METHOD AND MEANS FOR CHANGING PIT DEPTH ON AN OPTICAL RECORDABLE MEDIUM

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to the field of signal processing systems, and in particular to the field of waveform shaping in optical information recording systems. More specifically, the present invention relates to a dynamic optical modulator regulator and waveform shaping system employed in an optical disc mastering apparatus for improving the character and resolution of the indicia in a replicated optical disc while maintaining proper duty cycle and asymmetry of the recorded information. The present invention also provides a method and means for recording an auxiliary channel of input information in the depth or height of surface discontinuities in the recordable surface of a recordable medium.

Brief Description of the Prior Art

A great many systems are known for optically recording information on light responsive media. Digital information as well as analog information can be recorded on a variety of media, including photoresists, photochromic materials, and thermally responsive materials in the form of discs, drums, and tape.

Virtually all of these known systems employ some form of pulse code modulation (PCM) or frequency modulation (FM) due to the nonlinearities of known optical recording media. Additionally, virtually all of these known systems employ an optical system including an objective lens for focusing the writing beam of light to a small spot on the light sensitive surface of the medium. In order to maximize the information density of the recorded material, it is necessary to focus the writing beam to the smallest possible spot size. Due to diffraction effects, a focussed beam of coherent radiation forms a central bright spot

surrounded by concentric spaced rings of light known as an Airy disc, having an approximately Gaussian power distribution. The diameter of the central spot of light is defined by the wavelength of the recording light and the numerical aperture (NA) of the objective lens.

Most optical recording media exhibit a threshold effect, meaning that a level of laser writing beam power density exists above which the medium will be altered, and below which the medium will not be altered. Since the power density of the focussed writing beam varies as a function of the distance from the center of the central spot, it is possible to form altered areas on a medium which are smaller than the diameter of the central spot of the focussed light. In order to obtain an altered area of a specific size, the prior art has taught that it is merely necessary to adjust the peak intensity of the modulated beam such that the power density of the focussed spot at the specified diameter is equal to threshold level of the recording medium. Experimental results indicate that this technique works extremely well when there is no relative movement between the writing spot and the medium and no thermal conductivity effects diffusing the energy absorbed by the medium. In all practical systems, however, relative movement between the medium and the recording spot is necessary. This relative movement greatly complicates the calculation of the amount of energy absorbed by a particular region of the medium.

All light responsive media exhibit a tendency to integrate the amount of energy received over a period of time, so that the threshold level of the material does not define a specific instantaneous power density at which the material is altered, but rather defines an energy density which is the result of an integration of the received power over the time during which the power is received. In other words, the threshold level for the materials is actually an exposure level. Exposure level is defined as the radiant flux per unit area integrated over the exposure time. The radiant flux irradiating a particular point on the medium

at a particular time is a function of the position of the point within the focussed spot, as well as the instantaneous modulation level of the writing beam. Specifically, the exposure level at a particular point on the medium is equal to the convolution integral of the instantaneous power of the modulated writing beam as a function of time and the power density distribution function defined by the path and speed of the particular point of the medium through the focussed spot, evaluated over the exposure time. Since the power distribution of the focussed spot varies in two dimensions, the exposure level over the medium defines a three dimensional graph. The intersection points of this graph with a planar "slice" through the graph at the altitude corresponding to the threshold level of the medium maps the boundaries of the altered areas on the medium.

An important concept in determining the effect of the finite size of the recording spot is the concept of the spatial frequency of the information on the moving recording medium (in this description, it is to be understood that the movement of the recording medium is relative to the write or read head of an optical recorder or player. That is, the medium may be a stationary card writen on and read by a moving optical head). This is the subject of U.S. Patent No. 4,616,356 which is incorporated herein by reference.

Also incorporated herein by reference is U.S. Patent No. 4,225,873 describing signal processing techniques to achieve proper duty cycle of the recorded information and to minimize second harmonic distortion of the recorded information which are related parameters and which are improved by the present invention. In this description, the duty cycle of the recorded information will be referenced in detail, it being understood that second harmonic distortion is proportional thereto. That is, when duty cycle is controlled to approximately 50%, this minimizes the second harmonic distortion of the recorded information.

As previously indicated, when recording on a medium using laser light, the effects of the recording process may either be an ablation of the recording surface, a discoloration of the surface, a photo-hardening or a photo-softening of a photoresist coated surface, a raised bump or bubble formation, and the like. In all cases, a recording medium is moving relative to an impinging light beam, and the energy of the light beam is increased and decreased about a threshold level so as to cause or not cause the desired effect, respectively. Also in all cases, when the light beam is first turned on or caused to exceed threshold, the full effect of the energy on the recording surface is not instantaneously realized. Rather, and especially with media that are thermally responsive, the recorded effect (i.e., indicia) increases with time due primarily to the temperature of the medium increasing with time under the influence of the applied energy. That is, when the light beam is first turned on, instantaneously no alteration in a moving recording surface can be detected. If left on continuously, the full effect of the impinging light beam will cause a wide stripe of the effect on the recording surface, thereby defining a broadening of the track of the light beam with the passage of time.

On the other hand, when the light beam is turned off or falls below threshold level, the effect of the lack of sufficient energy from the light beam is almost immediately recognized by the disc surface, since the downstream portion of the disc is cold and unaltered. Accordingly, when the light beam is turned off quickly, an almost instantaneous stoppage of the recording effect takes place, and since the light beam is substantially circular at the point of impingement on the recording surface, a rather blunt end on the trailing edge of the recorded indicia can be observed.

If the moving recording surface is therefore impinged by a light beam having a sharp rising leading edge and a sharp falling trailing edge, a rather "pear-shaped" or "teardrop-shaped" surface effect will be noted, the leading

edge being tapered and widening to a constant width until the beam was shut off, at which point the recorded effect would define a rounded or blunted trailing end. This aspect of optical disc recording is the subject of U.S. Patent No. 5,297,129 which is incorporated herein by reference.

While the aforementioned characteristics of the recorded surface results regardless of the recording "effect" chosen, for ease of discussion in this description, it will be assumed that the recording light beam causes an ablation of the surface, thereby producing a "pit". It is to be understood, however, that a bump, discoloration, photoresist hardening, photoresist softening, or other indicia can be substituted for the term "pit" without departing from the nature of the technical description of the recording effect. It is further to be recognized that the term "pit" as used herein would be equivalent to the bump or pit formed after development of a photoresist if that were chosen for the recording surface. For the purposes of discussion herein, the term "surface discontinuity" will be used as a generic term meaning either a bump or a pit or other surface disturbance departing from a flat unrecorded disc surface. Finally, the term "recording surface" refers to that part of the disc which is sensitive to the impingement of light energy, whether it be on the outer surface of the disc or submerged beneath the surface being impinged by the light beam. Although it would be theoretically possible to apply some of the concepts of the present invention to all types of prior art mastering processes, from a practical viewpoint only recording processes which create physical "pits" or "bumps" will benefit, as will only mastering systems that permit direct-read-after-write (DRAW) disc mastering. Thus, photoresist type mastering systems cannot make use of the invention. This will be detailed later in this description.

One of the most important parameters in the recording of a compact disc (CD) master is the precise control of the

pit-to-land ratio. Each transition from land to pit and vice versa marks a zero crossing of the EFM (Eight-to-Fourteen Modulation) signal; therefore, the size of the land area holds as much digital information as the size of the corresponding pits. The ratio of pit to land size is the "duty cycle" of the recording. A duty cycle of 50% would represent a symmetrical signal with pits occupying 50% of the track area and land area the other 50%. Any recording that deviates from a 50% duty cycle would be represented in an eye-pattern (discussed in connection with Figure 2) as an asymmetrical signal. Due to limitations in the replication process, differences in the various CD player's optics, and variances in the electronic boost of the CD players, all CD recordings, even ones that were recorded with perfect 50-50 symmetry, may be seen by the playback optics as slightly asymmetrical. Circuitry within the CD player corrects for this asymmetry by shifting the "zero level" to a point where no timing differences between positive and negative half cycles exist on the average.

The optical head of a player "reads" the information on a disc by focusing a laser beam to a spot about 1 micron in diameter and scanning this spot along a spiral track of pits and lands on the disc. The lands reflect most of the light back to a photodetector in the head, but the pits (actually read by the read laser from the opposite side of the disc where the pits are seen as bumps) reflect little light back toward the read head. The photodetector generates an electrical signal proportional to the amount of light reflected by the area of the disc illuminated by the spot. Because the spot is nearly diffraction limited and is only slightly larger in diameter than the length of the shortest length pit on the disc, the rise and fall times of the electrical signal are relatively rather slow, and the amplitude of the signal representing the smallest length pits is smaller than the amplitude of the signals representing the longer pits. The difference in amplitude varies from player to player because of differences in optical quality, and from disc to disc because of pit

geometry. All players partially make up the difference in amplitude with an analog aperture compensation circuit which boosts the amplitude of the high frequency signals relative to the low frequency signals. Unfortunately, in the interests of economy, these boost circuits are not phase linear, so the harmonics of the signals are delayed by varying amounts, and the shape of the waveform is altered in addition to its amplitude.

The EFM signal recorded on a compact disc is a run length limited digital code which is self clocking and contains its digital information in the timing between transitions. On the disc, such transitions are the boundaries between pits and lands between pits, and vice versa. Therefore, the length of each pit is a quantum of data and the length of each land between pits is also a quantum of data.

The rules for the EFM code according to CD standards require that each and every transition occur at one of nine allowed times after the last transition. More specifically, the period between any two transitions must be nT, where T is a fixed period of time (about 231 nanoseconds) and n is an integer between 3 and 11. In order to decode the information, the player must decide how many T's pass between each transition. The rate of rotation of the disc under the playback head is not stable enough to simply time the transitions with a fixed clock. Instead, a channel clock running at an average of one cycle per T (4.3218 MHz) is phase locked to the recovered signal. This PLL (phase locked loop) operates by comparing the timing of each transition in the signal with the closest cycle end of the clock. If the transition consistently occurs just before a cycle end of the clock, the clock slowly speeds up until the transitions occur exactly at a cycle end.

Unfortunately, the rise and fall times of the analog signal from the disc are relatively long and may exceed T, such that a specific voltage must be chosen to define the instant of the transition. This voltage is the player's

"Decision Level". The player chooses this level with the help of another rule of the EFM code which states that, on the average (and ideally), the EFM signal will be "high" for exactly the same amount of time it is low. Knowing this, if a player picks a decision point too high in voltage, the EFM signal will be low (lower than the decision point) more often than it is high (higher than the decision point). A servo loop in the player slowly adjusts the limit voltage to find and maintain the proper decision level voltage.

It is important to realize that the player cannot change its decision level on a cycle by cycle basis, but the period between the transitions can vary from 3T to 11T instantly. Any frequency dependent influences on the shape of the waveform may cause the ideal decision point for the high frequency segments of the signal to be at a different voltage than the ideal decision point for the low frequency segments of the signal. The player will choose a decision point which is an average of these voltages. As mentioned earlier, the boost circuitry of the player is not phase linear and therefore causes a "spread" in the ideal decision point voltages with frequency.

In order to read the signal from the disc, the player must keep the small spot of light centered over the moving spiral track of pits on the disc. Various techniques are used for detecting the position of the spot relative to the track, and tracking devices of some players (using single-beam or push-pull trackers) are greatly influenced by the average duty cycle of the pits along the track. That is, these players will only reliably follow along the center of the track if the track consists of a certain percentage of pit area greater than the land area (a duty cycle greater than 50%). While recorded intelligence information is contained in both the pits and the lands, no tracking information is contained in the lands which are coplanar with the other unrecorded regions of the disc surface, i.e., the surface of the disc between tracks of pits. Accordingly, the greater the length of the pit relative to

the land between pits, the better the tracking subsystem works. As indicated, with any duty cycle less than about 50%, there is insufficient tracking information to enable push-pull trackers to stay on track. One solution to this dilemma, then, would be to increase the pit-to-land duty cycle to above 50% and rely upon the player's ability to readjust its "decision level" to compensate for the increase in recorded duty cycle. However, in order for the player's PLL to maintain a channel clock based on the EFM signal, the increase in the duty cycle must be uniform over the entire signal, but this does not happen because there is not an equal proportional increase in pit length over the nine different pit sizes (3T to 11T). A 3T pit will obviously have a greater geometric increase, percentage wise, than will a 6T or an 11T pit. Unfortunately, therefore, departing from a 50% duty cycle just to accommodate single-beam trackers sacrifices symmetry, and if asymmetry is too great, the player's phase lock loop may not be able to lock to the recovered signal.

Another consideration which has heretofore not been adequately provided for in the recording process is the fact that single-beam players, which tracking function depends on the amount of light deflected back to the photo-sensor in the direction of the tracking error, operate best with tapered (pointed) ends on the pits formed in the recording surface. The ideal pit would be an elongated groove with an apex on the bottom of the pit, similar to the impression that would be made by an upside down pyramid. The more the slope of the sides and the more tapered the ends, the better. Accordingly, any attempt to improve the pit definition tends to create a flat plateau region and eliminate the long narrow and tapered leading edges of the pits making tracking more difficult for such single-beam players. Moreover, pit length varies greatly pit-to-pit, i.e., from 3T to 11T, and a 3T width pit or land can be placed directly adjacent to an 11T pit or land. If the peak power level is increased to produce rounded (less tapered) higher definition 3T pits, the same peak

power level applied when forming an 11T pit would produce a very wide or blunted trailing end portion. This difference in geometry between 3T and 11T pits creates differential symmetry in which the 3T pits have one symmetry and the 11T pits have another symmetry configuration, and this consequently causes problems with player decoders. Ideally, there should be the same symmetry on each pit size. Otherwise, there will be a "spread in pattern" in the eye-pattern (discussed in connection with Figure 2).

There is yet another phenomenon which contributes to degraded optical disc replicas, and that concerns the variation of pit depth as a function of radius. It has been determined that even with a "perfect" stamper, pit depth in a replica varies according to radius apparently due to the lack of proper temperature and pressure at larger radii, the pits becoming shallower toward the outer edge of the replica.

Yet another phenomenon is the fact that, strictly due to the molding process, 3T pits have a greater depth than 4T pits which have a greater depth than 5T pits, and so on, independent of radius; and this is found to be true even when the bumps on the stamper have uniform heights for all pulse widths 3T-11T, i.e., the pits in the molded replica do not reflect the exact geometry of the bumps on the stamper. This phenomenon thus compounds the problem of attempting to maintain uniform pit depth when also considering the known pit depth variation caused by surface temperature differences for different length pulses during the mastering process as noted in the previous paragraph. This pit length related depth difference is significantly large between 3T and 4T pits and also between 4T and 5T pits. However, the depth difference is less significant between 5T through 11T pits. Ideally, all pits should be of the same depth.

It can therefore be appreciated that without the background knowledge discussed above, a simplistic master recorder design would simply maintain a 50% duty cycle in

the recorded information. In the ideal world, this would seem to be an obvious thing to do, since maintaining a 50% duty cycle would appear to be an essential requirement for the recording process. Methods and apparatuses of the distant prior art have thus merely provided a rectangular waveform in which the portion representing an nT length pit is equal in length to that portion of the waveform representing an nT length land between pits.

With experience, it has become evident that many factors must be considered in order to produce the optimal track of pits on the disc. For example, since the depth of a pit and its width vary along the track with the amount of time the beam is allowed to impinge on the surface, pit size and geometry is a function of surface speed -- an important factor for discs recorded in a constant angular velocity format. Other factors to be considered, already discussed, are duty cycle (>50%), the shape of the side walls of the pits in elevation (important for single-beam trackers), the asymmetry, and the pit resolution.

Pulse length can be increased to raise the duty cycle, but this increases asymmetry. Increasing the power level of the modulated light beam improves resolution at the leading edge and increases duty cycle but produces "pear-shaped" trailing edges and excessive asymmetry. Increasing peak power at the leading edge by using a stepped modulator driving pulse improves resolution of the leading edge but requires a reduction of pulse length to keep the duty cycle under control. Doing so gives unequal asymmetry for the different pulse lengths and requires an adjustment for each surface speed for best results. Threshold can be lowered to increase duty cycle, but this produces poorer resolution in the leading edges of the pits and ill-defined pit widths exhibiting substantial difference in geometrical shapes between a 3T and 11T pulse length. Finally, any attempts to increase pit resolution inherently diminishes the ability of single-beam trackers to track.

It can thus be appreciated that, while many adjustments of the parameters affecting the timing and

geometry of the pits are available, the interaction by making any adjustment which affects other parameters is a tremendous problem which reduces yield and requires constant attention by a recording operator.

There is therefore a need in the art for a method and apparatus for driving the light modulator with a pulse which permits independent control of geometry and asymmetry over wider ranges than heretofore possible. The method and apparatus should permit adjustment of pulse length and power to optimize (minimize) asymmetry and permit adjustment of the geometry of the pits over the entire surface of the disc. This rather independent control of these parameters is extremely important when considering that for any given process for manufacturing discs, taking into account the differences in chemicals, surface thicknesses on the disc, molding machines, and mastering machines, any particular system would require a different adjustment to obtain optimal pit geometry and asymmetry, and the prior art has failed to provide this flexibility by being unable to control certain of the parameters independently. The present invention therefore satisfies a long need in the art for a method and apparatus which not only can permit optimal adjustment of the modulator driving pulse for a particular system but can also be adjustable to account for differences system-to-system.

SUMMARY OF THE INVENTION

The present invention is directed to a method and apparatus for altering the depth or height of surface discontinuities recorded on an optical recordable medium in accordance with an information signal.

In one embodiment of the invention, the information signal is a ramped voltage to vary the depth of pits (or the height of bumps) in the recording surface as a function of radius.

In another embodiment of the invention, the information signal is a pulse wave shape modifying means

which varies the depth of pits (or the height of bumps) in the recording surface as a function of pit type identified from a series of different pit types in an input pulse train (e.g. an EFM input pulse train).

In yet a further embodiment of the invention, the pit depth (or bump height) is varied in accordance with an input intelligence signal. Such input intelligence signal may be of any desired format and can be continuous, in which case the pit depth (or bump height) will vary continuously in correspondence with the input signal, or it can be incremental, in which case the pit depth (or bump height) will change incrementally. In a simple case, but not limited thereto, the depth of pits can be made shallow to indicate that a functional switch in the player of the medium should be in a first position, and deeper pits can indicate a second position. As an example, in the audio portion of the playback device, shallow pits could indicate that a monophonic signal is being presented, while deeper pits could indicate stereo, or such a switch could turn on and off a center sound channel. In a video presentation, shallow versus deeper pits could identify a change in picture aspect ratio of the recorded video program.

If the change of pit depth (or bump height) is continuous, the information derived by the player due to varying pit depth along the track could be sound effects, an extra channel of audio, special video masking or enhancing signals, and the like. In effect, the variable pit depth (or bump height) is treated as another information channel, like pit or bump length along the track. The embodiments fully described herein, by way of example only, however, are of the first two of the above-mentioned embodiments.

The invention provides a uniquely altered modulator drive signal for use in an optical recording apparatus by providing a waveform processing means which receives a rectangular wave from the EFM processor, otherwise provided as a modulator drive signal to modulate the light beam, and produces therefrom a modulator drive signal which

dynamically varies in accordance with the position along the recorded information track, or in accordance with predetermined recorded information characteristics, or both. In a preferred embodiment of the invention, the modulator drive signal is dynamically altered as a function of radius on an optical disc, as a function of the width of pulses which form surface discontinuities of proportional lengths along the information track, or is dynamically altered as a function of pit length (3T-11T) of the EFM source signal, or both.

The remaining discussion assumes, but is not to be limited to, the use of a compact disc mastering machine which forms pits in the recordable surface of the disc and is capable of reading the recorded information immediately after it is recorded, i.e., the mastering machine is of a DRAW (Direct Read After Write) type. It is also presumed, but is not so limited, that the optical modulator used is an acousto-optical modulator, or AOM.

In one aspect of the invention, in order to compensate for inaccurate injection molding at the outer radius of a compact disc, the pit geometry is modified, in accordance with the invention, in a manner that offsets the lack of fidelity in molding. Towards the outer radii of a molded disc, the pits containing the data tend to be molded increasingly shallower than the rest of the disc. These shallower pits result in a lower signal during playback, and an associated rise in the error rate. By making the pits at the outer radii increasingly deeper during mastering, the detrimental effects of the molding can be cancelled out.

Contained within the machine controller of a compact disc mastering machine is a microcontroller and its associated firmware, which produces and controls the function of a duty cycle ramp. This microcontroller continuously monitors the current radius, and accordingly adjusts the recording duty cycle either continuously or, in a more intelligent control mode, in small steps. The values for the steps, and the radii at which they occur,

are contained in a selectable pre-programmed look-up table. The actual output that effects the change in duty cycle is a slowly changing, or ramping, DC voltage from a digital-to-analog converter in a radius-to-voltage converter. This ramping voltage, in turn, is routed to a wave shaping circuit to alter the recording duty cycle.

The ramping DC voltage from the machine controller is summed with the AOM bias voltage (produced in a high speed duty cycle servo loop) in the wave shaping circuit. The resulting voltage sets the charging current on timing capacitors for the one-shots that determine the duty cycle of the output waveform. The output waveform from the wave shaping circuit is routed to the AOM which modulates the record laser beam, and it in turn records the pits in, for example, the recording surface of a dye-polymer media.

The duty cycle servo utilizes DRAW technology to adjust the recording laser power to maintain a set playback asymmetry. By making the record duty cycle smaller, the laser power must increase to maintain a constant playback asymmetry. Another effect of the higher laser power is an increase in the recorded pit depth. This increase in pit depth is the objective of the duty cycle ramp technology.

In another aspect of the invention, in order to compensate for inaccurate injection molding of the pits on a pit-by-pit basis, e.g. 3T pits being shallower than 11T pits, the pit geometry is modified in a manner that records shorter pits with greater depth than longer pits. In accordance with the invention, a wave shape modifying function alters the effects of the duty cycle servo to produce a modulator drive signal which forms surface discontinuities having a varying duty cycle along said track of surface discontinuities, the wave shape modifying means altering the physical character of individual surface discontinuities along said track of surface discontinuities dependent upon the pulse types (i.e., 3T to 11T) corresponding to the individual (3T to 11T length) surface discontinuities.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be apparent from the following description of a particular embodiment of the invention, having reference to the attached drawings in which:

FIGURE 1 is a generalized block diagram of a recording apparatus employing the waveform shaping circuit according to the present invention;

FIGURE 2 is a representation of a perfectly symmetrical eye-pattern according to CD standard specifications;

FIGURE 3 is a more detailed block diagram than that of FIGURE 2, and additionally shows a pulse discrimination and shaping function;

FIGURE 4 is a more detailed block diagram of the pulse discrimination and shaping function generally depicted in FIGURE 3; and

FIGURE 5 illustrates a model modulation driver waveform showing various portions of the waveforms which can be altered by the pulse discrimination and shaping function of FIGURES 3 and 4.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The diagram of the recording apparatus of Figure 1 includes only those prior art features of the apparatus which are pertinent to the novelty of the present invention. For a description of a complete optical recording apparatus, reference is made to the aforementioned U.S. Patent No. 4,225,873.

The recording apparatus shown in Figures 1 and 3 is designed for recording information on a rotating disc-shaped medium 1. The disc is rotated by a spindle motor 3 which is controlled by a speed controller 5 (Figure 3). Naturally, the medium could be in the form of a drum, a card, or a linear tape with the necessary modifications of

the media moving systems being obvious to a skilled artisan.

A laser or similar high intensity light source 7 forms a writing beam 9 of a particular wavelength of light. The writing beam passes through an optical modulator 11 which varies the intensity of the writing beam in accordance with a drive signal on line 10. By way of example, the modulator 11 may be an acousto-optical modulator (AOM).

The beam 13 exiting the modulator will have an amplitude of modulation proportional to the amplitude of the drive signal and will have an average intensity controlled by the DC offset of the drive signal and the intensity of the unmodulated beam 9.

The modulated beam 13 is directed to the recording medium 1 and is focussed to a spot 15 by appropriate optics. These optics preferably include an objective lens 17 and a beam expanding lens 19 which spreads the beam from the modulator to fill the aperture of the objective lens 17. In the disclosed embodiment, the lenses 17 and 19 are mounted on a carriage 21 to allow radial movement of the spot 15 relative to the disc 1. Naturally, various other arrangements are possible for moving the spot 15 relative to the medium, including the movement of the spindle motor. In the disclosed embodiment, the carriage is moved by a translational drive system shown schematically at 23.

The drive signal for the optical modulator 11 is formed by a waveform shaping circuit 31. The waveform shaping circuit includes an EFM input 33 (Figure 1) or a processed EFM input 26 (Figure 3) defining for receiving the information to be recorded and may also include an input 35 for receiving a drive signal bias control for adjusting the average intensity of the modulated beam 13 (Figure 3 only). If the speed of the information medium relative to the focussed spot 15 is not constant, the signal processing system may include an input 37 for receiving a signal indicative of the instantaneous relative speed.

The recording medium 1 may include a substrate 41 and a light responsive recording layer 43 coated on the substrate.

A duty cycle servo 6 samples the "read" signal from disc 1 and sends correction signals to the wave shaping circuit 31 and laser power regulator 8 for, maintaining constant asymmetry.

Figure 2 is a representation of a perfectly symmetrical "eye-pattern" which would be readily understood by one skilled in the art and is presented here merely to show the necessity for controlled asymmetry in the recovered signal in the player. The diamond-shaped formations along the horizontal center line shows perfect zero crossover of all waveforms. Producing the idealized "eye-pattern" as shown provides for the greatest immunity to noise. If, for example, the I3 waveform (representing alternating 3T pits and 3T lands) were asymmetrical, i.e., the pit and land are not equal in length, a shift in one of the half cycles of the I3 waveform would not occur at the zero crossover point. If other waveforms also were asymmetrical to the point where it would be impossible along the horizontal center line of the graph of Figure 2 to distinguish one nT signal from another nT signal, an improper signal would be recovered from the played disc and the phase lock loop may not be able to lock to the signal, thereby losing the self-generated clock and destroying the integrity of the played back signal, or such asymmetry could ever result in detecting the edges of the pits falling in the wrong timing window created by the clock, again with disastrous results. The standard electrical output of the EFM processor for CD mastering for inputting on line 33, is a rectangular wave with a duty cycle average of about 50%, in spite of pulse-to-pulse variations in duration from 3T to 11T.

Generally, the present invention relates to analyzing the data stream from a direct read-after-write (DRAW) playback read head and adjusting the recording functions to make the playback signal as perfect as possible. In this

way, as close to perfect playback of the discs by consumers can be realized, and yet the mold used in injection molding of replica discs can be imperfect. The signal driving the optical modulator 11 can likewise be imperfect, such imperfections being purposely put in place in order that the final product, the molded replica, or playback disc, will be perfect. This purposeful adjusting the mastering processing away from theoretical ideals can only be done, from a practical viewpoint, with mastering systems that can employ a real-time direct read-after-write (DRAW) function. Mastering processes that employ photoresist cannot realize the same success due to the need to completely manufacture a replica disc, test the replica, make further adjustments, and then replicate again. The time and cost of such a procedure to arrive at optimum parameters for producing a perfect replica is prohibitive.

Further, the present invention can only be used with a mastering system and recording medium combination which can produce continuous gradations in the physical properties of the recording surface, e.g. a combination which can produce different depths of pits (or heights of bumps) on the media surface. Again, recording media employing photoresist cannot be use, because they are incapable of producing different pit depths.

As indicated, a primary objective of the invention is to produce a correction signal, or compensation signal, intended to compensate for molding phenomena, where at the outer edge of the disk, typically what is observed is the molding process does not mold all pits with equal pit depth. The pits get shallow at the outer edge. There is not enough pressure and temperature to make a good copy of the pits at the outer edge of a CD or Videodisc mold.

The present invention solves this problem by forcing individual theoretically fixed pulse lengths to be nonconstant. As is known in the art, it is a goal of the molding processing to dynamically adjust the laser recording power to hold the pulse length constant (for a particular pulse type, e.g. 3T-11T) over the entire surface

of the disc. In the present invention, however, the pulse length is purposely altered by a ramp function inserted to be effective for all radii or to be inserted at a certain radius. The ramp function is generated in a machine controller 20 shown to comprise a duty cycle ramp generator 4 which produces a ramped signal at its output coupled to wave shaping circuit 31. The ramped output level is determined by the radius of the write head of the mastering machine, and varies continuously as the radius of the write head changes. The ramp function may be linear, nonlinear, or follow any curve suitable for the particular disc type, size, and determined need for compensation, to make the surface discontinuities deeper or shallower at the outer edge. In a typical DRAW mastering machine, the ramp function makes the pits deeper with increasing radius.

Because a high speed duty cycle loop through duty use servo 6 is still working, still holding the asymmetry constant, when the radius dependent variable voltage level ramp function is inserted, the pulse length out of wave shaping circuit 31 gets shorter toward the outer radius of the disc, but the laser power rises under control of laser power regulator 8, and the asymmetry is still held constant. Thus, while the asymmetry is held constant, but the peak power is now greater, because the pulse length is shorter, the pits are made deeper as the recording process continues. Yet, the playback symmetry remains constant all across the surface of the disc. This combination of function may thus be referred to as a double nested servo loop, the ramp function effectively defining a low speed servo loop. It allows changing the pit depth and yet still maintaining constant asymmetry as a result of the two high and low speed servo loops. That is, when a compensating signal from duty cycle ramp generator is inserted into the servo loop, essentially causing the pulse length to get shorter, the laser power will increase to make up for the pulse length getting shorter, thereby producing constant asymmetry.

The constant asymmetry is due to the high speed pulse width servo loop comprising duty cycle servo 6, wave shaping circuit 31, optical modulator 11, and the read head (not shown) providing directly read information from the disc to servo 6. Thus, the high speed pulse width servo continues to do the same thing that it always has done, prior to implementing the present invention, that is, hold the asymmetry constant. But, the laser power, which has been holding the pulse length constant is, in accordance with the present invention, intentionally not being held constant, i.e., the laser power must increase for shorter pulse lengths in order to preserve asymmetry.

Employing this method, i.e., changing the depth of the pits as a function of radius without changing the asymmetry or virtually any of the other signals retrieved from an optical disc, is uniquely possible with DRAW mastering machines. Importantly, this method cannot be performed using a photoresist mastering procedure. The reason the aforedescribed method works with the type of optical disc recording technique with which the present invention is used, is that the recording medium used with the invention is not cut all the way through the recording layer. On the contrary, the depth of the pits follows the peak laser power.

In a second primary objective of the invention, shown in Figures 3 and 4, the modulation drive signal is dynamically altered on the basis of the length of EFM input pulses used to form corresponding surface discontinuities on the disc. Basically, this is accomplished in a dual function circuit comprising a pulse width discrimination 14 and a pulse shaping processor 32, the latter supplementing the shaping of the optical modulator output pulses by wave shaping circuit 31. The pulse width discriminator 14 senses the input EFM signal on line 33 for 3T, 4T, and 5T-11T pulses, then sends the EFM signal, delayed through delay circuit 50, along with the pit/pulse type to a channel selector 57. The delay on the EFM signal is to ensure that the pit/pulse type information is available to

the channel selector and pulse shaping processor 32 before the actual pit starts being formed. The pulse shaping processor 32 consists of three identical processing channels 16, 18, 20. Each channel 16, 18, 20 generates a specific waveform for forming 3T pit, 4T pit, and 5T-11T pits, i.e., it generates waveforms with different front and back edge delays, amplitude, offset, back slope, tip ratio, and time constant. Functional blocks 59, 61...85, 87 represent circuitry to perform these waveform alterations, and with knowledge of precisely what part of the modulator drive signal on line 10 is to be adjusted by reference to the waveform in Figure 5, a person of ordinary skill in the art will have no difficulty in selecting and arranging the appropriate electronic components to perform the desired functions. Of course, separate circuit stages are not necessary, and good design with efficient layout can minimize component complexity. For example, amplitude setting and offset setting can be performed in the same amplifier stage.

The discriminator consists of three blocks, a 3T pulse sensor 41, a 4T pulse sensor 47, and an EFM delay circuit 50. The 3T and 4T pulse sensors 41 and 47 use one-shots to qualify the signal. The default signal is qualified as sensing a pulse in the range 5T- 11T. The EFM delay is needed to account for decision time, so the pit/pulse type will be known beforehand.

The edge shaper blocks 59, 69, 79 provide for different delays, set by front and back pots 60 and 62, 70 and 72, and 80 and 82, respectively on the front and back edges to modify the laser on time by a fixed amount of time. One of the three edge shapers 59, 69, 79 is selected by the pit/pulse type control signal on line 55 from the pulse width discriminator 14.

The remaining blocks 61-67, 71-77, and 81-87 generate desired waveform through three independent channels for 3T, 4T, and 5T-11T pulses respectively; so different type of pits can be formed using a different waveform suitable for recording optimization. Each channel has its own offset

adjustment 63, 73, 83 to set the signal top level, amplitude adjustment 61, 71, 81 to define the signal amplitude, ratio adjustment 67, 77, 87 to set the flat bottom part of the signal, time constant adjustment 68, 78, 88 to change the RC time constant of the tip, and back slope adjustment 65, 75, 85 for setting the rising slope of the back edge.

The summing circuit 24 comprises an output stage which combines waveforms from the three wave shaping channels 16, 18, 20 and drives the output coax cable 26.

Importantly, the invention may employ both pit compensation functions, i.e., the radius dependent function and the EFM pulse width function. That is, in addition to having the ability to make the pits deeper as a function of radius by making the pulses shorter and recording them with higher laser power, as described earlier herein, the invention may simultaneously employ an equalization method that allows the changing of the depth of individual pits. That is, the 3T pits can be made deeper or shallower than the 4T pits which, in turn, can be made deeper or shallower than the 5T pits which, in turn, can be made deeper or shallower than the 5T through 11T pits. Moreover, if deemed necessary and appropriate, other individual pit lengths, e.g any or all pit lengths 5T through 11T can be customized as to depth. In the use of the preferred mastering system described herein, only three identically constructed channels (16, 18, 20) of pit depth alteration are needed, one channel each for the 3T, 4T, and 5T-11T pits. Shown in phantom in Figure 3 is channel 22 representing additional channels if desired.

A pulse width discriminator 14 is used to determine the pulse width of each pulse in the EFM input pulse train. If the pulse is a 3T pulse, it is shortened in channel 16 separately from the other detected pulses. This altering of the pulse length individually for the different 3T-11T pulses is in addition to the aforedescribed ramping function which shortens all pulses regardless of length as a function of radius. It is an ultimate goal of the

invention to, if needed, to tailor the 3T through 11T pulses independently. That is, by pulse duration, the invention decides how much to alter the length of each pulse individually. One skilled in the art can easily extrapolate by reference to Figure 3 how to implement the needed nT channels.

Individual pit depths are altered and controlled by pulse shaping processor 32, i.e., by electronic processing channels 16, 18, 20 which, after recognition of the pulse length, 3T - 11T, shortens or lengthens the pulse and, selectively, configures the pulse with an optimum waveform. The duty cycle servo 6 simultaneously adjusts laser peak power through laser power regulator 8. For example, when a 3T pulse is detected by discriminator 14, the appropriate electronic circuit 16, 18, 20, 22 may shorten or lengthen the pulse in width and increase or decrease, respectively, laser peak power for the duration of the pulse.

Using the example of the last paragraph, it is important to note that, if all that is needed is to make 3T pits shallower, only the laser power regulator 8 is needed to reduce the laser power for the duration of the pulse used to form the pit. However, if that were done, it would upset the asymmetry which, as discussed above, is essential to be kept in proper registration. This potential problem is overcome by making the 3T pulse shorter at the same time the laser power is increased during the pulse, or visa versa. The processing channel 16 thus adjusts both the amplitude, duration, and wave shape of all of the 3T pulses differently from all the 4T pulses (in processing channel 18) differently from all the 5T through 11T pulses (in processing channel 20).

The discriminator 14 predetermines how long the incoming EFM pulse is, then selects which channel is to process that pulse (3T, 4T, or 5T-11T channel). Each channel has adjustment potentiometers for setting the desired amplitude, duration, and wave shape of the emerging pulse to be summed with the other processed pulses in summing circuit 24, and sent over line 26 to the optical

modulator 11. Optionally, the processed pulse out of summing circuit 24 may be sent to a further wave shaping circuit 31 which performs the functions described supra in connection with Figure 1.

As compared to the prior art, some prior art schemes propose to cause the write pulse to have a sharp and high power leading edge, sloping off more gradually toward the trailing edge. While this process indeed affects the shorter 3T pulses more than the longer 11T ones, due to the greater percentage of pulse time the leading edge contributes for the shorter pulses, this is solely an amplitude adjusting process. The present invention differs in that it sets write output pulse width to the optical modulator as a function of write input pulse width of the EFM signal.

The manner of combining the two processes of compensating for pit depth variation as a function of radius and compensating for pit depth variation as a function of incoming pulse length, involves setting the individual pulse wave shape compensator 14, 16, 18, 20, 22 first at the inner radius of the master disc. Then, as radius increases, the radius dependent pulse alteration function is enabled. It should be noted that the radius dependent compensation can be enabled from the beginning of the track on the disc to the end, or can be enabled at a prescribed radius. Also, the compensation can be continuous or can change incrementally at a prescribed radius. Moreover, each pulse wave shape compensation circuit channel 16, 18, 20, 22 has the ability of not only adjusting for outgoing pulse width but also of modifying the leading and trailing edges of the pulse passing through the particular channel. Of course, this complex scheme of adjusting the write pulses in so many ways is possible only on DRAW machines where instant results can be verified and parameters set for each processing channel. For example, in such a case, the eye pattern is real-time observable to insure a minimization of the phase errors of the zero crossings. In any event, by using the feedback from the

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disc as it is being recorded, the write pulses can be observed to be the right length, duration, and wave shape, or not, and appropriate correction functions can be initiated on a pulse-by-pulse basis or on an averaging basis for each pulse/pit T-length. This insures that what will be played back on the disc will be as perfect as possible.

Regarding the radius ramp embodiment, the circuitry may have a programmable compensation in it so that, rather than having the master formed perfectly, the master may be formed purposely not perfect (has a built-in precompensation-for-molding function) so that the replicas can be perfect. This additional function must, however, be open loop, i.e., such a pre-molding offset function would have to be preset rather than having a servo loop perform the function to make the master perfect.

All aspects of the invention relate to looking at the data stream input to the mastering machine, and using the playback information of the disc to make the data stream have the character it should for best playback of replicas, whether a master disc produced by such a process is perfect or is precompensated for molding. In all cases, the invention can be used only with a DRAW mastering machine using a recording media that can be recorded with pits of different depths or bumps of different heights.

Previously described was an embodiment of the invention, whereby a channel of information, referred to herein and in Figures 1 and 2 as an auxiliary input 38, can be recorded as variations in the depth of pits or height of bumps on the recordable medium surface. For the ramp and pit-type functions described in detail supra, no external "auxiliary input" is required. However, in the embodiments where an additional channel of recorded information is desired, an auxiliary input 38 may be coupled as input to either the wave shaping circuit 31 or the laser power regulator 8, or both, for making the necessary pulse modifications to create variable pit depth (or bump height). If inputted to the wave shaping circuit 31, the

amplitude of the pulse on line 10 driving optical modulator 11 would be varied. On the other hand, if pit depth or bump height is to be more directly affected by the auxiliary channel of information, the auxiliary input 38 is sent to laser power regulator 8 which instantaneously controls the power of the laser 7 in accordance with the information contained in the auxiliary input.

In either case, inputting auxiliary information to wave shaping circuit 31 or laser power regulator 8, there will be a purposely varying duty cycle of the recorded pits or bumps along the track which the player would sense and make appropriate correction for by generating a player duty cycle servo signal. This correction signal is, in effect, the recorded auxiliary input information which can then be extracted for any desired use by the player.

Instead of a separate "auxiliary input" signal used to modify the modulator drive signal to effect variable depth pits (or bump heights), the input signal to the wave shaping circuit 31 (exemplified by EFM input 33 in Figures 1 and 2), the pit depth (or bump height) can be varied by encoding the "auxiliary information" as amplitude variations of the input signal 33.

Although the invention has been described in detail with reference to its presently preferred embodiment, it will be understood by one of ordinary skill in the art that various modifications can be made without departing from the spirit and scope of the invention. Accordingly, it is not intended that the invention be limited, except as by the appended claims.

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CLAIMS

1. A dynamic waveform shaping circuit for use in an optical recording apparatus which includes a writing light beam source and an optical modulator for modulating the intensity of the writing beam of light above and below a threshold level of a moving recording medium in response to a modulator drive signal for recording information on a surface of the medium, the light beam being capable of forming a track of surface discontinuities in the moving recording medium when the writing beam is above the threshold and incapable of forming said track of surface discontinuities in the moving recording medium when the writing beam is below the threshold, said waveform shaping circuit comprising:

a wave shaping circuit, coupled to said modulator, for receiving a substantially rectangular waveform provided as said modulator drive signal to modulate the writing beam;

a duty cycle servo coupled to said wave shaping circuit for maintaining a predetermined duty cycle of surface discontinuities along said track; and

wave shape modifying means, coupled to said wave shaping circuit, for altering the effects of said duty cycle servo to produce a modulator drive signal which forms surface discontinuities having a varying duty cycle along said track of surface discontinuities.

2. The dynamic waveform shaping circuit as claimed in Claim 1, wherein said wave shape modifying means comprises a ramp voltage generator which applies a ramped voltage input to said wave shaping circuit for continuously altering said duty cycle between predetermined positions along said track of surface discontinuities.

3. The dynamic waveform shaping circuit as claimed in Claim 2, wherein said recording medium is a disc, and said predetermined positions correlate with corresponding predetermined radii of the disc.

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4. The dynamic waveform shaping circuit as claimed in Claim 3, wherein:

said surface discontinuities are pits formed in said surface of said medium; and

said wave shape modifying means produces a ramp voltage which continuously shortens the duty cycle of said pits along said track.

5. The dynamic waveform shaping circuit as claimed in Claim 1, comprising a light power regulator for varying the intensity of light produced by said writing light beam source, and wherein:

said duty cycle servo is coupled to said light power regulator for altering the intensity of light from said source in a manner to vary the duty cycle along said track of surface discontinuities oppositely from the variance of the duty cycle caused by said wave shape modifying means, thereby forming a closed loop servo function which allows the variation of duty cycle caused by said wave shape modifying means to be offset by the variation of duty cycle caused by altering the intensity of the write beam.

6. The dynamic waveform shaping circuit as claimed in Claim 4, comprising a light power regulator for varying the intensity of light produced by said writing light beam source, and wherein:

said duty cycle servo is coupled to said light power regulator for altering the intensity of light from said source in a manner to vary the duty cycle along said track of surface discontinuities oppositely from the variance of the duty cycle caused by said wave shape modifying means, thereby forming a closed loop servo function which allows the variation of duty cycle caused by said wave shape modifying means to be offset by the variation of duty cycle caused by altering the intensity of the write beam.

7. The dynamic waveform shaping circuit as claimed in Claim 3, wherein said ramp voltage generator generates a stepped

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ramp for effecting incremental changes to the duty cycle servo along said track.

8. A dynamic waveform shaping circuit for use in an optical recording apparatus which includes a writing light beam source and an optical modulator for modulating the intensity of the writing beam of light above and below a threshold level of a recording medium, moving relative to the light beam, in response to a modulator drive signal for recording information on a surface of the medium, the light beam being capable of forming a track of surface discontinuities in the relatively moving recording medium when the writing beam is above the threshold and incapable of forming said track of surface discontinuities in the relatively moving recording medium when the writing beam is below the threshold, said waveform shaping circuit comprising:

a wave shaping circuit, coupled to said modulator, for receiving a series of pulses of substantially rectangular waveform and of identifiable pulse types provided as said modulator drive signal to modulate the writing beam;

a duty cycle servo coupled to said wave shaping circuit for maintaining a predetermined duty cycle of surface discontinuities along said track; and

wave shape modifying means, coupled to said wave shaping circuit, altering the effects of said duty cycle servo to produce a modulator drive signal which forms surface discontinuities having a varying duty cycle along said track of surface discontinuities, said wave shape modifying means comprising means for altering the physical character of individual surface discontinuities along said track of surface discontinuities dependent upon the pulse types corresponding to said individual surface discontinuities.

9. The dynamic waveform shaping circuit as claimed in Claim 8, wherein said substantially rectangular waveform is a series of rectangular pulse widths ranging from 3T through 11T, T being is a fixed period of time defined in the rules for the EFM code standard in the recording and reproduction of



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information discs commonly known as compact discs, and said means for altering the physical character of individual surface discontinuities includes:

means for detecting and altering only 3T pulse widths;

means for detecting and altering only 4T pulse widths; and

means for detecting and altering all 5T through 11T pulse widths.

10. A dynamic waveform shaping circuit for use in an optical recording apparatus which includes a writing light beam source and an optical modulator for modulating the intensity of the writing beam of light above and below a threshold level of a relatively moving recording medium in response to a modulator drive signal for recording information on a surface of the medium, the light beam being capable of forming a track of surface discontinuities in the relatively moving recording medium when the writing beam is above the threshold and incapable of forming said track of surface discontinuities in the relatively moving recording medium when the writing beam is below the threshold, said waveform shaping circuit comprising:

a wave shaping circuit, coupled to said modulator, for receiving a substantially rectangular waveform and of identifiable pulse types provided as said modulator drive signal to modulate the writing beam;

a duty cycle servo coupled to said wave shaping circuit for maintaining a predetermined duty cycle of surface discontinuities along said track; and

wave shape modifying means, coupled to said wave shaping circuit, for altering the effects of said duty cycle servo to produce a modulator drive signal which forms surface discontinuities having a varying duty cycle along said track of surface discontinuities, said wave shape modifying means comprising:

a ramp voltage generator which applies a ramped voltage input to said wave shaping circuit for continuously altering said duty cycle between predetermined positions along said track of surface discontinuities; and

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means for altering the physical character of individual surface discontinuities along said track of surface discontinuities dependent upon the pulse types corresponding to said individual surface discontinuities.

11. The dynamic waveform shaping circuit as claimed in Claim 10, wherein said recording medium is a disc, and said predetermined positions correlate with corresponding predetermined radii of the disc.

12. The dynamic waveform shaping circuit as claimed in Claim 11, wherein:

said surface discontinuities are pits formed in said surface of said medium; and

said wave shape modifying means produces a ramp voltage which continuously shortens the duty cycle of said pits along said track.

13. The dynamic waveform shaping circuit as claimed in Claim 10, comprising a light power regulator for varying the intensity of light produced by said writing light beam source, and wherein:

said duty cycle servo is coupled to said light power regulator for altering the intensity of light from said source in a manner to vary the duty cycle along said track of surface discontinuities oppositely from the variance of the duty cycle caused by said wave shape modifying means, thereby forming a closed loop servo function which allows the variation of duty cycle caused by said wave shape modifying means to be offset by the variation of duty cycle caused by altering the intensity of the write beam.

14. The dynamic waveform shaping circuit as claimed in Claim 12, comprising a light power regulator for varying the intensity of light produced by said writing light beam source, and wherein:

said duty cycle servo is coupled to said light power regulator for altering the intensity of light from said source

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in a manner to vary the duty cycle along said track of surface discontinuities oppositely from the variance of the duty cycle caused by said wave shape modifying means, thereby forming a closed loop servo function which allows the variation of duty cycle caused by said wave shape modifying means to be offset by the variation of duty cycle caused by altering the intensity of the write beam.

15. The dynamic waveform shaping circuit as claimed in Claim 11, wherein said ramp voltage generator generates a stepped ramp for effecting incremental changes to the duty cycle servo along said track.

16. A dynamic optical modulator driver circuit for use in an optical recording apparatus which includes a writing light beam source and an optical modulator for modulating the intensity of the writing beam of light above and below a threshold level of a relatively moving recording medium surface in response to a modulator drive signal for recording information on a surface of the medium, the light beam being capable of forming a track of surface discontinuities in the relatively moving recording medium surface when the writing beam is above the threshold and incapable of forming said track of surface discontinuities in the relatively moving recording medium surface when the writing beam is below the threshold, said recording medium responding to said light beam, when said writing beam is above the threshold, to produce surface discontinuities of variable dimension in a direction perpendicular to the recording medium surface in correlation with the intensity of the writing beam, said optical modulator driver circuit comprising:

a wave shaping circuit, coupled to said modulator, for receiving a series of pulses of substantially rectangular waveform, provided as said modulator drive signal to modulate the writing beam, and produce a series of drive pulses coupled to said optical modulator;

pulse modifying means, coupled to said wave shaping circuit, altering said series of drive pulses to produce a modulator drive signal which forms surface discontinuities having a varying

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dimension in a direction perpendicular to the recording surface; and

a duty cycle servo coupled to said wave shaping circuit for maintaining a predetermined duty cycle of surface discontinuities along said track.

17. The dynamic optical modulator driver circuit as claimed in Claim 16, wherein:

said writing light beam source is a laser; and

said dynamic optical modulator driver circuit further comprises a laser power regulator for regulating the peak power of the laser in accordance with an input signal;

whereby information contained in said signal to said laser power regulator is recorded on said medium as variable dimensions of said surface discontinuities in a direction perpendicular to the recording medium surface.

18. The dynamic optical modulator driver circuit as claimed in Claim 17, wherein:

said surface discontinuities are pits; and

said information contained in said input signal to said laser power regulator is recorded on said medium as variable depth pits.

19. An optical modulator driver circuit for use in an optical recording apparatus which creates surface discontinuities along a track in a recording surface of a recordable medium, said circuit comprising:

means for receiving a series of pulses having varying widths correlated to a first information signal, and coupling said series of pulses to an optical modulator for creating said surface discontinuities having lengths along the track correlated with the pulse width of pulses in the series of pulses; and

means for modifying the pulse train coupled to said optical modulator in correlation with a second information signal in a manner to vary the dimension of said surface discontinuities in a direction perpendicular to the recording surface of the recordable medium.



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20. The optical modulator driver circuit as claimed in Claim 19, wherein said surface discontinuities are pits formed in the recording surface of a recordable medium, and said second information signal is recorded on the medium as pits of varying depths along the track.



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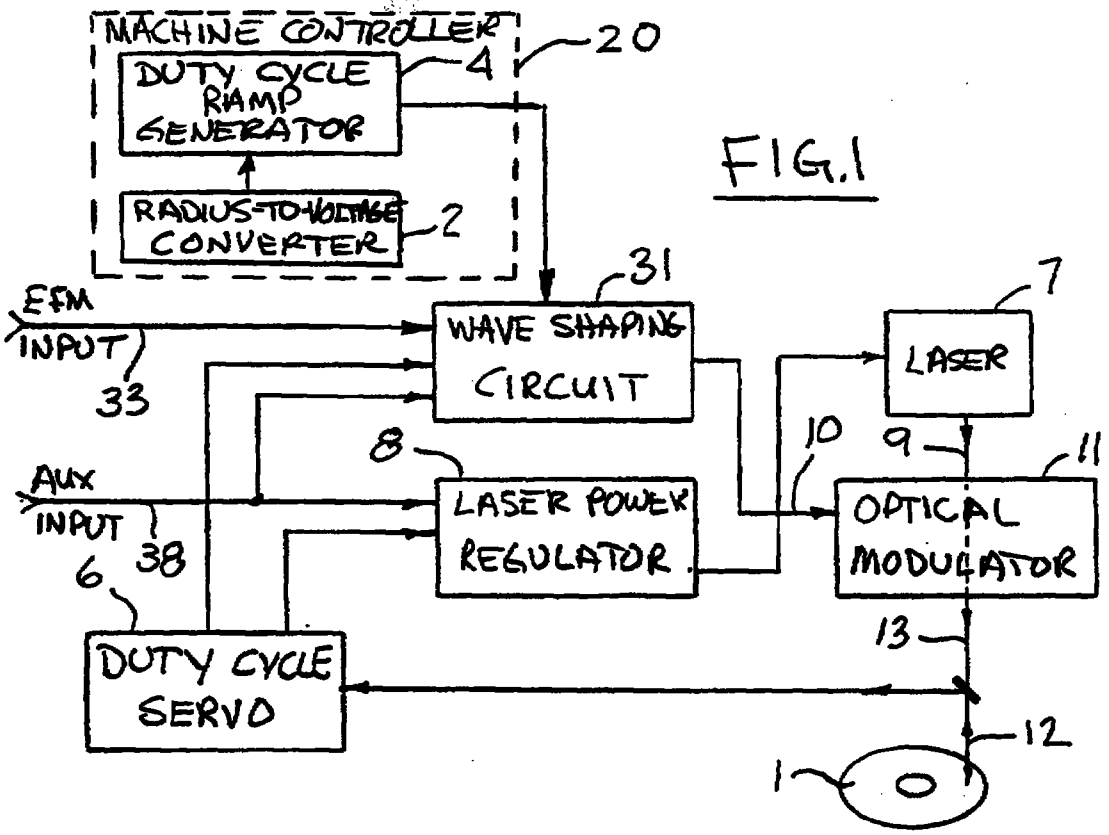


FIG.1

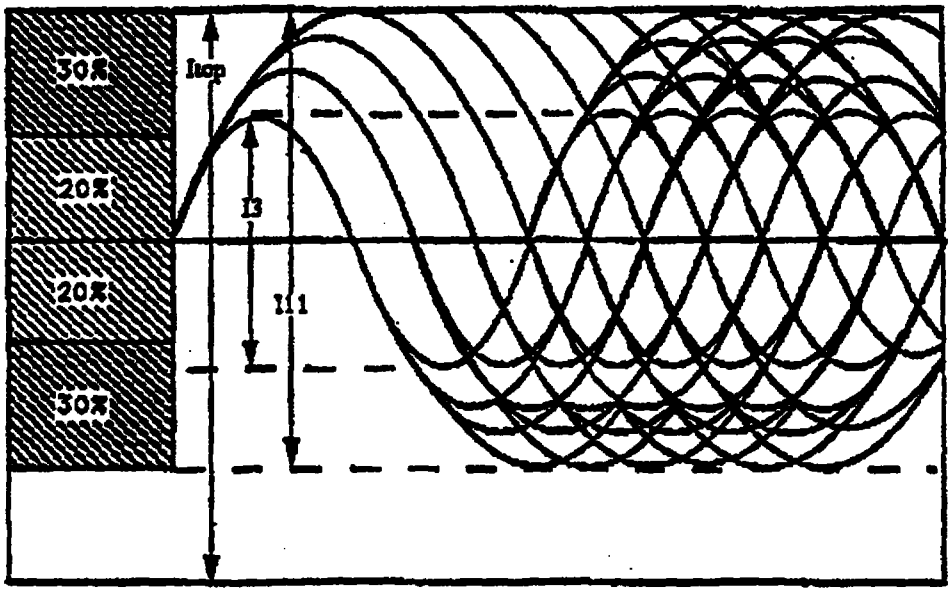


FIG. 2

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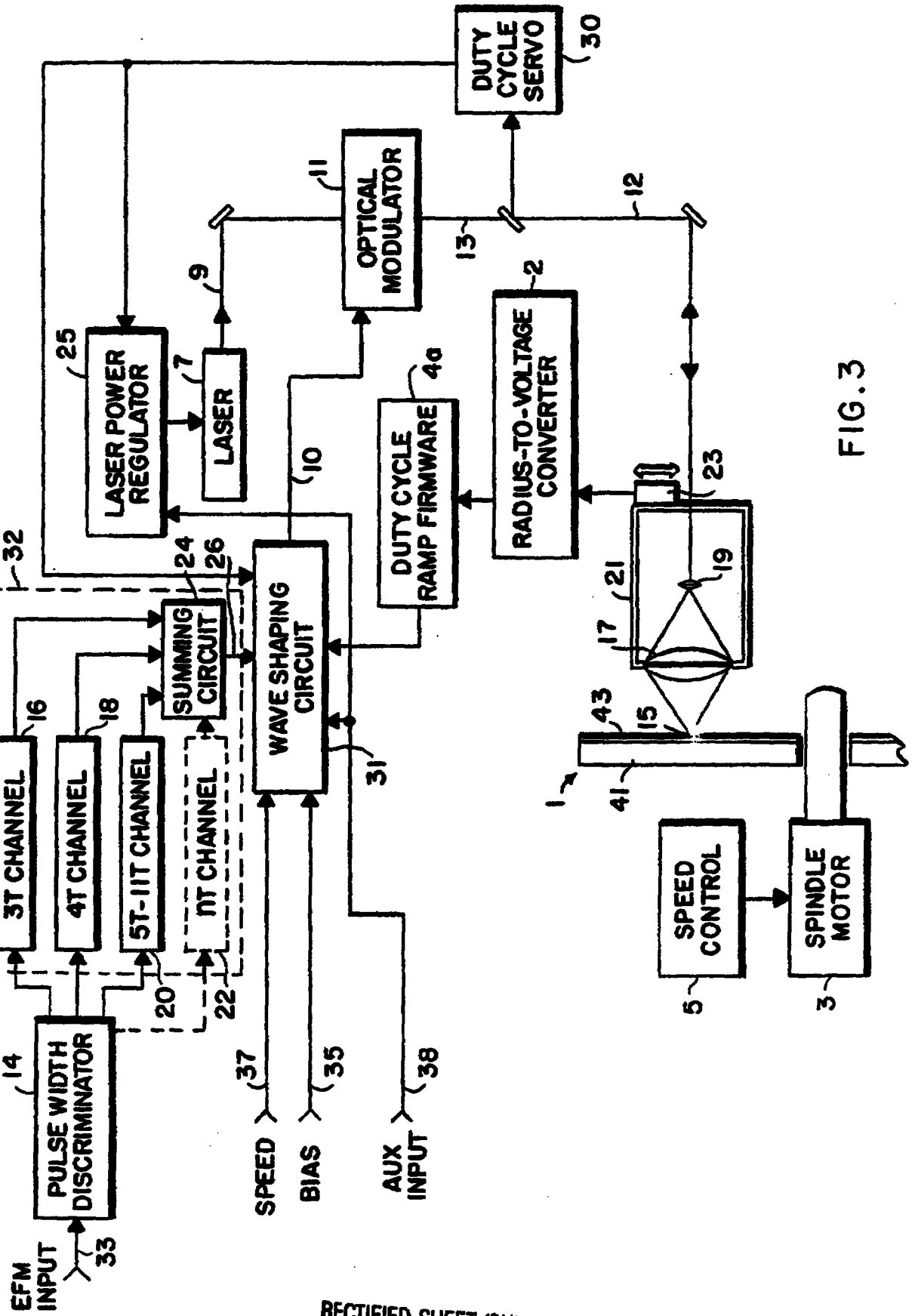
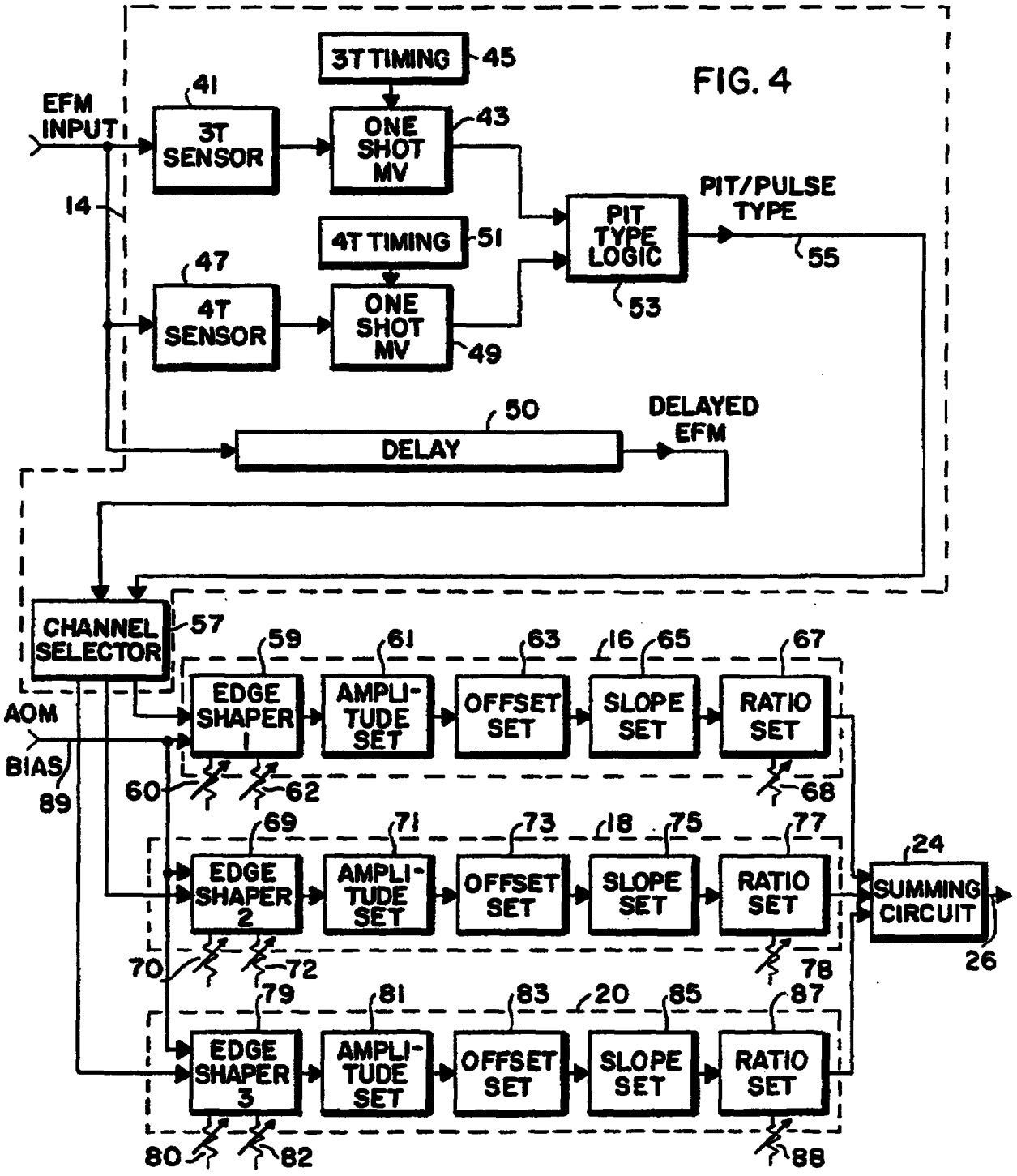


FIG. 3

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FIG. 4


3T TIMING
45
EFM INPUT
41
3T SENSOR
ONE SHOT MV
43
14
4T TIMING
51
PIT TYPE LOGIC
PIT/PULSE TYPE
55
53
47
4T SENSOR
ONE SHOT MV
49
50
DELAY
DELAYED EFM
CHANNEL SELECTOR
57
59
61
63
16
65
67
EDGE SHAPER 1
AMPLI-TUDE SET
OFFSET SET
SLOPE SET
RATIO SET
AOM
BIAS
89
60
62
68
69
71
73
18
75
77
24
EDGE SHAPER 2
AMPLI-TUDE SET
OFFSET SET
SLOPE SET
RATIO SET
SUMMING CIRCUIT
70
72
78
26
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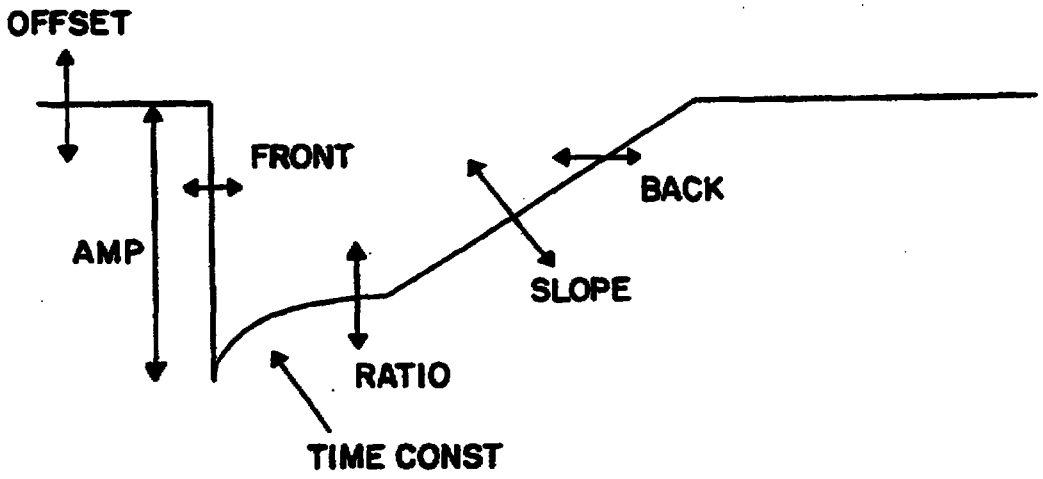


FIG.5

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IPEA/US 20 SEP 1996

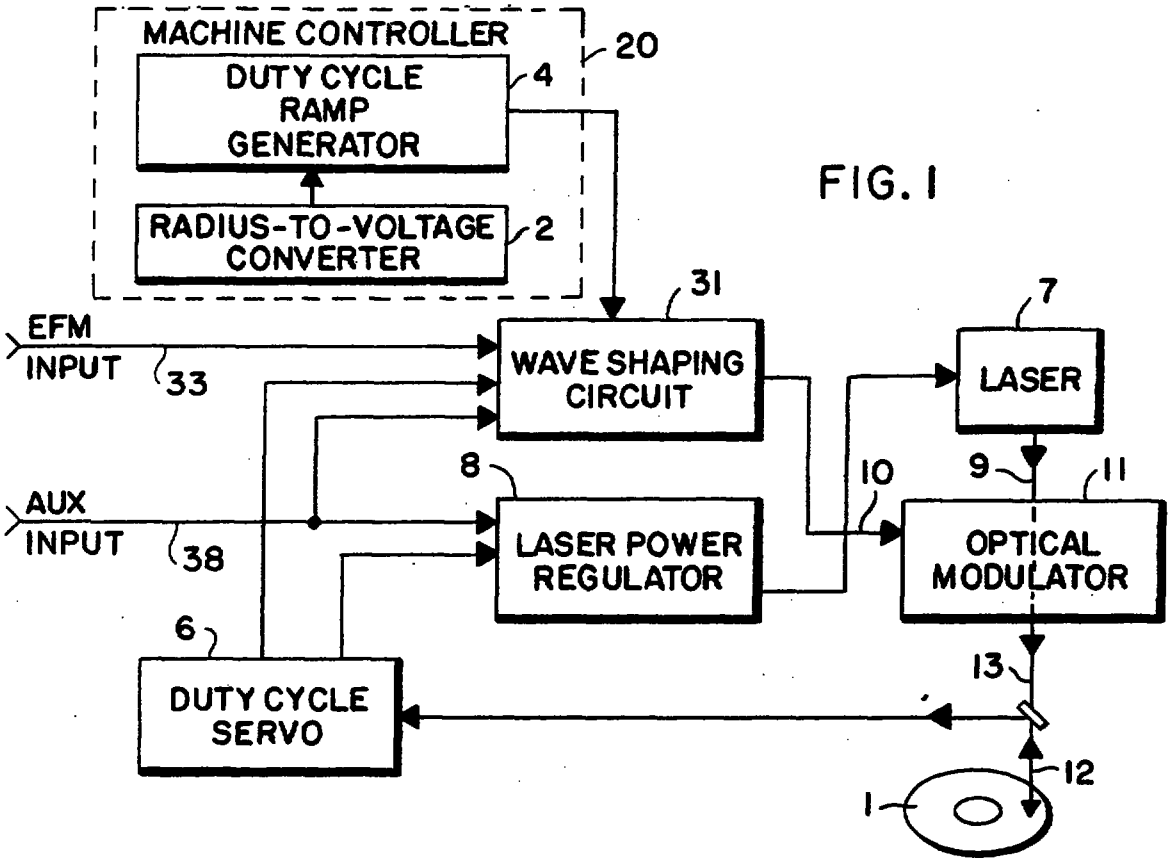


FIG. 1

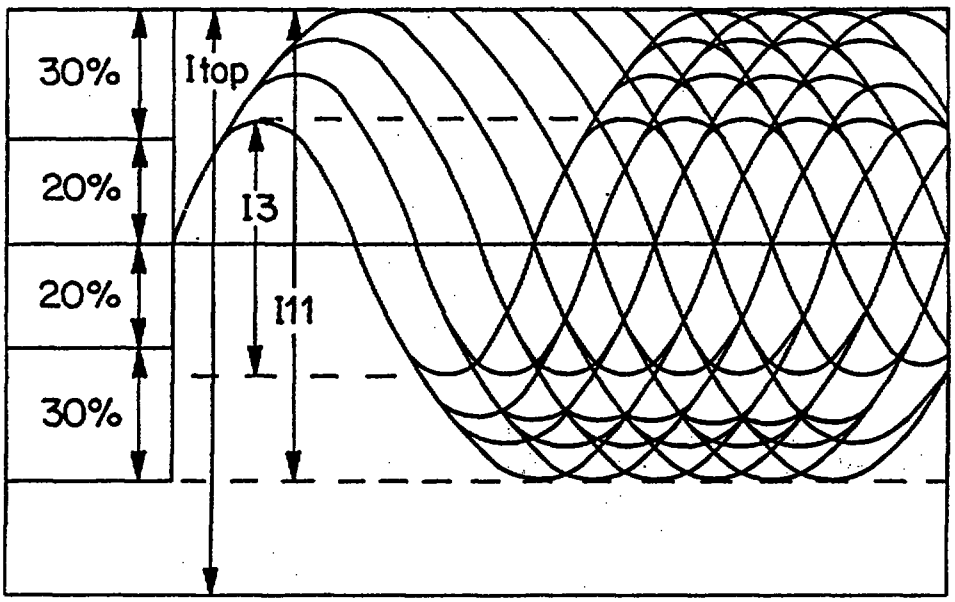


FIG. 2

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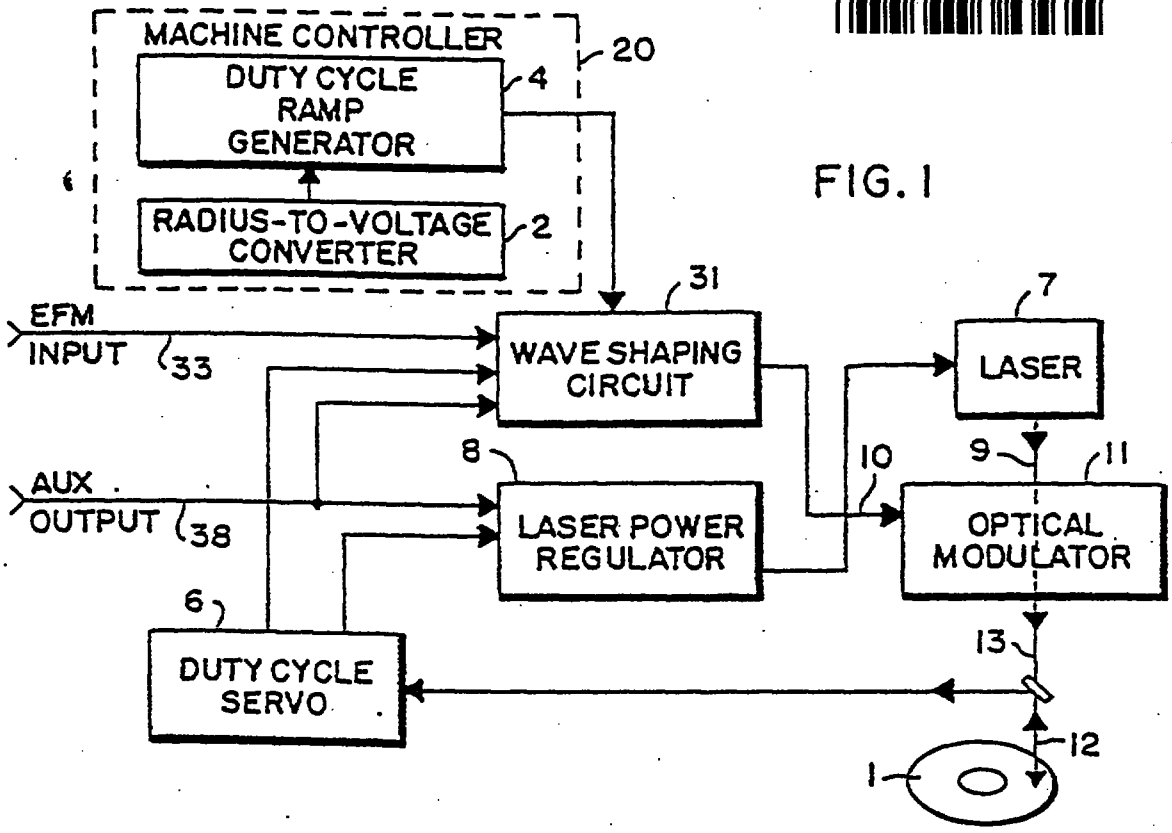


FIG. 1

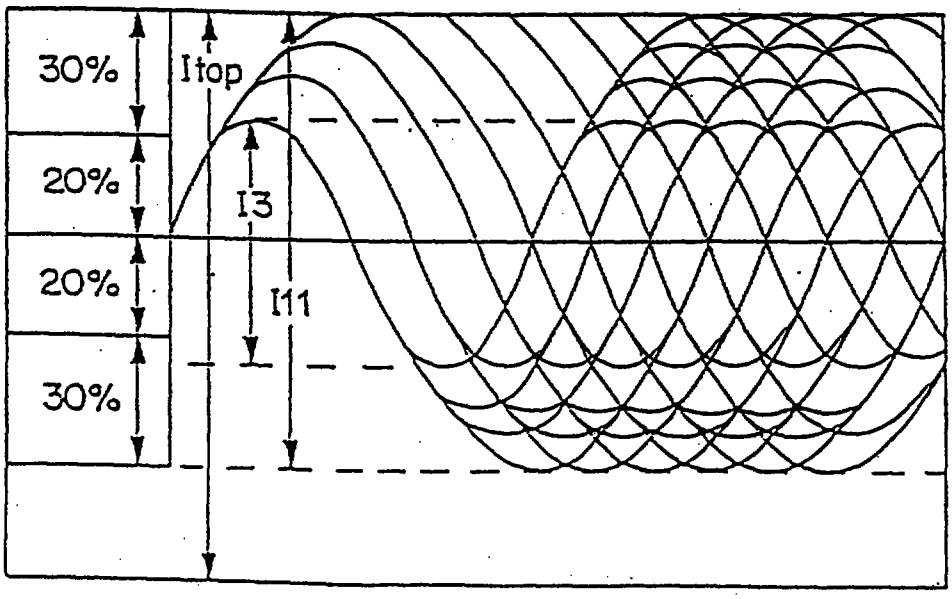


FIG. 2

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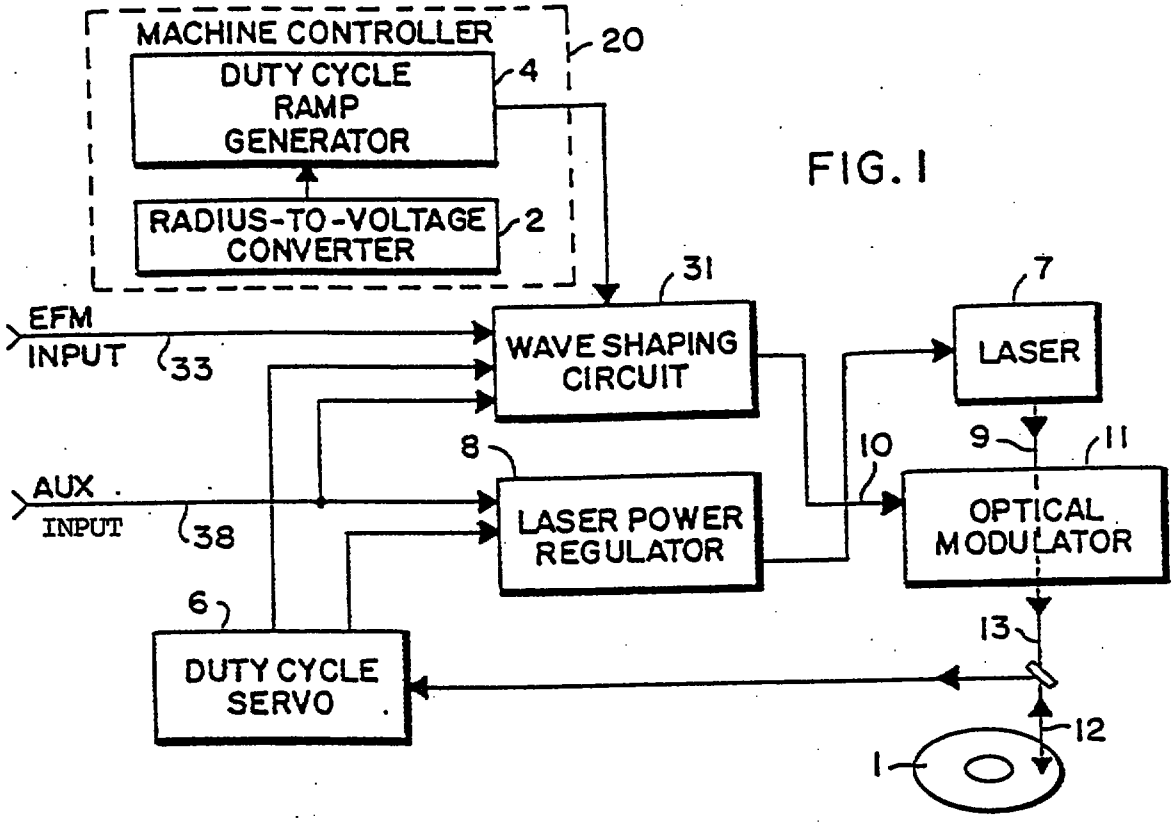


FIG. 1

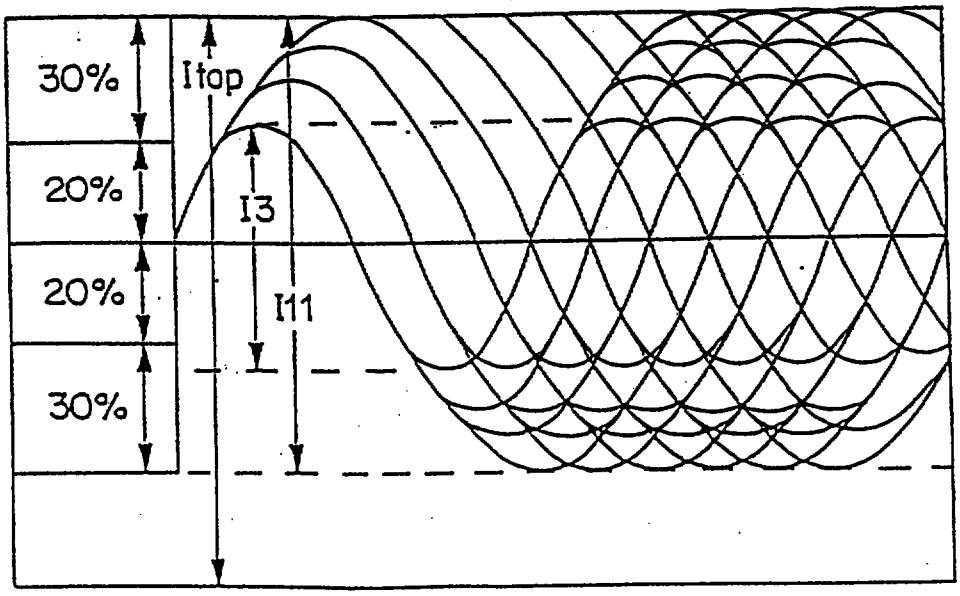


FIG. 2

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disc as it is being recorded, the write pulses can be observed to be the right length, duration, and wave shape, or not, and appropriate correction functions can be initiated on a pulse-by-pulse basis or on an averaging basis for each pulse/pit T-length. This insures that what will be played back on the disc will be as perfect as possible.

Regarding the radius ramp embodiment, the circuitry may have a programmable compensation in it so that, rather than having the master formed perfectly, the master may be formed purposely not perfect (has a built-in precompensation-for-molding function) so that the replicas can be perfect. This additional function must, however, be open loop, i.e., such a pre-molding offset function would have to be preset rather than having a servo loop perform the function to make the master perfect.

All aspects of the invention relate to looking at the data stream input to the mastering machine, and using the playback information of the disc to make the data stream have the character it should for best playback of replicas, whether a master disc produced by such a process is perfect or is precompensated for molding. In all cases, the invention can be used only with a DRAW mastering machine using a recording media that can be recorded with pits of different depths or bumps of different heights.

Previously described was an embodiment of the invention, whereby a channel of information, referred to herein and in Figures 1 and 3 as an auxiliary input 38, can be recorded as variations in the depth of pits or height of bumps on the recordable medium surface. For the ramp and pit-type functions described in detail supra, no external "auxiliary input" is required. However, in the embodiments where an additional channel of recorded information is desired, an auxiliary input 38 may be coupled as input to either the wave shaping circuit 31 or the laser power regulator 8, or both, for making the necessary pulse modifications to create variable pit depth (or bump height). If inputted to the wave shaping circuit 31, the

1. A dynamic waveform shaping circuit for use in optical recording apparatus which includes a writing beam source for recording information on a surface track of an optical recording medium, said circuit comprising means to generate a drive signal to modulate the intensity of the writing beam from said source above and below a threshold level of a recording medium, said beam being capable of forming a surface discontinuity in said track in the recording medium when the writing beam is above the write threshold of the medium and incapable of forming a surface discontinuity in said track when the writing beam is below the threshold, said waveform shaping circuit comprising:

a wave shaping circuit, for receiving a pulsed input signal and for producing said drive signal therefrom;

a duty cycle servo coupled to said wave shaping circuit for selectively maintaining a prescribed duty cycle of surface discontinuities along said track; and

wave shape modifying means, coupled to said wave shaping circuit, for selectively altering the effects of said duty cycle servo to cause said beam to form surface discontinuities having a selectively varying duty cycle along said track of surface discontinuities.

2. A circuit as claimed in Claim 1, wherein said wave shape modifying means comprises a ramp voltage generator which applies a ramped voltage input to said wave shaping circuit for altering said duty cycle between selective positions along said track of surface discontinuities.

3. A circuit according to Claim 2, wherein said wave shape modifying means comprises means for altering the physical character of individual surface discontinuities along said track of surface discontinuities dependent upon the pulse types corresponding to said individual surface discontinuities.

4. A circuit as claimed in Claim 2 or Claim 3, wherein said recording medium is a disc, and said selective positions correlate with corresponding selective radii of the disc.

5. A circuit as claimed in Claim 4, wherein:

said surface discontinuities are pits formed in said surface of said disc; and

said wave shape modifying means produces a ramp voltage which selectively alters the duty cycle of said pits along said track.

6. A circuit as claimed in any preceding claim, wherein said wave shaping circuit comprises a power regulator for varying the intensity of said writing beam, and wherein:

said duty cycle servo is coupled to said power regulator for altering the intensity of said

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beam in a manner to vary the duty cycle along said track of surface discontinuities oppositely from the variance of the duty cycle caused by said wave shape modifying means, thereby forming a closed loop servo function which allows the variation of duty cycle caused by said wave shape modifying means to be offset by the variation of the duty cycle caused by altering the intensity of the write beam.

7. A circuit as claimed in any preceding claim, wherein said wave shape modifying means produces a stepped voltage ramp.

8. A circuit according to Claim 1, wherein said wave shape modifying means comprises means for selectively altering the physical character of individual surface discontinuities along said track of surface discontinuities dependent upon the pulse types corresponding to said individual surface discontinuities.

9. A circuit as claimed in Claim 8, wherein said input signal comprises a series of rectangular pulse widths of nT duration, T being is a fixed period of time, and n being an integer of varying value.

10. A circuit as claimed in Claim 9, wherein said pulse widths range from 3T through IIT, T being a fixed period of time defined in the rules for the EFM code standard in the recording and reproduction of information discs commonly known as compact discs, and said altering means includes;

means for selectively detecting and altering only 3T pulse widths;
means for selectively detecting and altering only 4T pulse widths; and
means for selectively detecting and altering all 5T through 11T pulse widths.

11. A circuit as claimed in Claim 1, wherein said wave shape modifying means operates in response to a modification input signal, said wave shape modifying means causing information represented by said modification input signal to result in corresponding dimensional variation of said surface discontinuities.

12. A circuit as claimed in Claim 11, wherein;
said surface discontinuities are pits; and
information represented by said modification input signal is recorded on said medium as variable pit depths.

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* C L M S *

13. A circuit as claimed in Claim 11 or Claim 12, wherein said writing beam source is a laser.

14. A circuit as claimed in any of Claim 11- 13, wherein said recording medium is a disc, and further comprising radial position detection means providing an input to said wave shape modification means representative of the instantaneous radial position of said writing beam in respect to said disc, said wave shape modifying means operating in accordance with said input from said radial position detection means.

15. A circuit as claimed in any of Claims 1- 3, wherein said pulsed input signal to said wave shaping circuit comprises a first data stream and a second data stream, said writing beam selectively recording said first data stream and said second data stream as correspondingly varying dimensions of said surface discontinuities in a direction perpendicular to said recording medium surface.

16. A circuit as claimed in Claim 15, wherein said recording medium is a disc, and said selective positions correlate with corresponding selective radii of the disc.

17. A circuit as claimed in Claim 15 or Claim 16, wherein said surface discontinuities are pits formed as a track of pits on said recording surface of the recording medium, and said second data stream causes alteration of pit depths generated responsively to said first data stream.

18. A circuit as claimed in Claim 15 or Claim 16, wherein the operation of said wave shape modifying means is controlled, at least in part, by said second data stream.

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+ PF23 (AME

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International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G11B 7/00, 5/09, H04N 5/76 — A1

(11) International Publication Number: WO 96/27879

(43) International Publication Date: 12 September 1996 (12.09.96)

(21) International Application Number: PCT/US96/02931

(22) International Filing Date: 4 March 1996 (04.03.96)

(30) Priority Data:
400,671 — 8 March 1995 (08.03.95) — US
400,672 — 8 March 1995 (08.03.95) — US

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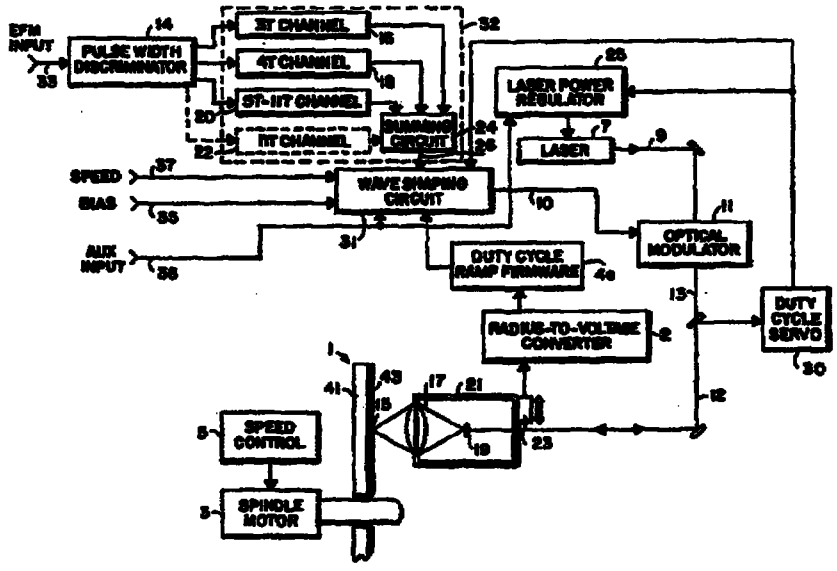
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(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: METHOD AND MEANS FOR CHANGING PIT DEPTH ON AN OPTICAL RECORDABLE MEDIUM



(57) Abstract

Method and apparatus for improving the characteristics of the surface effects on a replicated optical disc (1), the master for which is recorded on an optical recording apparatus which includes a writing light beam source (7) and an optical modulator (11) for modulating the intensity of the writing beam of light above and below a threshold level of a relatively moving recording medium response to a modulator drive signal (10) for recording information on the medium, the light beam being capable of forming a track of surface effects or indicia in the relatively moving master recording medium when the writing beam is above threshold and incapable of forming surface effects in the relatively moving recording medium when the writing beam is below threshold.