United States Patent [19]

Dickopp

[11] **3,798,388**

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[54] **RECORD CARRIER FOR STORING ANGULARLY MODULATED SIGNALS**

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[21] Appl. No.: **179,991**

Related U.S. Application Data

[62] Division of Ser. No. 5,341, Jan. 23, 1970.

[30] **Foreign Application Priority Data**

Jan. 23, 1969 Germany.................. P 19 03 822.3

[52] **U.S. Cl.179/100.4 R,** 178/6.6 TP, 179/100.3 V, 179/100.4 M, 179/100.41 L, 250/219 DD, 274/42 R, 179/100.4 C

[51] **Int. Cl.. G11b 23/00,** G11b 11/18, G11b 25/04

[58] **Field of Search** 179/100.4 R, 100.4 C, 100.1 B, 179/100.3 V, 100.4 M; 274/41.6 R, 42 R; 178/6.6 TP; 340/173 TP; 250/219 DP, 219 Q, 219 QA, 219 D

[56] **References Cited**

UNITED STATES PATENTS

3,287,563	11/1966	Clunis	178/6.6 TP
2,092,892	9/1937	Runge	179/100.3 V
2,654,810	10/1953	Miessner	179/100.3 V
1,956,626	5/1934	Roffins	274/41.6 R
3,403,233	9/1968	Cooper	179/100.4 C

OTHER PUBLICATIONS

Readout From Thermoplastic Record Element, Fleisher et al., IBM Tech. Disclosure Bulletin Vol. 10, No. 7, 12/67, p. 975–976.

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[57] **ABSTRACT**

A method and apparatus for reproducing signals stored on a carrier in the form of undulations corresponding to the signals, the undulations generally being formed in a spiral groove. The undulations on the carrier are moved past a suitable radiation source, such as a light source, and the density of the radiation emanating from the undulations, which is a function of the curvature of the undulation, is detected by a suitable radiation detector after it passes through a suitable slit aperture arranged at a predetermined distance from the carrier surface, so that variations in the density are a function of the undulations. The undulations may be either frequency or phase modulated with respect to the signal and their amplitude can be modified as a function of their recorded wavelength in such a maner that the curved surface portions of the undulations have nearly the same focal length for all occurring wavelengths. The carrier can have at least one recording surface in which is formed a groove having a trapezoidal cross section and having its bottom surface provided with the undulations.

8 Claims, 9 Drawing Figures

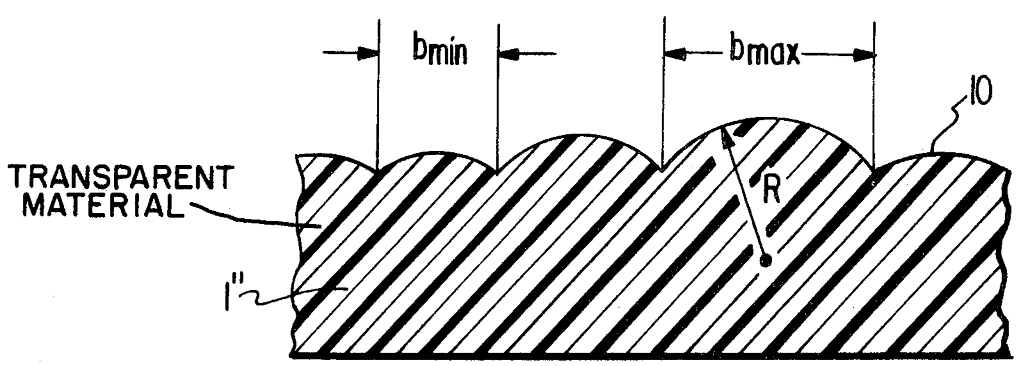
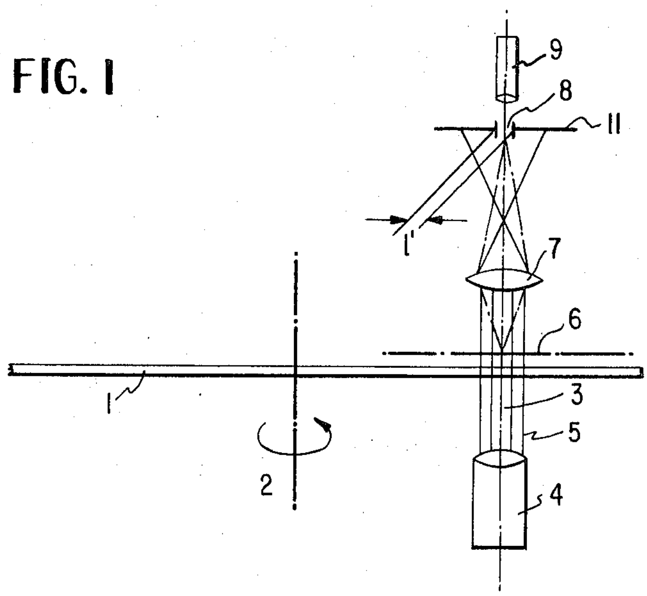


FIG. 1



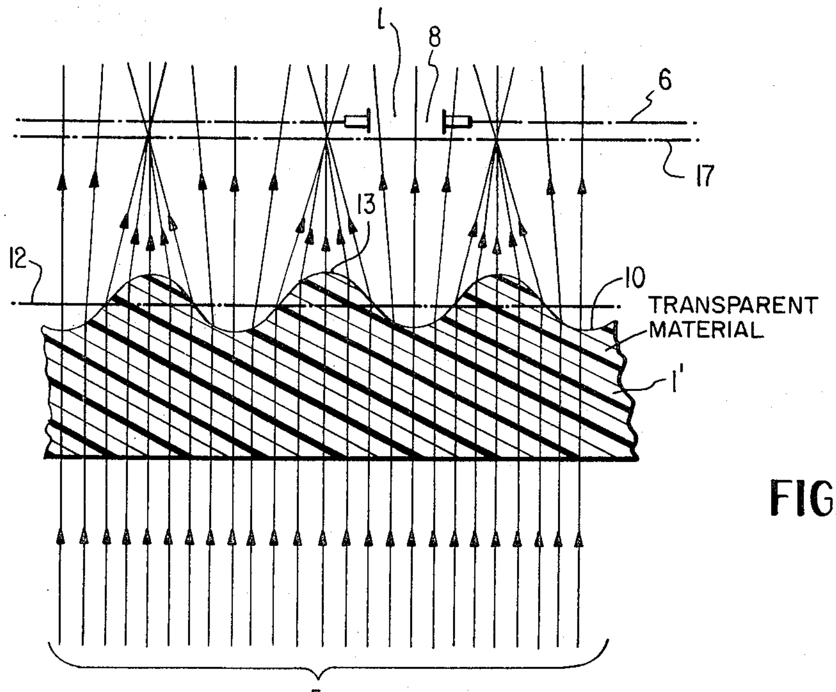


FIG. 2

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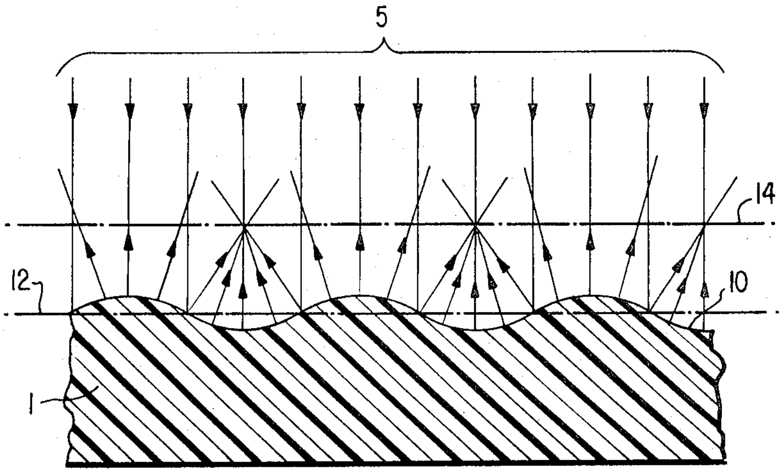

FIG. 3

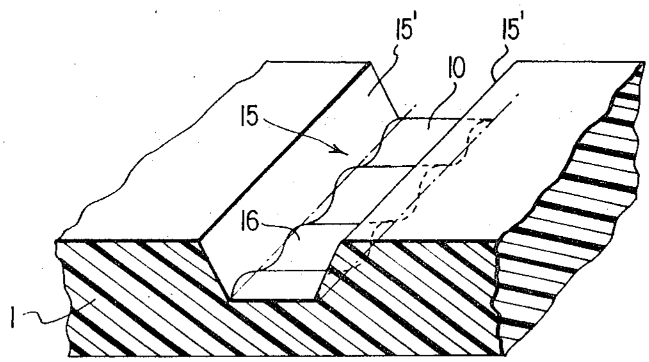

FIG. 4

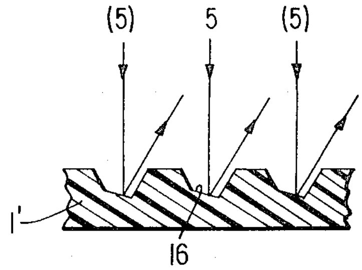

FIG. 5

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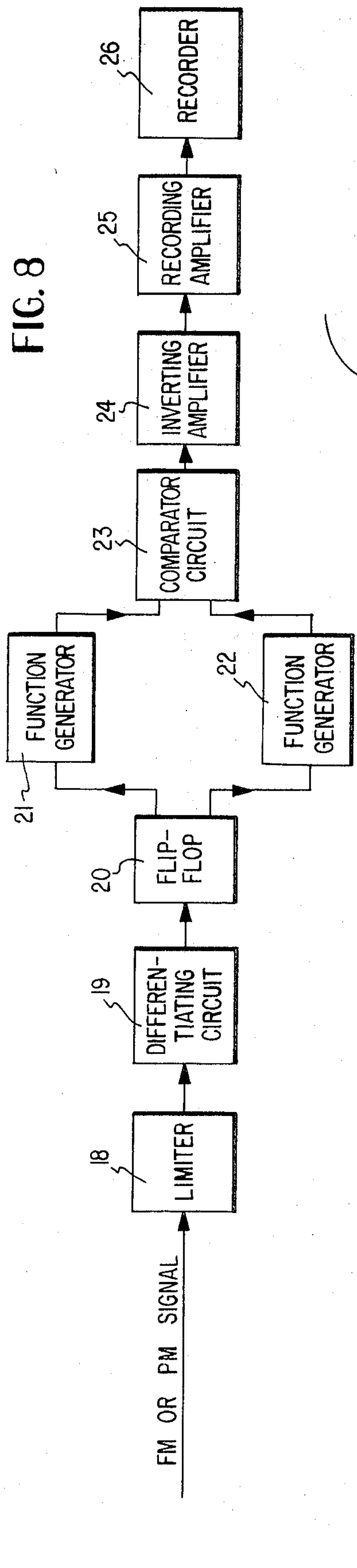
FIG. 8



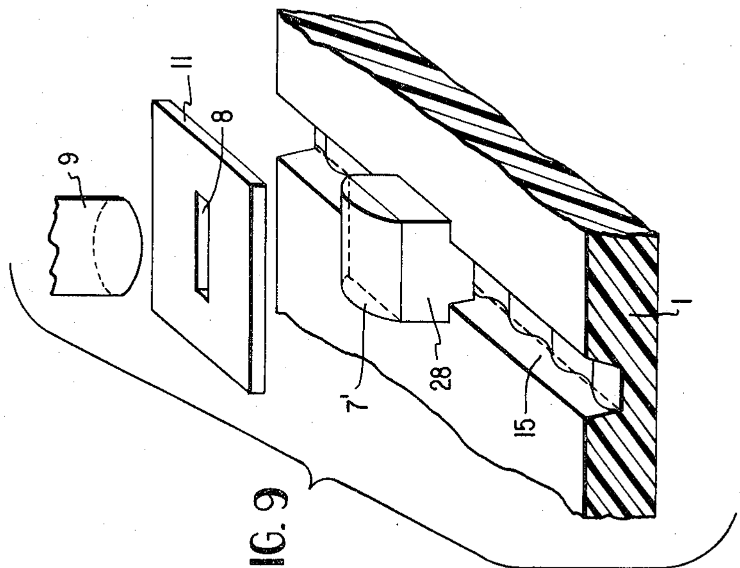


FIG. 9

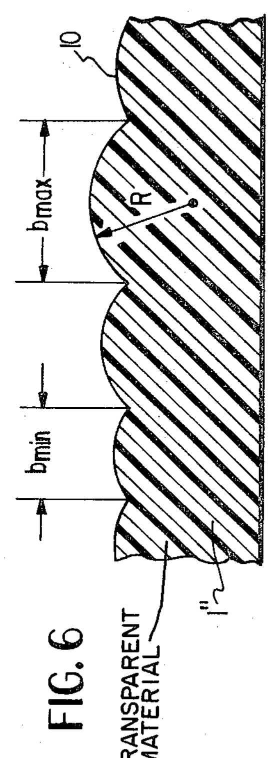


FIG. 6

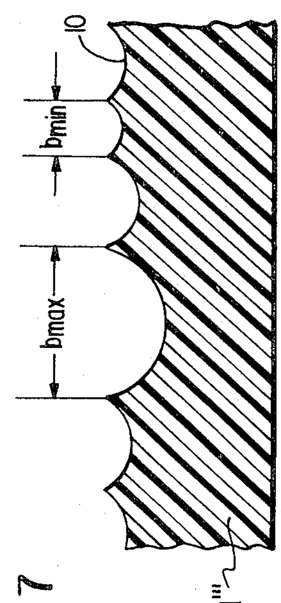


FIG. 7

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RECORD CARRIER FOR STORING ANGULARLY MODULATED SIGNALS

CROSS REFERENCE TO RELATED APPLICATION

This application is a division of copending application Ser. No. 5,341, filed Jan. 23, 1970, entitled "RADIATION TRANSDUCER SYSTEM."

BACKGROUND OF THE INVENTION

The present invention relates to a system for reproducing signals which are stored on a record carrier in the form of spatial undulations corresponding to the signals, the signals being reproduced by means of a pickup composed of a suitable source of radiation, such as light, and a radiation receiver.

The present invention, concerns a recording process and arrangement, a reproducing method and arrangement and a record carrier for storing the signals.

According to prior art techniques for reproducing signals which are stored as deformations in the surface of a carrier, for example, as vertical or lateral undulations formed in a groove, the playback is usually carried out by mechanical scanning employing a stylus moving in the groove. This stylus transmits the movements imparted to its tip by the undulations to an electromechanical transducer whose electrical output is a reproduction of the stored signals. With this type of scanning, the forces, producing the mass acceleration of the moveable transducer components, which forces increase linearly with signal frequency and amplitude, must be transmitted directly from the surface portions carrying the recorded signals to the tip of the scanning stylus. This not only results in increased wear, which increases with the frequency, amplitude and the relative speed of the components moving against one another, but also gives rise to difficulties due to the mass inertia of the moveable transducer components, limits increases in the signal frequency range in the direction of high frequencies.

Methods have already been proposed for scanning recording elements with the aid of light or comparable radiation. In these cases, the recording technique employed is either one in which the signals are recorded on the surface of a carrier, or recording element, as a track more or less darkened according to the recorded signal, in the manner of a variable-density sound motion-picture film recording system, or in the form of areas blackened to the same degree and configured in the manner of a variable-area optical sound motion-picture film recording system. The amount of light passed or reflected depends on the degree of darkening of the carrier portions on which the reading beam impinges, and this amount of light excites a light receiver whose electric output value forms a reproduction of the signal.

These methods have the disadvantage that copies of the recording elements can be obtained only by photochemical or similar processes, and not by simple stamping or pressing processes, such as used to manufacture phonograph records.

It is also known in the art to use optically scannable recording elements which contain the recorded signals in the form of surface deformations or undulations. It has been a major difficulty with these systems, however, to establish an unequivocal relationship between the amount of light reflected by the surface and the magnitude and type of undulations. For this reason, complicated optical systems are required which achieve a poor utilization of the reflected light and, thus, a low energy efficiency and a low signal-two-noise ratio.

As a result of this, signal reproduction systems, such as record players, employing light scanning have not been able to find acceptance.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a type of scanning which is free of mass inertia limitations and in which the scanning process itself does not produce any mechanical stresses on the surfaces carrying the recorded signals, while maintaining the advantages of a copying process which can avail itself of the known stamping or pressing techniques employed for manufacturing phonograph records.

This object is accomplished according to the present invention by providing a light scanning system which is simple and effective, and which also assures a good utilization by the light receiver of the reflected or refracted light.

A system according to the present invention employs a recording element, or record carrier, having a surface provided with undulations corresponding to the signal. These undulations are evaluated by means of light or comparable radiation acting on a radiation receiver. A slit aperture is disposed in the path of a reading beam and at such a distance from the undulations that a change in the density of the radiation emanating from the undulations occurs in the plane of the slit aperture. This density is dependent on the curvature of the undulations in the direction of movement of the carrier with respect to the reading beam and the changes in the density at least qualitatively follow the curvature variations. The signal is recorded in the form of a carrier undulation which is frequency or phase modulated in accordance with the signal.

In preferred embodiments of the present invention, the undulations containing the recorded signals constitute convex or concave lenses or mirror surfaces. These lenses or mirror surfaces density modulate the reading beam, which is preferably a collimated beam, in the plane of the slit aperture in a manner corresponding to the variations in the curvature of the undulation surface. This density modulation is thus at least a qualitative representation of the surface curvature and is a function of the well known laws of reflection and refraction. For example, in the case of light passing through the record carrier a convex surface increases, and a concave surface decreases, the light density in the plane of the slit aperture. A similar result is obtained when light is reflected from a mirror surface on the record carrier. In the case of reflection, a concave surface produces a converging effect with an increase in the light density, and a convex surface diverges the light to produce a decrease in the light density, in the plane of the slit aperture.

In order to maintain the distance between the record carrier and the plane of maximum convergence of the light originating from the reading beam substantially constant, the system according to the present invention a signal is recorded by frequency or phase modulating a carrier as a function of signal. This causes the wavelengths of the undulations containing the recorded signals to vary over a smaller range than would occur in the direct recording of the low frequency, wide bandwidth signal. If an arbitrary audio frequency signal were directly recorded in the undulations, the wavelengths and amplitude of the undulations making up the complex signal would vary over a large range. Generally, this would result in different curvatures and, thus, different focal lengths, for the cylindrical lenses or mirrors, defined by the undulation surface so that the plane of maximum convergence of the radiation emanating from the reading beam would lie at different distances from the plane representing the average undulation depth for different undulation wavelengths or amplitudes.

Recording of the signal by frequency or phase modulation of a carrier oscillation, according to the present invention, makes it possible to provide undulations having an approximately constant amplitude and a reduced wavelength range. Under these circumstances, it is possible to select a certain, predetermined optimum distance for the plane of the slit aperture from the center surface, or average undulation depth, plane of the record carrier.

A recording process is also provided, according to the present invention, in which the amplitude of the recorded carrier, which is frequency or phase modulated with the signals and recorded as undulations on the recording surface, is varied as a function of the undulation wavelength. This feature of the invention serves the purpose of maintaining approximately a constant focal length for the cylindrical lenses or mirrors for the entire wavelength range of the recorded undulations. If, in contrast the wavelength were to be reduced while maintaining the undulation amplitude constant, the curvature of the surface portion would be increased and, thus, a shortening of the focal length would result. This change is counteracted by a corresponding change in amplitude.

A particular advantage of the system according to the present invention over other systems employing light-scanning is that an appropriate selection of the focal plane location leads to a larger peak-to-peak variation in the amount of light passing through the scanning slit aperture. This results in a better signal to noise ratio.

The present invention also provides the possibility to record a very wide signal frequency band. This band may extend into the megahertz range on a record carrier fully comparable to a phonograph record. Another advantage of the present invention is that the record carrier may be duplicated by hot pressing a thermoplastic mass. This duplication method is well known in the phonograph record art, and permits the production of records containing, for example, television signals and even including information to be reproduced in color.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic, side elevation view of an embodiment of a system according to the present invention in which a surface of a recording element is scanned with the aid of a reading beam passing through the carrier.

FIG. 2 is a schematic, side elevational view showing a portion of the device of FIG. 1 on a much larger scale.

FIG. 3 is a schematic, side elevational view similar to FIG. 2, but showing an embodiment of the present invention where the light is reflected from the surface of the carrier or recording element.

FIG. 4 is a perspective view, partially in cross section, showing a portion of a recording element having a groove whose bottom surface contains undulations.

FIG. 5 is a schematic, side elevational, cross-sectional view of a portion of a recording element having a plurality of parallel grooves whose bottom surfaces are inclined with respect to a plane normal to the impinging reading beam.

FIG. 6 is a side elevational, cross-sectional view of a recording element having undulations in the form of cylindrical lenses having identical radii of curvature.

FIG. 7 is a side elevational, cross-sectional view of a recording element having undulations in the form of cylindrical parabolic mirrors whose lines of intersection with the plane of the drawing all form portions of the same parabola. A suitable synthetic foil material is e.g., polyvinylchloride or polystyrene.

FIG. 8 shows a cutting system and the necessary signal processing circuitry for cutting grooves having the configurations shown in FIGS. 6 and 7.

FIG. 9 shows an optical reading system and a pickup guided by groove walls.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a circular, disc-shaped carrier, or recording element 1, which is provided with surface undulations corresponding to the time sequence of the signal values; the undulations also corresponding to the system of the invention. This recording element 1 is assumed to be disposed on a support (not shown), such as a conventional turntable which may be transparent if necessary, by means of which it can be rotated in the direction of the arrow about its axis 2 which is perpendicular to the large-area surfaces of the carrier 1. FIG. 1 is directed to a preferred embodiment, where the recording element 1 consists of a suitable foil material, such as a synthetically produced plastic.

The recording element 1 is penetrated by the reading light rays 3, which emanates from a suitable, well-known light source 4. By means of a suitable optical arrangement associated with the light source 4, care is taken that the reading light rays 3 consist substantially of parallel rays of light, forming a readinb beam 5. The reading beam 5 penetrates into the material of the recording element, from the generally planar underside thereof, which is perpendicular to the axis of the beam without any appreciable deflection of the individual rays. The upper surface of recording element 1 is provided with the spatial deformations in which the recorded signal is stored. When the rays emerge from the surface they are refracted to a degree depending on the angle which the surface forms with respect to the beam. This effect will be explained later in detail with reference to FIG. 2. The light refraction in a cylindrical lens convex toward the top, which is present on the surface of the carrier 1, results in a convergence of the light; refraction in a cylindrical lens which is concave toward the top results in divergence of the light. It is here presupposed that carrier 1 is transparent in the area of the surface bearing the deformations and is disposed in the path of preferably parallel light rays between the light source 4 and that plane 6 in which rays collected by a quasi-cylindrical lens on its surface are optimally converged by the lens.

The greatest changes in light density also result in this plane when surface portions of recording element 1 having different curvatures pass through the area of reading beam **5**. These changes in light density are utilized by a suitable optic, such as a double-convex lens **7** of the arrangement according to FIG. **1**, in cooperation with a receiving slit **8**, which may be similar to the well-known mechanical slit in optical film sound reproducing systems, and a conventional radiation receiver **9**, such as a photoelectric cell. Experiments and calculations have shown that the plane at which occur the changes in light density sensed by the radiation receiver **9** should be spaced from the median surface plane **12** of carrier **1**, when based on cylindrical lenses whose lines of intersection with a plane perpendicular to the cylindrical axis are sine curves, by a distance somewhat greater than the distance between plane **12** and that plane in which the beams near the axis of symmetry of the optical arrangement formed by surface portions curved in the manner of cylindrical lenses or mirrors are maximally concentrated.

In the case of a reading beam with parallel rays, as is presupposed in FIG. **1**, the concentration of the rays at or near the axis of symmetry in a plane passing through the principal focus of the cylindrical lenses should be expected. The rays somewhat offset from the axis of symmetry, are not brought to a focus in this focal plane but, for a sinusoidal lens element, are converged somewhat therebehind. Thus, the plane of optimum light density variation lies, in this case, somewhat behind the principal focal plane.

If, however, cylindrical deformations having a circular cross section were used, the rays which are offset from the plane of symmetry would also converge almost in the principal focal plane and the two above-mentioned planes would practically coincide. It should be presupposed that the plane **6** shown in FIG. **1** forms that plane in which maximum light density variations result in both cases.

With the aid of an optical arrangement **7** which is schematically shown in FIG. **1** as a double convex lens, the plane **6**, in which there may be disposed the light receiver and a receiving slit, is reproduced or imaged, in plane **11**, where there is disposed a receiving slit aperture **8** which is spaced from plane **6** along the optical axis. This arrangement has the advantage that the slit **8** need not be disposed within plane **6**, i.e., in direct spatial proximity to the surface of carrier **1**. The use of an auxiliary optical arrangement **7** also has the advantage that it is possible to reproduce plane **6** in slit plane **11** to an enlarged scale. This makes it possible to dimension the slit aperture **8** in the direction of the relative velocity of the carrier with respect to the readinb beam i.e., the length **1** of the slit, somewhat larger than if the slit aperture were disposed directly in the plane **6**. It has been found that the length of the slit should be selected to be approximately equal to half, or less than half, the shortest wavelength of the carrier oscillations to be recorded, this dimension being with reference to plane **6**. The slit length in plane **11** may be selected to be different, depending on the degree of enlargement, and is marked **1'**. In FIG. **1** the beam path starting from the reading beam **5** is illustrated with solid lines for the case of penetration through plane surface portions. The dot-dash lines show the ray path of the optical arrangement **7** for reproduction of plane **6** in plane **11** of the slit aperture **8**.

FIG. **2** shows, to an enlarged scale, a portion of carrier **1** of FIG. **1** which is penetrated by the reading beam **5**. The illustration is a sectional view parallel to the rays of reading beam **5** and in the plane of the relative speed of carrier **1** with respect to the axis of the reading beam. FIG. **2** shows undulations **10** containing the recorded signals on the upper side of carrier **1**. Mirror-like, reversed undulations can also be disposed on the underside of carrier **1** (not shown). This would increase the lens effect of the deformations but the effect could only be optically utilized when carrier **1** is in the form of a foil whose thickness is not being substantially less than twice the amplitude of undulations **10**. Only in such a case could there be a useful cooperation of the curvatures on the upper side and the underside of the foil.

The undulations on the upper side of the carrier form quasi-cylindrical lenses which represent convex lenses above the surface center line **12** of carrier **1** and concave lenses therebelow. Their line of intersection with the plane of the drawing is assumed to be a sine curve.

The ray paths shown with arrows indicate that the rays of reading beam **5** remain parallel until they emerge from the surface provided with undulations **10**. In the area of the rays adjacent to the axis of symmetry **13** of a convex cylindrical lens, there occurs an intersection of the rays at the focal point plane **17**. The rays further away from the axis of symmetry **13** do not intersect exactly in this plane in the case cylindrical lenses having sinusoidal profiles. Instead, they converge in the plane of optimum light density variation slightly behind the focal point plane **17**, which plane of optimum light density variation is marked with the reference numeral **6** in FIGS. **1** and **2**. In this plane, therefore, as illustrated, there should be disposed the slit aperture **8** of the radiation receiver **9** when cylindrical lenses of the above-mentioned sine shape are being used. With cylindrical lenses having circular lines of intersection, planes **6** and **17** practically coincide.

In the area of the undulations **10** disposed below the surface center line **12**, which areas form a concave lens, there is produced a divergence of the beam. Thus, at these points in planes **17** or **6**, respectively, the light densities are reduced with respect to that of the collimated beam **5**.

If carrier **1** is now moved relative to the axis of the reading beam **5** at a relative speed in the direction of the center line **72** in FIG. **2**, the light density in plane **6** assumes variable values in dependence on the curvature of the undulations **10**. This is a qualitative representation of the curvatures of these deformations insofar as a positive curvature, or convex lens, corresponds to an increase in light density and a negative curvature, or concave lens, corresponds to a decrease in light density. This relationship further provides information about the quantitative changes in the curvature, since the functions of the light density changes and the curvatures are so associated with one another that changes in the same sense in one function always correspond to such changes in the other function. It would thus be possible to scan directly recorded audio frequency signals in this manner, where frequencies and amplitudes would be reproduced, but the effect of the varied wavelengths and the varied amplitudes would here be annoying because this would result in changes of the focal point distance. These changes are reduced to a substantial degree by the recording technique employed in the present invention where the signal values are recorded as frequency or phase modulated carrier oscillations, and they can be practically entirely eliminated by modulation simultaneously with a change in the amplitude.

Calculations have shown that when the deformation of the recording surface approximates a sinusodial path when viewed in a plane perpendicular to the plane of the center surface of the recording element and parallel to the direction of the relative speed between the recording element and the reading beam bundle in the proximity of the scanning range, the following relation should be approximately maintained for the change in amplitude as a function of the wave length in order to keep the change in focal length as small as possible;

$$A=\frac{y_B}{2}-\sqrt{\frac{y_B^2}{4}-\frac{1}{(n-1)k^2}}$$

where A is the amplitude, $k=2\pi/\lambda$ the number of waves (λ = wavelength), y_B is the distance to the focal plane and n is the index of refraction of the material used for the recording element. Optically, a sinusoidal path in the plane of the recording element referred to above is not the most favorable, but it is preferred because it is easily produced.

When scanning a disc-shaped carrier according to the system of the present invention, difficulties might occur due to disc wobble. This is caused by the carrier surface not being exactly perpendicular to the axis of rotation **2**, by deviations of the surface of the carrier **1** from one plane. When disc wobble occurs, the resulting angle between the impinging reading beam and the groove in its direction of movement then causes the point illuminated by the reading beam to move along that direction. This simulates an additional frequency modulation which might lead to scanning distortions. In a preferred embodiment of a playback arrangement for the system according to the present invention, it is provided that the reading beam **5** is directed to impinge on the carrier surface parallel to the axis of rotation **2** of the disc-shaped carrier **1**. In this manner the so-called up-and-down wobble of the carrier surface does not lead to displacements of the currently scanned surface elements in the direction of the relative speed, and only partial lengths within the beam path change to a slight degree.

FIG. 3 shows an enlarged view of carrier **1** for the case of reflection of the reading beam **5** from the surface of the carrier bearing the undulations **10**. At first glance, this arrangement seems to be more difficult to realize in practice because now the light source **4** and the radiation receiver **9** must be disposed on the same side of the carrier. As will be shown later on, however, this difficulty can be substantially overcome by additional measures.

In the arrangement according to FIG. 3, the rays of reading beam **5** which are reflected by the concave mirrors disposed below the surface center line **12** intersect at the focal plane **14** at which there may also be disposed the slit aperture **8** (see FIGS. **1** and **2**) and which corresponds to plane **17** of FIG. **2**. The distance of this plane from the surface center line **12**, however, is less for the reflection from the undulations **10**, as shown in FIG. **3**, than it would be for the case of refraction upon irradiation of the carrier according to FIG. **2**. In the case of reflection according to FIG. **3**, the distance of the plane of optimum light density variations from the surface center plane **12** is also somewhat larger, when undulations with sine-shaped lines of intersection are used, than the distance of the focal plane **14** from the same surface center plane. The undulations **10** disposed above the surface center plane **12** cause in the arrangement according to FIG. **3**, a divergence of the light. When the carrier **1** passes under reading beam **5** there result changes in the light density in the focal plane **14**, or in a plane parallel thereto, which represent a reproduction of the curvatures of the surface portions bearing undulations **10** and which can be made effective by a slit aperture with a light receiver disposed in one of these planes.

In order to effect as good a reflection as possible of the rays of beam **5** at the surface of the carrier, carrier **1** may advisably be provided with a reflective coating in the area of the surface bearing the undulations **10** so that then the light emanating from the light source is converged by reflection into a plane **14** disposed on the same side as the light source. A suitable material to be used as a reflective coating is e.g., aluminum or silver.

A further development of the present invention relates to a carrier for a recording method according to the system of the present invention, in which the undulations **10** are disposed on the bottom surface of a groove having a trapezoidal cross section and where the axes of the quasi-cylinders are disposed transverse to the direction of the groove center line. A portion of such a carrier is shown in FIG. **4**.

The groove **15** has two sides **15'** and bottom surface **16** which is first intended to be unmodulated. In the modulated state, as it is shown in FIG. **4**, the bottom surface **16** bears the undulations **10** which form the signal recording. In a playback arrangement, the groove sides **15'** may be used for the engagement of an auxiliary means for mechanically guiding the optical pickup. This auxiliary means need not come in contact with the bottom surface **16** of the groove, however. This bottom surface is rather evaluated in the above-described manner by its influence on the ray path of the reading beam **5**.

FIG. **5** shows a section through a portion of a carrier **1'** on which there are disposed a spiral groove, several turns of which are shown, having a trapezoidal cross section. The sectional view is shown perpendicular to the groove center lines. In order to facilitate the arrangement of the light source **4** and of radiation receiver **9** on the same side of the carrier for the case of reflection from the carrier surface, the bottom surface **16** of the groove, which is imagined to be still unmodulated, is so disposd that it forms an angle other than 90° with the axis of the reading beam **5**. In FIG. **5** the lines provided with arrows indicate the axis of the reading beam **5** which is directed onto the associated surface **16** of the groove. The impinging portion of the radiation is here directed, as presupposed, to be parallel to the axis of rotation **2** (FIG. **1**) whereas the reflected portion of the beam now forms an acute angle with the impinging portion. This acute angle offers sufficient room for the accommodation of the radiation receiver **9** adjacent the path of the impinging beam.

Thus far, it has been assumed that the line of intersection of the surface bearing a quasi-cylindrical undulation, e.g., of surface **16** in FIG. **4**, with a plane perpendicular to the surface center plane **12** and, containing the direction of the relative speed between carrier **1** and reading beam **5** in the scanning region is a sine wave, because such undulations directly correspond to the time sequence of a sinusoidal carrier oscillation and, thus, can be produced on a master with known means by a simple cutting process. However, the resulting quasi-cylindrical lenses or quasi-hollow mirrors, respectively, do not provide the optimum convergence of parallel beams in a certain focal plane. A better convergence results, according to a further development of the present invention, when the above-defined line of intersection is designed to be other than sine-shaped, and is approximately circular in the top and/or bottom portions. These portions approximately circular in the case of refraction and are approximately paraboloid in the case of reflection. This configuration can be achieved in a simple manner by incorporating appropriate distorting members in the path of the recording amplifier, for example when the sine oscillation is recorded after a full wave rectification. For the case of refraction, this results in optical conditions which are related to those which are known for spherical lens systems when the beam path is considered withon one axial plane. For the case of reflection, the conditions which result are those known from observations with parabolic mirrors. With these further developments it is thus possible to achieve further improvements in the convergence of the ray path, so that the relative changes to the light density in the plane utilized by the radiation receiver become even greater, and a better signal-to-noise ratio is achieved.

FIG. 6 shows an enlarged view of a portion of a carrier 1'' provided with undulations 10 on its surface which, according to the above-mentioned further development of the present invention, form portions of circularly cylindrical lenses, all having the same radius R. The widths of the lens portions between b_{max} and b_{min} are different from one another, however, such that the desired frequency or phase modulation of the light density changes effected in the focal plane results. The carrier shown in FIG. 6 is used in the same manner as the type discussed in connection with FIG. 2 for the light irradiation when plane 6 approximately coincides with plane 17. This would be exactly so if the top portions of the illustrated lenses were at the same distance from the focal point plane.

FIG. 7 is an enlarged view of a portion of a carrier 1''' which is provided with undulations 10 on its surface, which form portions of cylindrical parabolic hollow mirrors whose lines of intersection with the plane of the drawing are constituted by the same parabola for all mirror portions of different widths. That is, they all have the same equation of curvature. Accordingly, the focal lengths are also identical. Their length is, as is the length of the cylinder lens portion of FIG. 6, between b_{max} and b_{min}. The changes in length provide the desired frequency or phase modulation. The correct selection of the focal plane, causes a larger variation in the proportion of the light beam passing through the scanning slit. This results in a better signal to noise ratio.

Calculations have shown that these light density fluctuations are maintained over a relatively great distance range for the slit aperture 8 with respect to the surface center plane 12, so that the requirements for the vertical adjustment of the slit aperture 8 and the radiation receiver 9 with respect to the carrier surface are simplified. If, as shown in FIG. 1, the optical system 7 is employed to reproduce the plane of strong light density fluctuations in the plane of the slit aperture, this requirement is correspondingly reduced with respect to maintenance of the depth of field. Surface irregularities or variations in the surface height during rotation of carrier 1 on the playback apparatus due to disc wobble are therefore less of a problem than in known light-scanning processes.

FIG. 8 shows a block diagram of the recording system and the necessary signal processing circuitry. The frequency or phase modulated signal is limited in the limiter 18 and the limited signal is differentiated by the differentiating network 19. The needle pulses occurring at the output of the differentiating network control alternately two function generators 21 and 22 by a flip-flop-circuit 20. The function generators produce equal signals of circular or parabolic shape. The comparator circuit 23 selects always the higher one of the two signals and passes it to an inverting amplifier 24 to the following recording amplifier 25 and to the recorder 26. In case of recording a signal corresponding to FIG. 7 the inverting amplifier 24 is not necessary.

FIG. 9 shows an enlarged view of a portion of a carrier 1 and the optical pickup guided by the groove sides 15'. The pickup may consist in a cylindrical lens 7' connected to a transparent body 28 e.g., of diamond. The pickup is sliding in a groove 15. With the aid of the convex lens 7' the plane 6 in FIG. 1 is reproduced in plane 11, where there is dispened the receiving slit aperture 8 and above it the light receiver 9.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

I claim:

1. An element for storing a reproducible signal in the form of a carrier oscillation which is angularly modulated with the signal to be reproduced, comprising, in combination, signal storage means having at least one recording surface and at least one track arranged in said recording surface, and undulations having continuously curved surfaces formed in said at least one track so as to form a series of quasi-cylinders having axes extending transversely to the direction of the track, the undulations being a representation of a signal modulated with a carrier oscillation, and the successive undulations having lengths, in the direction of the track, which correspond to the periods of successive cycles of the modulated carrier oscillation while the heights of the undulations differ from one undulation to another, the height of each undulation being a direct function of its length such that all of the undulations have substantially the same focal length.

2. An element as defined in claim 1 wherein the storage means is to be scanned by radiation impinging on the undulations and the amplitude of each undulation is represented by:

$$A = \frac{y_B}{2} - \sqrt{\frac{y_B^2}{4} - \frac{1}{(n-1)k^2}}$$

wherein A is the amplitude, $k=2\pi/\lambda$, the number of waves, (λ = wavelength), y_B is the distance between the focal plane of the radiation emanating from the undulations and the plane of the center surface of said storage means, and n is the index of refraction of the material used to fabricate the carrier.

3. An element as defined in claim 1 wherein the bottom surface of said at least one groove is at an acute

angle with respect to said at least one recording surface.

4. An element as defined in claim **3** wherein the surface portion of each undulation has a substantially circular shape.

5. An element as defined in claim **4** wherein the radii of the substantially circular surface portion of a series of undulations are substantially equal to each other.

6. An element as defined in claim **3**, wherein the surface portion of each undulation has a substantially parabolic configuration.

7. An element as defined in claim **6** wherein the lines of intersection of the surface portions of a series of undulations are substantially parts of the same parabola.

8. An element as defined in claim **7** further comprising a reflective coating applied to the undulations.

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