

Record carrier and apparatus for scanning the record carrier

The invention relates to a record carrier comprising a servo track indicating an information track intended for recording information blocks, which servo track has a variation of a physical parameter at a predetermined frequency which variation is modulated for encoding record carrier information, and which servo track has modulated parts in which the frequency and/or phase of the variation deviates from the predetermined frequency, and non-modulated parts having only said periodic variation.

The invention further relates to recording and/or playback device comprising means for writing and/or reading information blocks in an information track on a record carrier that comprises a servo track indicating the information track, which device comprises means for scanning the servo track and demodulation means for retrieving record carrier information from a variation of a physical parameter of the servo track at a predetermined frequency, which servo track has modulated parts in which the frequency and/or phase of the variation deviates from the predetermined frequency, and non-modulated parts having only said periodic variation.

The invention further relates to a method for manufacturing the record carrier.

A record carrier and device for reading and/or writing information are known from WO 00/43996 (PHN 17323). The information is encoded into an information signal which includes address codes and is subdivided in accordance with the address codes into information blocks. The record carrier has a servo track, usually called pregroove, for causing servo signals to be generated when scanning the track. A physical parameter, e.g. the radial position, of the pregroove periodically varies constituting a so-called wobble. During the scanning of the track, this wobble leads to a variation of the servo signals and a wobble signal can be generated. The wobble is modulated using phase modulation for encoding position information. Usually the phase modulation used for encoding digital position information is called Phase Shift Keying (PSK). During recording the position information is retrieved from the wobble signal and is used for positioning the information blocks by keeping a predefined relation between the address codes in the information blocks and the position information.

A problem of the known system is that the wobble signal comprises low frequency components in the frequency range which is used by the tracking servo system. Hence the servo system is disturbed by the wobble modulation. Further the modulated wobble signal may comprise high frequency components in the frequency range of the information signal, and therefore disturb the correct detection of the information from the retrieved information signal.

It is an object of the invention, for example, to provide a record carrier and device in which the above disturbance due to the wobble signal is reduced.

According to the invention a record carrier as defined in the opening paragraph is characterized in that the slope of the variation is substantially continuous at transitions between the modulated and non-modulated parts. Further, the recording and/or playback device as described in the opening paragraph is characterized in that the demodulation means comprise detection means for detecting modulated parts starting at transitions between the modulated and non-modulated parts at which the slope of the variation is substantially continuous. The invention is based on the following recognition. Many optical recording formats contain a periodic variation of the servo track, usually called wobble, *inter alia* for write-clock generation, which wobble is usually predominantly monotonic to reduce write-clock jitter. In modulated parts the frequency is changed or even phase jumps are used, and the transitions between not modulated and modulated parts occur when the amplitude of the wobble is zero. The inventors have seen that due to the discontinuities in the slope of the wobble of such transitions additional low and high frequency components are generated in the resulting wobble signal. By shifting the transitions to a point in the wobble where the amplitude is not zero but where the slope of the non modulated signal before and the modulated signal after the transition are substantially equal such disturbing frequency components are reduced.

A further embodiment of the record carrier is characterized in that the variation is substantially sinusoidal and the transitions are located at the minima and/or maxima of said sinus. The advantage is that at the peak values of a sinus, i.e. the minima and maxima, the slope of the signal is zero. Hence a change in frequency can be applied while the slope of the signal is continuous.

Further preferred embodiments of the method, devices and record carrier according to the invention are given in the further claims.

These and other aspects of the invention will be apparent from and elucidated further with reference to the embodiments described by way of example in the following description and with reference to the accompanying drawings, in which

Fig. 1a shows a record carrier with a servo track (top view),

Fig. 1b shows a servo track (cross section),

Fig. 1c shows a wobble of a servo track (detail),

Fig. 1d shows a further wobble of a servo track (detail),

Fig. 2a shows the modulation of MSK-sin,

Fig. 2b shows the modulation of MSK-cos,

Fig. 3 shows MSK-sin and MSK-cos signals,

Fig. 4 shows shows the power spectral density of a data bit,

Fig. 5 shows a device for reading information blocks,

Fig. 6 shows a device for writing information blocks,

Fig. 7a shows the power spectral densities for a bit pattern

Fig. 7b shows the power spectral densities for a further bit pattern

In the Figures, elements which correspond to elements already described have the same reference numerals.

Fig. 1a shows a disc-shaped record carrier 1 provided with a track 9 intended for recording and a central hole 10. The track 9 is arranged in accordance with a spiral pattern of windings 3. Fig. 1b is a cross-section taken on the line b-b of the record carrier 1, in which a transparent substrate 5 is provided with a recording layer 6 and a protective layer 7. The recording layer 6 may be optically writable, for example via phase change, or magneto-optically writable by a device for writing information such as the known CD-Rewritable or CD-Recordable. The recording layer may also be provided with information via a production process, in which first a master disc is made which is subsequently multiplied through pressing. The information is organized in information blocks and is represented by optically readable marks in the form of a succession of areas reflecting much radiation and little radiation such as, for example a succession of pits of different lengths in a CD. In one embodiment, the track 9 on the record carrier of a rewritable type is indicated by a servopattern which is provided during manufacture of the blank record carrier. The

servopattern is formed, for example by a pregroove 4 which enables a write head to follow the track 9 during scanning. The pregroove 4 may be implemented as a deeper or a raised part, or as a material property deviating from its ambience. Alternatively, the servopattern may consist of an alternation of elevated and deeper windings, referred to as land and groove patterns, with a transition from land to groove or vice versa taking place per winding. Figs. 1c and 1d show two examples of a periodical variation of a physical parameter of the pregroove, called wobble. Fig. 1c shows variation of the lateral position, and Fig. 1d shows variation of the width. This wobble produces a wobble signal in a tracking servosensor. The wobble is, for example, frequency- modulated, and position information such as an address, a time code or winding information is coded in the modulation. A description of a rewritable CD system which is provided with position information in such a way can be found in US 4,901,300 (PHN 12.398). A servopattern may also consist of, for example, regularly distributed sub-patterns which periodically cause tracking signals.

The variation of the servo track includes relatively large parts of monotone wobble, so called non modulated parts. Further the servo track has relatively short parts where the frequency and/or phase of the wobble deviates from the predetermined wobble frequency, called modulated parts.

Figure 2a shows the modulation of MSK-sin. The figure shows the variations in a modulated part of the wobble. In the Minimum Shift Keying sinus type (MSK-sin) a data value 0 is represented by a full period of the wobble 21 or an inverted period 22, starting at the zero crossing of the wobble. The data value 1 is represented by a frequency which is 1.5 times higher, so a positive starting wobble 23 or a negative starting wobble 24. Hence the MSK modulation is based on sine waves with frequency 1.0 times the wobble frequency (f_{wob}) and sine waves with frequency $1.5 \cdot f_{wob}$. With MSK-sin the frequency changes at the zero crossings of the wobble signal. At the points where the frequency changes the slope is discontinuous.

Figure 2b shows the modulation of MSK-cos. The figure shows the variations in a modulated part of the wobble. In the Minimum Shift Keying cosinus type (MSK-cos) a data value 0 is represented by a full period of the wobble 25 or an inverted period 26, starting at the maximum or minimum amplitude of the wobble. The data value 1 is represented by a frequency which is 1.5 times higher, so a positive starting wobble 27 or a negative starting wobble 28, also starting at the maximum or minimum. Hence the MSK modulation is based on sine waves with frequency $1.0 \cdot f_{wob}$ and sine waves with frequency $1.5 \cdot f_{wob}$. With MSK-cos the frequency changes at the maxima or minima of the wobble signal. At the points

where the frequency changes the slope is continuous. It is to be noted that all waveforms of the MSK-cos are without a DC component when integrated on the length of one wobble frequency period, whereas the $1.5 * f_{wob}$ waveform of MSK-sin has a DC component. The DC component may be balanced by an inverted $1.5 * f_{wob}$ MSK-sin waveform, but the absence of such DC components in the MSK-cos modulation results in less disturbing frequency components in the low frequency range relevant to servo systems.

Figure 3 shows MSK-sin and MSK-cos signals. The figure shows examples of the modulated wave forms for MSK-sin (32) and MSK-cos (35) for a single data bit. The central traces (32,35) show the wave form on the disc (solid lines) for MSK-sin (left) and MSK-cos (right). For reference, the single-tone sine or cosine signals are also shown (dotted lines). Both examples are for data bit with a length of 3 wobble periods. The first and last parts of such a data bit are described above with reference to Figure 2a and 2b. In the middle period of said 3 periods an inverted wobble is present. The top traces (31,34) show the difference between the MSK-sin (left) and MSK-cos (right) wave forms and a reference not modulated wobble. The bottom traces (33,36) show the result of multiplying the wave forms (32,35) with the reference wobble.

Figure 4 shows the power spectral density of a data bit. The solid line 41 is the spectrum for MSK-sin, the dashed line 42 is the spectrum for MSK-cos. The spectrum 42 of MSK-cos is narrower than the spectrum 41 of MSK-sin. In other words, MSK-cos is producing less disturbing frequency components and can be filtered more narrowly by the detector than MSK-sin. The detection performance of MSK-cos will be better compared to MSK-sin, depending on the resulting signal to noise ratio after filtering.

Figure 5 shows a reading device for scanning a record carrier 1. Writing and reading of information on optical discs and formatting, error correcting and channel coding rules, are well-known in the art, e.g. from the CD system. The apparatus of Figure 5 is arranged for reading the record carrier 1, which record carrier is identical to the record carriers shown in Figure 1. The device is provided with a read head 52 for scanning the track on the record carrier and read control means comprising drive unit 55 for rotating the record carrier 1, a read circuit 53 for example comprising a channel decoder and an error corrector, tracking unit 51 and a system control unit 56. The read head comprises optical elements of the usual type for generating a radiation spot 66 focused on a track of the recording layer of the record carrier via a radiation beam 65 guided through optical elements. The radiation beam 65 is generated by a radiation source, e.g. a laser diode. The read head further comprises a focusing actuator for focusing the radiation beam 65 on the recording layer and a

tracking actuator 59 for fine positioning of the spot 66 in radial direction on the center of the track. The apparatus has a positioning unit 54 for coarsely positioning the read head 52 in the radial direction on the track. The tracking actuator 59 may comprise coils for radially moving an optical element or may be arranged for changing the angle of a reflecting element on a movable part of the read head or on a part on a fixed position in the case part of the optical system is mounted on a fixed position. The radiation reflected by the recording layer is detected by a detector of a usual type, e.g. a four-quadrant diode, for generating a detector signals 57 including a read signal, a tracking error and a focusing error signal. The tracking unit 51 is coupled to the read head for receiving the tracking error signal from the read head and controlling the tracking actuator 59. During reading, the read signal is converted into output information, indicated by arrow 64, in the read circuit 53. The apparatus is provided with an address detector 50 for detecting and the retrieving address information from the detector signals 57 when scanning the servo track of the record carrier. The device is further provided with a system control unit 56 for receiving commands from a controlling computer system or from a user and for controlling the apparatus via control lines 58, e.g. a system bus connected to the drive unit 55, the positioning unit 54, the address detector 50, the tracking unit 51 and the read circuit 53. To this end, the system control unit comprises control circuitry, for example a microprocessor, a program memory and control gates, for performing the procedures described below. The system control unit 56 may also be implemented as a state machine in logic circuits. The read device is arranged for reading a disc having tracks having a periodic variation, e.g. a continuous wobble. The read control unit are arranged for detecting the periodic variations and for reading in dependence thereon a predetermined amount data from the track. In an embodiment the read clock is synchronized to the periodic variations and the read circuit 53 reads a fixed number of channel bits for each instance of the periodic variations. In an embodiment the read control means are arranged for retrieving the data from an area of the track following an unrecorded area. In the read circuit 53 the read clock is synchronized to the periodic variations in the unrecorded area and the reading speed is adjusted during scanning the unrecorded area. Hence at the start of the recorded area the read circuit 53 is locked in to the speed of the recorded data. In particular the address detector 50 is arranged for reading record carrier information, e.g. position information and recording control data, from the modulated signal derived from the modulated wobble. The address detector 50 has a detection unit for detecting modulated wobbles starting at a predefined transition point in the wobble signal, at which transition point the slope of the wobble is continuous. For a sinusoidal wobble having the transitions at the maxima (or minima) the

detecting starting point is at said maxima (or minima). In a preferred embodiment the address detector 50 includes a matched filter based on the frequency spectrum of the wobble signal. The matched filter improves the signal to noise ratio of the modulated wobble signal, because the frequency spectrum of the wobble signal is narrower than the spectrum of a wobble signal having transitions at the zero crossing. The address detector further has a word detection unit for retrieving the words of record carrier information. The beginning of such a word is detected from a synchronisation signal after a long sequence of non modulated wobbles. The occurrence and value of a data bit is detected based on the modulated wobbles. In further embodiments other types of synchronisation or decoding of the values of the record carrier information may be applied.

Figure 6 shows a device for writing information on a record carrier according to the invention of a type which is (re)writable in, for example a magneto-optical or optical manner (via phase change or dye) by means of a beam 65 of electromagnetic radiation. The device is also equipped for reading and comprises the same elements as the apparatus for reading described above with Figure 5, except that it has a write/read head 62 and recording control means which comprise the same elements as the read control means, except for a write circuit 60 that comprises for example a formatter, an error encoder and a channel encoder. The write/read head 62 has the same function as the read head 52 together with a write function and is coupled to the write circuit 60. The information presented to the input of the write circuit 60 (indicated by the arrow 63) is distributed over logical and physical sectors according to formatting and encoding rules and converted into a write signal 61 for the write/read head 62. The system control unit 56 is arranged for controlling the write circuit 60 and for performing the position information recovery and positioning procedure as described above for the reading apparatus. During the writing operation, marks representing the information are formed on the record carrier. The recording control means are arranged for detecting the periodic variations, for example by locking a phase locked loop to the periodicity thereof. The address detector 50 is described above with reference to Figure 5.

Figures 7a and 7b show the power spectral densities (PSDs) for MSK-sin and MSK-cos for two different bit patterns that are repeated periodically. Figure 7a shows for a certain bit pattern the PSD 71 for MSK-sin and the PSD 72 for MSK-cos. Figure 7b shows for another bit pattern the PSD 73 for MSK-sin and the PSD 74 for MSK-cos. It shows that the PSDs for MSK-sin and MSK-cos are substantially the same in the central parts of the spectrum. However, at low frequencies around $0.1 \cdot f_{wob}$ the PSD of MSK-cos is more than 10 dB lower than the PSD of MSK-sin. This is related to the absence of DC content of a one

fwob period segment of the MSK-cos signal (for example at $1.5 * fwob$), whereas such a one period segment of MSK-sin does have a DC content which is compensated later in the signal at the next (inverse) MSK-sin segment. The low-frequency spectrum of MSK-cos is thus substantially lower than that of MSK-sin which is an advantage because of the lower distortion of the servo. Further, a more smooth wave form for MSK-cos is caused by the continuous slope in contrast to MSK-sin where the slope is discontinuous at the point where the frequency changes. Also in the high frequency range above $2*fwob$ the PSD for MSK-cos is somewhat lower than the PSD for MSK-sin. Hence less disturbing frequency components are present in the higher frequency ranges also.

Although the invention has been explained by embodiments using a wobble modulation, any other suitable parameter of the track may be modulated, e.g. the track width. Also for the record carrier an optical disc has been described, but other media, such as a magnetic disc or tape, may be used. It is noted, that in this document the word 'comprising' does not exclude the presence of other elements or steps than those listed and the word 'a' or 'an' preceding an element does not exclude the presence of a plurality of such elements, that any reference signs do not limit the scope of the claims, that the invention may be implemented by means of both hardware and software, and that several 'means' may be represented by the same item of hardware. Further, the scope of the invention is not limited to the embodiments, and the invention lies in each and every novel feature or combination of features described above.

CLAIMS:

1. Record carrier comprising a servo track (4) indicating an information track (9) intended for recording information blocks, which servo track (4) has a variation of a physical parameter at a predetermined frequency which variation is modulated for encoding record carrier information, and which servo track has modulated parts in which the frequency and/or
5 phase of the variation deviates from the predetermined frequency, and non-modulated parts having only said periodic variation, the non-modulated parts being relatively large with respect to the modulated parts, characterized in that the slope of the variation is substantially continuous at transitions between the modulated and non-modulated parts.
- 10 2. Record carrier as claimed in claim 1, wherein the variation is substantially sinusoidal and the transitions are located at the minima and/or maxima of said sinus.
3. Record carrier as claimed in claim 1 or 2, wherein a first part of the modulated parts comprises a variation at a transition frequency, the length of the first part corresponding to
15 m periods of the predetermined frequency and corresponding to $n + 0.5$ periods of the transition frequency, n and m being integers.
4. Record carrier as claimed in claim 3, wherein the first part has a length corresponding to one period of the predetermined frequency, and n equals 1.
- 20 5. Record carrier as claimed in claim 1, wherein the modulated parts comprise at least one variation of a phase inverse to the phase of the not modulated periodic variations.
6. Record carrier as claimed in claim 1 or 2, wherein at least one of the modulated
25 parts comprises a variation at a second frequency, the length of said modulated part corresponding to $m / 2$ periods of the predetermined frequency and corresponding to $p / 2$ periods of the second frequency, n and p being different integers and being both odd or both even.

7. Recording and/or playback device comprising means for writing and/or reading information blocks in an information track (9) on a record carrier that comprises a servo track (4) indicating the information track (9), which device comprises means for scanning the servo track (4) and demodulation means for retrieving record carrier information from a signal
5 generated by a variation of a physical parameter of the servo track at a predetermined frequency, which servo track has modulated parts in which the frequency and/or phase of the variation deviates from the predetermined frequency, and non-modulated parts having only said periodic variation, the non-modulated parts being relatively large with respect to the modulated parts, characterized in that the demodulation means comprise detection means (50) for detecting the
10 modulated parts starting at transitions between the modulated and non-modulated parts at which the slope of the variation is substantially continuous.

8. Device as claimed in claim 7, wherein the variation is sinusoidal and the transitions are located at the minima and/or maxima of said sinus, and the detection means (50)
15 are for detecting starting at said minima and/or maxima.

9. Device as claimed in claim 7, wherein the detection means (50) are for detecting a number of periodic variations of a phase inverse to the phase of the not modulated periodic variations.

20 10. Device as claimed in claim 7, wherein the detection means (50) comprise a matched filter based on the frequency spectrum of the signal generated by the modulated parts.

11. Method of manufacturing a record carrier, in which the record carrier is provided
25 with a servo track (4) indicating an information track (9) intended for recording information blocks, which servo track (4) is provided with a variation of a physical parameter at a predetermined frequency which variation is modulated for encoding record carrier information, and which servo track is provided with modulated parts in which the frequency and/or phase of the variation deviates from the predetermined frequency, and non-modulated parts having only
30 said periodic variation, , the non-modulated parts being relatively large with respect to the modulated parts, characterized in that transitions between the modulated and non-modulated parts are provided keeping the slope of the variation substantially continuous.