finite period - a blanking period - which can be a significant portion of the active field period. As a result the efficiency of the system is reduced;

3. The requirement of a fold in the optical path, for the reflective microscan to operate, limits the lowest f-number which the lens can achieve without vignetting, typically to greater than f/2.8;

4. The backworking distance of the lens must be maximised to fit the optical fold in; and

5. The entire assembly is difficult and costly to manufacture, requiring precision design and fabrication due to the large number of components competing for space close to the focal plane.

According to the present invention there is provided an imager comprising a lens, an array of sensing elements and a member which includes at least one refractive region transmissive to radiation to which the sensing elements are responsive, wherein the member is moveable such that a refractive region of the member is repeatedly interposed in a radiation path between the lens and the array whereby the image focused on the array is moved relative to the array.

By employing the present invention movement of an image across the array of sensing elements is achieved by refracting the radiation prior to incidence upon the array. The radiation may be refracted alternately in different directions, or alternatively successively refracted and allowed to pass to the array without being refracted.

Preferably the member comprises a plurality of refractive regions arranged, such that in operation movement of the member causes different transmissive regions to be interposed in turn in said radiation path whereby the image focused on the array is sequentially moved in different directions relative to the array. This thereby provides a mechanical means of implementing microscan with a low cost easy to manufacture unit.

When the sensor elements are of the pyroelectric type, where a resetting period is required, then preferably the member includes at least one region which is substantially non-transmissive to said radiation which is interposable in the radiation path, thereby the member provides both a microscanning and chopper arrangement. Usually the refractive and non-transmissive regions are adjacent to one another so they have common boundaries. However the member could also include apertures allowing radiation to travel straight through without deflection.

Such arrangements eliminate the need for an optical fold required with previous mirror arrangements, thereby relaxing the backworking distance requirement of the primary optical component and permitting the use of low f-number optics without problems of vignetting being encountered.

Furthermore, microscan is achieved without any additional moving parts or power consumption, thereby reducing the weight of the imager.

One embodiment of the invention will now be described with reference to the accompanying Figures 3, 4, 5, 6 and 7 of which:

Figure 3 shows the principle behind the operation of an imager constructed in accordance with the invention;

Figure 4 schematically illustrates an imager in accordance with the invention;

Figure 5 illustrates a first member suitable for use with the imager of Figure 4;

Figure 6 shows an improved member suitable for use with the imager of Figure 4; and

Figure 7 schematically illustrates the microscan obtained by operating the imager of Figure 4 when fitted with the member illustrated in Figure 6.

Referring now to Figure 3 there is illustrated the principle of refraction employed by the present invention. A refractive transparent block of material 9 when positioned at A, so that it is perpendicular to an optical axis 10, will transmit light straight through it. However when the material is rotated through an angle i to a position B, rays

of light are refracted towards the normal of the block 9 when entering it and exit parallel to the original ray with a displacement which is a function of the refractive index, the angle of tilt, and the thickness of the material, the exact distance by which it is refracted is given by :

$$d = t \, \mathrm{SIN} \, i \left[1 - \frac{\mathrm{COS} \, i}{\sqrt{(n^2 - \mathrm{SIN}^2 i)}} \right]$$

where t = thickness of refractive element
i = angle of tilt of refractive element
n = refractive index of element

In Figure 4 there is illustrated an imager 11 which in accordance with the invention utilises the refraction principles illustrated in Figure 3 to implement microscan. The imager comprises a lens 12 for focusing radiation onto a array of pyroelectric detectors 13, which are read by the electronic circuit 14. The output of the circuit energises a cathode ray tube 15 which produces an image representative of the scene viewed by the array of sensor elements 13. The cathode ray tube 15, electronic circuit 14 and sensor array 13 are supplied with electrical energy by battery 16 which also energises motor 17 rotating a chopper 18 located between the lens 12 and the sensor array 13.

One type of chopper 18, is illustrated in Figure 5,

and comprises a central hub 19 which rotates about the perpendicular axis 20. The hub supports four non transmissive sections 21 and four transparent refractive sections 22 each tilted in a different axis, as indicated by the arrows.

The sensor array 13 of Figure 4, is read by the electronic circuit 14 in synchronism with rotation of the chopper 18, so that a blanking period resetting the pyroelectric elements 13 is obtained when each non-transmissive region 21 passes across the elements. When each transmissive section 22 passes across the detector array 13, an image is read out, the read out being made line by line as the leading edge of the non transmissive region passes over it. Each of the four images generated, corresponding to one rotation of the chopper, will be refracted in four directions thereby generating the desired microscan effect.

One limitation of the microscan chopper depicted in Figure 5 is that the image prescribes a segment of an arc as the chopper 18 rotates. For example a 2x2 microscan chopper with a minimum of four sectors would result in the image prescribing 45° arc in each position. Clearly this would reduce the achievable MTF of the system considerably, and is

unacceptable. The effect can however be reduced proportionally by increasing the number of sectors in the chopper by an integral factor, producing several microscan sequences per revolution. A suitable chopper 18 is illustrated in Figure 6.

The chopper 18 of Figure 6 is suitable for use with the pyroelectric detector elements 13 of Figure 4. The interelement pitch of the FPA is 100×10^{-6}m requiring a microscan shift of 50×10^{-6}m between fields. The chopper has a total of 8 active sectors resulting in the generation of two 2x2 microscan frames per revolution. The chopper 18 uses a more complex geometry than that of Figure 5, the spiral shape of the blade edges 23 ensuring a constant linear velocity of the edge across the entire detector 13, produced directly from the constant angular velocity of the motor 17.

Each transparent segment 25 of the chopper 18 is made of 0.5mm thick germanium optical flats, anti reflection coated for the $8-14 \times 10^{-6}$m band. To achieve a 50×10^{-6}m displacement between fields, the image is displaced by 35.36×10^{-6}m ($\sqrt{2} \times 25 \times 10^{-6}$m) from the nominal position in the direction of the arrows. The resultant displacement from a nominal position 26 is illustrated in Figure 7, it

can be seen that an image shift of $\pm 25 \times 10^{-6}$ m in each direction between fields is obtained. In the $8\text{-}14 \times 10^{-6}$ m band, germanium has a refractive index of 4, so the 35.36×10^{-6} m displacement is achieved by tilting each germanium flat by approximately 5.4° in the directions shown by the arrows in Figure 6.

Although in the embodiment illustrated the chopper 18 comprises a piece-part construction with the optical flats being inserted onto an accurately machined mount, it could alternatively comprise a monolithic fabrication in a refractive material, such as germanium or plastic, optionally having selected regions blanked by the application of a suitable coating.

The invention has hereinbefore been described in relation to producing a display, on a C.R.T. or otherwise, however it will be realized that the scope of invention extends to devices where no image is displayed, but which generate data relating to the imaged scene, for example data may be generated relating to the relative coordinates in the image of specific points.

CLAIMS

1. An imager comprising a lens, an array of sensing elements and a member which includes at least one refractive region transmissive to radiation to which the sensing elements are responsive, wherein the member is moveable such that a refractive region of the member is repeatedly interposed in a radiation path between the lens and the array whereby the image focused on the array is moved relative to the array.

2. An imager as claimed in claim 1 wherein the member comprises a plurality of said refractive regions arranged such that in operation movement of the member causes different transmissive regions to be interposed in turn in said radiation path whereby the image focused on the array is sequentially moved in different directions relative to the array.

3. An imager as claimed in claim 1 or 2 wherein the member includes at least one region which is substantially non-transmissive to said radiation which is interposable in the radiation path.

4. An imager as claimed in claim 2 or 3 wherein each transmissive and non-transmissive region has nominally substantially identical dimensions.

5. An imager as claimed in any preceding claim wherein the member is substantially planer and is rotatable about an axis at a constant angular velocity.

6. An imager as claimed in any preceding claim wherein successive transmissive regions comprising refractive material, refract radiation in opposite directions.

7. An imager as claimed in any preceding claim wherein the refractive material refracts radiation such that an image focused on the sensing elements by the lens is refracted by a distance less than the distance between centres of adjacent sensing elements.

8. An imager as claimed in any preceding claim comprising a motor for driving the member in synchronism with the readout of the sensing elements.

9. An imager as claimed in any preceding claim for imaging thermal radiation.

10. An imager as claimed in claim 9 wherein the sensing elements are pyroelectic elements.

11. An imager as claimed in any preceding claim wherein the radiation is sequentially refracted in four orthogonal directions.

12. An imager as claimed in any preceding claim wherein the member is a disc and comprises a plurality of transmissive refractive regions arranged alternately with non transmissive regions around its periphery, the boundary between adjacent regions being curved such that the said boundary passes over the array with a substantially constant linear velocity.

13. An imager as claimed in any preceding claim wherein the member comprises eight transmissive refractive regions interposed between eight non transmissive regions, each successive refractive region refracting radiation in a direction at 90° to the previous region.

14. An imager as substantially as hereinbefore described with reference to Figures 4, 5 and 6 of the accompanying drawings.

Amendments to the claims have been filed as follows

1. An imager comprising a lens, an array of sensing elements arranged in rows and columns and a member which includes at least one refractive region transmissive to radiation to which the sensing elements are responsive, wherein the member is moveable such that a refractive region of the member is repeatedly interposed in a radiation path between the lens and the array whereby the image focused on the array is displaced diagonally relative to the rows and columns of the array.

2. An imager as claimed in claim 1 wherein the member comprises a plurality of said refractive regions arranged such that in operation movement of the member causes different transmissive regions to be interposed in turn in said radiation path whereby the image focused on the array is sequentially moved in different directions relative to the array.

3. An imager as claimed in claim 1 or 2 wherein the member includes at least one region which is substantially non-transmissive to said radiation which is interposable in the radiation path.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number 9019337.6

Relevant Technical fields

(i) UK Cl (Edition K) H4F (FCB, FCC, FCK, FDX, FJB, FJC, FJS)

(ii) Int Cl (Edition 5) H04N

Search Examiner

J P Coules

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

12 February 1991

Documents considered relevant following a search in respect of claims 1-13

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB A 2152781 (Ferranti) see whole document	1-3, 5 7, 8
A	GB A 2204210 (GEC-Marconi) see figures 1-4	1
A	EP A2 0133890 (BODENSEEWERK) see figures 9 and 10	1

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

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