

R.T. BOXALL

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(54) APPARATUS FOR READING RECORDS OPTICALLY

(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:-

5 The invention relates to apparatus for reading a flat record or record carrier on which information, for example video and/or audio information, is recorded in an optically readable information structure comprising a number of parallel tracks. The term "parallel" is used generically to indicate constant spacing. In the case of a record of disc form, 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.

10 The type of apparatus to which the invention relates specifically comprises a radiation source, an objective system for supplying radiation from the radiation source *via* the record carrier to a radiation-sensitive information detection system, which detection system converts the read beam which is supplied by the radiation source and modulated by the information structure into an electric signal, and which apparatus further comprises a focussing detection system and a centring detection system, which systems are connected to electronic circuits for deriving control signals for correcting respectively the focussing of the objective system and the centring of the read beam relative to a track portion to be read.

15 A "focussing detection system" is to be understood to mean a detection system which supplies an electric signal which provides an indication of a deviation between the focal plane of the objective system and the plane of the information structure to be read. A radiation-sensitive "centring detection system" is one which supplies a signal which provides an indication of deviations between the centre of a read spot of radiation which is projected on the information structure and the centre line of the track to be read.

20 In patent Specifications 1,391,541 and 1,441,175 (co-pending Application 41111/73, and in "Philips' Technical Review" 33, No. 7 (pages 186-193) apparatus is described for reading a record carrier of disc form. In the record of the latter example a colour television programme is stored as follows. The information structure consists of tracks which constitute the successive turns of a spiral and comprise a multitude of pits which are pressed in the record carrier, the luminance information being contained in the frequency of the pits and the chrominance and sound information being contained in a variation of the lengths of the pits. A read beam is focussed onto the information structure so as to obtain a radiation spot whose dimensions are of the order of magnitude of those of the pits. By moving the record carrier relative to the read beam, said beam is intensity-modulated in accordance with the stored information. A radiation-sensitive information detector converts the modulation of the read beam into an electric signal. In an electronic circuit said signal is processed in such a manner that it is suitable to be applied to a colour television receiving apparatus.

35 During reading of the record carrier care must be taken that the centre of the read spot of radiation is always projected substantially on the centre-line of the track to be read, because otherwise cross-talk between adjacent tracks may occur and the modulation depth of the signal which is supplied by the information detector becomes too small. Therefore, the position of the radiation spot must be detected and corrected continually. The objective system which is employed in the read apparatus has a high numerical aperture and a small depth of focus. Therefore, it is always necessary to focus sharply on the information structure. Deviations between the desired position of the focal plane and the actual position of said plane, which may for

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example result from constructional tolerances in the bearing of the record carrier or warping of the record carrier or vibrations of the elements of the read apparatus, must be detected continually and the focussing must be readjusted with the aid thereof.

The apparatus described in the cited articles comprises two separate auxiliary systems for detecting centring errors and focussing errors. In the centring auxiliary system two sub-beams are produced which are focussed on the edges of the track to be read. For each of the sub-beams a separate auxiliary detector is provided. The focussing auxiliary system comprises a plate of an electrically conducting material which is connected to the objective system, which plate constitutes a capacitance in conjunction with the electrically conductive surface of the record carrier, and an electronic circuit for measuring the capacitance value. In the prior apparatus, in addition to the optical elements required for the actual read operation, a substantial number of auxiliary elements are required for detecting centring and focussing errors.

It is an object of the present invention to provide a read apparatus in which centring and focussing errors can be detected with a minimal number of additional optical elements. The invention provides apparatus for reading a flat record carrier on which information is recorded in an optically readable information structure, comprising a number of parallel tracks, which apparatus comprises a radiation source, an objective system for supplying radiation from the radiation source via the record carrier to a radiation-sensitive information detection system, which detection system converts the read beam which is supplied by the radiation source and modulated by the information structure into an electric signal, and which apparatus further comprises a focussing detection system and a centring detection system, which systems are connected to electronic circuits for deriving control signals for correcting respectively the focussing of the objective system and the centring of the read beam relative to a track portion to be read, characterized in that the centring detection system and the focussing detection system comprise at least two radiation-sensitive detectors disposed in a first plane normal to the optical axis of said objective system, said first plane being disposed in the far afieid (as herein defined) of the information structure, both said detectors being disposed to the same side of a second plane containing (a) the optical axis of the objective system and (b) a line which is parallel to the centre-line of the track portion to be read, which detectors are situated in a detector area around the point where a line from the track portion to be read which makes an angle of $\beta/2$ with the optical axis of the objective system intersects the first plane, where β is the angle at which a first-order beam is diffracted in a direction transverse to the tracks.

The detectors may be disposed in the actual exit pupil of the objective system if said pupil is readily accessible, or in an image of the actual pupil formed by an auxiliary lens, or in a shadow image of the actual pupil, if said pupil is not readily accessible. The detectors are always located in a plane where the different diffraction orders can satisfactorily be distinguished, i.e. in a plane which is sufficiently remote from the image of the information structure. Herein, this defines the meaning of the expression: the detectors are disposed in the "far field" of the information structure.

The invention is based on the recognition of the fact that when the record carrier which may be regarded as a two-dimensional diffraction grating is read, centring and focussing errors result in additional phase shifts between the zero-order beam and higher-order beams. Said phase shifts are visible in said "far field" as a pattern of interference lines, whose period, which is determined by the focussing, and whose phase, which is determined by the centring, can be measured. The centring and focussing errors can be detected with the aid of additional detectors alone and without any further optical elements or auxiliary beams. With the aid of the resulting error signals the centring and focussing of the read beam can be readjusted so that interference lines no longer appear and the radiation intensity in the plane of the detectors has a specific level.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows read apparatus which is a preferred embodiment of the invention,

Figures 2 through 11 illustrate the principle of the invention, and

Figures 12 through 17 show different detector arrangements embodying the invention.

Figure 1 shows a round-disc-shaped record carrier 1 in radial cross-section. The plane of the information structure is assumed to be reflective and is designated 2. The information tracks are denoted by reference 3. A radiation source 6, for example a helium-neon laser, emits a read beam *b*. Said beam is reflected by mirror 9 to an objective system 11, which is schematically represented by a single lens. The path of the read beam includes an auxiliary lens 7 which ensures that the read beam completely fills the pupil of the objective system. In that case a radiation spot of minimal dimensions is projected onto the plane of the information structure.

The read beam is reflected by the information structure and, as the record carrier is rotated about a spindle 5 which projects through a central opening 4, is modulated in time in accordance with the information which is stored in the track to be read. The modulated read beam passes through the objective system again and is reflected by the mirror 9 in the direction of the beam which is emitted by the source. The radiation path of the read beam includes elements for

separating the paths of the modulated and unmodulated read beams. Said elements may for example comprise an assembly of a polarization-sensitive dividing prism and a $\lambda/4$ plate. In Figure 1 it has been assumed for the sake of simplicity that said means are formed by a semi-transparent mirror 8. Said mirror reflects a part of the modulated read beam to a radiation-sensitive detector 12. At the output of said detector an electric signal is obtained in accordance with the information which is stored in the track to be read. This signal is decoded in an electronic circuit 16, so that an information signal S_i is obtained, which can be applied to a conventional television receiving apparatus 17.

The optical details of the information structure are very small. As an example, the width of a track is $0.5 \mu\text{m}$, the track spacing $1.1 \mu\text{m}$ and the average length of the information areas, which hereinafter are assumed to be pits, is $1.5 \mu\text{m}$ for a disc-shaped record carrier on which a television programme of 30 minutes duration is recorded within an annular band with an inner diameter of 12 cm and an outer diameter of 27 cm. The read spot must therefore remain very accurately centred on the track to be read, and the read beam must always remain sharply focussed on the plane of the information structure.

In order to be able to detect centring and focussing errors two additional detectors 13 and 14 are provided in addition to the detector 12. These three detectors are for example disposed in the plane u in which the actual exit pupil of the objective system is imaged with the aid of an auxiliary lens 23, as shown by dotted lines. For convenience only the image a' of a point a of the exit pupil is indicated in Figure 1 with dotted lines. The detectors may also be disposed in a different plane provided that the different diffraction orders can be distinguished adequately in said plane, and herein it is in this sense that the detectors are defined as being disposed in the "far afield" of the information structure.

The signals supplied by the detectors 13 and 14 can be added and further processed in an electronic circuit 21. At the output of said circuit a control signal S_r is obtained which is applied to a schematically shown drive means 22, which may be known *per se*, which is capable of tilting the mirror 9 (as indicated by arrow 10 in Figure 1).

The electric signals from the detectors 13 and 14 can also be applied to electronic circuit 18 in which they are subtracted from each other and further processed into a control signal S_r . Said control signal may for example be applied to a device 19 which is also schematically shown and may be known *per se*, for moving the objective system in a vertical direction (as indicated by arrow 20 in Figure 1).

Now the influence of focussing and centring errors on the signal applied by the detectors 13 and 14 will be discussed. For simplicity it will be assumed that the record carrier is radiation-transmitting. However, the following considerations also apply to a radiation-reflecting record carrier.

The information structure of the record carrier, which consists of tracks, which in their turn consist of a multitude of short areas, may be regarded as a two-dimensional diffraction grating. Figure 2 shows a part of said grating in accordance with a cross-section in a direction transverse to the tracks 3.

The grating g divides a read beam b into a zero-order beam $b(0,0)$ and two first-order beams $b(0,+1)$ and $b(0,-1)$ and a number of higher-order beams, not shown. The zero-order beam in itself does not comprise any information about the position of the grating; this information is distributed over the beams of the other orders. When the pupil of the lens L is sufficiently large, all orders together provide an accurate image 'g' of the grating g in the image plane of said lens. In said image plane the individual orders cannot be distinguished. However, in the plane v of the exit pupil of the lens L , the orders are more or less separated. Figure 3 represents the situation in said plane.

The circle 30 with its centre 33 in Figure 3 represents the section of the beam $b(0,0)$ in the plane of the exit pupil, and the circles 31 and 32 the sections of the beams $b(0,+1)$ and $b(0,-1)$ respectively. The distances of the centres 34 and 35 of the circles 31 and 32 respectively from the centre 33 is determined by the period p_r of the grating formed by the tracks. The angle β , (Figure 2) between the chief ray of the beam $b(0,0)$ and the chief rays of the beams $b(0,+1)$ and $b(0,-1)$ is given by:

$$\sin \beta = \frac{\lambda}{p_r}$$

where λ represents the wavelength of the radiation of the read beam.

In the shaded areas in Figure 3 the beams $b(0,+1)$ and $b(0,-1)$ partly overlap the beam $b(0,0)$ and interference occurs. Owing to focussing errors and centring errors variations occur in the phases of the beams $b(0,+1)$ and $b(0,-1)$. This results in intensity variations in the effective exit pupil, which variations can be measured with suitable disposed detectors.

In addition to the beams shown in Figure 2, beams of the orders $(+1,0)$ and $(-1,0)$ will occur when the information structure is illuminated. The cross-sections of these beams in the plane of the exit pupil consist of circles with centres 36 and 37 and with the same radius as the circles 30,

31 and 32. These beams are caused by the information areas in the tracks. The phase variations in these beams as a result of the movement of the areas relative to the read beam are of a high frequency, for example 1-10 MHz, and their effect on the low-frequency (e.g. 0-30 KHz) focussing and centring error signals is negligible.

Figure 3 is a fairly good representation of the situation when an information structure with a period p_r of $1.66 \mu\text{m}$ is read with helium-neon laser radiation ($\lambda=0.63 \mu\text{m}$), an objective with a numerical aperture N.A. = 0.4 being used. The overlapping area of three orders around point 33 is comparatively small.

Figures 4a, 4b, 4c and 4d show the variation of the phases of the beams $b(0,+1)$ and $b(0,-1)$ relative to the phase of the beam $b(0,0)$. The electric field vector $\vec{E}_{0,0}$ of the beam $b(0,0)$ rotates with the frequency of light, which is also the case with those of the beams $b(0,+1)$ and $b(0,-1)$. For a specific position of the centre of the read spot relative to the centre of the track to be read, the beam $b(0,+1)$ has a phase vector $\vec{p}$, which makes a certain angle with the vector $\vec{E}_{0,0}$. The beam $b(0,-1)$ then has a phase vector $\vec{q}$ at the same angle as the vector $\vec{p}$. When the read spot moves over the information pattern in the transverse direction of the tracks, for example from left to right in Figure 2, the phase angle of the beam $b(0,+1)$ will decrease and the phase angle of the beam $b(0,-1)$ will increase. Consequently, the vectors $\vec{p}$ and $\vec{q}$ will rotate in opposite directions.

Starting from an initial situation as shown in Figure 4a, the situation of Figure 4b will occur after the read spot has moved over a distance which equals a quarter of the track period p_r . Figure 4c shows the situation after the read spot has moved over a distance equal to half a track period p_r , and Figure 4d the situation after a distance has been covered which equals three quarters of the track period p_r . After the read spot has moved a full track period p_r , the situation of Figure 4a is restored.

The component of the vector $\vec{p}$ in the direction of the vector $\vec{E}_{0,0}$ increases from a minimum to 0 (Figure 4b) then becomes a maximum (Figure 4c) and finally becomes zero again. The component of the vector $\vec{q}$ in the direction of the vector $\vec{E}_{0,0}$ exhibits the same variation. As the read spot moves in a direction transverse to the tracks, constructive and destructive interference will occur alternately in the common areas of the circles 30 and 31 and those of the circles 30 and 32. By measuring the radiation intensity at a radiation-sensitive detector which is disposed in one of the common areas and by comparison with a reference value, the degree of centring of the read spot can be determined.

In Figure 4a a specific initial position for the phase vectors $\vec{p}$ and $\vec{q}$ has been assumed. This initial position is determined by an optical characteristic of the information structure, in the case of a phase structure mainly by the difference in optical path length caused by the information areas, and thus also by the tracks, in the read beam. The phase vector diagram of Figure 4a applies to the case in which a record carrier is read whose tracks cause a difference in optical path length of half a wavelength of the read radiation in the read beam. For a radiation-reflecting information structure consisting of pits and adjoining air, this means that the pits must be a quarter wavelength deep. Furthermore, it is to be noted that a vector diagram like that of Figures 4a to 4d also applies when a record carrier with a so-called black-and-white information pattern, i.e. an absorption pattern is read.

The phase difference between the beam $b(0,0)$ and the beams $b(0,+1)$ and $b(0,-1)$ in the areas of overlap of Figure 3, is determined not only by the nature of the information structure and the degree of centring but also by the degree to which the read beam is focussed on the plane of the information structure. This will be explained with reference to Figure 5.

In this Figure a part of the information pattern is shown in radial section. The read beam is focussed in a plane which is disposed at a distance Δz from the information pattern. Owing to said defocussing an additional difference in path length is obtained between the beam $b(0,0)$ and the beam $b(0,+1)$ and $b(0,-1)$. Only the chief rays of these beams are shown in Figure 5. For a direction lying at an arbitrary angle to the chief ray of the beam $b(0,0)$, the difference in path length between the beam $b(0,0)$ and the beam $b(0,+1)$ is given by:

$$\Delta w = \Delta z \cos \alpha - \Delta z \cos (\beta - \alpha)$$

For a small angle α and for a small difference between the angles $(\beta - \alpha)$, the path length difference in close approximation, i.e. with third-order accuracy, is:

$$\Delta w = \Delta z \left[1 - \frac{\alpha^2}{2} - \left(1 - \frac{(\beta - \alpha)^2}{2} \right) \right]$$

or:

$$\Delta w = \Delta z \frac{\beta}{2} (\beta - 2\alpha)$$

The phase difference caused by the defocussing in a direction at an angle α to the optical axis of the objective system is then:

$$\Delta \varphi_{\Delta z} = 2\pi \frac{\Delta w}{\lambda} = 2\pi \frac{\Delta z}{\lambda} \beta \left(\frac{\beta}{2} - \alpha \right)$$

The phase difference $\Delta\varphi_{\Delta z}$ is a linear function of the angle α and may be represented by a straight line which passes through zero for $\alpha = \frac{\beta}{2}$. In Figure 6 $\Delta\varphi_{\Delta z}$ is shown for a specific value of Δz . The

slope of the line is given by: $\tan \gamma = c \cdot \Delta z$, where the constant $c = \frac{2\pi}{\lambda} \beta$. As a result of the phase variation shown in Figure 6 an intensity distribution I as shown in Figure 7 is obtained in the exit pupil of the objective system. The spatial frequency of the periodical intensity variation is a function of Δz . The distance d is inversely proportional to Δz . At increasing focussing errors the spatial frequency of the intensity pattern will increase. The effect of a focussing error Δz on the radiation intensity differs for different positions in the exit pupil.

Figure 8 represents the total phase difference $\Delta\varphi_t$ between the beam $b(0,0)$ and the beam $b(0,+1)$ as a function of the angle α . This total phase difference is the sum of:

1. The constant phase difference $\Delta\varphi_s$ due to the nature of the information structure (the depths of the pits).

2. The phase difference $\Delta\varphi_{\Delta r}$ which depends on the degree of centring, which difference is independent of the angle α .

3. The phase difference $\Delta\varphi_{\Delta z}$ which depends on the degree of focussing and on the angle α . When reading a record carrier care must be taken than in the entire area of overlap the phase difference between the beam $b(0,0)$ and the beam $b(0,+1)$ should be as close as possible approximately $\Delta\varphi_s$, i.e. that $\Delta\varphi_{\Delta z}$ and $\Delta\varphi_{\Delta r}$ should be as close as possible to zero, because the read beam is then centred and focussed to an optimum extent. A specific phase difference $\Delta\varphi_s$ corresponds to a specific radiation intensity in the area of overlap of these beams. Whether the desired focussing and centring adjustment is achieved can be ascertained in the present example, in which the pits cause a phase difference of π rad, by measuring the radiation intensity in one half of the far field. Figure 9 shows a detector arrangement for this purpose.

In this Figure, as in Figure 3, the effective exit pupil of the objective system is represented by the circle 30, whilst the circles 31 and 32 represent the cross-sections of the beams $b(0,+1)$ and $b(0,-1)$ in the plane of the exit pupil. If a reflecting record carrier is read and the objective system is disposed in the path of the modulated read beam, only those parts of the beams $b(0,1)$ and $b(0,-1)$ which fall inside the circle 30 will be transmitted. A first radiation sensitive detector D_1 is disposed in the far field of the information structure at the location $p(\beta/2)$, which location is determined by the angle $\beta/2$. The radiation intensity on this detector is independent of the degree of focussing. As long as the period d is sufficiently great relative to the width of the detector D_1 , i.e. as long as Δz is small, the output signal of this detector will only depend on the centring of the read spot relative to the track to be read. The output signal of the detector D_1 may be compared with the value which this signal would have if there were only a phase difference $\Delta\varphi_s$ between the beams $b(0,0)$ and $b(0,+1)$. With the control signal S_r (Figure 1) thus obtained the position of the read spot relative to the track to be read can be corrected, for example with the aid of the tilting mirror 9, in such a manner that the signal S_r becomes zero.

The phase difference in the exit pupil is then only determined by $\Delta\varphi_s$ and $\Delta\varphi_{\Delta z}$ (as indicated by the chain-dotted line in Figure 8). The phase difference due to defocussing can be detected by means of a second detector (a focussing detector) D_2 which is disposed adjacent to the first detector D_1 . The output signal of the detector D_2 may be compared with the value which this signal would have if there were only a phase difference $\Delta\varphi_s$ between the beams $b(0,0)$ and $b(0,-1)$. The control signal S_f thus obtained enables the focussing to be corrected, for example in the manner shown in Figure 1, until the signal S_f is zero. The read beam is then also sharply focussed on the information structure.

Another focussing detector D_3 may be disposed at the other side of the detector D_1 . By adding the output signals of the detectors D_3 and D_2 the focussing error signal may be increased by a factor of 2, so that a better signal-to-noise ratio is obtained.

The described error detection may be substantially improved when use is made of a record carrier whose tracks undulate in the plane of the information structure, i.e. exhibit periodical excursions in a direction transverse to the tracks. The amplitude of these excursions must be smaller than the track width, whilst the period of the undulation must be materially greater than the average period of the pits in the tracks. Such a record carrier has already been described in Patent Specification No. 1,489,756, Patent Application 44519/74. Owing to the undulation of the tracks an additional modulation is impressed on the output signals of the detectors D_1 , D_2 and D_3 so that dynamic detection is possible.

If the read beam is not fully centred on the track to be read, the output signal of the detector D_1 contains a first component with a frequency of for example 30 kHz, which corresponds to the spatial frequency of the undulation. However, once the read beam is correctly centred, said first component will no longer be present in the detector signal, but a second component is left with a frequency which corresponds to twice the spatial frequency of the undulation. When a record carrier is used with undulating tracks the centring in the read apparatus of Figure 1 can be corrected so that said first component has disappeared from the signal of the detector D_1 .

So-called synchronous detection is then applied in the circuit 18.

The direction or sign of a centring error which occurs can be determined by comparing the phase of the first component with a reference phase. In the case of a television programme stored on the record carrier, steps can be taken to ensure that the tracks have excursions only at those locations which correspond to the line synchronizing pulses in the television signal. The reference phase for determining the direction of a centring error can then be derived from the television signal.

The use of a record carrier with undulating tracks also permits dynamic detection of focussing errors. This can be explained with reference to Figure 10. In this Figure the curve 40 represents the intensity variation $\Delta I_{\Delta z}$ in the far field of the information structure for a specific value of the defocussing Δz and as a function of the position p in the far field. The curve 41 represents the intensity variation in the far field due to undulation of the track t . For a radiation sensitive detector which is disposed to the left of the position p ($\beta/2$), the detector signal (s_1) is time-modulated in accordance with the curve 42, whilst for a detector which is disposed to the right of the position p ($\beta/2$) the detector signal (s_2) will vary in time in accordance with the curve 43. The signals s_1 and s_2 exhibit a phase difference of 180° . This phase difference remains as long as the read beam is not sharply focussed on the information structure, i.e. as long as Δz is not zero. From the difference between s_1 and s_2 the magnitude and direction of the defocussing can be derived. Said difference signal will be great for high values of Δz , for s_1 and s_2 are then great and their difference will be twice as great as s_1 or s_2 when the detectors are disposed symmetrically relative to the position $p(\beta/2)$. For small values of Δz the difference signal will decrease. The difference signal will be zero when the information structure is in focus, for in that case the curve 40 will change into a straight line parallel to the p -axis. An advantage of this is that a fairly large error signal is available also in the case of small focussing errors, because the signals s_1 and s_2 are subtracted from each other.

When reading a record carrier with undulating tracks using a detector arrangement as in Figure 9, the centring is corrected first in such a way that the signal of the detector D_1 contains no component with a frequency which corresponds to the spatial frequency of the undulation. Subsequently, the focussing is corrected until the difference between the signals supplied by the detectors D_2 and D_3 is zero.

Dynamic detection of focussing and centring errors may also be achieved by periodically moving the read spot over the information structure in a direction transverse to the tracks, the amplitude of the movement again being small relative to the width of the tracks. Such a movement, which can be achieved by periodically moving the tilting mirror 9 in the apparatus of Figure 1, has the same effect as undulation of the tracks.

In the above description of the focussing and centring detection, only first-order beams have been mentioned. It is obvious that the grating like information structure will also cause higher-order diffraction of the radiation. However, the radiation energy in the higher-order beams is fairly low and the diffraction angles are such that only a small part of the higher-order beam falls within the pupil of the objective system. For the detection methods described the higher-order beam may be neglected.

When the arrangement described so far is used the pits or information areas should preferably have a phase depth π , i.e. cause a phase difference of π rad in the read beams. If the pits have a different depth, a deviation in the centring may occur, whilst no error is detected by the detector D_1 , D_2 and D_3 . The servo-system for the centring then effects such control that the centre of the read spot remains at a constant distance from the centre-line of a track to be read.

However, it is possible to detect whether the information areas have the correct phase depth π , by disposing an additional detector D_4 , shown dotted in Figure 9, in the far field. In the righthand part of Figure 11 N_1 denotes the intensity level in the right-hand part of the far field, if the detectors D_1 , D_2 and D_3 have signalled no errors. When the pits of the information structure have a phase depth which differs from π , a different intensity level will exist in the left-hand part of the far field, denoted by N_2 . The dotted line 44 through the point 33 marks the demarcation between said left and right parts. The difference between the levels N_1 and N_2 provides an indication of the deviation between the actual phase depth and the phase depth π of the pits. This difference in intensity levels may be used for changing a control voltage in the centring servo-control electronics in such a manner that the read spot is so positioned relative to the track to be read that the intensity levels in the left and right parts of the far field are equal, as indicated by level N_3 in Figure 11.

The deviation between the actual phase depth of the pits and the value π can be measured (after such control that the detectors D_1 , D_2 and D_3 indicate no errors), by comparing the output signals of the detectors D_4 and D_1 . If the record carrier which is being read has undulating tracks, or if during reading the read spot is periodically moved in a direction transverse to the tracks, said deviation may also be derived from the signal of the detector D_4 alone, namely from the quotient $c(\Omega)/c(2\Omega)$ where $c(\Omega)$ and $c(2\Omega)$ are the components of the detector signal of the frequency Ω and 2Ω respectively, Ω corresponding to the spatial frequency of the track undulation or to the

frequency with which the read spot is moved.

The additional control by means of the detector D_4 will not be strictly necessary, when only record carriers of a specific type are to be read which are all assumed to have a specific phase depth. Fairly large deviations in the phase depths of the pits may occur without impairing the read process. Only when these deviations approximate half the desired phase depth, correct reading will no longer be possible. Such large deviations will hardly ever occur with the present technologies used in the manufacture of record carriers. The additional control is therefore intended to enable not only record carriers with a phase depth π , but also other record carriers with an intentionally differently selected phase depth to be read. When the record carrier is initially read the phase depth is determined first in the previously described manner and the control voltage in the servo system for the centring is adjusted. This adjustment further remains unchanged during reading of the complete information structure.

It is obvious that in the left and right parts of the far field the same situations are obtained. Therefore, the arrangement of Figure 9 can be modified so that the detectors D_1 , D_2 and D_3 are disposed at the left and the detector D_4 at the right. The position of the detector D_4 in its half of the far field and its dimensions are non-critical. In Figure 9 this detector is only shown in position $p(-\beta/2)$ by way of example.

So far it has been assumed that the detectors have a rectangular shape e.g. as in Figure 12a. With these detectors an intensity variation as in accordance with Figure 7 is detected, an intensity variation whose spatial frequency is a function of Δz and thus variable. The response, or the Fourier transform of a rectangular detector having a width e , to such an intensity variation as a function of the spatial frequency ($1/d$) is represented by the curve 45 of Figure 12b and has a $\frac{\sin x}{x}$ shape. At a frequency $1/e$ the curve passes through zero, because then the detector will always "see" one period of the intensity variation and will always receive the same amount of radiation, independently of the phase of the intensity pattern and thus independently of the centring. When the spatial frequency of the intensity pattern of Figure 7 becomes greater than $1/e$, a negative part is obtained in the curve 45 of Figure 12b. This means that the centring servo system will control in the wrong direction and that a centring error, if any, is increased. At still greater values of the spatial frequency, curve 45 becomes positive again and the servo-system may hold the centre of the read spot at a fixed distance from the centreline of the track to be read.

In order to avoid this problem it is possible according to a feature of the invention to employ a detector D' of triangular shape (see Figure 13a). The response of such a detector to the intensity pattern of Figure 7 is a square function, in particular a $(\frac{\sin x}{x})^2$ function (see Figure 13b). The curve 46 comprises no negative portion, and there is no risk that the servo-control for centring will operate in the wrong direction.

The detector system for determining focussing and centring errors need not consist of separate focussing detectors and separate centring detectors. Figures 14a-14b show different (preferred) embodiments for rectangular and triangular detectors respectively. The system consists of two oppositely disposed detectors 50-51 and 52-53 respectively which are disposed in or substantially in position $p(\beta/2)$. The signals from the detectors 50, 51 and 52, 53 respectively are applied to both an adder circuit 54 and a differential amplifier 55. At the output of the circuit 54 a signal s' is obtained with which the centring can be corrected, and at the output of the differential amplifier 55, a signal s'' is obtained with which the focussing can be corrected.

As previously stated, the width e of the detector of Figure 12a should not equal the spatial period d of the intensity pattern, because in that case the centring control will not function any longer. For large focussing errors d is small and for a large control range a narrow detector should be selected. However, for small focussing errors d is large and for accurate detection the detector must be wide. In order to comply with these contrary requirements it is possible to employ a detection system in accordance with Figure 15. Said system, which is a special embodiment of the detection system of Figure 14b, consists of two detectors 52 and 53 which are each divided into two sub-detectors A_1 and a_1 and A_r and a_r respectively. The signals from the detectors a_1 and A_1 and those of the detectors a_r and A_r may be added to each other or not, which possibilities are schematically represented by the switches 56 and 57.

When a large focussing error is measured switches 56 and 57 interrupt the circuit and control takes place in response to the signals of the detectors a_1 and a_r only. When the focussing error decreases below a specific value, the switches 56 and 57 are closed and the complete radiation-sensitive areas of the detectors 52 and 53 are utilized.

In an application of a detection system in accordance with Figure 15, in which the largest width of the detectors 52 and 53 was $850 \mu\text{m}$ and that of the sub-detectors a_1 and a_r was $425 \mu\text{m}$, focussing errors to a maximum of $45 \mu\text{m}$ could be detected with the detectors a_1 and a_r . When the focussing error becomes smaller than $10 \mu\text{m}$, the parts A_1 and A_r were switched on.

It is evident that a rectangular detection system in accordance with Figure 14a may also be divided in a manner similar to that of Figure 15.

The focussing and centring detectors cover only a small portion of the far field of the information structure. The rest of this far field can be covered by the detector by which the stored information, for example a television programme, is read, or in other words by the detector with which the interference between the beam $b(0,0)$ and the beams $b(+1,0)$ and $b(-1,0)$ is measured. In the far field of the information structure one round radiation-sensitive detector may then be disposed, whose diameter is equal to or greater than the beam diameter at the location of the detector, which detector comprises separate radiation-sensitive sections D_i and D_c . Shown in Figure 16. Section D_i serves for reading the information stored on the record carrier, and the section D_c , which may have the shape of the detection system of Figure 15, supplies the focussing and centring error signals. Alternatively, another separate detector section D_4 may be provided.

The detector section D_i has a fairly large area. To enable high-frequency information to be read with a detector which has a high capacitance per unit of area, an arrangement as in Figure 17 may then be chosen. The system 52, 53 for detecting focussing and centring errors is disposed in the far field of the information structure, whilst the high-frequency information detector 12 is disposed in or substantially in the plane in which the information structure is imaged. However, it is alternatively possible to use a so-called PIN photo-diode for the detector of Figure 16. This diode has a low capacitance per unit of area. The advantage of a large detector is that it need not be aligned as accurately as a small detector.

In the arrangement of Figure 17 a semi-transparent mirror may be included in the radiation path to the detector 12 and the detectors 52 and 53 may be disposed in the path of the radiation which is reflected by said mirror.

WHAT WE CLAIM IS:-

1. Apparatus for reading a flat record carrier on which information is recorded in an optically readable information structure, comprising a number of parallel tracks, which apparatus comprises a radiation source, an objective system for supplying radiation from the radiation source *via* the record carrier to a radiation-sensitive information detection system, which detection system converts the read beam which is supplied by the radiation source and modulated by the information structure into an electric signal, and which apparatus further comprises a focussing detection system and a centring detection system, which systems are connected to electronic circuits for deriving control signals for correcting respectively the focussing of the objective system and the centring of the read beam relative to a track portion to be read, characterized in that the centring detection system and the focussing detection system comprise at least two radiation-sensitive detectors disposed in a first plane normal to the optical axis of said objective system, said first plane being disposed in the far field (as herein defined) of the information structure, both said detectors being disposed to the same side of a second plane containing (a) the optical axis of the objective system and (b) a line which is parallel to the centre-line of the track portion to be read, which detectors are situated in a detector area around the point where a line from the track portion to be read which makes an angle of $\beta/2$ with the optical axis of the objective system intersects the first plane, where β is the angle at which a first-order beam is diffracted in a direction transverse to the tracks.

2. Apparatus as claimed in Claim 1, characterized in that a further radiation-sensitive detector is disposed in the far field of the information structure on the opposite side of said second plane from said detectors.

3. Apparatus as claimed in Claim 1 or Claim 2, characterized in that the centring detection system comprises a first radiation-sensitive detector disposed in said detector area and in that the focussing detection system is formed by at least one further radiation-sensitive detector which is disposed adjacent to the first detector.

4. Apparatus as claimed in Claim 3, characterized in that the focussing detection system consists of two radiation-sensitive detectors disposed on either side of the first detector, whose outputs are connected to an adder circuit.

5. Apparatus as claimed in Claim 3, comprising means for moving the read beam and the tracks periodically relative to each other during reading in a direction transverse to the tracks, characterized in that the focussing detection system consists of two radiation-sensitive detectors which are disposed on either side of the first detector, whose outputs are connected to a differential amplifier.

6. Apparatus as claimed in Claim 1 or 2, characterized in that the centring and focussing detection system comprise two detectors which are each triangular, a boundary line between which detectors is effectively parallel to the centre-line of a track portion to be read and is disposed in said detector area, whilst the two other boundary lines of the detectors effectively make an acute angle with the centre-line of the track portion to be read, and that the output of each of the detectors is connected to a differential amplifier and to a summation amplifier, the differential amplifier supplying a focussing error signal and the summation amplifier a centring error signal.

7. Apparatus as claimed in Claim 6, characterized in that each of the detectors is divided into two sub-detectors, the dividing lines effectively making a more acute angle with the centre-line of



The focussing and centring detectors cover only a small portion of the far field of the information structure. The rest of this far field can be covered by the detector by which the stored information, for example a television programme, is read, or in other words by the detector with which the interference between the beam $b(0,0)$ and the beams $b(+1,0)$ and $b(-1,0)$ is measured.

5 In the far field of the information structure one round radiation-sensitive detector may then be disposed, whose diameter is equal to or greater than the beam diameter at the location of the detector, which detector comprises separate radiation-sensitive sections D_1 and D_c . Shown in Figure 16. Section D_1 serves for reading the information stored on the record carrier, and the section D_c , which may have the shape of the detection system of Figure 15, supplies the focussing and centring error signals. Alternatively, another separate detector section D_4 may be provided. 10

The detector section D_1 has a fairly large area. To enable high-frequency information to be read with a detector which has a high capacitance per unit of area, an arrangement as in Figure 17 may then be chosen. The system 52, 53 for detecting focussing and centring errors is disposed in the far field of the information structure, whilst the high-frequency information detector 12 is disposed in or substantially in the plane in which the information structure is imaged. However, it is 15 alternatively possible to use a so-called PIN photo-diode for the detector of Figure 16. This diode has a low capacitance per unit of area. The advantage of a large detector is that it need not be aligned as accurately as a small detector.

In the arrangement of Figure 17 a semi-transparent mirror may be included in the radiation path to the detector 12 and the detectors 52 and 53 may be disposed in the path of the radiation which 20 is reflected by said mirror.

WHAT WE CLAIM IS:-

1. Apparatus for reading a flat record carrier on which information is recorded in an optically readable information structure, comprising a number of parallel tracks, which apparatus comprises 25 a radiation source, an objective system for supplying radiation from the radiation source *via* the record carrier to a radiation-sensitive information detection system, which detection system converts the read beam which is supplied by the radiation source and modulated by the information structure into an electric signal, and which apparatus further comprises a focussing detection system and a centring detection system, which systems are connected to electronic 30 circuits for deriving control signals for correcting respectively the focussing of the objective system and the centring of the read beam relative to a track portion to be read, characterized in that the centring detection system and the focussing detection system comprise at least two radiation-sensitive detectors disposed in a first plane normal to the optical axis of said objective system, said first plane being disposed in the far field (as herein defined) of the information structure, both said 35 detectors being disposed to the same side of a second plane containing (a) the optical axis of the objective system and (b) a line which is parallel to the centre-line of the track portion to be read, which detectors are situated in a detector area around the point where a line from the track portion to be read which makes an angle of $\beta/2$ with the optical axis of the objective system intersects the first plane, where β is the angle at which a first-order beam is diffracted in a direction 40 transverse to the tracks.

2. Apparatus as claimed in Claim 1, characterized in that a further radiation-sensitive detector is disposed in the far field of the information structure on the opposite side of said second plane from said detectors.

3. Apparatus as claimed in Claim 1 or Claim 2, characterized in that the centring detection system comprises a first radiation-sensitive detector disposed in said detector area and in that the focussing detection system is formed by at least one further radiation-sensitive detector which is 45 disposed adjacent to the first detector.

4. Apparatus as claimed in Claim 3, characterized in that the focussing detection system consists of two radiation-sensitive detectors disposed on either side of the first detector, whose 50 outputs are connected to an adder circuit.

5. Apparatus as claimed in Claim 3, comprising means for moving the read beam and the tracks periodically relative to each other during reading in a direction transverse to the tracks, characterized in that the focussing detection system consists of two radiation-sensitive detectors which are disposed on either side of the first detector, whose outputs are connected to a 55 differential amplifier.

6. Apparatus as claimed in Claim 1 or 2, characterized in that the centring and focussing detection system comprise two detectors which are each triangular, a boundary line between which detectors is effectively parallel to the centre-line of a track portion to be read and is disposed in said detector area, whilst the two other boundary lines of the detectors effectively 60 make an acute angle with the centre-line of the track portion to be read, and that the output of each of the detectors is connected to a differential amplifier and to a summation amplifier, the differential amplifier supplying a focussing error signal and the summation amplifier a centring error signal.

7. Apparatus as claimed in Claim 6, characterized in that each of the detectors is divided into 65 two sub-detectors, the dividing lines effectively making a more acute angle with the centre-line of



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the track portion to be read than the boundary lines of the composite detector.

5 8. Apparatus as claimed in any one of the preceding Claims, characterized in that in the far field of the information structure one integrated radiation-sensitive detector is disposed which detector has dimensions which are at least equal to the beam cross-section at the location of the detector, which detector comprises mutually separated detector sections of which a first section comparatively large section constitutes the information detection system and a second, smaller, section supplies the focussing and centring error signals.

9. Apparatus as claimed in Claim 8, characterized in that the integrated detector is constituted by a PIN photo-diode.

10 10. Apparatus as claimed in any of the Claims 1 through 7, characterized in that the detectors of the centring and focussing detection systems are disposed in a plane which is nearer to the objective system than the plane in which the information detector is disposed.

11. Apparatus substantially as described with reference to the accompanying drawings.

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C.A. CLARK,
Chartered Patent Agent,
Berkshire House,
168-173 High Holborn,
London WC1V 7AQ
Agent for the Applicant

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