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(54) INFORMATION CARRIER OF DISC FORM FOR SOUND AND/OR VIDEO SIGNALS

(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 information carriers of disc form provided with parallel tracks in which sound and/or video signals are stored. (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 invention also relates to apparatus for reading by optical means the signals stored in such an information carrier.

A carrier and an apparatus of the above type are known. The known carrier has a spiral groove the bottom of which has an undulating profile. Although in reproducing the known carrier the conventional gramophone disc record technology is used, manufacture of the master carrier is a time-consuming laborious process, for the information is stored in the form of grooves which can only be formed by means of machine tools.

When detecting the information stored in the known carrier the angle at which the surfaces of the undulating grooves are to the plane of the carrier plays an essential part. Moreover the lands between the consecutive tracks play an essential role in following the track. This renders it necessary to provide a complicated three-dimensional profile on the carrier.

The disadvantage to which the known carrier is subject are avoided in the carrier according to the invention which has a substantially two-dimensional profile. The carrier according to the invention may comparatively simply and rapidly be manufactured by photographic and etching methods.

The invention provides an information carrier of disc form having parallel tracks as herein defined wherein:—

(a) audio and/or video signals are stored in the tracks as a topographical structure composed of first areas which all lie in a first plane and are separated by second areas which all lie in a second plane parallel to and spaced from first plane by a distance comparable to a wavelength of optical radiation,

(b) said signals are represented by variations in the lengths of said first areas and/or said second areas in the track direction,

(c) the first areas have coefficients of optical reflection or of optical transmission equal to each other and to those of the second areas, and

(d) the carrier and its track structure are such that the optical path length for a read beam of optical radiation reflected from or transmitted through the carrier at a first area differs from the corresponding path length at a second area in such manner that radiation reflected at or transmitted by the first areas has a phase difference with respect to radiation reflected at or transmitted by the second areas.

The first and second areas are impressed on such a carrier or disc as a stream of signals or information recorded on a track in a pulse modulated form. The start of a pulse may be indicated by a change from the first area state to the second area state, the end of the pulse by a reverse change. As will be explained, and according to a further aspect of the invention, optical means for reading

such pulse modulated records can produce light changes which alternate between two distinctive phase states which can then be converted into amplitudes corresponding to the two states. The recorded information can be defined by the length of a block as defined by the instants of transition between these two amplitudes and not in the values of these amplitudes, which require only to be distinctive. Thus the recurrence of characteristic values of the signal can be detected, for example the recurrence of the passages through zero of the alternating-voltage component of the signal. Variations in the luminous flux of the source of light and defocussing do not affect the mutual time differences between these passages through zero.

In most cases it is sufficient or even desirable for the plane of the first areas or that of the second area of the disc to coincide with a plane containing areas provided as the spacings between adjacent tracks.

If the disc has the latter form, with one set of track areas (e.g. the said second areas) lying in a general plane of the recorded surface of the disc, then the other track areas (e.g. said first areas) can be referred to as "blocks" since they are distinct from what is now a general background plane (the second areas can then be referred to simply as "areas" of the track). This form of disc permits relatively cheap and simple methods of manufacture, e.g. by photographic and etching methods or by lithographic processes.

Reverting to the question of optical reading methods, since a track structure in accordance with the invention is designed to provide phase differences rather than amplitude changes, such a track structure can be referred to as a phase structure. In fact the phase of a wavefront of a reading beam incident on a block is changed with respect to the phase of another part of the same wavefront incident on an area of the track. Such a phase change is produced by a change of optical path length. If the blocks and areas of the track are optically transparent, the path length change may be produced by a change of dimension such as an increase or decrease of thickness of the disc at the blocks as compared with the thickness at the areas. If the blocks and areas are reflective surfaces, the path length change occurs in a transparent medium (which may be air) adjacent to said surfaces. However produced, such phase changes give rise to amplitude changes which can be sensed with the aid of optical reading equipment by a radiation detector.

Examples of this reading mode will be described using apparatus essentially based on the known principles of interference microscopy.

As will be restated in greater detail, apparatus for reading the information stored in the carrier employs a beam of optical radiation which is diffracted by the information in the carrier and is divided thereby into two parts which have a mutual difference in direction and in phase.

The transitions between successive blocks and areas may be either abrupt or smooth, both in the direction of the track and in the axial direction of the carrier. To protect the recorded information, the surface on which the information is provided may be covered by a transparent protective layer.

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

Figure 1 shows an information carrier according to the invention, and

Figures 2, 3, 4, 5 and 6 illustrate apparatus for reading the information stored in a carrier according to the invention.

Figure 1*a* is a schematic plan view of part of an information carrier 1. The carrier 1 contains a large number of parallel tracks which may be the turns of a spiral or may alternatively be concentric as shown. Only part of two adjacent tracks (designated 12 and 13) is shown. Each track is formed as a crenellated topographical structure the profile of which is shown in exaggerated form in Figure 1*b* as a section taken along the track 12. Audio and/or video signals are stored in each track as a structure composed of first areas 3, 5, 7 etc which all lie in a first plane and are separated by second areas which are recessed and all lies in a second plane parallel to the first plane. The said signals are represented by variations in the lengths of said first areas (and preferably also those of said second areas) in the track direction. Figures 1*a*—1*b* are purely schematic:— in particular, the spacings required to separate adjacent tracks are represented by black circles. Since the first areas (3, 5, 7) are located on elements which project from the general plane of the carrier or disc, the said areas will be referred to as the blocks whereas the intervening second areas will be referred to simply as "areas".

Since the planes of the blocks and areas are parallel to each other, the heights 4, 6 etc of the blocks are all equal to one another and, in the case of a transparent disc intended to be read by beam transmission, they are preferably, as will be explained, chosen to introduce about one half of a wavelength of path difference into part of the radiation beam by means of which the carrier is to be read or scanned. In the case of an optically reflecting disc the heights 4, 6 are preferably chosen to introduce substantially one quarter of a wavelength of path difference into part of the radiation beam by means of which the carrier is to be scanned. Thus, the overall effect, in either case, is to introduce a path difference of half a wavelength.

The carrier may, for example, be made of

polyvinyl acetate. The spacing between adjacent tracks is, for example, about 4 μm, and the smallest period in the recording along each track is, for example, about 2.5 μm. The carrier rotates at a speed of, for example, 1,500 revolutions per minute about its axis, which in Figure 1*a* is designated by 0. The arrow in Figure 1*b* indicates the travelling direction of a track past a reading beam.

In the reading apparatus shown in Figure 2 a collimated beam of light from a source of light 20 is incident via a polarizer 21 on the carrier 1 the tracks of which have a crenellated structure. A lens 25 produces on a detector 23 an image of the part of the carrier 1 on which the light beam falls. A Wollaston prism 24 is inserted in the path of the light beam between the carrier 1 and the detector 23. The Wollaston prism comprises two congruent prisms 27 and 28 which each consist of a uniaxial birefringent crystal and together form a plane-parallel plate 24. The optic axis C_1 of the crystal 28 is parallel to the plane of the drawing and the optic axis C_2 of the crystal 27 is at right angles to the plane of the drawing. The light beam incident on one of the parallel larger surfaces of the Wollaston prism 24 is divided in the prism into two parts hereinafter referred to as sub-beams which are polarized at right angles to one another and diverge at a small angle to one another.

Consequently, in the image plane of the detector 23 two images of the illuminated part of the carrier 1 are produced which are separated. Between the Wollaston prism 24 and the detector 23 there is arranged a polarizer 26 the direction of polarization of which is at an angle of 45° to the optic axes C_1 and C_2 of the crystals 28 and 27.

Thus, the differences between the intensities of the two images measured in the detector 23 are maximised. These differences are due to the optical path length differences of the light beam in the crenellated structure and, owing to the choice of about one wavelength for the height of the blocks in this transmission case, these optical path length differences are $1/2\ \lambda$. This is due to the values of the refractive indices of typical transparent materials which can be used to make the disc.

The additional path length difference of the sub-beams (forming the two images) which is produced in the Wollaston prism 24 is compensated by a path length difference produced in a Wollaston prism 22 which is identical to the prism 24 and is inserted between the carrier 1 and the polarizer 21.

The Wollaston prism 24 may be replaced by a Savart plate. A Savart plate consists of two equally thick plane-parallel quartz plates the optic axes of which are at angles of 45° to the plane-parallel surfaces and are crossed. A light beam normally incident on one of the plane-parallel surfaces of the Savart plate is split in the first quartz plate into an ordinary ray and an extra-ordinary ray, which at the interface between the first and the second quartz plates are converted into an extra-ordinary ray and an ordinary ray respectively, since the optic axes of the two crystals are at right angles to one another. From the Savart plate there emerge two sub-beams which are polarized at right angles to one another and are shifted relatively to one another. An analyzer 26 again is at 45° with respect to the optic axes of the Savart plate. In this embodiment also, the path difference between the two rays due to the Savart plate is compensated by the insertion of an identical Savart plate between the carrier 1 and the light source 20.

The apparatus shown in Figure 3 an image of the carrier 1 is formed by a lens 31 on the detector 23. From the carrier 1 there again emerges a wave front having phase differences impressed on it due to the path length differences in the crenellated structure of the track on the carrier 1.

An interferometer block 32 is arranged between the lens 31 and the detector 23. The interferometer 32 comprises two prisms made of a suitable glass and cemented together. At the semi-reflecting interface 33 of the prisms part of the beam is transmitted and part is reflected so that two sub-beams are formed.

The transmitted and reflected sub-beams are reflected at the reflective lateral surfaces 34 and 35 respectively of the component prisms. In known manner, these surfaces are almost, but not quite, at right angles to one another. The sub-beams reflected by the surfaces 34 and 35 are then respectively reflected at and transmitted through the interface 33 and thus form closely adjacent parallel images the intensity difference between which is again determined by the crenellated structure.

The apparatus of Figure 4 employs a modified phase-contrast microscope. Owing to the regularity of the track spacing on the carrier or disc 1, the latter can be regarded as a diffraction grating. In this apparatus a divergent light-beam emitted by a point source 65 is converted by a lens 66 into a collimated light beam which falls on the carrier 1. The zero-order beam which is transmitted by the carrier 1 without diffraction is converted by a lens 67 into a converegent beam which is focused at a point M of a phase plate 68.

The beams transmitted by the carrier 1 as diffracted beams, for example those of the order $+1$ and -1, are converged by the lens 67 at a point which, viewed in the direction of propagation of the radiation beams, lies beyond the phase plate 68. These beams do not pass through the point M of the phase plate 68. At the plane in which a detector element is arranged inside detector unit 69 the

undiffracted beam (zero-order beam) and the diffracted beams (+1st-order and −1st-order beams) unite, and a real image of the carrier 1 is formed.

The phase plate is proportioned so as to introduce a 90° phase difference between the +1-order and −1-order beams on the one hand and the zero-order beams on the other. Thus, the intensity differences in the carrier image in the detector unit 69 are as large as possible.

The source of light used in apparatus for detecting the signals stored in the carrier may be a source having a great brightness and a high degree of coherence as provided by a laser. The light source may alternatively be an incoherent source of great brightness, for example a photo-emissive diode. As a further alternative the light source may be a gas discharge tube.

The detector used may be a photomultiplier or a solid-state photo-detector, for example a silicon photo-detector.

An advantageous apparatus for detecting the information stored in the carrier is shown in Figure 5. Carrier 70 has a reflective crenellated track structure and rotates about an axis which in the Figure is shown as a chain-dotted line 0.

A light beam of small numerical aperture produced by a source of light 71 and a small opening in a mirror 72 is focused onto the carrier 70 by a lens 74. The crenellated or block-and-area structure on the carrier 70 reflects the focused light beam.

On the plane portions of the crenellated structure, i.e. the portions which extend at right angles to the rotation axis, the light beam is incident at an angle of incidence which is nearly zero degrees. The reflected light beam then has a direction which is substantially opposite to that of the incident beam and a numerical aperture which is equal to that of the beam incident on the carrier. This reflected light beam emerges through the opening in the mirror 72 and is lost.

When, however, the light beam is incident on the carrier 70 at surfaces between the plane portions, i.e. where it straddles the upright edges of the blocks, then since there is a phase difference between radiation coming from either side of the upright edges the reflected beam will have a larger numerical aperture than has the incident beam owing to interference effects. By means of an annular objective 75 this light beam scattered outside the aperture of lens 74 at the upright edges of the blocks is focused onto a detector 73 after reflection at mirror 72. The upright edges are thus imaged with a high contrast.

Another apparatus for detecting the information stored in the carrier is shown in Figure 6. A source of light 81 is imaged by a lens 82 on an opening of a screen 83. From the opening a light beam emerges which via a mirror 84 and a lens 85 is focused onto a carrier 80. The image of the opening on the carrier 80 is smaller than, or equal to, the dimensions of the blocks in the track structure on the carrier 80.

The light transmitted by the transparent carrier 80 is imaged via an objective 86 on a detector 87 which may be of comparatively large size. This imaged light is reduced in amount when the light beam straddles an upright face of a block owing to some light being thrown outside the aperture of lens 86 by the interference effect described with reference to Figure 5. Thus, the detector signal is reduced when a block edge is under the light beam.

Obviously the carrier 80 may alternatively be reflective in which case the mirror 84 takes the form of a semi-transparent mirror.

The detector 87 may alternatively be replaced by the combination of an opening in a diaphragm and a detector which, viewed in the direction of propagation of the light, is located behind the opening. This opening is required to eliminate that portion of the light beam which may have interacted with other tracks that the track to be scanned.

WHAT WE CLAIM IS:—

1. An information carrier of disc form having parallel tracks as herein defined wherein:—

(a) audio and/or video signals are stored in the tracks as a topographical structure composed of first areas which all lie in a first plane and are separated by second areas which all lies in a second plane parallel to and spaced from first plane by a distance comparable to a wavelength of optical radiation.

(b) said signals are represented by variations in the lengths of said first areas and/or said second areas in the track direction,

(c) the first areas have coefficients of optical reflection or of optical transmission equal to each other and to those of the second areas and,

(d) the carrier and its track structure are such that the optical path length for a read beam of optical radiation reflected from or transmitted through the carrier at a first area differs from the corresponding path length at a second area in such manner that radiation reflected at or transmitted by the first areas has a phase difference with respect to radiation reflected at or transmitted by the second areas.

2. An information carrier as claimed in Claim 1 which carrier is reflective and wherein the first and second areas of the tracks lie in planes that are spaced apart by an optical path length substantially equal to one quarter of a wavelength of optical radiation.

* C L M S *

undiffracted beam (zero-order beam) and the diffracted beams (+1st-order and −1st-order beams) unite, and a real image of the carrier 1 is formed.

The phase plate is proportioned so as to introduce a 90° phase difference between the +1-order and −1-order beams on the one hand and the zero-order beams on the other. Thus, the intensity differences in the carrier image in the detector unit 69 are as large as possible.

The source of light used in apparatus for detecting the signals stored in the carrier may be a source having a great brightness and a high degree of coherence as provided by a laser. The light source may alternatively be an incoherent source of great brightness, for example a photo-emissive diode. As a further alternative the light source may be a gas discharge tube.

The detector used may be a photomultiplier or a solid-state photo-detector, for example a silicon photo-detector.

An advantageous apparatus for detecting the information stored in the carrier is shown in Figure 5. Carrier 70 has a reflective crenellated track structure and rotates about an axis which in the Figure is shown as a chain-dotted line 0.

A light beam of small numerical aperture produced by a source of light 71 and a small opening in a mirror 72 is focused onto the carrier 70 by a lens 74. The crenellated or block-and-area structure on the carrier 70 reflects the focused light beam.

On the plane portions of the crenellated structure, i.e. the portions which extend at right angles to the rotation axis, the light beam is incident at an angle of incidence which is nearly zero degrees. The reflected light beam then has a direction which is substantially opposite to that of the incident beam and a numerical aperture which is equal to that of the beam incident on the carrier. This reflected light beam emerges through the opening in the mirror 72 and is lost.

When, however, the light beam is incident on the carrier 70 at surfaces between the plane portions, i.e. where it straddles the upright edges of the blocks, then since there is a phase difference between radiation coming from either side of the upright edges the reflected beam will have a larger numerical aperture than has the incident beam owing to interference effects. By means of an annular objective 75 this light beam scattered outside the aperture of lens 74 at the upright edges of the blocks is focused onto a detector 73 after reflection at mirror 72. The upright edges are thus imaged with a high contrast.

Another apparatus for detecting the information stored in the carrier is shown in Figure 6. A source of light 81 is imaged by a lens 82 on an opening of a screen 83. From the opening a light beam emerges which via a mirror 84 and a lens 85 is focused onto a carrier 80. The image of the opening on the carrier 80 is smaller than, or equal to, the dimensions of the blocks in the track structure on the carrier 80.

The light transmitted by the transparent carrier 80 is imaged via an objective 86 on a detector 87 which may be of comparatively large size. This imaged light is reduced in amount when the light beam straddles an upright face of a block owing to some light being thrown outside the aperture of lens 86 by the interference effect described with reference to Figure 5. Thus, the detector signal is reduced when a block edge is under the light beam.

Obviously the carrier 80 may alternatively be reflective in which case the mirror 84 takes the form of a semi-transparent mirror.

The detector 87 may alternatively be replaced by the combination of an opening in a diaphragm and a detector which, viewed in the direction of propagation of the light, is located behind the opening. This opening is required to eliminate that portion of the light beam which may have interacted with other tracks that the track to be scanned.

WHAT WE CLAIM IS:—

1. An information carrier of disc form having parallel tracks as herein defined wherein:—

(a) audio and/or video signals are stored in the tracks as a topographical structure composed of first areas which all lie in a first plane and are separated by second areas which all lies in a second plane parallel to and spaced from first plane by a distance comparable to a wavelength of optical radiation.

(b) said signals are represented by variations in the lengths of said first areas and/or said second areas in the track direction,

(c) the first areas have coefficients of optical reflection or of optical transmission equal to each other and to those of the second areas and,

(d) the carrier and its track structure are such that the optical path length for a read beam of optical radiation reflected from or transmitted through the carrier at a first area differs from the corresponding path length at a second area in such manner that radiation reflected at or transmitted by the first areas has a phase difference with respect to radiation reflected at or transmitted by the second areas.

2. An information carrier as claimed in Claim 1 which carrier is reflective and wherein the first and second areas of the tracks lie in planes that are spaced apart by an optical path length substantially equal to one quarter of a wavelength of optical radiation.

3. An information carrier as claimed in Claim 1 which carrier is transparent and wherein the first and second areas of the tracks lie in planes that are spaced apart by an optical path length substantially equal to one half of a wavelength of optical radiation.

4. An information carrier as claimed in any preceding claim wherein the plane of the first areas or that of the second areas of the tracks coincide with a plane containing areas provided as spacings between adjacent tracks.

5. An information carrier as claimed in any preceding claim provided with a protective transparent layer.

6. An information carrier as claimed in any preceding claim wherein the smallest period in the recording along each track is about 2.5 μm.

7. An information carrier substantially as described with reference to Figures 1*a* and 1*b* of the accompanying drawings.

8. Apparatus for reading optically an information carrier of disc form as claimed in any preceding claim, the apparatus comprising means for supporting and rotating the disc, optical means for directing a read beam of radiation at the carrier track structure so that the optical path length for said read beam of optical radiation reflected from or transmitted through the carrier at a first area differs from the corresponding path length at a second area and so that radiation reflected at or transmitted by the first areas has a phase difference with respect to radiation reflected at or transmitted by the second areas, means for converting said difference in phase into an intensity difference by an optical interference method and a detector for converting said intensity difference into an electric output signal having amplitude variations corresponding to the information stored in the disc.

9. Apparatus as claimed in Claim 8 wherein the reading means comprise a modified phase-contrast microscope combined with a photo-detector.

10. Apparatus as claimed in Claim 8 or Claim 9 adapted to operate with a reflective information carrier and having the beam source and the reading means on the same side of the disc position.

11. Apparatus for reading optically an information carrier in combination with a reflective information carrier of disc form as claimed in Claim 2, the apparatus means for supporting and rotating the disc, optical means for directing a read beam of radiation of a wavelength λ at the carrier track structure so that the optical path length for said read beam of optical radiation when reflected from the carrier at a first area differs from the corresponding path length at a second area and so that radiation reflected at the first areas has a phase difference corresponding to half of said wavelength λ with respect to radiation reflected at the second areas, means for converting said difference in phase into an intensity difference by an optical interference method and a detector for converting said intensity difference into an electric output signal having amplitude variations corresponding to the information stored in the disc.

12. Apparatus for reading optically an information carrier in combination with a transparent information carrier of disc form as claimed in claim 3, the apparatus comprising means for supporting and rotating the disc, optical means for directing a read beam of radiation of a wavelength λ at the carrier track structure so that the optical path length for said read beam of optical radiation when transmitted through the carrier at a first area differs from the corresponding path length at a second area and so that radiation transmitted by the first areas has a phase difference corresponding to half of said wavelength λ with respect to radiation transmitted by the second areas, means for converting said difference in phase into an intensity difference by an optical interference method and a detector for converting said intensity difference into an electric output signal having amplitude variations corresponding to the information stored in the disc.

13. Apparatus substantially as described with reference to Figure 2, Figure 3 or Figure 4 of the accompanying drawings.

14. Apparatus substantially as described with reference to Figure 5 of the accompanying drawings.

15. Apparatus substantially as described with reference to Figure 6 of the accompanying drawings.

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