(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 September 2001 (13.09.2001)

PCT

(10) International Publication Number
WO 01/67450 A2

(51) International Patent Classification[7]: G11B 20/14, H03M 7/30, 5/14, G11B 20/10

(21) International Application Number: PCT/GB01/00961

(22) International Filing Date: 7 March 2001 (07.03.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0005332.2 7 March 2000 (07.03.2000) GB
0029432.2 2 December 2000 (02.12.2000) GB

(71) Applicant *(for all designated States except US)*: **KEELE HIGH DENSITY LIMITED** [GB/GB]; 31 Harley Street, London W1N 1DA (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **WILLIAMS, Edward, W.** [GB/GB]; Min-y-Nant, Llandyrnog, Denbigh, Denbighshire LL16 4HB (GB).

(74) Agent: **FOX-MALE, Nicholas, H.**; Eric Potter Clarkson, Park View House, 58 The Ropewalk, Nottingham NG1 5DD (GB).

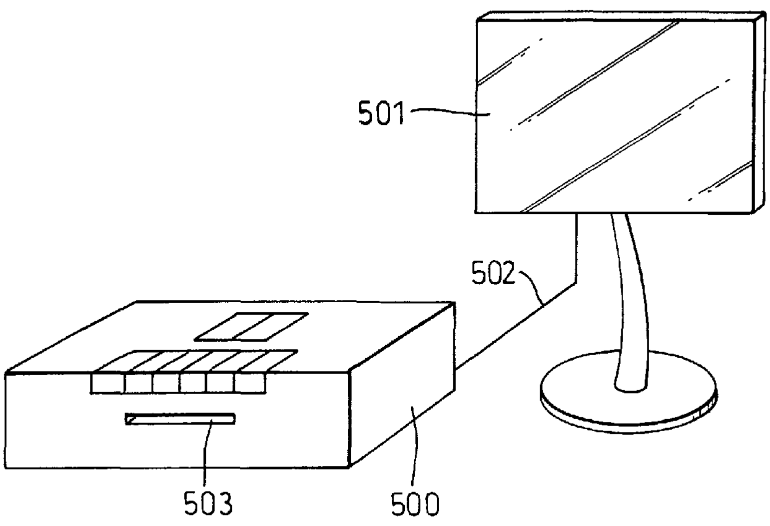
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: HIGH DENSITY STORAGE SYSTEMS



(57) Abstract: A laser readable storage system for recording and/or reading compressed data into a plurality of storage areas on a recording medium, comprising a magneto-optic medium having a silicon optical coating of about 160 Angstrom thickness on it, to form a plurality of storage areas, at least one being a magneto-optic memory.

WO 01/67450 A2

HIGH DENSITY STORAGE SYSTEMS

The present invention relates to high density storage systems and more particularly to optical laser readable memory systems for cards and other storage mediums.

A known system for recording information on cards is described in European Patent No. 0642687. In this system a visible bar code is used in conjunction with a laser readable memory to provide additional memory.

It is an object of the present invention to provide a card with the capability of storing either a very large or a smaller amount of information under controlled conditions, utilising the full capability of optical storage media on the card.

The present invention provides a system for the compression of digital data, the system comprising means to process digital data in a signal, the processor means comprising compression means, said compressions means comprising means to compare a bit word in the signal with a predecessor bit in the signal and means to record only the difference between said predecessor bit and said bit.

The present invention also provides a system for the compression of digital data, the system comprising means to process digital data in a signal, the processor means comprising compression means, said compression means comprising means to compare a bit word in the signal with a predecessor bit in the signal and means to record the predecessor bit and only the difference between said predecessor bit and said bit. Preferably, the system includes the features of any one or more of dependent Claims 3 to 17.

The present invention also provides a system for the compression of digital data, the system comprising means to process digital data in a signal, the processor means comprising compression means, said compression means comprising means to records a bit in the signal, means to compare the next bit in the signal with the recorded bit, means to record the difference between the two bits. The system may include the features of Claims 19 and/or 20

Also, the present invention includes apparatus for the compression of digital data, the apparatus comprising means to process digital data in a signal, the processor means comprising compression means comprising means to compare a bit in the signal with a predecessor bit in the signal, and means to record only the difference between said predecessor bit and said bit.

The present invention also provides apparatus for the compression of digital data, the apparatus comprising means to process digital data in a signal, the processor means comprising compression means comprising means to compare a bit in the signal with a predecessor bit in the signal, and means to record the predecessor bit and only the difference between said predecessor bit and said bit.

Preferably the apparatus also comprises the preferred features of the present invention as defined herein.

The present invention also provides apparatus for the processing of compressed data to return it to the original format.

The present invention also provides a method for the compression of digital data, the method comprising processing digital data signal, compressing data by comparing a bit in the signal with a predecessor bit in the signal, and recording only the difference between said predecessor bit and said bit.

The present invention also provides a method for the compression of digital data, the method comprising processing digital data signals, compressing data by comparing a bit in the signal with a predecessor bit in the signal, and recording the predecessor bit and only the difference between said predecessor bit and said bit.

The method can comprise any of the features of the present invention as defined in any of the claims herein.

The present invention also provides a method for the processing of compressed data to return it to the original format.

The present invention also provides a computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of the method of the present invention when said product is run on a computer.

The present invention also provides a computer program stored on a computer usable medium, comprisin: computer readable program for a computer to compare a bit in a signal with a predecessor bit in the signal; computer readable program means for causing the computer to record only the difference between said predecessor bit and said bit.

The present invention also provides recording apparatus for the recording of signals compressed using the technique of the present invention; likewise the present invention provides playback apparatus for the compressed signals, and re-formatting apparatus for restoring compressed signals to their original format.

Another aspect of the present invention provides a laser readable high density storage system for recording and/or reading data on a magneto-optic medium having a silicon optical coating layer. The system may include the features of any one or more of Claims 30 to 33.

According to this aspect, there is also provided a medium with a silicon optical coating as so defined, apparatus to effect processing, recording and/or reading signals and a method of processing said signals.

Another aspect of the present invention provides a system for recording and/or reading data comprising means for enhancing data bits of a signal, the system comprising two parallel surfaces with the separation remaining constant, or substantially so, over the whole length of the enhancing means and reflectivity of the reflection layer within 0.1%. The system may include the features of any one or more of Claims 35 to 46.

According to this aspect, there is also provided recording apparatus, reading apparatus, and/or a method of enhancing signals.

Another aspect of the present invention provides a reader for a storage system, the reader comprising at least one optical fibre guide means, a ball lens, magnetic and/or electomagnetic means to effect control of the optical fibre.

The reader may include the features of any one of Claims 42 to 47.

The present invention provides a laser readable high density storage system for recording and/or reading data on a magneto-optic recording medium having a silicon optical coating layer.

Preferably, the silicon layer has a thickness in the range of 150 to 170 Angstrom, advantageously of or about 160 Angstrom.

The present invention also providing laser readable high density storage system for recording and reading data into a plurality of storage areas on a recording medium at least one storage area being a magneto-optic medium, and at least one storage area being a silicon medium.

The present invention also provides a laser readable high density storage system for recoding and reading data into at least one storage area on a magneto-optic recording medium comprising means to encode data in "run-length-limited" format.

The present invention also provides:-

- recording apparatus for such a system.
- a reader for such a system.
- a method for recording and/or reading data for such a system, a method for operating for such recording apparatus, and/or a method for operating for such a reader.
- a medium for the system, for recording apparatus and for the reader.

Preferably, the medium used for recording is a magneto-optic medium but in alternatives it is a phase-change medium or it is a silicon semi-conductor material (e.g. a chip memory or EPROM); in one preferred form, the medium may comprise at least one magneto-optic memory portion and at least one silicon memory portion.

An advantage of the present system is that data can be stored on more than one layer of storage medium. This enables the amount of data to be stored in each area to be substantially increased.

Preferably the recording medium comprises a plastic card.

The present invention also provides a computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of a method embodying the present invention when said product is run on a computer.

The present invention also provides methods and apparatus for the compression of data in the manner described herein, especially but not solely in relation to hybrid magneto-optic silicon memory with an RLL code for data compression.

The present invention also provides methods and apparatus for the reverse operation of expansion of data in appropriate manner.

The present invention also provides methods and apparatus for the processing, operation, storage, transfer and/or communication of data compressed according to the present invention, and the reverse operation thereof.

The present invention also provides methods and equipment of operation in any appropriate manner and associated with such apparatus.

Particularly, the present invention provides such methods and apparatus associated with communication e.g. on the internet and/or digital communication, including use with LAN's and other networks.

The present invention may be used in association with, or as replacement of, existing data compression techniques including for example jpeg and mpeg formats and standards.

The present invention also provides serial and parallel processing and/or encryption of such methods and apparatus.

The present invention also provides an enhancer comprising two parallel surfaces with the separation remaining constant , or substantially so, over the whole length of the enhancer and reflectivity of the reflection layer within 0.1%. The enhancer comprises means to produce multiple reflections on the magneto-optic layer such that every time a reflection occurs on the magneto-optic layer the Kerr angle is enhanced.

Advantages of the present invention may be the provision of increased band-width capacity (e.g. up to eight times), speeding up of processing operations (e.g. in microprocessors) and increased memory capacity.

In order that the invention may more readily be understood, a description is now given, by way of example only, reference being made to the accompanying drawings in which :-

Figure 1 shows a domestic video playback unit embodying the present invention;

Figure 2 shows disc for use in the unit of Figure 1;

Figure 3 shows schematically the optical head of the unit of Figure 1;

Figure 4 shows the laser reading system of Figure 1;

Figure 5 shows a data-block for a second embodiment of the present invention;

Figure 6 diagrammatically shows a card incorporating an optical reading system according to the present invention;

Figure 7 shows a detail of the optical section of the card of Figure 6 incorporating a plurality of recording areas;

Figure 8 shows a detail of a single optical storage area of the arrangement of Figure 7;

Figure 9 shows a possible recording path in each recording;

Figure 10 illustrates a two level recording arrangement for the areas in Figures 6 to 9;

Figure 11 diagrammatically shows in cross-section an arrangement enabling two level recording;

Figure 12 illustrates a 3 dimensional recording system according to the present invention;

Figure 13 illustrates card movement for recording and reading;

Figure 14 illustrates the direction of laser movement for x,y recording in any path such as shown in Figure;

Figure 15 illustrates the operation of a laser reading and recording system for multilevel recording;

Figure 16 shows an arrangement of storage areas illustrating a second possible recording system;

Figure 17 shows diagrammatically the use of the storage system of the present invention on a laser disc illustrating a spiral recording path comprising a plurality of storage areas;

Figure 18 illustrates a staggered optical head system for possible use to store data on the disc system of Figure 12 or on a card;

Figure 19 shows a servo drive apparatus for use with the laser disc of Figure 17;

Figure 20 shows an alternative apparatus for card movement and reading but which apparatus can also be adapted for optical discs;

Figure 21 shows a recording unit and part of a storage card of a further embodiment of the present invention;

Figure 22 shows signals for storage in the system of Figure 21;

Figure 23 shows signals in a variant of Figure 21;

Figure 24A and 24B show a variant to Figure 21;

Figure 25 shows schematically the encoding of a signal in a further embodiment of the present invention;

Figure 26 is code table as such in the system of Figure 25;

Figure 27 to 29 show further operations of the system of Figure 24;

Figures 30 and 31 show characteristic curves of two thin film materials for comparison;

Figure 32 is a code table; and

Figure 33 shows an enhancer.

Figure 1 show a domestic video playback unit 500 electrically connected to the thin-film display monitor 501 by wiring 502, unit 500 having an entry port 503 for a data-block disc 504 of $1.2x10^{-2}$ metres diameter and thickness $1.2x10^{-3}$ metres.

Disc 504 has a polycarbonate substrate, one side 505 of which (See Figure 2) has a silicon protective layer 510, three magneto-optic layers 511, 512, 513, prepared by sputtering or metal-organic vapour deposition, for example 3 to 20 double layers of ZnOCo multilayers or TbFeCo triple layers containing a total of up to 360 Gigabits of compressed data for processing and display on monitor 501. The other side 506 of disc 504 has data in the standard CD-R and/or DVD-R format enabling additional display or operation of particular features of unit 500, for example a family holiday video.

In a variant, disc 504 has a "write-once only" magneto-optic layer on one side, and an "erasable only" magneto-optic layer on the other side of disc 504.

In either form, disc 504 has tracking wells of 0.1 micron in width and concentric with a pitch of 0.2 micron. Unit 500 incorporates a violet laser enabling 15 Gigabit storage which, with compression of 8 times using the techniques as described hereinafter, provides 120 Gigabit storage per layer with three layers being possible.

1 to 3 mW of laser power are used to read the magnetised '1' or '-1' magentised in the magneto-optic domain and 10mW is needed to write a '1' or '-1'.

For the reading of compressed data on disc 504, unit 500 includes an optical head 507, a laser 508, and detector 509 (see Figure 3). Optical head 507 has:

- melted ball lens on the 'send' and 'receive' pair of fibres;
- magnetic coating to couple with the x,y electromagnet drives;
- lubricant to suppress vibration at the silicon surface.

A 3D memory using magneto-optic sputtered films and an amorphous silicon layer, 20 times signal enhancer is deposited on top of the third magneto-optic film. The mirror is deposited first and this further enhances the signal further by multiple reflections between the mirror and any of the magneto-optic surfaces. The fibre head moves but the media keeps still.

Optical head 507 reads each of the three magneto-optical layers simultaneously and has an adaptive optical element that is based on liquid crystals. Axial foci are separated by a spacing of 55μm - equivalent to the distance between the layers. This distance can be varied automatically. Dielectric gratings with high aspect ratios are used to separate the reflected light into TE and TM polarized light, which corresponds to each of the layers.

About 85% of the light from the laser passes through a beam-splitter unaffected and it is focused on the layers by the liquid-crystal lenses and the objective lens. Around 10% of the reflected light is diffracted by the beamsplitter and directed to the polarizing beam-splitter.

The adaptive optical element consists of a convex liquid-crystal (CLC) lens and an adaptive liquid-crystal (ADLC) lens, both of which use nematic liquid crystals.

The ADLC lens is made from two parallel glass plates, one of which has a circular electrode structure that consists of 64 rings.

These rings can be switched individually which results in a change in the refractive index in the area between the electrode plate and the second glass plate. The ADLC lens switches faster than the CLC lens.

Figure 4 shows the laser system of unit 500.

Unit 500 contains silicon circuits, (2,7) code table for RLL encoding and RLL decoding; 16 bit shift registers for synchronisation and signal subtraction and decoding; delay lines to synchronise two neighbouring words; laser power control for the READ, ERASE, WRITE; laser temperature controller for 3D wavelength modulation; detector power control and output signal noise control.

(2,7) RLL coding gives a 5 times compression, and (1,3) gives 8 times compression. The variable word length means that RLL coding of the (1,3) and (2,7) life type occupies less space than the 16 bit data stream words.

M1 is the first RLL word and is stored in the silicon memory first. If serial processing is used, only one silicon memory is required as each word is processed in succession.. An area x-y memory can be used for parallel processing, and this speeds up the process by, e.g. 16 times if 16 words are processed at once using a 4x4 memory store array. The increase in processing speed is proportional to the number of memories. An x-y area memory is cheaper than using memories sequentially. The choice of silicon memory depends on cost in most cases since the speed of processing is generally very fast.

The compression operation involves a daisy-chain formation by comparing each RLL word with its predecessor, and reading and storing only the difference. Typically, there are 8 to 64 or more words in the daisy-chain. For example, there may be alignment of the words from the (2,7) RLL code by using the '1's which gives clock synchronisation. Variable small lengths and subtraction gives compression. An error correction scrambling code can be used for encryption for the silicon memory and for error correction of major errors in the magneto-optic memory.

Minor errors are less than a daisy-chain length and are automatically corrected as the silicon memory is transferred to the magneto-optic memory. There is at least one storage area on the silicon single crystal surface and one on the magneto-optic layer deposited on the silicon.

There is shown in Figure 5 a card 600 comprising a polycarbonate substrate of dimensions $8x10^{-2}$ meters by $5.3x10^{-2}$ metres (approximately credit card size) and of $1.2x10^{-3}$ metres thickness capable of storing up to 1.8 TeraBytes of compressed data using the compression technique of the present invention.

The card 600 comprises a silicon chip 601 and interfaces 602 in a protection casing and three zones 603, 604, 605; each zone is of size $1x10^{-2}$ metre square, having a magneto-optic layer and backing mirror, for the storage of personal data. Zone 603 is for the storage of medical data, zone 604 is for the storage of general data, and zone 605 is for the storage of financial data.

Card 600 is inserted in reader unit to read out data in the respective zones as required. The data can be displayed once the card is placed in the unit, or it can be accessed only after a predetermined numerical code is input to the unit.

In an alternative form, card 600 comprises one silicon chip and five zones each of $2x10^{-2}$ metres square, containing about up to about 10 TB of data stored, all relating to instruction manuals, working examples references, tutorials and background reading for one year of a University Undergraduate course.

Code software relies on:

A. Reduction in error correction due to the daisy-chain word blocks, their scrambling and the variable delays introduced by the delay lines.

B. Three voltage level code to signify a '1' and a '0' and a space.

C. Elimination of extra bits between the words for synchronisation by alignment of the '1's in the shift registers for each RLL word.

An example of the encoding process is:

(a) 16 bit input data word first;

(b) 16 bit input data word second;

(c) convert to (2,7) words from the (2,7) code table to give M1 and M2 where, for example, M1=0100 and M2 is 1000. M1 is the reference origin and never changes from 0100 in this example;

(d) (2,7) code words in volts +1volt='1', -1 volt = '0' dash - = space;

(e) voltage threshold detector set to +0.8 volts to detect the '1's;

(f) delay lines set to give synchronization of the '1's in M1, M2 etc;

(g) 32 bit shift registers;

(h) M1, M1 - M2 that is 0100, 0---0 stored in the silicon RAM memory;

(i) 0100, 0---0 etc stored in the MO memory.

Note that an electromagnet must be to ensure three voltage level coding can be carried out.

Two other important factors are that (2,7) code words are of variable length and also much smaller than the 32 bits of the data stream code that they replace. Because they are shorter in length, they can be recorded very quickly into the magneto-optic memory.

Error correction with cross-interleave Reed-Solomon error correction code (CIRC) is used for CD and other optical memory discs and copes with both random and burst errors. (Fingerprints, dust and scratches cause burst errors). CIRC encoding would be initially in the card 600. The signal is scrambled and some of the (2,7) words are delayed. This scrambling and delay is cancelled out when the symbol is decoded. This CIRC error correction takes up 10% of the memory in conventional CD and DVD recording.

The daisy-chain used in the card 600 reduces the error correction, since the number of words in the daisy-chain is known and scrambling of the daisy-chain words will not be required for applications in which card 600 are protected from human handling.

In the case of card 600, protection from human fingerprints is essential for the highest TeraByte memory applications such as those listed above.

With reference now to Figures 6 to 10, the present invention is described with reference to a rectangular shaped card. However, the card could be of any shape and the storage (recording and reading) areas could be on substrates other than a card. They could, for example, be on a label for attachment to a product.

In Figure 6 the card 10 comprises a general area 12 which may have visible information thereon. A visible bar code 14 is positioned in one corner but could be positioned anywhere on the card.

An area 16 incorporates a laser readable storage section which will now be described in greater detail.

In the area 16 smaller storage areas 160,162,164 etc are provided.

As shown in Figure 8 each area 160 etc is provided with a code section 1600. The code section 1600 is used to control the manner in which the data is stored within each area 160 etc.

A simple preferred form of data storage is shown in Figure 9. In Figure 9 data 170 is stored horizontally in rows 172,174 etc.

While Figure 9 indicates scanning in one direction, of course, in another implementation scanning occurs in the opposite direction to that shown.

Dependent on the length of code 1600, the data in the area 160 can be recorded in a relatively simple manner, as indicated in Figure 9, or can be recorded in a more complex manner. Alternatively, the coded information in 1600 can be used to determine the size of the area used to record each bit of data. By such control the amount of data recordable on each card is also controllable. The code can therefore be used to indicate characteristics of the recorded data including whether a card or a portion of a card in a defined sub area 160 can be altered and if so in what manner.

With reference now to Figure 10, in the present invention, in a preferred embodiment, it is possible to record data on two or more levels, two being illustrated in Figure 10.

A first data level 163 (z=1 in Figure 11) is shown in Figure 6 to 9 and a second level 161 (z=0 in Figure 6) is situated below the first level 163.

As shown in Figure 11, the card comprises a laminated structure with a top layer 80 (from the laser reading direction 82) and then the memory layers 163,161 are sandwiched by two dielectric layers 84,86.

As can be seen in Figure 15, the recording of data on the two layers 163,161 is interposed such that the data bits may be recorded by the same laser with appropriate focus.

However, using the two levels of Figures 10 and 11 the coded section 1600 can also direct the laser to record, and to therefore read, in x,y and z directions as shown in Figure 12.

Once data has been recorded in a specific pattern, as dictated by the code 1600, further data can be recorded using the same pattern or using a different pattern as dictated by the amount of space left on the area 160,162 etc.

The code recorded in area 1600 is therefore read by the laser prior to reading the data in the main areas 160 etc. and the data is therefore readable by recording the coded instructions in a control 131 memory for the laser.

With reference now to Figures 13 to 16, a typical card is shown schematically. The card 10 comprises, in addition to features 12, 14 and 16, a signature section 13 and a holograph section 15 for visual identification.

The card 10 is inserted into a card reader and slides in a direction X under control of a servo controlled roller mechanism (not shown) in known manner.

Once in the reader, the laser recording/reading point can be moved in the X direction by known means under the control of a known mechanism such as the mirror lens mechanism 142,141 shown in Figure 15.

As shown in Figure 15, the laser depth can be adjusted to record on a lower layer (see Figure 11).

In the present invention it is possible to include a large number of sub areas 160 etc in a 1 cm square area 16. Up to 108 (100,000,000) such sub areas can be provided in each area 16 and in each sub area up to 300 characters can be stored. With a blue laser, and memory recorded on both card sides, up to 9.1

TB of data can be stored in the area 16, this being made possible because the bar code 1600 indicates the manner in which the data is recorded in each sub area 160,162 etc.

In addition to providing data on the manner in which the data is recorded in each sub area, the bar code can be used to dictate the spacing between recorded data bits. Thus, if it is required to record less information on a certain area then the spacing between dots can be dictated by the bar code to ensure that the required amount of data is recorded. Thus, for example, if each dot 90,91 has a spot site of 1 micron, then the width W between dots can be 1,2 or 3 microns etc to thereby limit the amount of storage on each area 16 or sub area 160,162 etc.

By providing a characterising bar code 14, the use of each card 10 can be dictated to either store large or small amounts of data. As may be understood, the balance between (i) a card or other storage medium which will store large amounts of information but which will require a sophisticated reader and (ii) a card or other storage medium which will record a small amount of information but may be read by a simpler reader is a matter for a commercial decision. The present invention enables a card which will require small or large amounts of data to be recorded. Thus, the bar codes 14,1600 can be used to control the data density and then the characteristic storage map in each area, thereby providing an extremely versatile system.

Preferably, as shown in Figure 10 and as described hereinbefore, the memory comprises two layers z=0 and z=1. The bar code 1600 can be used to dictate storage of data in the first or second layer in each sub area. The bar code 1600 can also be used to dictate storage of the first part of a sequence of data in a first layer and then storage of the second part of a sequence data in the second layer, thereby increasing the storage capacity of each sub area by ensuring complete use of all available data space.

In addition, by storing more secure data in the lower layer 163 and less secure data in the upper layer 161, the data which requires the greater security can be provided with a higher degree of physical protection.

The bar code 1600 which can typically be up to 36 characters can therefore dictate a complex path through each sub area, thereby enabling more data to be recorded in each sub area than would be possible with the use of the normal raster scanning system. Additionally, by the use of a plurality of layers and by the use of the bar code 1600 to dictate transfer between layers, the amount of data which can be stored in a given area is very substantially increased.

In a further embodiment, two lasers are utilised such that the second laser stores data in between the dots of data recorded by the first laser. For example, with present laser designs the spot sizes for an infra red laser is 1 micron, for a red laser it is 0.23 micron and for a blue laser 0.12 micron.

By use of bar code 1600 the red laser can be made to read data only in certain readers. Therefore hidden data can be included on a medium to be readable only by certain readers, for example by those companies issuing the cards.

This feature can be used in combination with multiple layer recording to enable secure data to be recorded on any medium.

With reference now to Figure 17, the inventive principle can be applied to a laser disc by recording (and reading) data into a plurality of storage areas 1700 on a disc 17. The storage areas 1700 will, as for areas 160 (Figure 8) each contain a bar code providing control information relating to the data stored within each area 1700. As shown in Figure 17, the storage areas 1700 are preferably arranged in a spiral for reading by a single optical reading/writing head.

Because the amount of data stored in each area 1700 an optical disc can store an enormous amount of data dependent on its diameter.

To assist in reading/writing the data into the areas 1700 a staggered array of optical heads 1800,1802 etc shown schematically in Figure 18 may be provided. As explained with reference to Figure 20, these heads may only be lenses.

Each head 1800,1802 etc may record/read data within a series of storage areas 1700 on a predetermined track 1804,1806 etc. If sufficient heads 1800,1802 etc are provided then data can be recorded in a series of concentric circles rather than in a spiral. For example, 20 heads 1800,1803 etc could be provided to form a staggered array and the head array could be moved slowly in the Y direction thereby providing storage in a multiple plurality of tracks. Previously described in track storage multiple depth storage etc can be used in this system to substantially increase the storage capacity.

With reference now to Figure 19, apparatus for use in recording and reading data onto the disc 17 as shown in Figure 17 is shown. The apparatus comprises a reader 190 which may include multiple heads. The output 192 of the reader 19 comprises data information in relation to the data being read by each head. Multiplexing techniques may be used for the multiple heads.

The output information 192 will also contain information read from the bar code 1600 (see Figure 3) relating to the storage area 1700 etc. This control data is fed together with the information data to a decoder 194, the output of which comprises a data output 196 and a control output 198. The control output 198 is used to control the position of both the disc and/or the optical heads by means of a controller 197 which has control outputs 195,193 respectively to control the speed of revolution of disc 17 via drive 191. The disc 17 may be driven extremely slowly, possibly at only 1 rpm because the laser 190 can capture all data within a storage area 1700 etc by raster scanning over the area of the box 1700 before moving to the next box area 1702.

The drive can be servo controlled due to the feedback loop established by the laser read output.

In Figure 20 an alternative structure to mounting each laser 202,204 on top of a gantry structure for movement over a card or disc is shown. In this alternative structure a single laser or a plurality of lasers 202,204 are mounted in a fixed relationship relative to the reader 20 illustrated very diagrammatically by a dotted outline. Each laser 202,204 has an associated electronic circuitry 2022, 2042 which provides drive power for writing and also electronic processing for reading. All these are stationary.

Each laser has a focusing unit 2024,2044 shown here as a simple lens. The focused light is fed to a respective optical fibre cable 2026,2046 and then to a respective lens arrangement 2028,2048 on an overhead gantry arrangement 2030.

By way of example, gantry 2030 may move in the Y direction and the card 10 may move in the X direction to provide complete coverage. If a disc 17 is to be recorded/read, the gantry 230 may be above the disc which, as shown in

Figure 19, may rotate slowly to provide the required additional dimensional movement.

The advantages of this arrangement are firstly that the laser and electronics do not have to be mounted to be movable and secondly that because the lens arrangements 2028,2048 can be extremely small a close stacked arrangement such as shown in Figure 18 can readily be assembled.

In addition, a fibre optic head can be used to write and read very small spots (see below).

As shown in Figure 21, a sequence (hereafter referred to as SX) of a plurality of word bits in the standard (2,7) optical code are input to recorder unit 3000. In addition to (2,7), any of the codes (0,2), (0,3), (1,3), (1,7) and (3,7) can be used. The first word of sequence SX is converted by clock generator 3001 into a clock pulse signal which comprises: a "O" bit, then a "-1" bit, then the optical code bits (which in the example of Figure 22 is "000010000"). This clock pulse (hereafter referred to as CP) is passed to a memory 3002 in recorder 3000.

The next word in SX is passed to comparator unit 3003 in which it is compared with CP to form, at signal generator 3004, a signal M1 having (see Figure 22 a first portion identifying that it relates to Mode 1 and a second portion indicating differences in the position of any "1"s as comprised with CP. This resultant signal M1 is stored separately in memory 3002. The next word in sequence SX passes to comparator unit 3003 in which it is compared with CP to form a signal M2 having a first portion identifying that it relates to Mode 2 and a second portion indicating any differences from CP. The resultant signal M2 is stored separately in memory 3001.

This is repeated twice more to produce signals M3 and M4, each compared to CP. In a variant, each of signals M1 to M4 is compared to its previous signal rather than to CP.

Then CP and M1 to M4 are the output from memory 3001 and are added together in a combiner unit 3005 and then passed to a recorder head 3006 so that the composite signal CS operates laser 3007 which records it on the medium 3008 being part of a card 3009.

The procedure is repeated to record another appropriate composite signal CS (derived from SX) on the next portion of recording medium 3008.

To read the recorded data, the operation is repeated in reverse order, each such portion of the recording medium is taken in turn, the composite signal CX is read from that portion, is separated into its constituent parts and formatted with the (2,7) optical form.

In a variant, clock generator 3001 (or data for it) is located on card 3009 (or the corresponding recording medium) for example in place of (or as part or all or) one of the storage areas, advantageously on the first area to be read by the laser of the reading unit.

Data for clock generation can be included in, and/or as part of, the barcode for one or more of the areas.

In the system described with reference to Figures 21 and 22, signal SX is processed word by word. In a variant, signal SX is processed in strings, of which each contains a plurality of words, whereby each string comprises, for example, up to 14 bits in (2,7) optical code; in this way, each area can be used more efficiently.

Figure 24A shows a data storage unit in which there is recording of one sector at a time. Figure 24B shows a reading unit, M_0, M_1, M_2 etc having an ID code using the laser. The photodetector signal is RF (radio frequency) and identical to laser power mentioned hereinabove.

A system embodying the present invention may provide very high density recording and fast reading of data. Based on the red laser spot size of 0.23 micron and the spacing tracks of 0.6 micron, conventional techniques may achieve data storage of 0.23 GB per cm2; however by using the five modes of the multi-mode recording technique of the Figures 20 and 22 embodiments, and by using the three layers of the recording medium, the present invention may achieve up to 3.45 GB per cm2 data storage. Thus, a card with 40 cm2 of storage area (typically the size of a "credit card") can hold 138 GB of data and, with separate tracking between layers and a blue laser, 828 GB.

In a particularly advantageous embodiment, the system utilises fibre-optic tip recording with a 0.1 micron resolution on a data storage card made of polycarbonate media incorporating the silicon part. A blue laser is used with 0.1 micron spot size and a track spacing of 0.2 microns. A special optical coating (typically 150 to 170 Angstrom thick, advantageously 160 Angstrom), over the magneto-optic media is used on the card that enhances signal resolution by as much as 40 times - this allows at least three layers within the card to be addressed without significant practical signal degradation. The optical coating considerably enhances the rotational polarising effect and therefore signal/noise ratio.

In each 1 cm^2 section of the data card, there are 265 million addressable dots of 0.1 micron size, giving a basic capacity of 0.625 GB. This capacity can be enhanced by the following techniques:-

1. Spot-edge recording increasing capacity by a factor of 2 (to 1.25GB).
2. The use of three layers within the card are used, (1.25 x3 = 3.75GB/cm^2)
3. Both sides of the media are used (3.75 x 2 = 7.5GB/ cm^2)
4. Blue laser used, doubling the capacity 7.5 x 2 = 15GB/ cm^2)
5. The use of (1, 3) code enables average message length to be reduced from 32 bits to 4 bits. This increases capacity by 8 times.
6. The card has a hybrid memory with separate silicon and magneto-optical regions.
7. The location of each start message is recorded in a bar area in each segment.

The above techniques require no additional timing pulses to be recorded, as all messages are recorded sequentially with the start point for each being recorded in magneto-optic bar code in each sector. To ensure a perfect square wave in the right position, it is necessary to carry out wave-shaping of the detector signal output.

Tests have shown that, with the silicon coating, it is possible to write/read through 20 layers, although with some progressive degradation. At maximum practical usage, it is calculated that the equivalent capacity of at least six full layers can be accessed in this way (i.e. doubling the capacities calculated hereinabove).

The card has a region of silicon to provide a 1 MB silicon memory used to temporarily hold messages in (1,3) code or (2,7) code, and to identify those parts of the next (1,3) code that is the same as the fixed standard 1,3 code and/or the previous messages. When the data in the silicon memory is converted and downloaded to magneto-optic media, any parts that remain unchanged will be left as a neutral charge on the magneto-optic media. There is therefore no increase in the capacity because of the comparison of one message with the next (because use of spaces where a 0 or 1 would otherwise have been) but there is an increase in the speed because the laser does not write to "0" or "1". Reading a message is the exact reverse of writing it.

The location of each message recorded in a bar code area is each segment - this takes up minimal space. If a fixed standard (1,3) code in used, then reading starts at the beginning of any (1,3) word in the message. If the previous word is being used as the reference base, then each reading starts at the beginning of each section that was originally held in the silicon memory because it has to read a complete "word" first, before being able to work-out the spaces.

Code types can be mixed; for example, (1,3) codes can be mixed with (2,7) codes.

This system produces an extremely high memory capacity by combining a number of features such that a data store of credit-card size has a memory capacity of 4800GB, no error correction required.

The major memory capacity increases are obtained by using (1,3) or (2,7) codes to achieve the considerable compression level of 8 times, plus the ability to use three or more layers because of the optical coatings employed. These two factors alone increase memory capacity by up to 48 times (equivalent to 6 layers) over that achievable otherwise. Combined with the use of other technology (blue lasers, fibre-optic tips) the overall memory capacity is a high as 9.6TB using six layers.

Figure 25 shows the encoding of the signal. A 16-bit digital signal data string is scrambled in unit 30 using a CIRC error correction code (CIRC being the "cross-Interleaved Reed - Solomon error correction code). The scrambled signal is then multiplexed (in MUX unit 31) with RLL (2,7) code (RLL means run length limited and 2,7 means that there are a minimum of 2 and a maximum of 7 zeros after the 1). In this case, only a single 1 is used in the code word. The (2,7) code table is shown in Figure 26. The "100" part of the code word is called the core since it is unchanged for every one of the 20 words shown.

The clock memory unit 32 initially stores all the (2,7) signal word, being modified so that the clock memory unit stores them as 3 voltage levels namely:

(i) +1 equals "1" bit,

(ii) 0v denotes the beginning and end of the code word, and a space between a "1" and a "0"

(iii) -1v is a "0" bit.

Please note that the (2,7) code word in this example contains only one "1" bit and the "1" always occurs at the same time.

Because of this timing of the "1", the twenty (2,7) code words can be recorded on the "1" without ambiguity, so that a data compression can be achieved.

To cut down on the storage required by the clock memory, the changes between two successive (2,7) clock words are recorded by the clock memory and taken into the clock memory store. The clock memory is a semiconductor RAM high speed memory with, for example, a 1MB capacity.

As an example, consider five variable length binary input words converted into (2,7) Code clock words, as follows:

	Data Form	(2,7) Code Form
M1	10	0100
M2	11	1000
M3	011	001000
M4	000	000100
M5	0011	00010000

To cut down on storage space, the difference between successive clock words is stored with the exception of M1 which is kept as a reference or starting point. The information actually held in the stores is as follows:

M1	0100
M2-M1	0- - -0
M3-M2	00- - - -
M4-M3	0 - - - - -0
M5-M4	- - - - - -0

To recover from the 5 stores:-

M1	0	
M2		0
M3	00	0
M4	000	
M5	000	00

The superposition of code words on the "1" on the magneto-optic media, and the subtraction of successive code words, is simply achieved with a variable delay and a shift register as shown in Figure 28. The first code word that arrives in the clock memory, M1, is delayed by 5D, and the second code word that arrives in the clock memory, M2, is delayed by 4D, so that M2 is in synchronization with M1, and so on until M5 is reached. Thus all the words are in synchronization. Subtraction of the delayed code words is carried out in four silicon shift registers in the example given in Figure 28.

Software programmes and long term storage can be transferred to the magneto-optic card. This long term memory is on the lowest layer (layer 3 or 6 or up to 20) since that is physically protected and takes longer to access.

80 lines can be stored using a 1MB silicon memory. When the 80 lines have been used up, the data in the silicon store is transferred to the magneto-optic store. In the magneto-optic store, “1”s and “0”s are stored in the normal way.

Data input/output for the silicon memory is very fast, the access time being well below 1msec.

Figure 29 shows decoding of the signal input from the detector on the first two layers of the memory. The red laser is set at the read power value of 1 mW. Signal processing is used to reproduce a clean digital "squared off" signal by waveshaping. This digital signal then identifies the “1” location so that this is synchronised with the clock memory changes. The clock memory changes are then de-multiplexed (DMUX) into the 16-bit digital output words. Using the CIRC code again the signal is descrambled.

In the hybrid memory, on the encoding side of the digital channel a 16 bit digital data input word stream is replaced by a variable length (2,7) RLL code. Since the (2,7) code words are smaller than 16 bits, they require less space so they can be processed at a faster speed.

To link the (2,7) code words, the second word is subtracted from the first word when the "1"s are synchronised, and the third from the second, and so on. This "daisy chain" of word differences means that for most applications error correction and synchronization are not required with the magneto-optic part of memory.

The silicon memory, if it is limited to 1 MB, when the memory is full, the subtracted (2,7) code words are stored on one of the three or six magneto-optic storage levels.

An example of five (2,7) subtracted code words for storage is given below. Please note that M1 is the original word and is stored first.

M1	0100
M2	1000
M3	001000
M4	000100
M5	00010000

M1	0100
M2-M1	0 - - -0
M3-M2	00 - - - -
M4-M3	0- - - - - 0
M5-M4	- - - - - - 00

If 32-bit (or 35 - bit) output words had been used, then 160 bits of magneto-optic memory would have been required. In practice, in the example shown, only 29 bits are required. These bits include one "1" and ten "0"s and 18 bits where there is no net magnetisation. Laser pulses of 200ns in a 400 oersted bias field is typical for a Curie Temperature of about 200 degrees C. Since only 29 bits are required instead of 160, this gives an expansion of memory capacity of five times.

To summarize the encoding process:

1. Input 16 bit word digital data stream;
2. Look-up table
3. (2,7) code word in volts - plus 1 volt = "1", minus 1 volt = "0"
4. Voltage threshold detector set at 0.8 volts to detect "1"s
5. Delay lines set at 23T, 19T, 13T, 6T for the above example
6. Shift registers
7. M1,M1-M2 etc stored initially in the silicon memory
8. M1, M1-M2 etc transferred to the magneto-optic memory

Note that decoding starts with M1 as the start word then M2, M3 etc can be derived and converted back to the original data using the look-up table. Also note that the electromagnet must be used with the magneto-optic media to ensure that the three states can be achieved - "1", "0" and - clock T space. Fibre Optic writing and reading with 0.1 micron spot size has been achieved by narrowing a single mode 5 micron fibre.

The provision of an optically transparent silicon layer enhances optical coupling and provides appropriate gain on reflection at the magneto-optic layer as compared to the normal change (i.e without the layer) being 0.1 degree which is very hard to read. With the layer as described , the achieved gain is of the order of 2 to 40 thereby providing a proportionately higher signal strength. The thickness range (as specified) of this silicon layer is very important as the optical rotation angle, varies with layer thickness.

In the absence of this silicon overcoat, since these films are vertically magnetised, the fringing fields are very small making inductive readout very difficult. These vertically magnetised regions form "1"s or "0"s depending on the external field direction, either up or down. Unmagnetised or longitudinal magnetised region may be used as spacers to separate the code words. Magnetisation of "1"s and "0"s is carried out when the laser induced temperature is the Curie temperature minus the ambient temperature. Erasure can be carried out by using a heating cycle and a small vertical magnetic field to convert all the "1"s to "0"s or vice versa.

Accordingly, Figure 30 shows the variation of ϕ_K the polar Kerr rotation polarisation with thickness D of an amorphous film of cobalt gadolinium which is sputtered onto a substrate, the curve having the characteristic peak of 0.2 degree followed by a constant region of 0.1 degree.

However, there is shown in Figure 31 the variation of ϕ_K with thickness D of the same cobalt gadolinium film at a thickness of 20 nanometres but with a silicon overcoat of varying thickness D in the range 0 to 20 nanometres. The curve has a very prominent negative valve of -4 at about 16 nm thickness which indicates a 20 to 40 times enhancement of the magneto-optic signal. Regarding the production or implementation of a material substrate with a hybrid magneto-optic memory a custom silicon chip has, for example:-

1. EEPROM 1M byte silicon memory (two transistors per bit)
2. RLL (2,7) code encode/decode
3. Shift registers to subtract neighbouring code words
4. Laser driver programmed by subtracted code words or differences from the 'standard' word

5. Silicon detector circuits
6. A magneto-optic memory film or up to 6 films produced by sputtering or MOCVD coats the whole card or is coated on the silicon chip
7. The final optical coating on the magneto-optic memory is amorphous silicon.

This amorphous silicon is coated by sputtering. Thickness control is vital to increase the polar-Kerr angle from the normal 0.1 degree up to 4 degrees. A thickness monitor measures the thickness accurately as the process progresses.

Concerning information transfer between memories, a blue or red laser with 10 to 30 m watts of power is used to write on the small on-chip magneto-optic memory of 1 cm square or onto the credit card sized magneto-optic film. The same laser also reads information when it is set to a lower power level of 1 to 3 m watts. Erasure is carried out with the same power on the laser as for writing.

The reflected light and the change in polarization (polar-Kerr angle) at the magneto-optic film is measured by four silicon detectors in a quadrant. The silicon detectors can be fabricated on the silicon chip. The r.f. signal is waveshaped to produce a square pulse to match the square pulse produced by the silicon clock. This square wave can be fed into the silicon processor in order to recall data that has been stored on the magneto-optic film. In summary, the laser records on the magneto-optic memory when instructed by the silicon processor and reads the data on the magneto-optic film by sending its reflected light to a silicon detector that is connected to the silicon processor.

The standard twin-axis optical head with a CD-type lens is limited to 0.2 microns even with a blue laser light source. To move down to 0.1 microns, a fibre optic light delivery system is used, for example a tapered optical fibre with a flat tip 20 nm (0.02 micron) in diameter. Bits of 60 nm (0.06 micron) and track-to-track spacing of 120nm (0.12 micron) are readily achieved.

A spherical lens is melted onto a 0.1 micron tip tapered polarisation fibre, such that the fibre tip is coated and magnetised so that two electromagnets, situated, for example, on the boundary of the 1 square cm sector, control the position of the tip which is floated in a lubricant on the surface to damp the movement and it is bent to take up the change in tip position. Another alternative is to curve the plastic card when it is recorded, read or erased.

There is also described a hybrid magneto optic-silicon memory with an RLL code for data compression.

It is evident 2D recording is approaching saturation, and so implementation of 3D (Three Dimensional) computer memories has increased.

Magneto-optical (MO) recording is particularly suitable technology since most MO alloys are amorphous and can be deposited in thin film form on signal crystal silicon. A novel 3D memory consisting of a high speed silicon short-term cache memory and a long-term high density MO memory is now described.

This hybrid memory requires a suitable channel code. A RLL (run length limited) code offers better dc stability, accurate timing synchronization and can support a higher storage density if a variable length code is used. RLL code is normally defined by code rules that can support a higher density into a larger sequence of channel bits during encoding. RLL (2,7) code has at least 2 "0's following each channel bit '1' and at most 7 '0's. In addition, the constant channel clock must correspond to a constant data rate.

"A DAISY CHAIN" RLL code is provided. In every case data compression occurs and the MO memory capacity is increased dramatically by as much as 8 times. This "DAISY CHAIN" links each memory level to the nearest neighbour level and no wastage occurs at the memory edges. Some very small amount of error correction is required for major defects by comparing the MO recording with the original silicon memory from which it originated. Normal serial data word processing can be used but high quality multi-wavelength lasers and position sensitive detectors are preferable especially with parallel processing at very high speed for communications.

Excellent magneto-optic properties can be obtained by sputtering amorphous film of terbium-iron-cobalt onto single crystal silicon. Coercivity of close to 8,000 oersted on silicon substrates can be achieved on commercially available magneto-optic media on a polycarbonate substrate.

With a special overcoat, these rare earth films can give up to a 20 times magneto-optic signal enhancement.

Since these films are vertically magnetised, the fringing fields are very small and inductive readout is very difficult. These vertically magnetised regions form '1's or '0's depending on the external field direction, either up or down. Unmagnetised or longitudinal magnetised regions can be used as spacers to separate the code words. Magnetisation of '1's and '0's is carried out when the laser induced temperature is the Curie Temperature. Erasure can be carried by using a heating cycle and a small vertical magnetic field to convert all the '1's to '0's or vice versa.

In the hybrid memory on the encoding side of the digital channel, a 16 bit digital data input word stream is replaced by a variable length (2,7) RLL code. Since the (2,7) code words are smaller than 16 bits, they require less space so they can be processed at a faster speed.

To link the (2,7) code words, the second is subtracted from the first when the '1's are synchronised, and the third from the second, and so on. This 'daisy chain' of word differences means that for most applications error correction and synchronization will not be required with the magneto-optic part of the memory.

Because the silicon memory is limited to, for example, 1 MB, the subtracted (2,7) code words are stored on one of the three magneto-optic storage levels when the silicon memory is full.

Figure 32 shows 20 (2,7) code words which have only one '1'.

An example of 5 (2,7) subtracted code words for storage is given below. Note that M1 is the origin and is stored first.

M1	0100
M2	1000
M3	001000
M4	000100
M5	00010000
M1	0100
M2-M1	0 - - -0
M3-M2	00 - - - -
M4-M3	0 - - - - - 0
M5-M4	- - - - - - 00

If 16 bit (or 19) words had been used, then 80 bits of magneto-optic memory would be required. In practice, in the example shown, only 29 bits are required. These bits include one '1' and ten '0's and 18 bits where there is no net magnetisation. Consequently, only 11 laser pulses are required instead of 31 for the original five (2,7) code words. Laser pluses of 200ns in a 400 oersted bias field is typical for a Curie Temperature of about 200 degrees C. Hence, recording or reading is speeded up by approximately 3 times. Since only 29 bits are required instead of 80, this gives expansion of the memory of 4x.

To summarize the encoding process.

1. Input 16 bit word digital data stream.
2. Look-up table.
3. (2,7) code words in volts - plus 1 volt ='1', minus 1 volt = '0'.
4. Voltage threshold detector set at 0.8 volts to detect '1's.
5. Delay lines set at 23T, 19T, 13T, 6T for the above example.

6. Shift registers.
7. M1, M1 - M2 etc stored initially in the silicon memory.
8. M1, M1 - M2 etc transferred to a magneto-optic memory.

Note that decoding starts with M1 as the origin then M2, M3 etc can be derived and converted back to the original data using the look-up table. Also note that an electromagnet must be used with the magneto-optic media to ensure that three states can be achieved - '1', '0' and - clock T space.

Finally, Fibre Optic writing and reading with 0.1 micron spot size has been achieved by narrowing a single mode 5 micron fibre.

Calculation of compression factor

Assuming that input words 16 bit long are used, then, since subtraction of successive words is required for the channel RLL code, two input words of a total length of 32 bits are required. Taking the example of Figure 6, for (2,7) code, there can be 5 'O's before the '1' Hence:

'0's	unused
1	31
to	to
12	20

12 words and 306 bits unused. 6.5 bits on average out of 32 bits. Therefore, 20% are used and the compression is x5.

Data compression of up to x8 is achieved by forming a daisy chain of channel RLL variable length code words. The daisy chain is formed by subtracting the code word from the next code word neighbour in time for the serial processing. The '1' in the code words are aligned so that synchronisation is obtained.

Error correction is minimised because the subtraction is carried out in a silicon memory which has zero defects in it. Any major defects in the MO memory can be registered and corrected for.

Further work on error correction and the calculation of the highest compression factor show that memories of 10.8 TB on a credit card size can be achieved.

In the method of the present invention, variable length of the data enables the incorporation of more information in a given size of signal.

The enhancer is a simple way to increase the MO signal when reading, being shown in Figure 33. Multiple reflections of the laser beam onto the MO film will increase the FOM (Figure of Merit) and hence the signal to noise will also increase. A quick calculation shows that the first reflection has an FOM of 2.9 for TbFeCo. At the second reflection the FOM increases to 5.6 or almost twice the signal. The angle of incidence of the laser light has to be as close to normal as possible or the light scattering will be too large. The red laser reflectivity is 96% from aluminium.

Figure 33 shows how the enhancer works.

This enhancer is readily included in the low density storage systems. High density systems might require a separate enhancer on the edge of each MO storage level with a micro-mirror to direct the tenth reflection onto the storage section.

(FOM) Figure of Merit = $\text{Ø}\sqrt{R}$

1. Kerr angle Ø = 0.3 Reflectivity R_1 =96

FOM = 2.939

2. R_2 = 96% of 96 = 92.16

3. R_3 = 96% of 92.16 = 88.47

$\O_{K3}$ = 0.6

FOM = 5.64

Taking the FOM's in 1 and 3 respectively, there is shown an enhancement of 1.93.

The enhancer can be used with a flat surface, alternatively it can be incorporated in a flexible and/or curved film. An advantage of the enhancer being formed on a curved surface is that the same device can be used as detector and emitter, e.g. on the same integrated optic block

CLAIMS

1. A system for the compression of digital data, the system comprising means to process digital data in a signal, the processor means comprising compression means, said compression means comprising means to compare a bit word in the signal with a predecessor bit in the signal and means to record only the difference between said predecessor bit and said bit.

2. A system for the compression of digital data, the system comprising means to process digital data in a signal, the processor means comprising compression means, said compression means comprising means to compare a bit word in the signal with a predecessor bit in the signal and means to record the predecessor bit and only the difference between said predecessor bit and said bit.

3. A system according to Claim 1 or 2 comprising means to compare a bit with the immediately preceding bit.

4. A system according to any preceding claim comprising a laser readable high density storage system for recording and reading data into at least one storage area on a magneto-optic recording medium comprising means to encode data in "run-length-limited" format.

5. A system according to Claim 4 wherein the "run-length-limited" format comprises one or more of the following code formats:-

(1,3)
(2,7)
(0,2)

(0,3)

(1,7)

(3,7)

(4,14)

(5,17).

6. A system according to any preceding claim comprising a magneto-optic medium for the recording of the difference data.

7. A system according to Claim 6 comprising an area of a second medium for storage of data.

8. A system according to Claim 7 wherein the second medium comprises semi-conductor material or a phase-change medium.

9. A system according to any preceding claim comprising means to hold instructions on the processing of data in bar code format.

10. A system according to any preceding Claim comprising storing the bit words in a three-voltage level format.

11. A system according to Claim 10 wherein a bit of "1" voltage level is stored as "+1", a bit of "0" is stored as a "-1" voltage level, and the beginning or end of a word is stored as a "0" voltage level.

12. A system according to any preceding claim comprising means to effect error correction by scrambling at least one word in the bit stream.

13. A system according to any preceding claim comprising means to effect

de-scrambling when decoding take place on the silicon.

14. A system according to any preceding claim comprising means to incorporate variable length sequences of the bits.

15. A system according to any preceding claim comprising means to effect alignment of the words in the RLL words.

16. A system according to Claim 15 comprising means to set a voltage level at 0.8 volts to detect '+1' bits and to set a voltage level at -0.8 volts to detect '-1' bits.

17. A system according to any preceding claim comprising to return it to the original format.

18. A system for the compression of digital data, the system comprising means to process digital data in a signal, the processor means comprising compression means, said compression means comprising means to records a bit in the signal, means to compare the next bit in the signal with the recorded bit, means to record the difference between the two bits.

19. A system according to Claim 18 comprising means to compare the successive bit with the recorded data on said next bit, and means to record the difference between said successive bit and said next bit.

20. A system according to Claim 18 or 19 comprising recording the difference between each new bit and the last recorded bit.

21. Apparatus for the compression of digital data, the apparatus comprising means to process digital data in a signal, the processor means comprising compression means comprising means to compare a bit in the signal with a predecessor bit in the signal, and means to record only the difference said predecessor bit and said bit.

22. Apparatus for the compression of digital data, the apparatus comprising means to process digital data in a signal, the processor means comprising compression means comprising means to compare a bit in the signal with a predecessor bit in the signal, and means to record the predecessor bit and only the difference between said predecessor bit and said bit.

23. Apparatus according to Claim 21 or 22 comprising means to return compressed data to the original format.

24. A method for the compression of digital data, the method comprising processing digital data signal, comprising compressing data by comparing a bit in the signal with a predecessor bit in the signal, and recording only the difference between said predecessor bit and said bit.

25. A method for the compression of digital data, the method comprising processing digital data signal, comprising compressing data by comparing a bit in the signal with a predecessor bit in the signal, and recording the predecessor bit and only the difference between said predecessor bit and said bit.

26. A computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of Claims 24 or 25 when said product is run on a computer.

27. A computer program product stored on a computer usable medium, comprising:

computer readable program for a computer to compare a bit in a signal with a predecessor bit in the signal;

computer readable program means for causing the computer to record only the difference between said predecessor bit and said bit.

28. Electronic distribution of a computer program according to Claim 26 or 27.

29. A laser readable high density storage system for recording and/or reading data on a magneto-optic medium having a silicon optical coating layer.

30. A system according to Claim 29 in which the silicon coating layer has a thickness in the range of 150 to 170 Angstrom.

31. A system according to Claim 29 or 30 in which the silicon coating layer has a thickness of or about 160 Angstrom.

32. A system according to any of Claims 29 to 31 comprising 2 to 8 layers.

33. A system according to any of Claims 25 to 28 comprising a top layer of amorphous silicon.

34. A system for recording and/or reading data comprising means for enhancing data bits of a signal, the system comprising two parallel surfaces with the separation remaining constant, or substantially so, over the whole length of the enhancing means and reflectivity of the reflection layer within

0.1%.

35. A system according to Claim 34 comprising means to produce multiple reflections on the magneto-optic layer such that every time a reflection occurs on the magneto-optic layer the Kerr angle is enhanced.

36. A system according to Claim 34 or 35 comprising enhancing means on the edge of each magneto-optic storage level.

37. A system according to any of Claims 34 to 35 comprising a micro-mirror to direct the tenth reflection on to a storage section.

38. A system according to any of Claims 34 to 37 comprising enhancing means provided on a flat surface.

39. A system according to any of Claims 34 to 38 comprising enhancing means provided on a curved surface.

40. A system according to any of Claims 34 to 39 comprising enhancing means provided on a flexible surface.

41. A reader for a storage system, the reader comprising at least one optical fibre guide means, a ball lens, magnetic and/or electromagnetic means to effect control of the optical fibre .

42. A reader according to Claim 41 comprising two tapered single mode optical fibres for separate light-in and light-out channels.

43. A reader for a storage system according to Claims 41 or 42 comprising

a flat tip e.g. of 20nm in diameter.

44. A reader for a storage system according to any of Claims 41 to 43 comprising a spherical lens melted onto a tapered polarisation fibre.

45. A reader for a storage system according to any of Claims 41 to 44 comprising a plurality of electromagnets to control positioning of the tip.

46. A reader for a storage system according to any of Claims 41 to 45 wherein the tip floats in lubricant for damping of movement.

47. A reader according to any of Claims 41 to 42 comprising a violet laser.

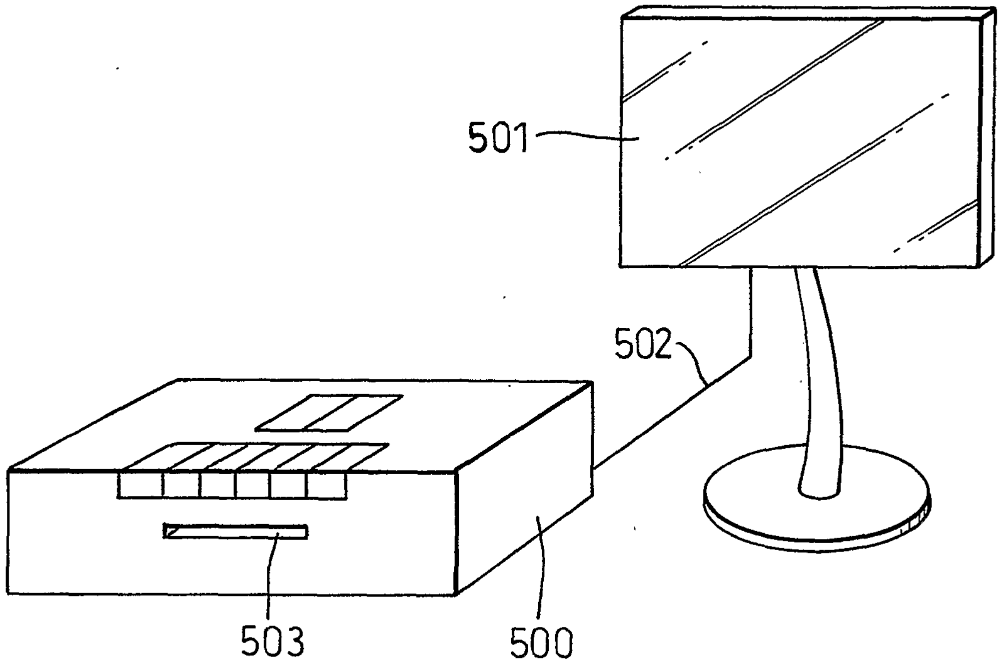

501
502
503
500

Fig. 1

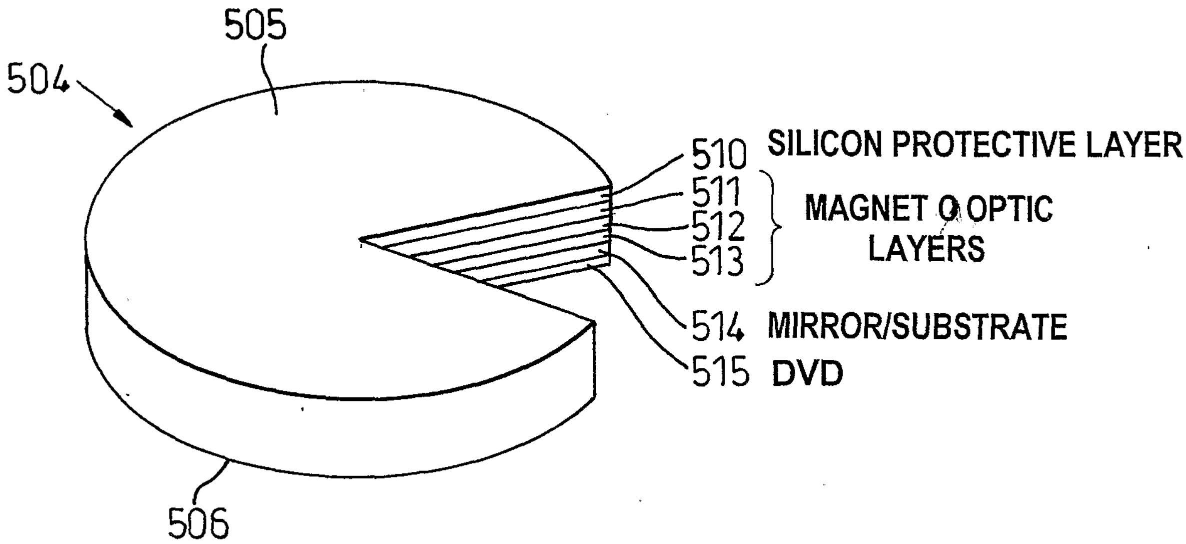

505
504
510 SILICON PROTECTIVE LAYER
511
512
513
MAGNET O OPTIC LAYERS
514 MIRROR/SUBSTRATE
515 DVD
506

Fig. 2

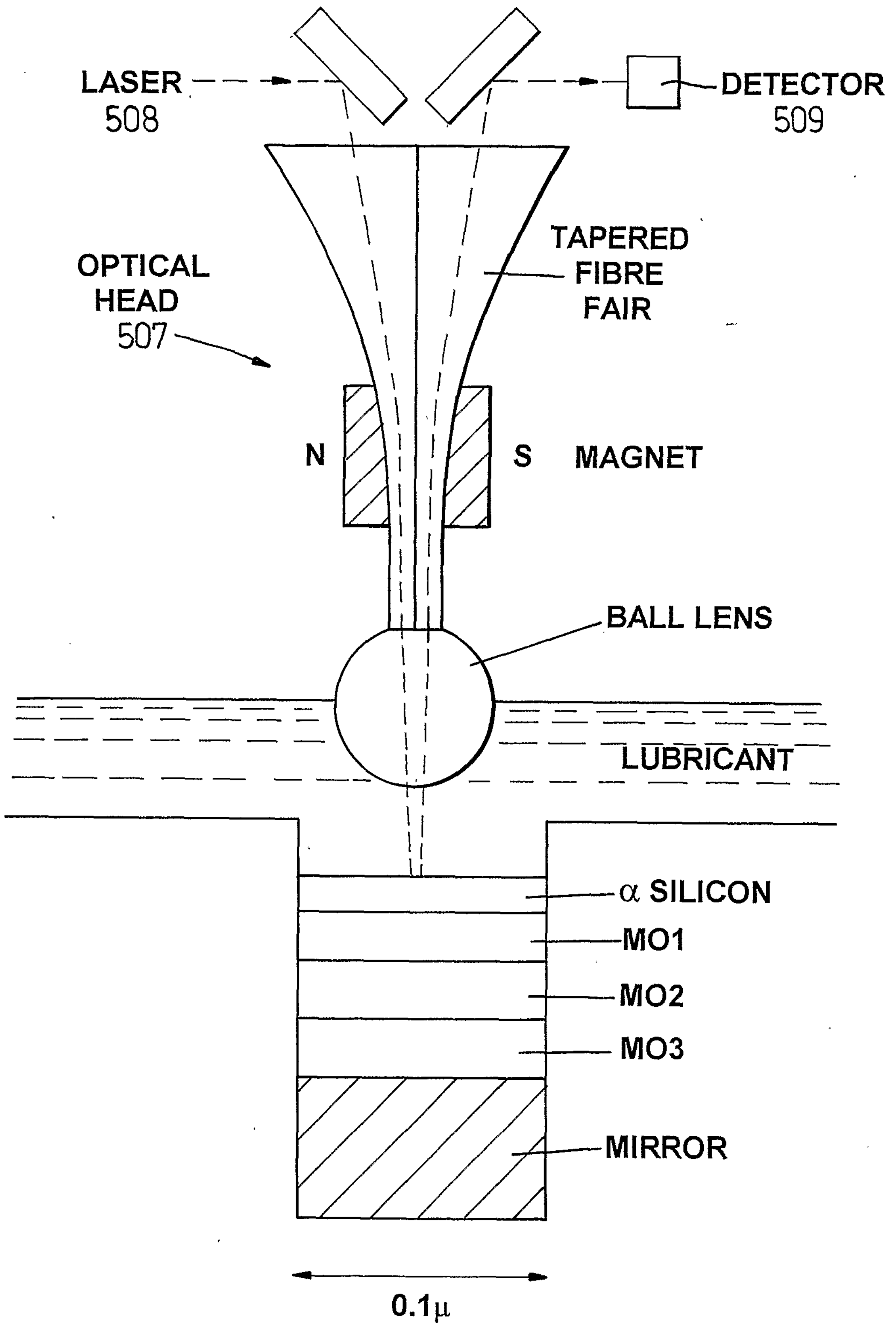

LASER
508
DETECTOR
509
TAPERED
FIBRE
FAIR
OPTICAL
HEAD
507
N
S
MAGNET
BALL LENS
LUBRICANT
α SILICON
MO1
MO2
MO3
MIRROR
0.1μ

Fig. 3

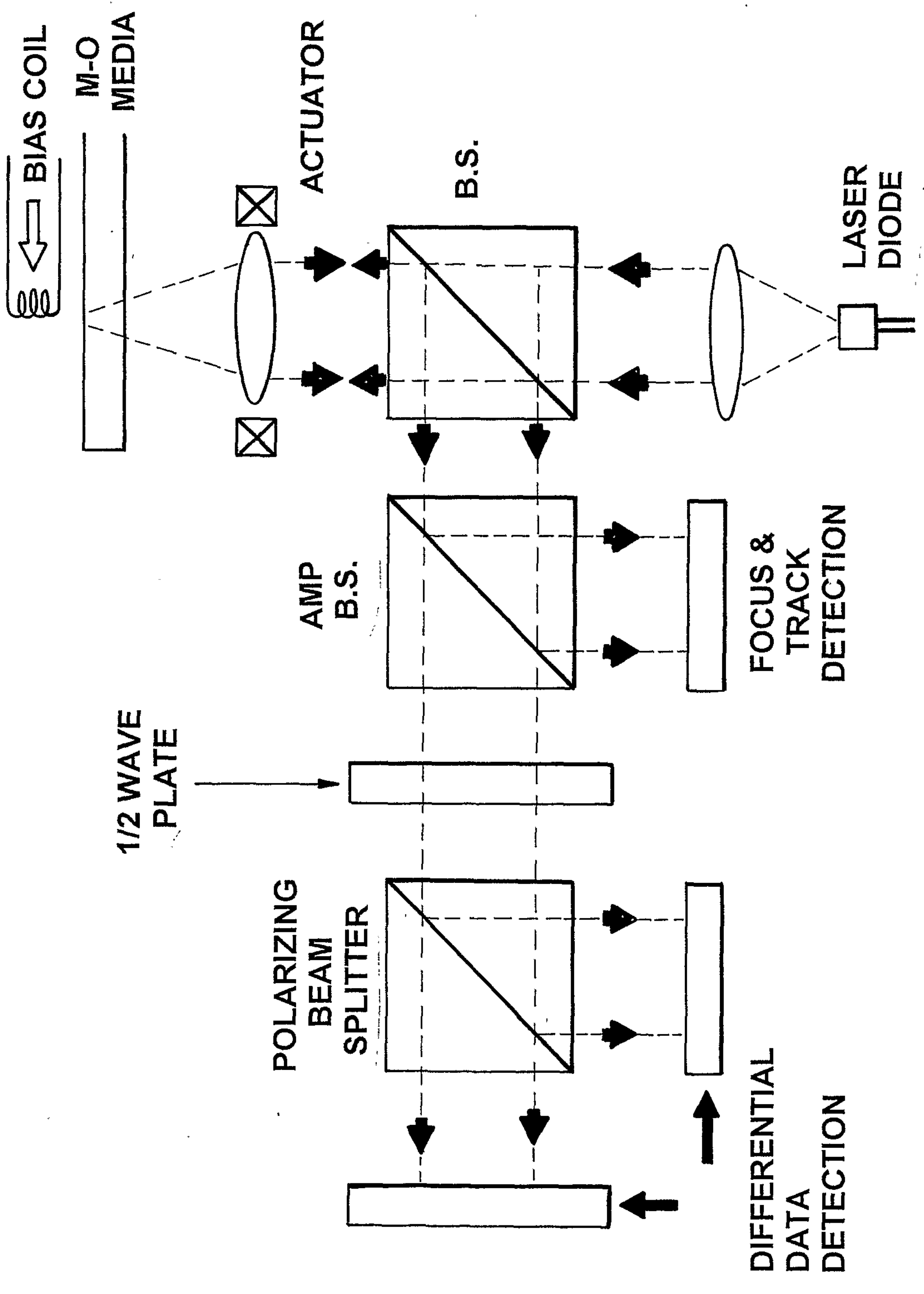

BIAS COIL
M-O
MEDIA
ACTUATOR
B.S.
LASER
DIODE
AMP
B.S.
FOCUS &
TRACK
DETECTION
1/2 WAVE
PLATE
POLARIZING
BEAM
SPLITTER
DIFFERENTIAL
DATA
DETECTION

Fig. 4

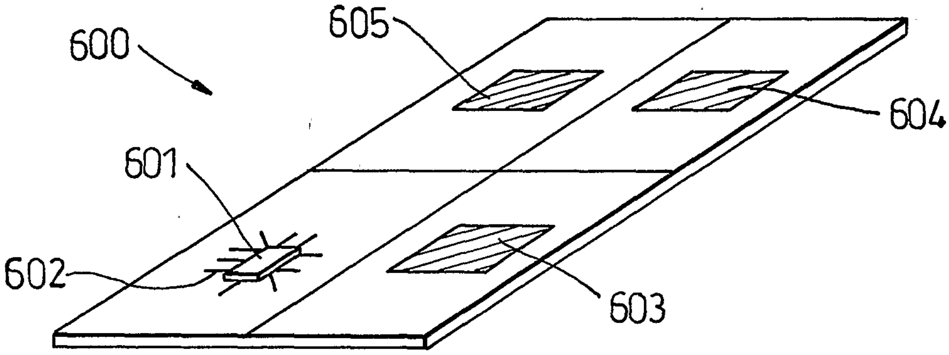


Fig. 5

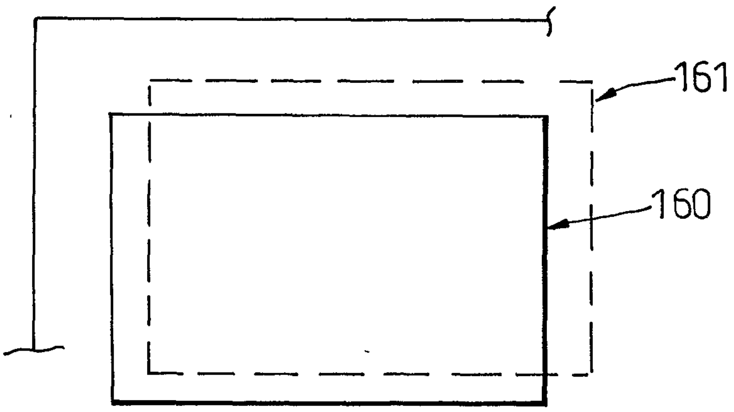


Fig. 10

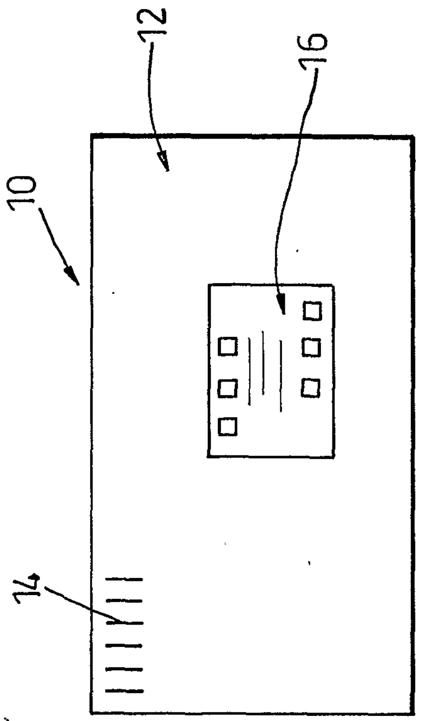


Fig. 6

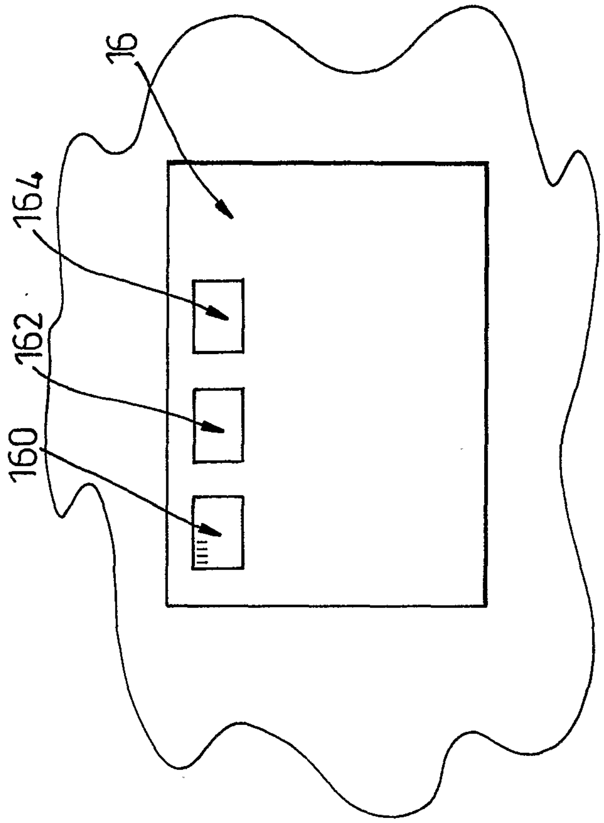


Fig. 7

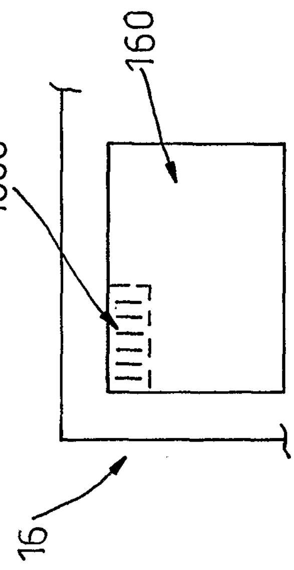


Fig. 8

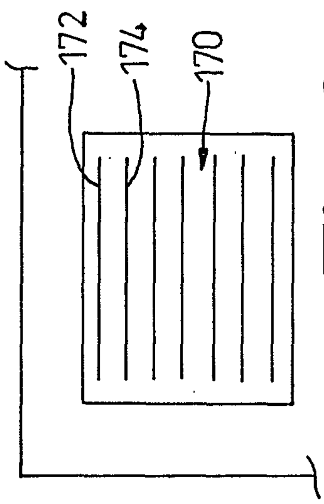


Fig. 9

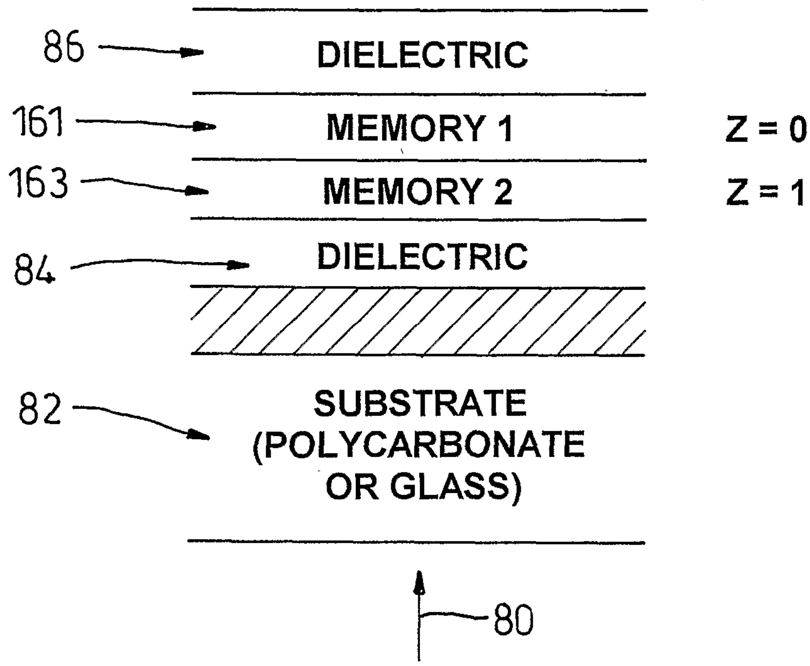

86
DIELECTRIC
161
MEMORY 1
Z = 0
163
MEMORY 2
Z = 1
84
DIELECTRIC
82
SUBSTRATE
(POLYCARBONATE
OR GLASS)
80

Fig. 11

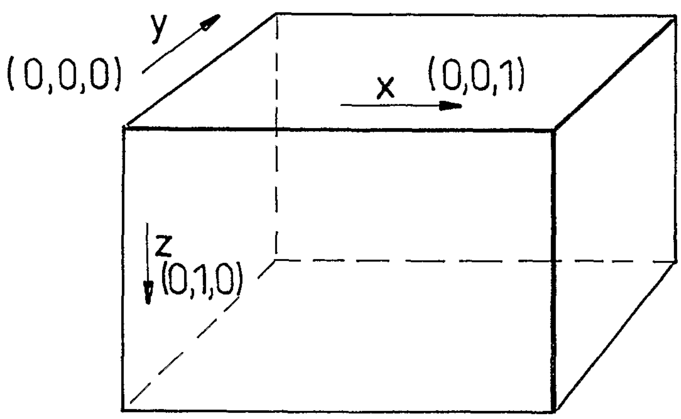

y
(0,0,0)
x
(0,0,1)
z
(0,1,0)

Fig. 12

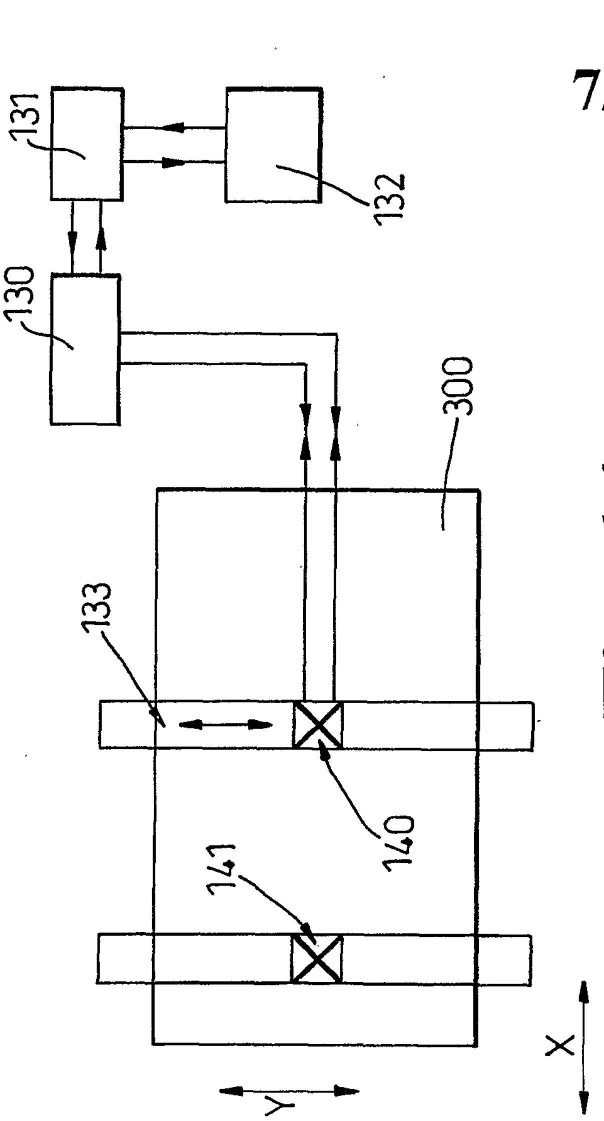


Fig. 14

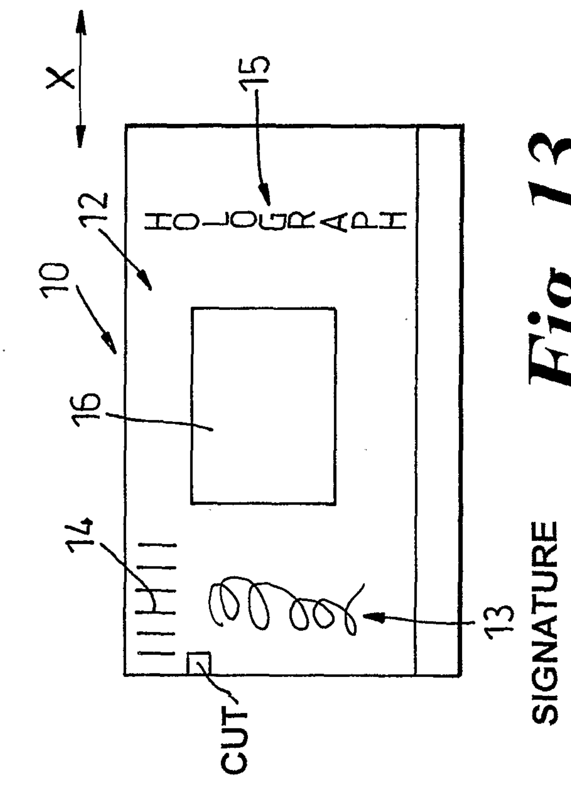


Fig. 13

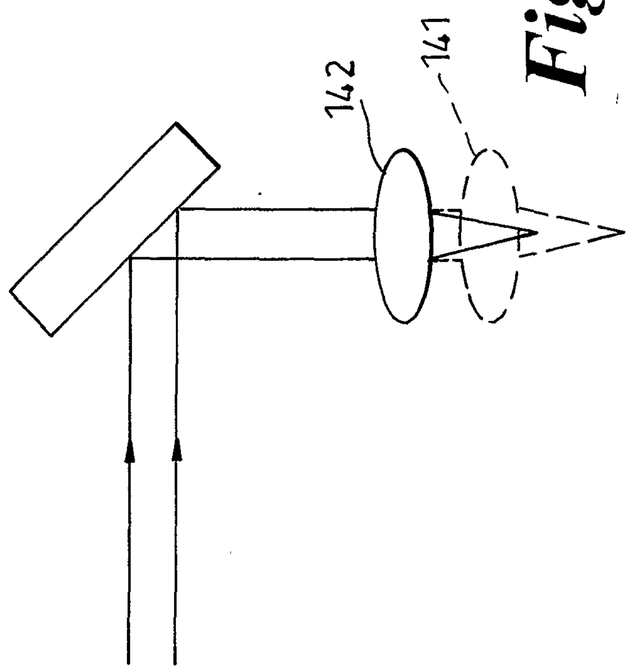


Fig. 15

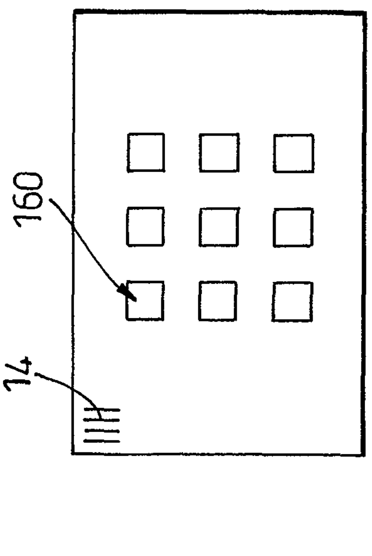


Fig. 16

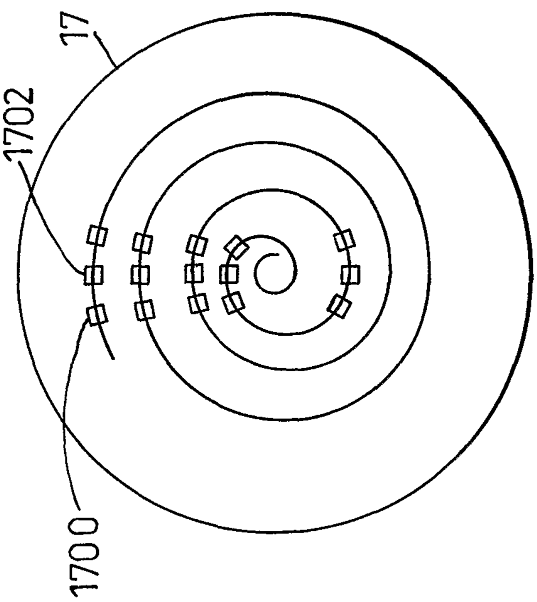


Fig. 17

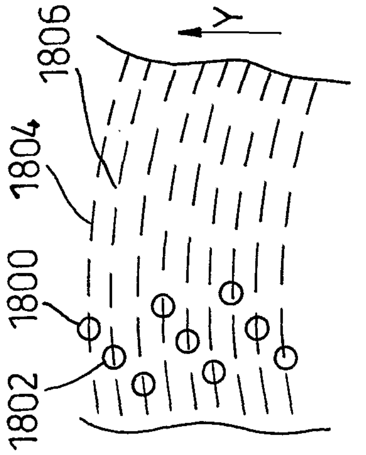


Fig. 18

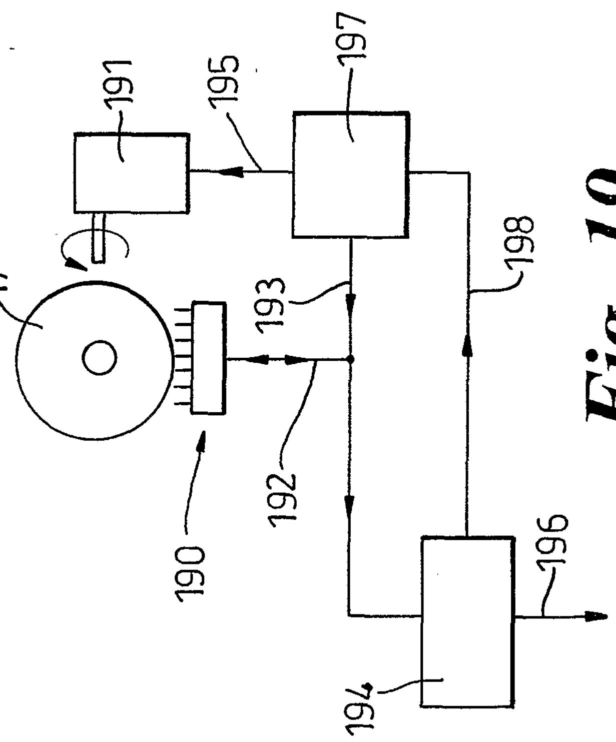


Fig. 19

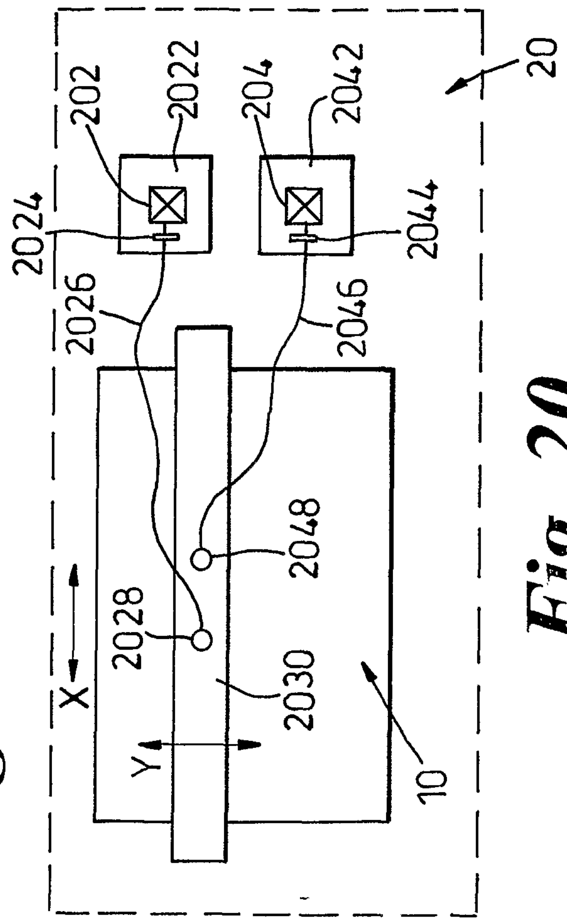


Fig. 20

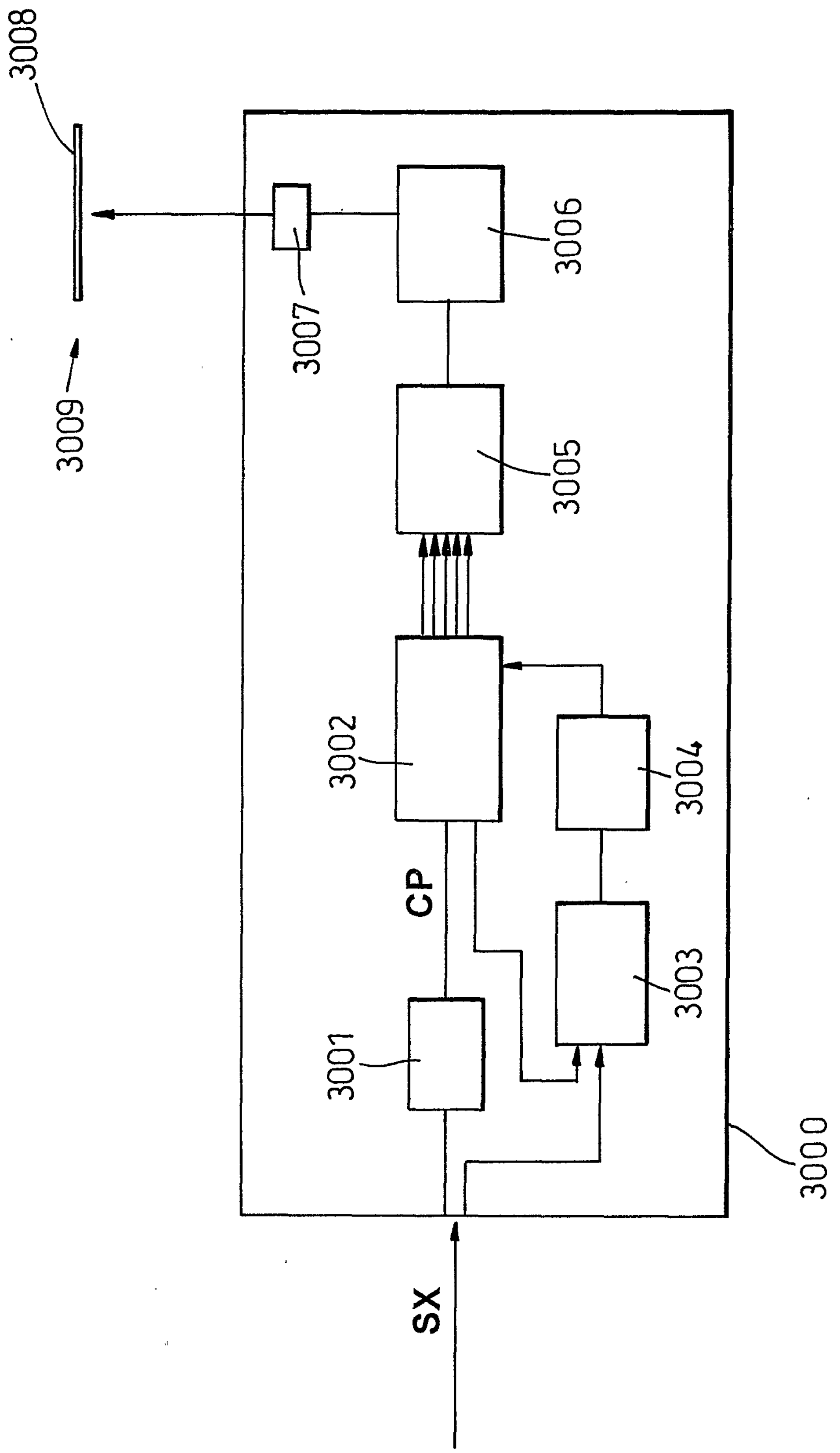


Fig. 21

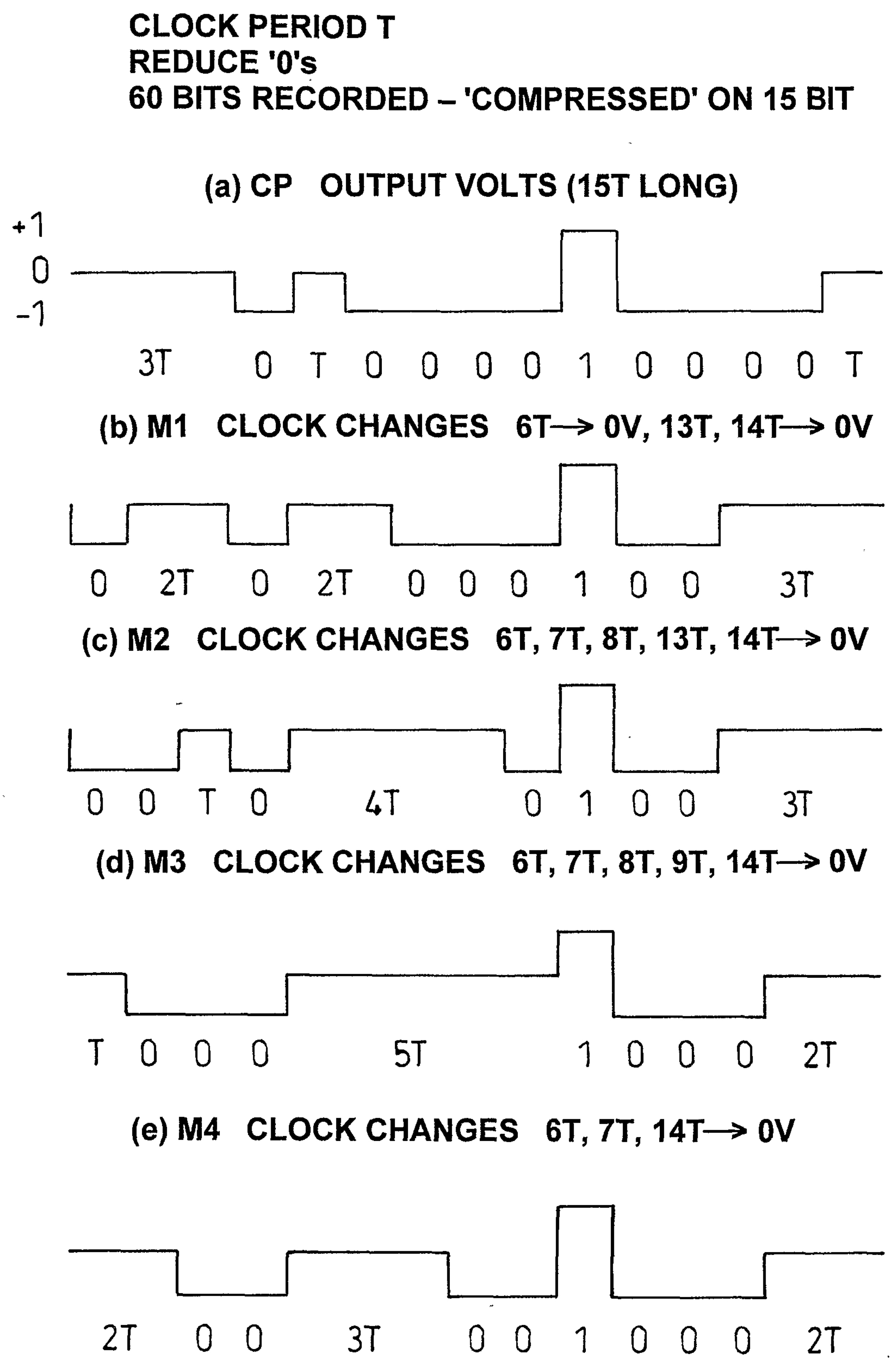

CLOCK PERIOD T
REDUCE '0's
60 BITS RECORDED – 'COMPRESSED' ON 15 BIT
(a) CP OUTPUT VOLTS (15T LONG)
+1
0
-1
3T 0 T 0 0 0 0 1 0 0 0 0 T
(b) M1 CLOCK CHANGES 6T—> 0V, 13T, 14T—> 0V
0 2T 0 2T 0 0 0 1 0 0 3T
(c) M2 CLOCK CHANGES 6T, 7T, 8T, 13T, 14T—> 0V
0 0 T 0 4T 0 1 0 0 3T
(d) M3 CLOCK CHANGES 6T, 7T, 8T, 9T, 14T—> 0V
T 0 0 0 5T 1 0 0 0 2T
(e) M4 CLOCK CHANGES 6T, 7T, 14T—> 0V
2T 0 0 3T 0 0 1 0 0 0 2T

Fig. 22

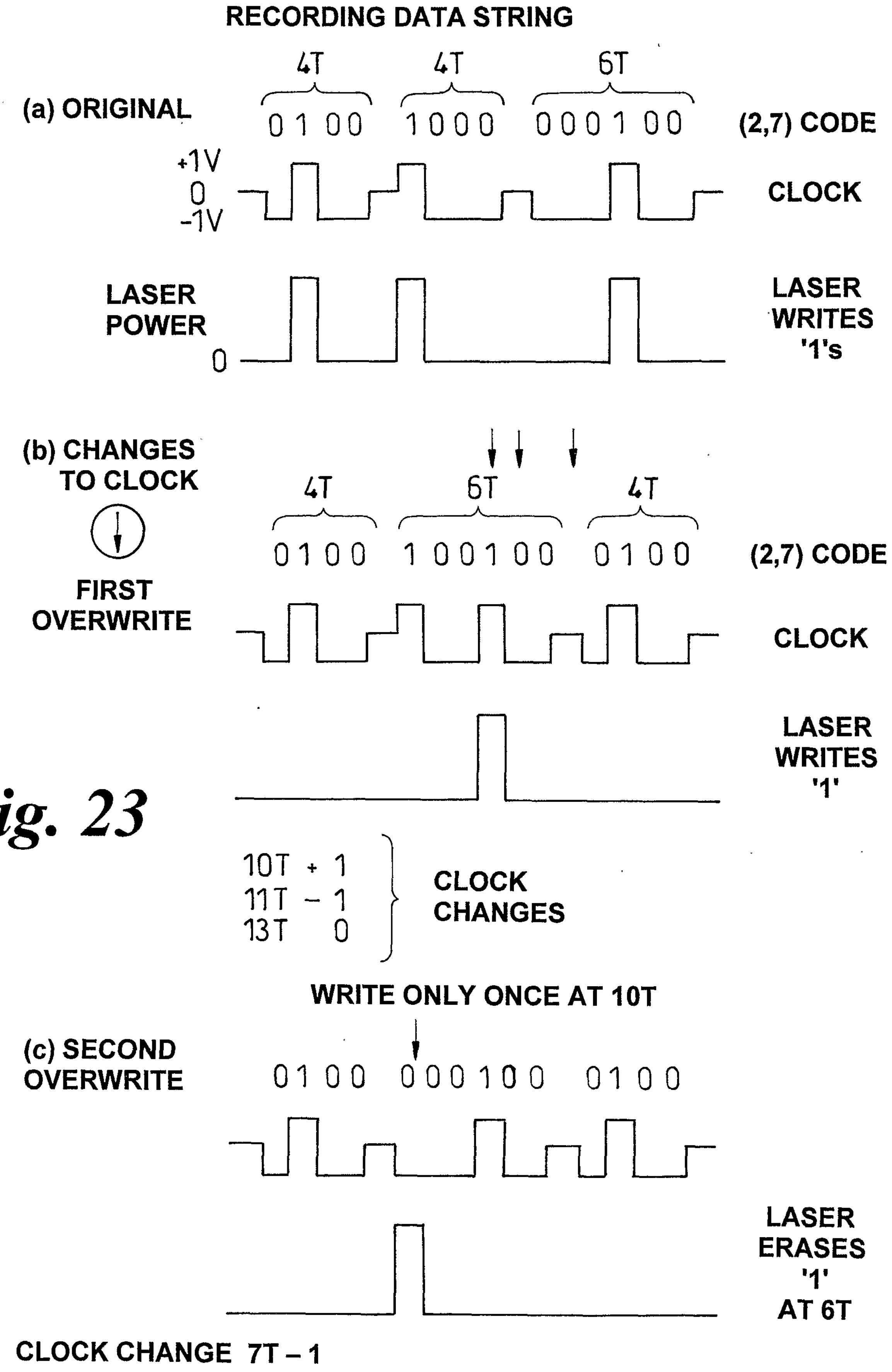

RECORDING DATA STRING
(a) ORIGINAL
4T
4T
6T
0100 1000 000100
(2,7) CODE
+1V
0
-1V
CLOCK
LASER POWER
0
LASER WRITES '1's
(b) CHANGES TO CLOCK
FIRST OVERWRITE
4T
6T
4T
0100 100100 0100
(2,7) CODE
CLOCK
LASER WRITES '1'
10T + 1
11T − 1
13T 0
CLOCK CHANGES
WRITE ONLY ONCE AT 10T
(c) SECOND OVERWRITE
0100 000100 0100
LASER ERASES '1' AT 6T
CLOCK CHANGE 7T – 1

Fig. 23

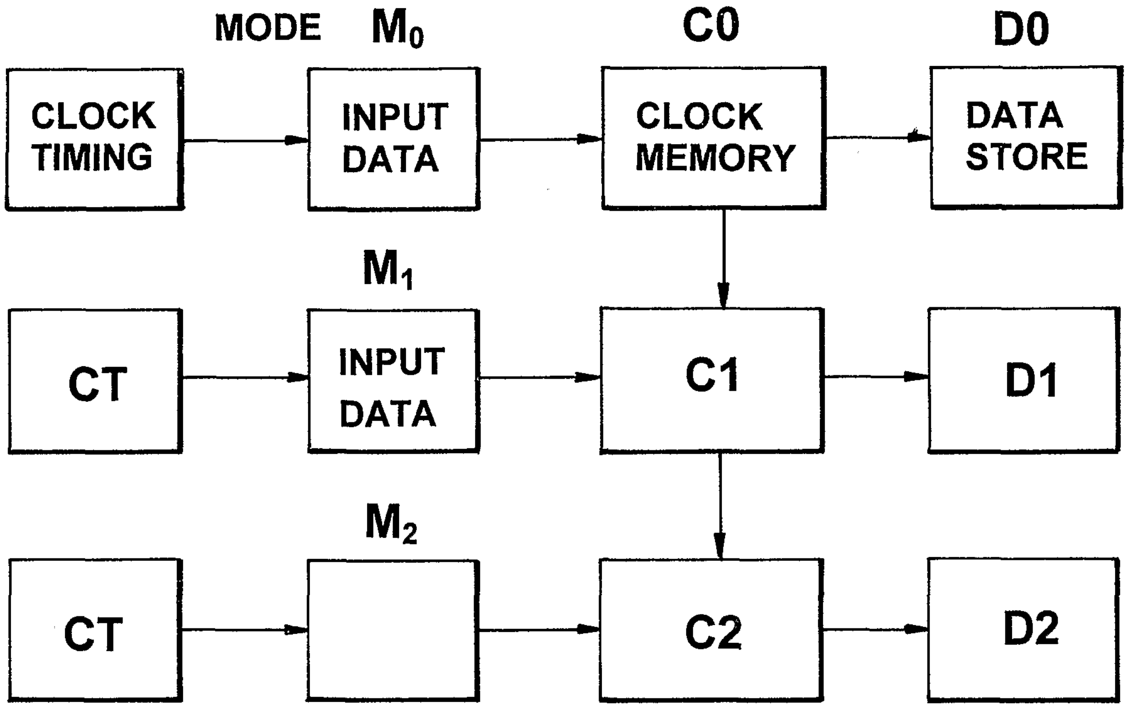


Fig. 24A

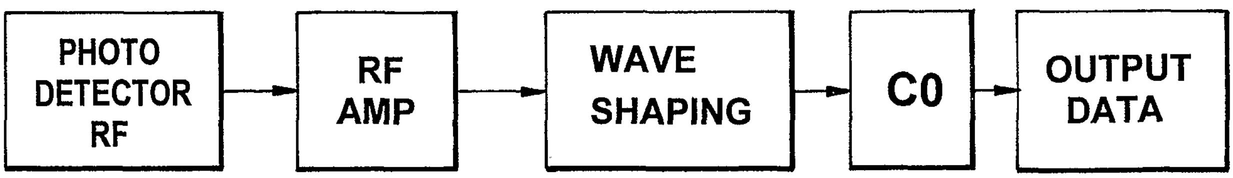


Fig. 24B

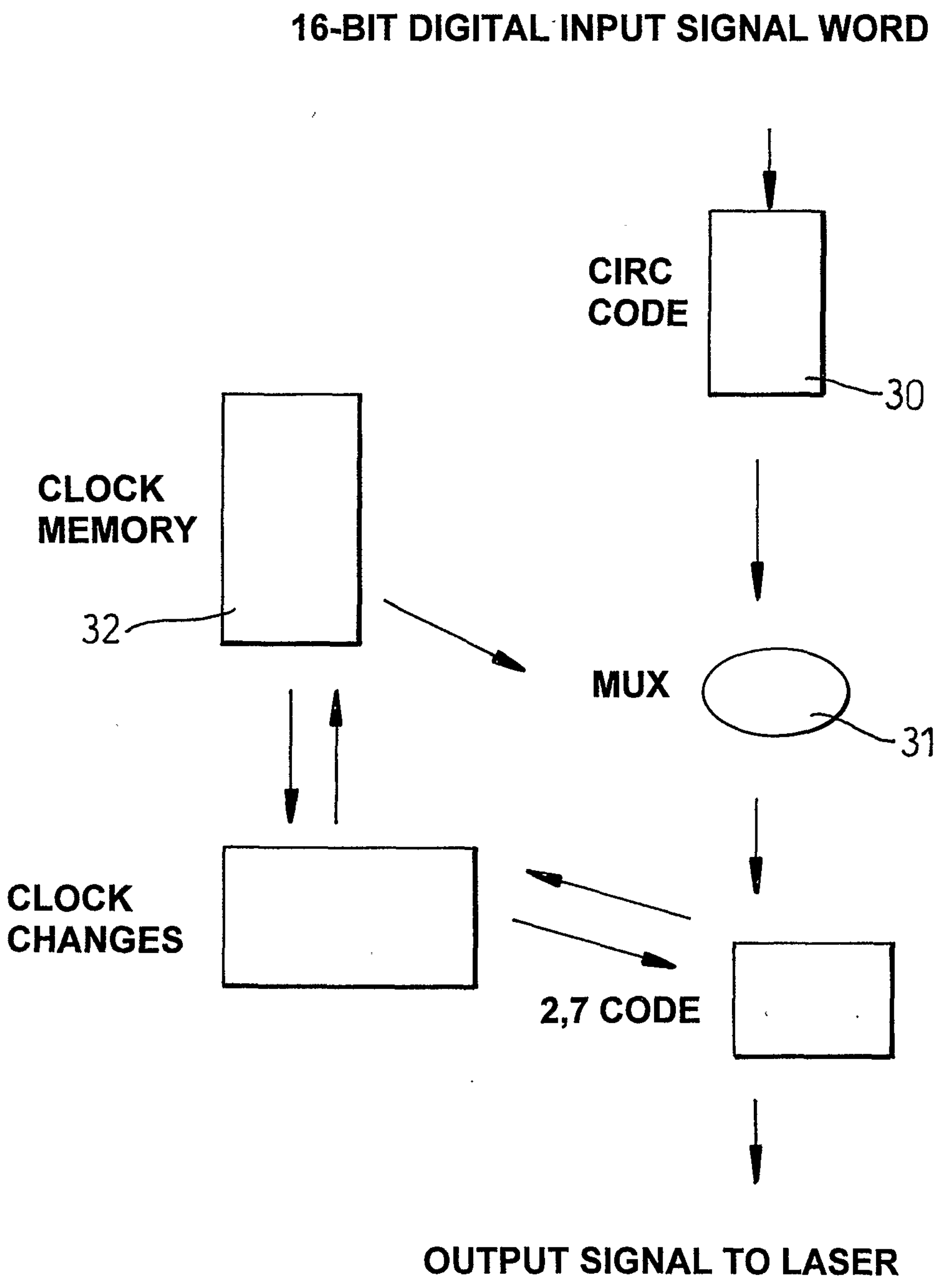

16-BIT DIGITAL INPUT SIGNAL WORD
CIRC
CODE
30
CLOCK
MEMORY
32
MUX
31
CLOCK
CHANGES
2,7 CODE
OUTPUT SIGNAL TO LASER

Fig. 25

					1	0	0					
					1	0	0	0				
					1	0	0	0	0			
					1	0	0	0	0	0		
					1	0	0	0	0	0	0	
					1	0	0	0	0	0	0	0
	0	0	0	0	1	0	0	0				
				0	1	0	0					
		0	0	0	1	0	0					
			0	0	1	0	0	0				
0	0	0	0	0	1	0	0					
	0	0	0	0	1	0	0					
			0	0	1	0	0					
				0	1	0	0	0				
		0	0	0	1	0	0	0				
			0	0	1	0	0	0	0			
				0	1	0	0	0	0			
		0	0	0	1	0	0	0	0			
			0	0	1	0	0	0	0	0		
				0	1	0	0	0	0	0		

(2,7) CODE TABLE

Fig. 26

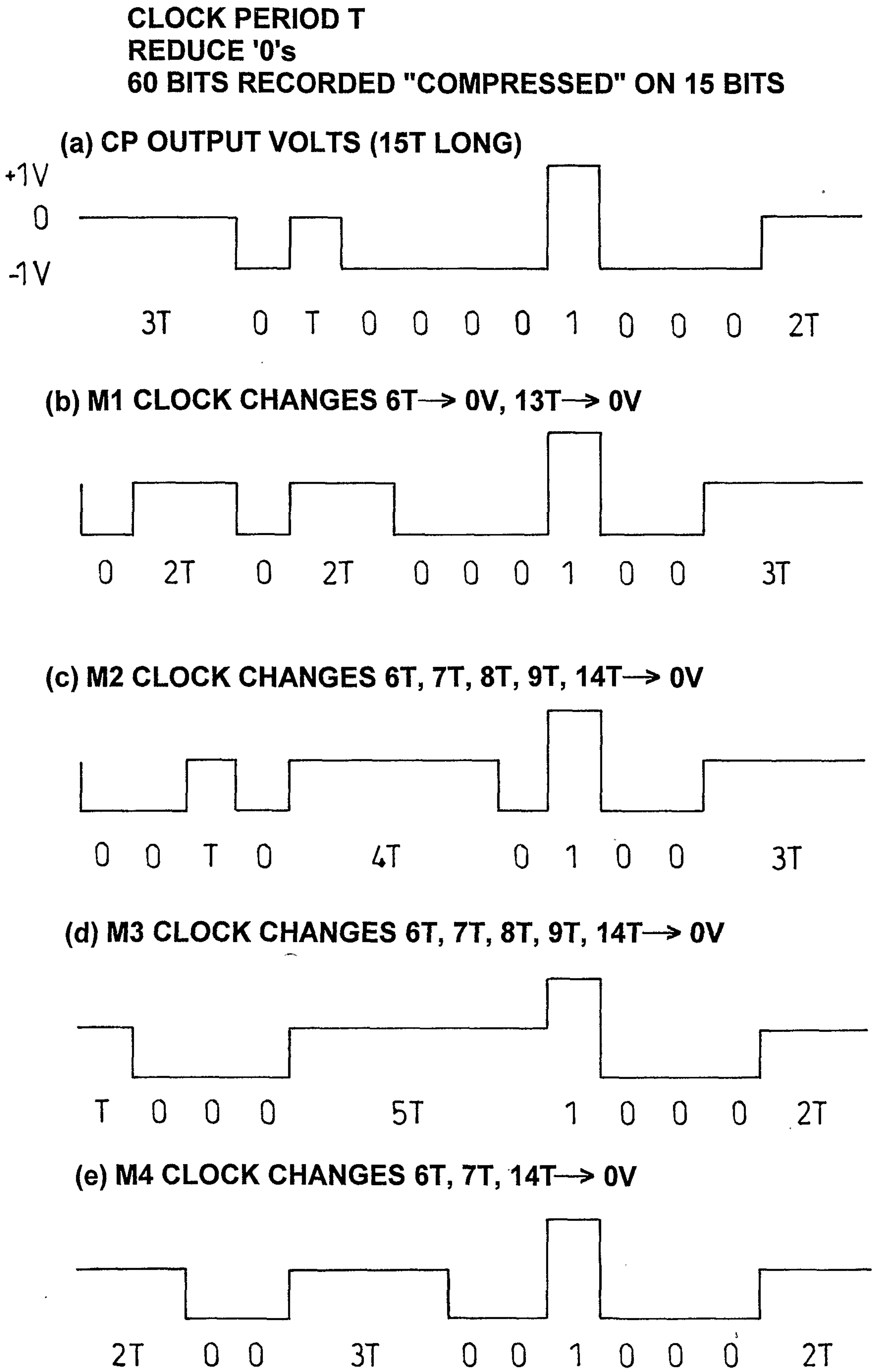

CLOCK PERIOD T
REDUCE '0's
60 BITS RECORDED "COMPRESSED" ON 15 BITS
(a) CP OUTPUT VOLTS (15T LONG)
+1V
0
-1V
3T 0 T 0 0 0 0 1 0 0 0 2T
(b) M1 CLOCK CHANGES 6T—> 0V, 13T—> 0V
0 2T 0 2T 0 0 0 1 0 0 3T
(c) M2 CLOCK CHANGES 6T, 7T, 8T, 9T, 14T—> 0V
0 0 T 0 4T 0 1 0 0 3T
(d) M3 CLOCK CHANGES 6T, 7T, 8T, 9T, 14T—> 0V
T 0 0 0 5T 1 0 0 0 2T
(e) M4 CLOCK CHANGES 6T, 7T, 14T—> 0V
2T 0 0 3T 0 0 1 0 0 0 2T

Fig. 27

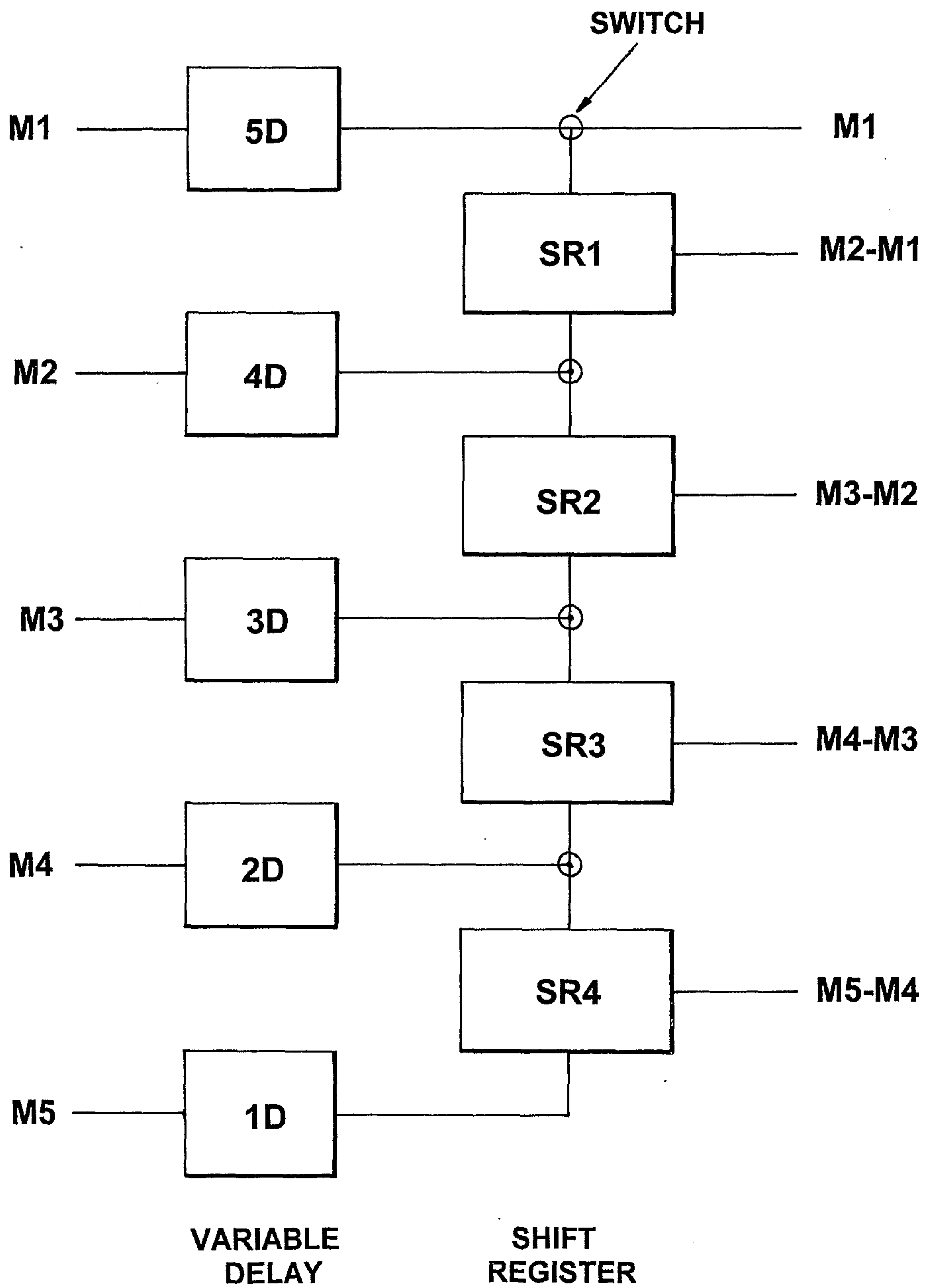

SWITCH
M1
5D
M1
SR1
M2-M1
M2
4D
SR2
M3-M2
M3
3D
SR3
M4-M3
M4
2D
SR4
M5-M4
M5
1D
VARIABLE DELAY
SHIFT REGISTER

Fig. 28

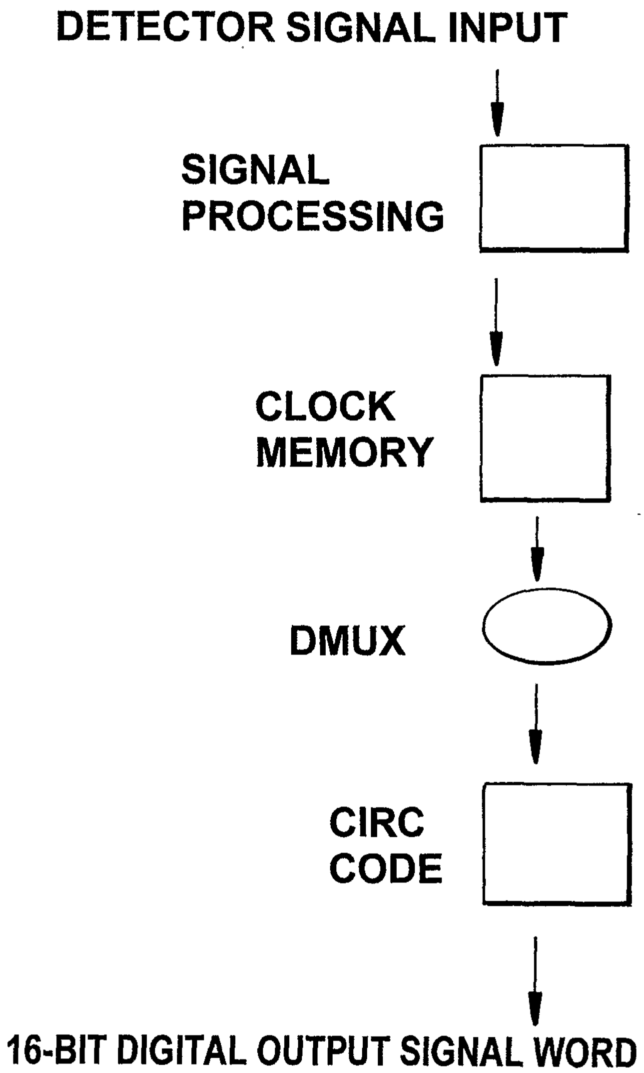

DETECTOR SIGNAL INPUT
SIGNAL PROCESSING
CLOCK MEMORY
DMUX
CIRC CODE
16-BIT DIGITAL OUTPUT SIGNAL WORD

Fig. 29

MATCHED LAYER THICKNESS

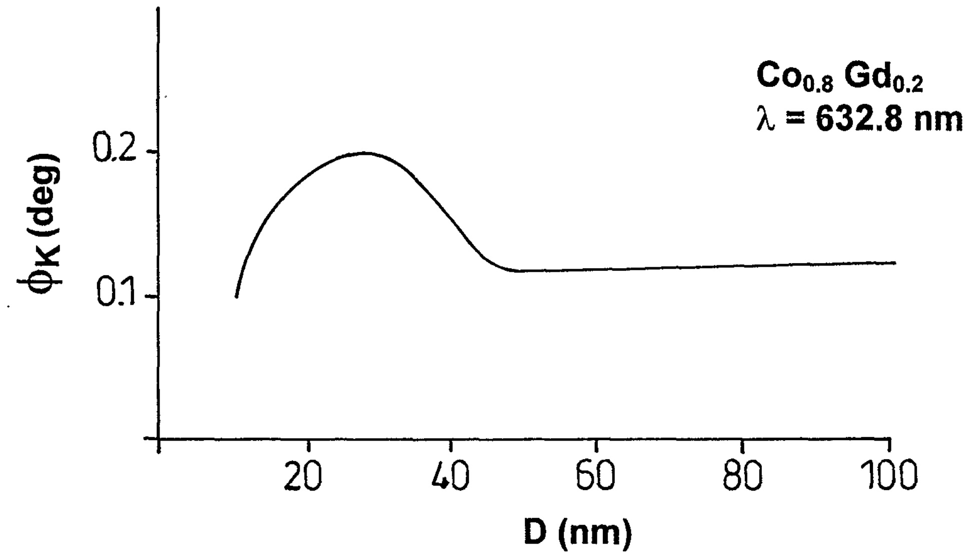


Fig. 30

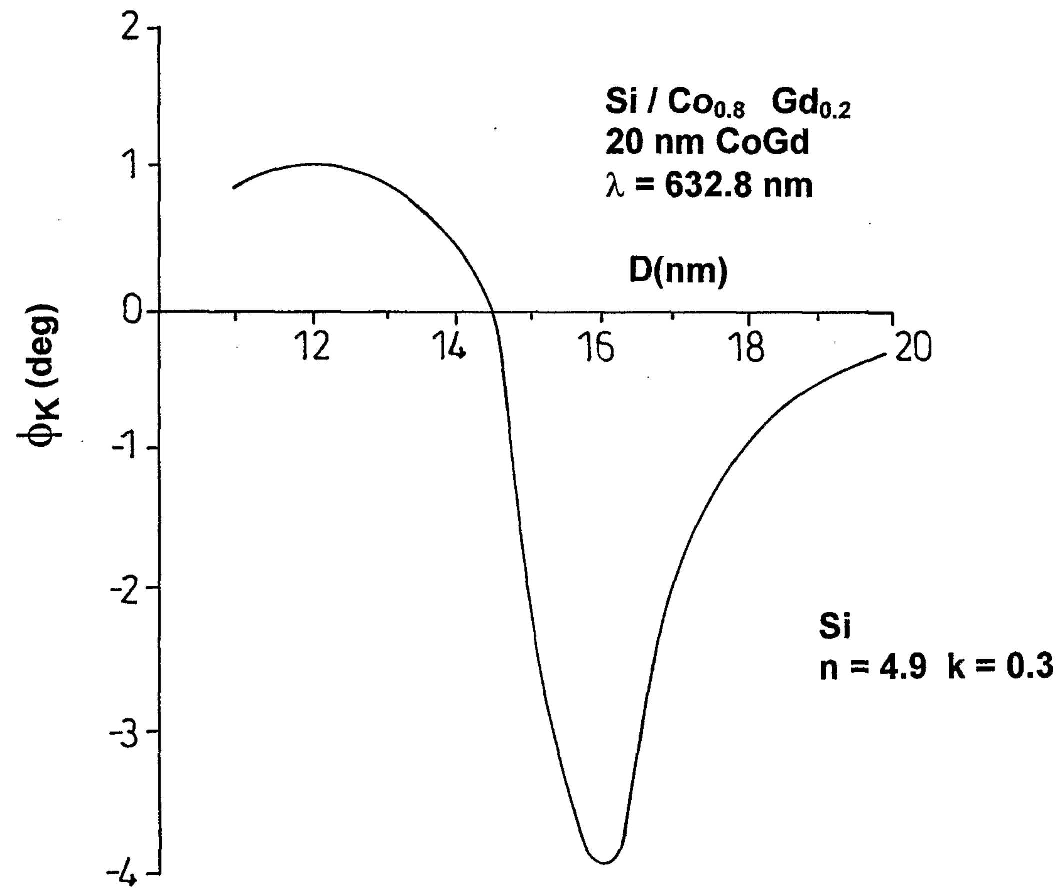


Fig. 31

(2/7) CODE TABLE

					1	0	0					
					1	0	0	0				
					1	0	0	0	0			
					1	0	0	0	0	0		
					1	0	0	0	0	0	0	
					1	0	0	0	0	0	0	0
	0	0	0	0	1	0	0	0				
				0	1	0	0					
		0	0	0	1	0	0					
			0	0	1	0	0	0				
0	0	0	0	0	1	0	0					
	0	0	0	0	1	0	0					
			0	0	1	0	0					
				0	1	0	0	0				
		0	0	0	1	0	0	0				
			0	0	1	0	0	0	0			
				0	1	0	0	0	0			
		0	0	0	1	0	0	0	0			
			0	0	1	0	0	0	0	0		
				0	1	0	0	0	0	0		

Fig. 32

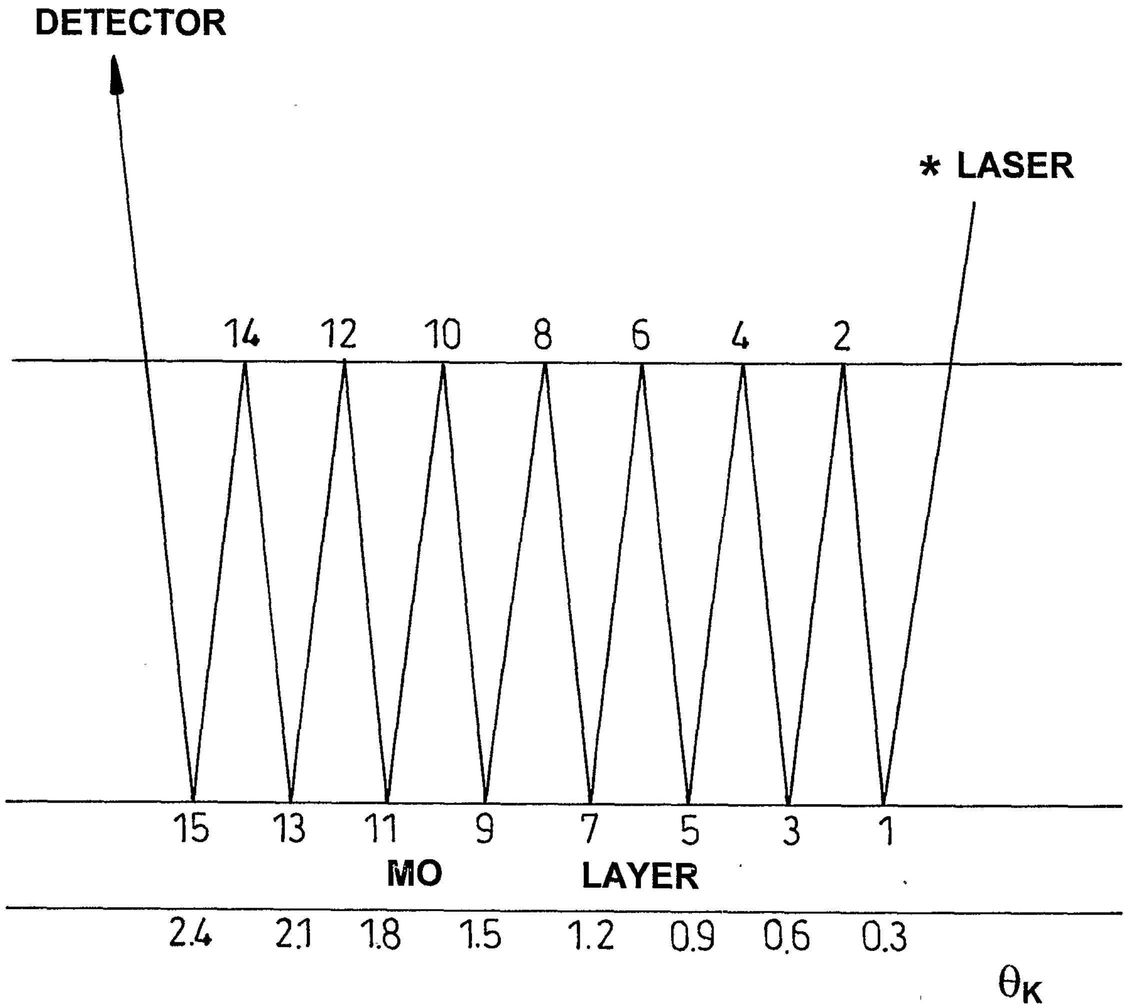

DETECTOR
* LASER
14
12
10
8
6
4
2
15
13
11
9
7
5
3
1
MO
LAYER
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
θ_K

Fig. 33