

R.J. BOXALL

N6295.

PATENT SPECIFICATION

(11) 1435 922

1435 922

- (21) Application No. 21902/73 (22) Filed 8 May 1973
 (31) Convention Application No. 7206377 (32) Filed 11 May 1972
 (31) Convention Application No. 7305517 (32) Filed 19 April 1973 in
 (33) Netherlands (NL)
 (44) Complete Specification published 19 May 1976
 (51) INT CL² G11B 7/00//21/10 25/04 25/06
 (52) Index at acceptance



G5R B186 B203 B263 B333 B345 B361 B36Y B37Y B452
 B512 B571 B57X B584 B58Y B623 B633 B63Y
 B701 B72Y B788 B789
 G1A 205 207 211 21X 21Y 247 248 269 307 357 358 369
 403 407 420 422 427 428 42Y 430 432 437 438
 43Y 447 448 457 458 466 46Y 477 491 494 521
 52Y 53Y 540 548 549 54X 54Y 590 599 59Y 675

(54) READING OPTICAL RECORDINGS

(71) We PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to apparatus for reading a flat reflecting record on which information, for example video and/or audio information, is recorded in parallel tracks having an optically readable structure, which apparatus comprises reading means employing a source of optical radiation combined with a radiation-sensitive signal detection system for converting a read beam emitted by the source and modulated by the information into electric signals. (In the case of a circular record the term "parallel tracks" is to be understood to mean a number of tracks constituting the successive turns of a spiral or a number of separate circular concentric tracks). The optical radiation may be light or radiation dealt with as light.

The term "a flat record" is to be understood to mean any record the optical structure of which lies in a flat surface at the location at which the track structure is read. The term "a reflecting record" is to be understood to mean a record in which the information is recorded in a reflecting structure. Such as structure may take the form of co-planar radiation-reflecting blocks and intermediate areas which have a reflection coefficient different from that of the blocks or of radiation-reflecting blocks and areas situated at different levels. Apparatus for reading flat records are described *inter alia* in British Patent Specification No. 1,146,843. For reading a circular record the record is rotated so that the signal detection system successively picks up radiation from different parts

of a track of the record. All the tracks can be consecutively read by relative radial movement of the record and the signal detection system.

In the known read apparatus the distances from the source of radiation to the record and from the record to the signal detection system are such that only a small part of a track, of a size of about the smallest detail in the optical structure of the track, is imaged on the signal detection system. The radiation path from the source of the radiation to the plane of the part of the record to be read and the radiation path from this plane to the signal detection system may be subject to small variations. These variations may have different causes. First the surface of the record may not be perfectly flat. Secondly, when the record is a foil rotation thereof may give rise to undulations. Furthermore the optical elements of the read system may be subject to vibrations.

When these variations occur, the signal detection system receives not only radiation from the part of a track to be read, but also radiation from the surroundings of this part. As a result, the depth of modulation of the signal produced by the signal detection system is decreased, and moreover, because radiation from adjacent tracks may then impinge on the signal detection system, cross-talk may occur. The reduced modulation depth and the cross-talk then prevent satisfactory signal detection.

It is an object of the present invention to provide read apparatus for use with a reflecting record, in which differences between the desired position of the plane of the part of the record to be read, i.e. the position in which the desired part only of the record carrier is imaged on the signal detection system, and the actual position of this plane are detected, enabling the focus of an optical element inserted in the path of the radiation

45

50

55

60

65

70

75

80

85

from the radiation source to the radiation detection system to be correspondingly adjusted. For this purpose the invention provides apparatus for reading optically a flat reflecting record on which video and/or audio information is recorded in parallel tracks (as defined herein) having an optically readable structure, which apparatus comprises reading means employing a source of optical radiation combined with a radiation-sensitive signal detection system for converting a read beam emitted by said source and modulated by said information into electric signals, and separation indication apparatus for providing an indication of the separation between the part of said record to be read and said reading means, said separation indication apparatus comprising (a) means for deriving an auxiliary radiation beam from said source, (b) a lens system shared by said reading means and inserted in the path of said auxiliary beam from said source to said record and in the path of said auxiliary beam reflected by said record towards said signal detection system, which signal detection system lies in a plane intersecting the optical axis of said lens system and includes at least two radiation sensitive detectors, (c) means including said lens for causing said auxiliary beam to pass through said lens system, to be incident on the record at an acute angle and hence at a position on the record determined by said separation, to be reflected back through said lens and to fall upon said signal detection system at a position also determined by the said separation, and (d) means for processing the outputs of said radiation detectors to provide a separation signal indicating the said separation.

It should be noted that in Patent Specification No. 1,391,335, co-pending Patent Application 10792/72 and Patent Specification No. (Serial No. 1,428,731) co-pending Patent Application 14452/73, it is proposed to use two detectors for detecting the position of the plane of the part of the record to be read. However, in these proposed apparatus either the information of a large number of tracks in the vicinity of the track to be read (Patent Specification No. 1,391,335) or the information of the track to be read (Patent Application 14452/73) (Serial No. 1,428,731) is used, so that in contradistinction to the apparatus in accordance with the present invention more than the reflective property alone of the record is used.

According to a first feature of the invention said signal detection system comprises a pair of radiation sensitive detectors disposed so that said reflected auxiliary beam falls in part on each of said pair of detectors to produce equal output signals from said pair of detectors when there is a desired separation between said record and said optical read system. The principal ray of the

auxiliary beam is inclined at an acute angle to the plane of the track part to be read. Owing to the inclined incidence of this principal ray on the plane of the track part to be read a small displacement of this plane will result in a large change in the location at which the principal ray impinges on this plane.

According to another and a preferred feature of the invention said auxiliary radiation beam is small in diameter compared with the aperture of said lens system and the path of said auxiliary beam enters the aperture of said lens system at a position spaced from the optical axis of said lens system. The path of said auxiliary radiation beam may pass through a slit in a mask and said radiation sensitive detectors may be secured to said mask on either side of said slit so as to intercept the reflected auxiliary radiation beam.

In a first modification of the invention said auxiliary beam forms part of said read beam and said reflected auxiliary and read beams are operative to form an image of said source at the edge of a radiation absorbing screen transverse to the optical axis of said lens when the separation between said record and said optical read system has a desired value, said radiation sensitive signal detection system comprising a pair of radiation sensitive detectors placed beyond said screen as viewed from said lens, one detector of said pair being placed to receive radiation passing beyond and away from said edge as viewed from said lens, the other detector of said pair being placed to receive radiation passing beyond and behind said edge as viewed from said lens.

If the plane of the part of the record to be read occupies the desired position, the detectors arranged behind the screen receive equal radiation intensities. In the case of a deviation from the desired position one of the detectors receives a greater amount of radiation than the other.

In a second modification of the invention said plane of said signal detection system is inclined at an acute angle to the plane of the part of the record to be read and said signal detection system comprises a plurality of radiation sensitive detectors spaced from one another by slits and said source is adapted to direct radiation through said slits as a plurality of auxiliary beams towards said lens system such that one of said slits is imaged upon itself by the corresponding reflected auxiliary radiation beam when there is a desired separation between said record and said optical read system. Said source may comprise a number of separate radiation sources disposed one each in said slits.

Embodiments of the invention will now be described, by way of example, with reference

to the accompanying diagrammatic drawings, in which:

Figure 1 shows a previously proposed apparatus for reading a reflecting record carrier,

Figure 2 shows part of the optical structure of the record carrier to be read, and

Figures 5 and 6 show two examples of separation indication apparatus which can be added to the apparatus of Figure 1 according to the invention,

Figures 3 and 4 show two examples of separation indication apparatus which can be added to Figure 1 according to modifications of the invention,

Figures 3a, 8, 9 and 12 show elements for use in the apparatus shown in Figures 3 and 6 respectively, and

Figures 7, 10 and 11 illustrate the operation of the apparatus shown in Figure 6.

Referring now to Figure 1, in the apparatus shown a circular record 1 is rotated by means of a spindle 4 which is driven by a motor, not shown, and passes through a centre hole 2 in the record. A beam of radiation 10 emitted by a source of radiation 5 is reflected to the record by a half-silvered mirror 6. A lens 7 focuses the beam on one of the tracks 3 formed on the lower surface of the record. After being modulated by a track the beam is reflected and passes through the lens 7 a second time, so that an image of a small part of the record to be read is formed via the half-silvered mirror 6 on a radiation-sensitive detector 8. The output of the detector is connected to a device 9 provided with known electronic means for converting the output signal from the detector into picture and sound. The lens 7 has to satisfy exacting requirements, because it should form and be capable of resolving the smallest detail in the optical structure of the track.

Fig. 2 is an inverted plan view of part of the optical structure of the record. An arrow 15 indicates the direction in which the record is moved relative to the read system. The structure is composed of tracks 3 which each comprise blocks *b* alternating with areas *g*. The tracks 3 are separated by neutral intermediate stripes 13. The tracks 3 may be arranged on the record so as to be parallel to one another, i.e. concentric. As an alternative a single spiral track may be formed on the record. The lengths of the blocks and areas represent the stored information. A radiation beam which has been modulated by the track shows pulsatory variations in time in accordance with the sequence of blocks and areas. The blocks and areas of a track may be co-planar, in which case the coefficient of reflection of a block may be different from that of an area. Alternatively, the blocks and areas may have equal co-

efficients of reflection but be situated on different levels.

In an example of an optical structure the mean period in the direction of length of a track is $4\text{ }\mu\text{m}$ and the minimum length in a track is $2\text{ }\mu\text{m}$ so that the image formed on the detector must be smaller than $2\text{ }\mu\text{m}$. This requires the plane of the optical structure to lie within the depth of focus of, for example, $1\text{ }\mu\text{m}$ of the lens 7. Therefore any shift of this plane in a direction at right angles to the plane must be detected so as to permit corrective adjustment.

Before describing embodiments of the invention proper, two modifications thereof will now be described with reference to Figures 3 and 4.

In Figure 3 slit 30 is illuminated by a source of radiation 36. Rays 31 which pass through the slit impinge on a half-silvered mirror 32 and are reflected by it to an objective lens 33. The lens 33 forms an image of the slit on a record 1. After reflection at the record the rays traverse the lens a second time and pass through the half-silvered mirror 32, thus forming a second image of the slit. A radiation-absorbing screen 34 is inserted in the path of the rays reflected by the record two radiation-sensitive detectors 35' and 35'' being arranged behind the screen.

When the plane of the part of the record to be read is in the correct position (position *d*) a sharp image D of the slit is formed at the edge of the screen, as is shown by solid lines. In this case the two detectors 35' and 35'' receive equal amounts of radiation. When the plane of the part of the record being read shifts to a position *f* the rays follow the path shown by dot dash lines, an image F being formed in front of the screen. The screen then intercepts rays directed towards the detector 35'', so that this detector receives a smaller amount of radiation than does the detector 35'. The converse will occur when an image E is formed behind the screen. This is the case, as is indicated by broken lines, when the plane of the part of the record being read is in a position *e*.

A comparison of the output signals *S'* and *S''* from the detectors 35' and 35'' respectively enables the amount by which, and the direction in which, the plane of the part of the record being read differs from the desired position to be determined. The signals *S'* and *S''* may be electronically processed in known manner to give a control signal by which, for example, the focussing of the lens 33 may be adjusted.

The detectors may also be used for reading the information of the record as a signal derived from its sum of signals *S'* and *S''*, if care is taken to ensure that, if the plane of the track part to be read is in the position *d*,

a part of the track equal in size to the smallest optical detail is imaged on the detectors.

For the sake of clarity, in Fig. 3 the distances $d-e$ and $d-f$ are shown greatly exaggerated in comparison to the lens diameter.

In the apparatus shown in Fig. 3 inaccuracies in the read system, for example a shift of the slit 30 or of any of the other optical elements, may cause the output signals from the detectors 35' and 35'' to be different in spite of the fact that an image of the slit 30 is formed at the edge of the screen 34, in other words when the plane of the part of the record to be read is in the desired position. To prevent such inaccuracies, two additional radiation-sensitive detectors may be provided and the half-silvered mirror 32 may be pivotable. In this case the detectors 35' and 35'' and the radiation-absorbing screen are located in the space on one side of the plane of the drawing, whilst the additional detectors 37' and 37'' are located in the space on the other side of this plane. This is illustrated in Fig. 3a which is a sectional view, taken along a line XX, of the apparatus according to Fig. 3 when provided with additional detectors 37' and 37''. A shift of the radiation beam over the detectors 37' and 37'' due to instabilities in the optical system causes different low-frequency signals to be produced at the outputs of these detectors. These signals may be electronically processed to give a control signal by means of which the half-silvered mirror 32 is pivoted in the direction indicated by an arrow 38, until the detectors 37' and 37'' supply equal output signals. Thus the points in which the radiation beam strikes the detectors 35' and 35'' may be rendered independent of instabilities in the optical system.

Fig. 4 shows a second embodiment of separation indication apparatus in accordance with another modification of the invention. A plurality of radiation-sensitive detectors D_1 to D_n are aligned. The detectors are separated from one another by slits S_1 to S_n which are illuminated by a source of radiation 41. A lens 43 forms an image S_1' to S_n' of the row of slits which row is inclined at an acute angle to the plane of the track, the image of which is therefore also inclined thereto. Via the reflecting record a second image S_1'' to S_n'' of the images S_1' to S_n' is formed on the original row of slits S_1 to S_n . Because the row of slits is inclined to the plane of the track, only a small part of this row, namely the part surrounding a point the image of which lies in the plane of the track, is sharply imaged on itself. When the plane of the track is in the position d , the slit S_4 is sharply imaged on itself ($S_4=S_4''$). A sharp image of a slit

situated on either side of the slit do not receive radiation emanating from this slit. Thus, in the position d of the plane of the track detectors D_4 and D_5 receive no radiation emanating from the slit S_4 . In the position f of the plane of the track the slit S_4 is sharply imaged on itself ($S_4=S_4''$) and detectors D_1 and D_2 receive no radiation emanating from the slit S_4 . From the values of the output signals from the detectors the magnitude and the direction of a deviation of the actual position of the plane of the record from the desired position can be determined.

The source of radiation 41 arranged behind the row of slits may be replaced by a row of radiation sources, for example semiconductor radiation sources such as photo-emissive diodes, which radiation sources then are disposed in the slits between the detectors.

In an embodiment of apparatus in accordance with the invention, as in the other embodiments, the fact is utilized that the location at which a beam of radiation the principal ray of which is incident on the plane of the part of the record to be read at a sharp angle impinges on this plane depends upon the position of this plane. In this case, the location also on the detection system at which the beam reflected by the record impinges on this detection system is dependent upon the position of the said plane.

In the embodiment of the invention shown in Fig. 5 a beam of radiation 51 emitted by a source 50 is incident on a grating 54. This grating may be a phase grating which is blazed so that the intensities of the beams of orders higher than the first are substantially suppressed. The grating 54 causes three diffraction images of the source 50 to be formed by beams 51a, 51b and 51c. For clarity only one ray of each of these beams is shown.

The Figure clearly shows that when the plane of the record is in the position d the beams 51a, 51b and 51c shown by solid lines impinge at other locations on the said plane and hence on detectors 55, 56 and 57 than when the plane of the record occupies the position f , because for the positions d and f the beams after being reflected pass through the lens at different heights and hence are refracted through different angles. The information from the record can be read by means of the detector 55. The auxiliary detector 56 comprises two component detectors 56' and 56'' the output signals from which are equal only if the record occupies the desired position (d). A comparison of the output signals from the detectors 56' and 56'' permits of determining whether the actual position of the plane of the part of the record to be read differs from the desired position of this plane and in which direction a deviation, if found, occurs.

To obtain maximum sensitivity in determining the position of the plane of the track to be read it is ensured that the first-order beams pass through the edge of the lens 53.

5 For this purpose the grating is spaced from the lens by a distance equal to a few times the focal distance of the lens.

A shift of the plane of the track to be read through a distance of S μm causes a change Δp of the position p in which a beam having an obliquely incident principal ray impinges on the plane, where $\Delta p \sim S \cdot (\text{N.A.})$, where N.A. represents the numerical aperture. Because the record is used as a mirror and because the lens forms an image which is magnified by a factor v , a shift through Δp means a displacement of the image over the detectors 56' and 56'' of $\Delta p' = 2v^2 S \cdot (\text{N.A.})$. When using a lens having a N.A. of 0.4 and a magnification v of 20 a shift of the plane of the track through 0.5 μm will cause a displacement of the image over the detectors of about 160 μm . It is assumed that the source of radiation, for example a laser, is stable in respect of position and direction. In practice this means that, for example, the two ends of the laser source must be mounted so as to be stable within 0.15 mm relative to the optical elements. Otherwise a small displacement of the radiation source may cause an error signal to be derived from the output signals of the detectors 56' and 56'' in spite of the fact that the plane of the record occupies the required position.

35 To enable a sufficient degree of accuracy to be obtained without the stability of the radiation source being required to satisfy stringent requirements, an additional provision may be made in the form of a half-silvered mirror 52 which is pivotable and an additional detector 57 which is divided into two component detectors 57' and 57''. Displacements of the radiation beams over the component detectors 57' and 57'' due to instabilities of the radiation source cause low-frequency signals to be produced at the outputs of these detectors. These signals may electronically be processed to give a control signal by means of which the half-silvered mirror 52 may be pivoted in the direction indicated by an arrow 58. In this manner the locations at which the radiation beams 51a and 51b impinge on the detectors 55 and 56 may be rendered independent of instabilities of the source of light.

Fig. 6 shows a second and a preferred embodiment of the invention. A laser source 60 emits a small-diameter beam of radiation 61. This radiation beam enters a beam splitter 62 through a surface 63 thereof. A surface 64 of the beam splitter is semitransparent, so that part of the radiation beam 61 is transmitted as a radiation beam 65 and another part is reflected to the surface 63. This part is totally reflected at the surface 63 and

then leaves the beam splitter as a second radiation beam 66. The radiation beam 66 acts as an auxiliary radiation beam and passes through a slit or aperture 67. The aperture 67 is bounded by two radiation-sensitive detectors 68 and 69. An objective lens 70 the optical axis of which is indicated by OO' is arranged beyond the slit 67. The auxiliary radiation beam 66 enters the lens 70 at a location spaced by a comparatively large distance from the optical axis OO' . After refraction by the lens 70 the auxiliary radiation beam 66 impinges on a record 1. The record acts as a mirror for the auxiliary radiation beam.

If the record 1 is in the correct position (position d), an image of the aperture 67 is formed in the plane of this aperture so as to be symmetrical with respect to the aperture. In this case the radiation-sensitive detectors 68 and 69 situated one on either side of the aperture receive about equal radiation intensities, so that the difference between the electric signals supplied by these detectors is negligible.

When the record shifts to a position f , the reflected auxiliary ray beam travels along a path indicated by broken lines. The reflected auxiliary radiation beam passes through the lens 70 at another level than in the case d , so that it is refracted through a smaller angle. As a result, the image of the aperture 67 will shift towards the detector 69, so that the larger part of the reflected auxiliary radiation beam strikes this detector. Thus, the electric signal supplied by the detector 69 considerably exceeds the output signal from the detector 68. When the record 1 is shifted to the right-hand side in the drawing, the image of the aperture 67 will shift in the direction towards the radiation-sensitive detector 68. In this case the output signal from the detector 68 considerably exceeds that from the detector 69.

A comparison of the output signals from the detectors 68 and 69 permits of ascertaining whether the plane of the part of the record to be read is in the desired position and of determining the direction of a deviation. The output signals from the detectors may be electronically processed in known manner to provide a control signal which, for example, enables the focussing of a lens, such as the lens 70, by means of which an image of a small part of a track is formed on the signal detection system, not shown, to be adjusted.

The slit 67 which provides the small-diameter auxiliary radiation beam may be separated from the elements 68 and 69 which intercept the reflected auxiliary radiation beam. However, the arrangement shown in Fig. 6 is to be preferred, because the position of the slit 67 is defined by the positions of the elements 68 and 69, so that no positional deviations between these elements and the

source of radiation can occur, as is the case in the embodiments shown in Figs. 3 and 5. Consequently no additional provisions, for example in the form of additional radiation-sensitive detectors and a pivotable mirror, for compensating for the said deviations need be made.

In the embodiment of Fig. 6 as described so far the source of radiation which supplies the auxiliary radiation beam is imaged in the vicinity of the record by the objective lens 70. Depending upon the position of this record the size of this image will vary and so will the size of the spot which after reflection at the record is formed on the radiation-sensitive detectors 68 and 69. The radiation source which supplies the auxiliary radiation beam does not lie in the plane of the slit and the radiation-sensitive detectors. As is shown in Fig. 7, this would cause the size of the spot 73 to vary asymmetrically as a function of the location. Lines 74 and 75 show the boundaries of this spot on the detectors 68 and 69. Evidently the variation of the size of the spot 73 may give rise to an erroneous indication.

To avoid such an erroneous indication, an auxiliary lens 71 is inserted in the path of the auxiliary radiation beam 66 between the beam splitter and the slit 67. This auxiliary lens forms an image of the radiation source in the focal plane of the objective lens 70, so that the auxiliary radiation beam emerges from the objective lens as a parallel beam. Thus an image of constant size is formed on the record carrier so that the spot on the detectors 68 and 69 also will have a constant size, as is indicated by broken lines 76 and 77 in Fig. 7. As a result, the influence of the radiation source on the measurement is substantially eliminated.

Instead of two radiation-sensitive detectors 68 and 69 two reflecting elements may be arranged one on either side of the slit 67. These elements then reflect the radiation along two different paths. A radiation-sensitive detector must be inserted in either path. However, the embodiment shown in Fig. 6, in which the slit is bounded by two radiation-sensitive detectors, is to be preferred, because no additional optical elements are required for concentrating the radiation from the reflecting elements onto the detectors and furthermore no difficult alignment problems arise.

In the apparatus shown in Fig. 6 the radiation beam 65 split from the beam 61 by the beam splitter 63 passes through a lens 72 and acts as the read-out beam. Only two rays of this beam are shown by dot dash lines. The read-out beam 65 is focussed onto a track of the record 1 by the lens 70. The beam which is reflected from the record and is modulated in accordance with the information in a track passes again through the lens 70

and then may, for example, be reflected to the signal detection system, not shown, by a half-silvered mirror, not shown.

The apparatus shown in Fig. 6 may be combined with means for determining the radial position of the point of incidence of the read-out beam on the record relative to the track to be read. Thus, for example, the read beam may be divided into three sub-beams by a grating which is arranged in front of the plane of the slit 67 and the lines of which lie in a plane perpendicular to the optical axis OO' . This causes three spots of radiation to be formed on the track to be read, one at the centre of the track and one on each track edge. The middle spot is used for reading the information and the two outer spots are used for radially positioning the read beam with respect to the track.

Fig. 8 is a sectional view taken on the line AA' of Fig. 6. An opaque plate 78 has an opening 79 formed in it through which the said three sub-beams can pass. Two radiation-sensitive detectors 68 and 69 are arranged on the plate 78 so as to define a narrow transparent slit 67.

The width of the slit is determined *inter alia* by the signal-to-noise ratio of the detection system. In practice, the radiation source 60 will frequently be a source of laser radiation having a Gaussian distribution of intensity. When using a comparatively narrow slit 67 the radiation emerging from the slit will have a comparatively constant intensity. In this case, however, the overall intensity is small and hence the electric signals from the detectors are small also. When a wider slit 67 is used, the overall intensity of the radiation beam which emerges from the slit is greater. In this case, however, the radiation beam and hence the radiation reflected to the detectors 68 and 69 will show a spatially inhomogeneous intensity distribution.

The radiation-sensitive detectors may be photodiodes. As is shown in Fig. 9, such a photodiode comprises an inner portion (80 and 81 respectively) which is made of a photo-sensitive semiconductor material and is surrounded by "blind" margins (82 and 83 respectively) which are insensitive to the radiation. With conventional diodes the width of the blind margin will be of the order of $100\text{ }\mu\text{m}$ and hence roughly equal to the width of the aperture 67. When such wide-margin photodiodes are used, the curve which in Fig. 10 shows the electric difference signal (S) as a function of the displacement (V) of the part of the record to be read will have a substantially horizontal portion in a comparatively large region (2a) around the zero crossing. In this region the focussing of the objective 70 cannot be adjusted with sufficient accuracy.

Fig. 11 shows an improved curve of the

electrical difference signal as a function of the displacement. In the vicinity of the zero crossing the curve has a slope which is substantially equal to that at locations more remote from the zero crossing.

In order to attain the said improved curve care is taken in the manufacture of the photodiodes to ensure that those margins of the photodiodes which are adjacent to the slit-shaped aperture are as narrow as possible. The photodiodes are simultaneously manufactured in large numbers on a chip of semiconductor material and then cut from the chip. The cutting process may give rise to mechanical stresses in the material which in turn may give rise to large leakage currents when the photodiodes are used in the apparatus shown in Fig. 6. If, however, the margins 84 and 85 (Fig. 9) which define the slit 67 are made narrow and the remaining margins 82 and 83 are made much wider, the likelihood of leakage currents can be reduced whilst the photodiodes are highly suitable for use in the apparatus described.

The sensitivity of the apparatus *i.e.* the smallest detectable deviation of the actual position of the plane of the part of the record to be read from its desired position, is given by:

$$G = k_1 \cdot r \quad (1)$$

where k_1 is a constant and r is the distance of the optical axis from the point at which the auxiliary beam impinges on the lens 70. The lock-in range, *i.e.* the maximum detectable deviation, is given by

$$I = k_2 \cdot \frac{l}{r} \quad (2)$$

where r is the same parameter as in equation (1), k_2 is a constant and l is the length of the diodes (cf. Fig. 10). According to the equations (1) and (2) r has to satisfy conflicting requirements. Hence the value of r will in practice be a compromise.

In addition to the auxiliary radiation beam reflected from the record, stray radiation, for example radiation reflected from the objective 70, may strike the photodiodes. The influence of the stray radiation may be considerably reduced as is shown in Fig. 12, each by dividing detector into two separate component detectors 80', 80'' and 81', 81'' respectively. The lengths of the component detectors 80'' and 81'' are much smaller than those of the component detectors 80' and 81'. It is ensured that at the same intensity of the incident radiation the electric output signals from the component detectors 80'' and 81'' greatly exceed those from the component detectors 80' and 81'. This is obtainable either by making the component detectors

80'' and 81'' more sensitive than the component detectors 80' and 81' or by amplifying the signals from the component detectors 80'' and 81'' by a higher factor (for example a factor of 10) than the signals from the component detectors 80' and 81'.

When the deviation of the actual position of the plane of the part of the record to be read from the desired position is small, the influence of the stray radiation incident on almost the entire surface area of the detectors 80' and 81' will be negligible. In this case, the component detectors 80'' and 81'' substantially alone contribute to the control signal.

The influence of the stray radiation may be further reduced by making the widths also of the component detectors 80'' and 81'' smaller than those of the component detectors 80' and 81' (see Fig. 12).

The detector arrangement shown in Fig. 12 not only causes the influence of stray radiation to be reduced but also improves the control slope. In the vicinity of the origin the slope of the difference signal versus the position of the plane of the part of the record to be read is much steeper than in Fig. 11.

In a practical embodiment of an apparatus as shown in Fig. 6 the width of the margins 84 and 85 was 10 μ m and that of the remaining margins of the photodiodes was 200 μ m. The width of the slit-shaped aperture was 250 μ m. The radiation source 60 emitted a laser beam having a Gaussian distribution of intensity the half-value width of which was 700 μ m. The smallest detectable deviation of the actual position of the plane of the part of the record to be read from the desired position was 1 μ m with a lock-in range of 1mm.

Hereinbefore apparatus for reading a disk-shaped record has been described. Obviously the invention may also be applied to reading other records, for example tape-shaped records in which the structure which represents the information lies in a flat surface at the location at which it is read, a small part of this structure being imaged on a radiation-sensitive detector.

WHAT WE CLAIM IS:—

1. Apparatus for reading optically a flat reflecting record on which video and/or audio information is recorded in parallel tracks (as defined herein) having an optically readable structure, which apparatus comprises reading means employing a source of optical radiation combined with a radiation-sensitive signal detection system for converting a read beam emitted by said source and modulated by said information into electric signals, and separation indication apparatus for providing an indication of the separation between the part of said record to be read and said read-

electrical difference signal as a function of the displacement. In the vicinity of the zero crossing the curve has a slope which is substantially equal to that at locations more remote from the zero crossing.

In order to attain the said improved curve care is taken in the manufacture of the photodiodes to ensure that those margins of the photodiodes which are adjacent to the slit-shaped aperture are as narrow as possible. The photodiodes are simultaneously manufactured in large numbers on a chip of semiconductor material and then cut from the chip. The cutting process may give rise to mechanical stresses in the material which in turn may give rise to large leakage currents when the photodiodes are used in the apparatus shown in Fig. 6. If, however, the margins 84 and 85 (Fig. 9) which define the slit 67 are made narrow and the remaining margins 82 and 83 are made much wider, the likelihood of leakage currents can be reduced whilst the photodiodes are highly suitable for use in the apparatus described.

The sensitivity of the apparatus *i.e.* the smallest detectable deviation of the actual position of the plane of the part of the record to be read from its desired position, is given by:

$$G = k_1 \cdot r \quad (1)$$

where k_1 is a constant and r is the distance of the optical axis from the point at which the auxiliary beam impinges on the lens 70. The lock-in range, *i.e.* the maximum detectable deviation, is given by

$$I = k_2 \cdot \frac{l}{r} \quad (2)$$

where r is the same parameter as in equation (1), k_2 is a constant and l is the length of the diodes (cf. Fig. 10). According to the equations (1) and (2) r has to satisfy conflicting requirements. Hence the value of r in practice be a compromise.

In addition to the auxiliary radiation beam reflected from the record, stray radiation, for example radiation reflected from the objective 70, may strike the photodiodes. The influence of the stray radiation may be considerably reduced as is shown in Fig. 12, each by dividing detector into two separate component detectors 80', 80'' and 81', 81'' respectively. The lengths of the component detectors 80'' and 81'' are much smaller than those of the component detectors 80' and 81'. It is ensured that at the same intensity of the incident radiation the electric output signals from the component detectors 80'' and 81'' greatly exceed those from the component detectors 80' and 81'. This is obtainable either by making the component detectors

80'' and 81'' more sensitive than the component detectors 80' and 81' or by amplifying the signals from the component detectors 80'' and 81'' by a higher factor (for example a factor of 10) than the signals from the component detectors 80' and 81'.

When the deviation of the actual position of the plane of the part of the record to be read from the desired position is small, the influence of the stray radiation incident on almost the entire surface area of the detectors 80' and 81' will be negligible. In this case, the component detectors 80'' and 81'' substantially alone contribute to the control signal.

The influence of the stray radiation may be further reduced by making the widths also of the component detectors 80'' and 81'' smaller than those of the component detectors 80' and 81' (see Fig. 12).

The detector arrangement shown in Fig. 12 not only causes the influence of stray radiation to be reduced but also improves the control slope. In the vicinity of the origin the slope of the difference signal versus the position of the plane of the part of the record to be read is much steeper than in Fig. 11.

In a practical embodiment of an apparatus as shown in Fig. 6 the width of the margins 84 and 85 was 10 μm and that of the remaining margins of the photodiodes was 200 μm . The width of the slit-shaped aperture was 250 μm . The radiation source 60 emitted a laser beam having a Gaussian distribution of intensity the half-value width of which was 700 μm . The smallest detectable deviation of the actual position of the plane of the part of the record to be read from the desired position was 1 μm with a lock-in range of 1mm.

Hereinbefore apparatus for reading a disk-shaped record has been described. Obviously the invention may also be applied to reading other records, for example tape-shaped records in which the structure which represents the information lies in a flat surface at the location at which it is read, a small part of this structure being imaged on a radiation-sensitive detector.

WHAT WE CLAIM IS:—

1. Apparatus for reading optically a flat reflecting record on which video and/or audio information is recorded in parallel tracks (as defined herein) having an optically readable structure, which apparatus comprises reading means employing a source of optical radiation combined with a radiation-sensitive signal detection system for converting a read beam emitted by said source and modulated by said information into electric signals, and separation indication apparatus for providing an indication of the separation between the part of said record to be read and said read-



ing means, said separation indication apparatus comprising (a) means for deriving an auxiliary radiation beam from said source, (b) a lens system shared by said reading means and inserted in the path of said auxiliary beam from said source to said record and in the path of said auxiliary beam reflected by said record towards said signal detection system, which signal detection system lies in a plane intersecting the optical axis of said lens system and includes at least two radiation sensitive detectors, (c) means including said lens for causing said auxiliary beam to pass through said lens system, to be incident on the record at an acute angle and hence at a position on the record determined by said separation, to be reflected back through said lens and to fall upon said signal detection system at a position also determined by the said separation, and (d) means for processing the outputs of said radiation detectors to provide a separation signal indicating the said separation.

2. Apparatus as claimed in Claim 1 wherein said signal detection system comprises a pair of radiation sensitive detectors disposed so that said reflected auxiliary beam falls in part on each of said pair of detectors to produce equal output signals from said pair of detectors when there is a desired separation between said record and said optical read system.

3. Apparatus as claimed in Claim 2 wherein a pair of radiation detectors are provided for each of two auxiliary radiation beams.

4. Apparatus as claimed in Claim 2 or Claim 3, wherein said auxiliary radiation beams are derived from said source by means of a grating disposed between said source and said lens system, said lens system forming diffraction images of the source in the plane of the part of the record to be read.

5. Apparatus as claimed in Claim 1 wherein said auxiliary radiation beam is small in diameter compared with the aperture of said lens system and wherein the path of said auxiliary beam enters the aperture of said lens system at a position spaced from the optical axis of said lens system.

6. Apparatus as claimed in Claim 5, wherein the path of said auxiliary radiation beam passes through a slit in a mask and wherein said radiation sensitive detectors are secured to said mask on either side of said slit so as to intercept the reflected auxiliary radiation beam.

7. Apparatus as claimed in Claim 6 wherein there is inserted in the radiation path from said source to said slit an auxiliary lens system which forms an image of said source in the focal plane of said lens system nearest to said slit.

8. Apparatus as claimed in Claim 6 or Claim 7 or in which the radiation-sensitive detectors are photodiodes wherein radiation-

insensitive margins of said photodiodes adjacent to the slit have widths which are appreciably smaller than those of other radiation-insensitive margins of said photodiodes.

9. Apparatus as claimed in Claim 8, wherein the radiation-sensitive area of each photodiode is divided into two parts of appreciably different area the smaller part being nearest to the slit and separated from the remainder of the radiation-sensitive surface area, the arrangement being such that in operation the electric output signal derived from the smaller part appreciably exceeds that from said remainder when the intensities of the radiation incident on the separate parts are equal.

10. Apparatus as claimed in Claim 9 wherein the side of said smaller part adjacent to said slit extends over only part of the side of said remainder adjacent to said slit, said smaller part being symmetrically disposed with respect to the centre of said side of said remainder.

11. Apparatus as claimed in Claim 9 or Claim 10 wherein the radiation-sensitivity of the smaller part appreciably exceeds that of said remainder.

12. A modification of apparatus as claimed in Claim 1 wherein said auxiliary beam forms part of said read beam and wherein said reflected auxiliary and read beams are operative to form an image of said source at the edge of a radiation absorbing screen transverse to the optical axis of said lens when the separation between said record and said optical read system has a desired value, said radiation sensitive signal detection system comprising a pair of radiation sensitive detectors placed beyond said screen as viewed from said lens, one detector of said pair being placed to receive radiation passing beyond and away from said edge as viewed from said lens, the other detector of said pair being placed to receive radiation passing beyond and behind said edge as viewed from said lens.

13. Apparatus as claimed in Claim 12 wherein said radiation detection system comprises a further pair of radiation sensitive detectors placed to be unobscured by said screen, one each of said further pair of detectors being laterally adjacent to one each of said pair of detectors, said processing means being adapted to generate a misalignment signal from the output signals of said further pair of detectors indicating the misalignment of said image of said source with said edge, and wherein beam deflection means in the path of said auxiliary beam is responsive to said misalignment signal to maintain said image aligned with said edge.

14. A modification of apparatus as claimed in Claim 1 wherein said plane of said signal detection system is inclined at an acute angle to the plane of the part of the record to



21

5 he read and wherein said signal detection system comprises a plurality of radiation sensitive detectors spaced from one another by slits and wherein said source is adapted to direct radiation through said slits as a plurality of auxiliary beams towards said lens system so that one of said slits is imaged upon itself by the corresponding reflected auxiliary radiation beam when there is a desired separation between said record and said optical read system.

10 15. Apparatus as claimed in Claim 14 wherein said source comprises a number of separate radiation sources disposed one each in said slits.

15 16. Apparatus as claimed in any preceding Claim comprising means for adjusting the focus of said lens system in response to said separation signal.

20 17. Apparatus for reading optically a flat reflecting record substantially as herein described with reference to Figures 1 and 5 of the accompanying drawings.

18. Apparatus for reading optically a flat reflecting record substantially as herein described with reference to Figures 1 and 6 or Figures 1, 6 and 8 or Figures 1, 6 and 9 or Figures 1, 6 and 12 of the accompanying drawings.

19. Apparatus as claimed in Claim 12 substantially as described with reference to Figures 1 and 3 or Figures 1, 3 and 3a of the accompanying drawings.

20. Apparatus as claimed in Claim 14 substantially as described with reference to Figures 1 and 4 of the accompanying drawings.

C. A. CLARK,
Chartered Patent Agent,
Century House,
Shaftesbury Avenue,
London, W.C.2.,
Agent for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1976.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

