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(54) Video camera for borehole inspection.

(57) The invention relates to a borehole logging camera for viewing the inner wall of a cylindrical cavity such as a casing placed in a borehole. The camera includes means (19, 21, 22, 27) for illuminating the inner wall (20) of the cavity, an hemispherical mirror (28) centered inside a cylindrical transparent window (16), focusing means (29) for focusing the image reflected by the mirror, and a plurality of photosensitive elements (41) arranged in an annular array, each photosensitive element being responsive to the reflection from a corresponding elementary area of the wall (20) of the cavity. The photosensitive elements (41) are preferably photodiodes which are mounted inside a thermal flask (102) and kept at a constant temperature by means of thermoelectric elements (104).

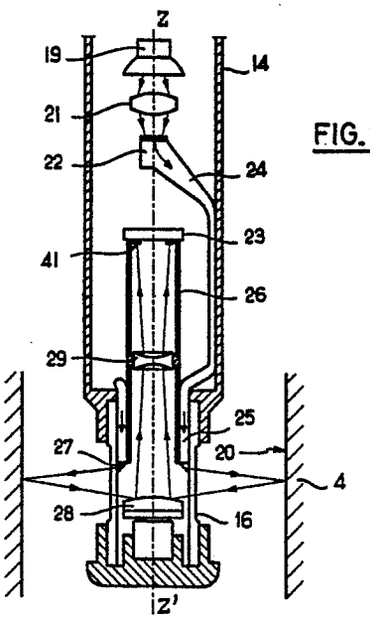

FIG.2

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VIDEO CAMERA FOR BOREHOLE INSPECTION

The present invention is directed to a borehole video camera for inspecting the inner wall of a substantially cylindrical cavity, and in particular for viewing from a remote location the wall of a borehole or the inner surface of a well casing.

Once a borehole is drilled up to certain depth into the earth, it may be desirable to inspect the walls of the borehole in order to collect valuable information concerning the geological formations traversed by said borehole. Also, monitoring of the inner surface of the casing placed in the borehole may also be extremely valuable in detecting corrosion and cracks and checking the effectiveness of production perforations.

Inspection of the inner surface of a casing has been considered with different kinds of physical principles such as optics and acoustics. Acoustic type devices such as the one described in US-A-4,255,798 are well suited for use in liquid filled holes, but do not operate in gas. Optical type devices are not sensitive to the phase of the fluid but require a transparent fluid such as clean water or gas in order to avoid undesirable light transmisstion losses.

Amongst the disclosed optical type devices, US-A-2,912,495 describes a device for viewing oil well borehole comprising a television camera pointing towards a conical mirror coaxial with the longitudinal axis of the borehole. A light source illuminates the wall of the borehole, the light being reflected back via the conical mirror towards the television camera. Such an arrangement allows to obtain instantaneously a 360° view of the borehole. Figures 6 to 8 of US-A-3,279,085 which describes a similar device making use of spherical mirror instead of a conical mirror illustrate very well the view obtained with such known devices. It will easily be understood that any longitudinal movement of the camera inside the cylindrical cavity will cause the outer part of the view to shrink towards the center part of the view, thus requiring extensive processing for reconstructing an undistorted image.

Thus a drawback of the above described device is that the view is a perspective view which does not reflect the true dimensions, in other words the view is distorted.

The object of the invention is to obtain a high resolution undistorted view of the inner wall of a substantially cylindrical cavity.

According to the invention, a borehole logging camera for viewing the inner wall of a substantially cylindrical cavity comprises a longitudinal housing which includes a cylindrical transparent window and which is adapted to receive therein:

-means for illuminating the inner wall of the cavity opposite said window;

-reflecting means placed opposite said window and whose reflecting area is axisymmetric in order to reflect the radially impinging image of the inner wall of the cavity substantially in the direction of the longitudinal axis of said cylindrical window;

-focusing means for focusing the image reflected by said reflecting means;

-a plurality of photosensitive elements arranged in an annular array and responsive to the image received from said focusing means.

The use of an annular array of photosensitive elements advantageously reduces the amount of data to be transmitted to the remote location via the borehole logging cable whose length may typically reach 8000 meters. Such a reduction also allows the use of small diameter logging cable (i.e. a two electrical conductor cable) which is particularly well suited for use in gas wells under high wellhead pressure.

Figure 1 illustrates a borehole logging tool comprising a camera according to the invention and the associated surface instrumentation;

Figure 2 represents a schematic drawing of the operating principle of the camera according to the invention;

Figure 3 represents a substrate carrying the annular array of photosensitive elements such as photodiodes ;

Figure 4 is the block diagram of the downhole electronic circuitry associated with the camera ;

Figure 5 shows a particular embodiment of a borehole camera according to the invention ;

Figure 6 is a cross-sectional view of figure 5.

With reference to Figure 1, a downhole logging device 1 is suspended at the end of a cable 2 in a borehole 3 fitted with a casing 4 and traversing underground formations 5. The cable 2 is connected to a surface cable correction filter 6 for amplifying, correcting and adapting the signals coming up hole prior being fed into a processing unit 7. The processing unit includes an analog to digital converter, random access memories and a digital to analog converter (not shown) and is driven by the timing and control circuit 8 into which the pulses of a depth encoder system 9 are fed. The video part comprises the video time base 10 and the video mix circuit 11 which delivers appropriate signals to a magnetic recorder 12 and a video monitor 13.

The downhole logging device 1 comprises as pressure resistant housing 14 inside which the camera assembly 15 and the corresponding electronic circuitry 16 are located. Part of the housing

14 is made of a cylindrical window 16 transparent to light. Said window is preferably made of high strength glass. The downhole logging device is centered in the casing by means of suitable well known centering devices 17 and 18.

Figure 2 illustrates the optical principle of the camera according to the invention. The light for illuminating the inner wall 20' of the casing 4 is provided by means of an halogen bulb 19 placed inside the housing 14. The light emitted by the bulb 19 is focused through a yellow band-pass filter 21 into a bundle 22 of fiber optic cables. The bundle 22 is split into three strands 24 (only one being shown) which are routed around the substrate 23 carrying the photosensitive elements 41 and then recombined as one hollow cylindrical bundle 25 around a cylindrical aluminum sheath 26 which extends up to the transparent window 16. The aluminum sheath 26 acts as a shield against direct light interferences between the cylindrical fiber optic bundle 25 and the photodiode substrate 23. The cylindrical fiber optic bundle 25 shines out onto an annular prism mirror 27 which reflects radially the light energy through the window 16 towards the inner wall 20 of the casing 4.

The image reflected back by the inner wall 20 of casing 4 converges radially through the window 16 onto a hemispherical mirror 28 centered inside the window 16 whose axis is represented by zz'. Mirror 28 is adapted to reflect the impinging image towards a lens 29 which will focus the beams onto the respective individual photodiodes 41 of the substrate 23. While a substantially hemispherical form of the reflecting area of mirror 28 is preferred, it will be understood that any conical area or any other axisymmetrical area whose axis is aligned with axis zz' can possibly be used.

Figure 3 represents a front view of the substrate 23 carrying the photosensitive elements 41 which are preferably photodiodes. Substrate 23 comprises an annular array 40 of photodiodes 41, each photodiode being responsive to the reflection from a corresponding elementary area of the inner wall 20 of the casing 4. Such substrates are available on the market with an annular array of 720 photodiodes, thus giving an azimuthal resolution of half a degree.

Figure 4 represents the bloc diagram of the downhole electronic circuitry. The signal of a pixel oscillator 50 is fed into a time base circuit 51 which delivers suitable signals to the clock drivers 52. The photodiodes 41 of the substrate 23 are scanned every 25 ms with a read out time of 2 ms. This signal is fed into an differential amplifier 53 , then combined with a synchronization pulse in a sample/hold circuit 54. A cable correction filter 55 boosts the signal before being fed into cable 2 by the cable drive circuit 56.

Figure 5 and cross-sectional view shown in Fig. 6 illustrate an embodiment of the invention particularly well suited for boreholes where the ambient temperature may often be above 100° C. The light source 119, the lens 121 and the fiber optic bundle 122 are carried by a cylindrical support 100 which is located inside the pressure resistant housing 114. The support member 101 carrying the lens 121 acts as a thermal shield in order to prevent heat transfer from the source 119 towards the photodiode substrate 123.

Located inside a thermal flask 102, the photodiode substrate 123 is mounted with its face parallel to the axis zz' of the cylindrical window 116 and is facing a prism mirror 103. The mirror 103 is mounted on a support member 113 and reflects at a right angle the image received from the focusing lens 129 towards the photodiode substrate 123. A cylindrical extension 126 of the thermal flask 102 acts as a shield against direct light interferences between the cylindrical fiber optic bundle 125 and the photodiode substrate 123. The cylindrical extension 126 does also support the annular prism mirror 127 which illuminates the well casing (not shown in figure 5).

The photodiode substrate 123 is mounted on thermoelectric elements 104 which are adapted to regulate the temperature inside the thermal flask 102. The elements 104 are dynamically controlled by a thermometer (not shown) placed on the face of the substrate 123, the Peltier current being adjusted to maintain the temperature of the substrate below 70 ° C. A heat sink 105 evacuates the thermal energy to the borehole fluid via the housing 114. Such a temperature regulating system allows to operate the camera at an outside temperature of about 125° C, while maintaining substantially constant, over a wide temperature range, the response of the camera.

The electric wiring 110 of photodiodes 141 and Peltier elements 104 traverses the thermal flask 102 and the support member 101 by means of suitable connectors or thermal packings 111 and 112.

The cylindrical glass window 116 is sealingly mounted at the end of the housing 114 by means of a threaded nut 106. The other end of the window is sealingly provided with a bottom pressure resistant plug 107 by means of threaded nut 108. Glass window 116 has to withstand the pressure of the surrounding medium which typically can reach a few hundred bar.

The hemispherical mirror 128 is carried by the plug 107, its position being adjustable by means of a screw 109 which allows proper optical matching. The use of a hemispherical mirror advantageously renders the optical alignment of the mirror 128 with the focusing lens 129 much simpler.

The overall magnification of the above described optical system is a function of pipe size and ranges from approximately 2.5 in a 60 mm diameter pipe to 1 in a 160 mm diameter pipe. The optical configuration yields a depth of field of 30 mm to 90 mm radius, thus avoiding additional adjustable focusing means. With the 720 photodiodes substrate the azimuthal resolution is half a degree, the vertical resolution of the camera being around I mm.

It should be pointed out that the conversion from the 720 pixels to a standard 512 pixels for viewing the inner wall of cavity on a standard video monitor 13 is handled by the surface processing unit 7, thus reducing slightly the azimuthal resolution of the view observed on the video monitor 13.

While the above described invention corresponds to a camera for borehole logging, it will be understood that the claimed invention can be used for inspecting any substantially cylindrical cavity and that the claimed invention is not limited to the described lightening and focusing means.

Claims

1. A borehole logging camera for viewing the inner wall (20) of a substantially cylindrical cavity (4) comprising a longitudinal housing (14) which includes a cylindrical transparent window (16) and which is adapted to receive therein:
-means (19, 21, 22, 27) for illuminating the inner wall (20) of the cavity opposite said window;
-reflecting means (28) placed opposite said window and whose reflecting area presents a symmetry of revolution in order to reflect the radially impinging image of the inner wall of the cavity towards a direction corresponding substantially to the longitudinal axis of said cylindrical window;
-focusing means (29) for focusing the image reflected by said reflecting means;
-a plurality of photosensitive elements (41) arranged in an annular array (40) and adapted to deliver signals representative of the image received from said focusing means.

2. A borehole logging camera according to claim 1, characterized in that said photosensitive elements are placed on a substrate (23) substantially perpendicular to the longitudinal axis (zz') of said cylindrical window.

3. A borehole logging camera according to claim 1, characterized in that said photosensitive elements are placed on a substrate (123) whose face is substantially parallel to the longitudinal axis (zz') of said cylindrical window (116) and said focusing means (129) include a prism mirror (103) for reflecting the image at a right angle.

4. A borehole logging camera according to any one of claims 1, 2 or 3, characterized in that said photosensitive elements (41) are photodiodes.

5. A borehole logging camera according to claim 4, characterized in that the photodiodes (141) are mounted inside a thermal flask (102) on thermoelectric elements (104) adapted to regulate the temperature inside said thermal flask.

6. A borehole logging camera according to any one of the preceeding claims, characterized in that said means for illuminating the inner wall of cavity includes an halogen bulb (119) directed towards one end of a fiber optic bundle (122), the other end of said fiber optic bundle forming a hollow cylindrical bundle (125) shining out via an annular prism mirror (127) towards the inner wall (20) of the cavity.

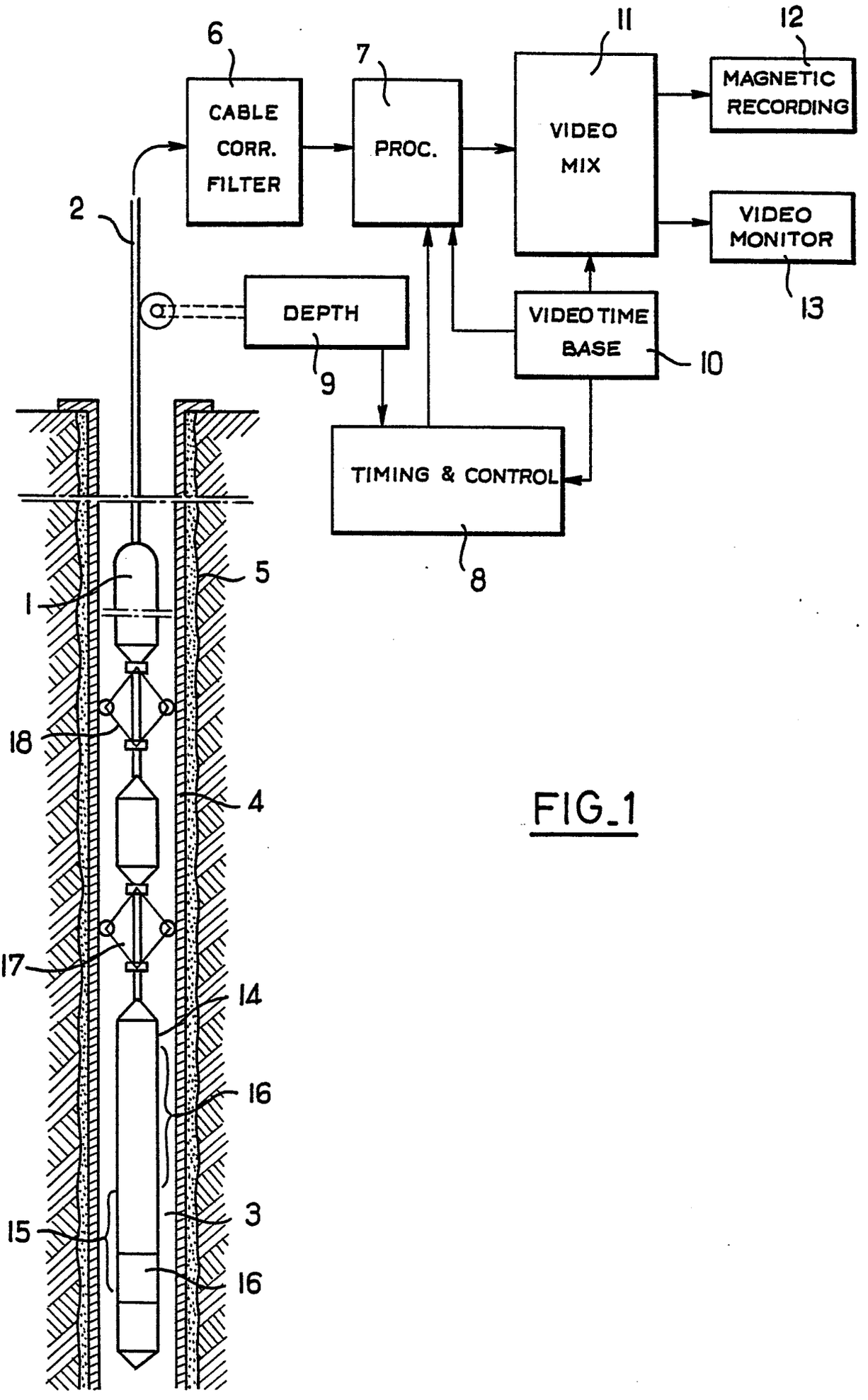

6
CABLE
CORR.
FILTER
7
PROC.
11
VIDEO
MIX
12
MAGNETIC
RECORDING
VIDEO
MONITOR
13
2
DEPTH
9
VIDEO TIME
BASE
10
TIMING & CONTROL
8
5
1
18
4
17
14
16
3
15
16

FIG_1

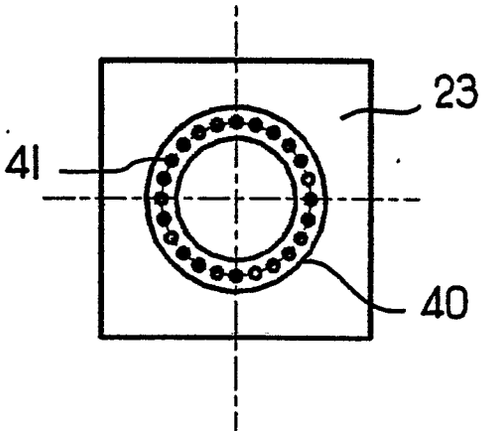


FIG_3

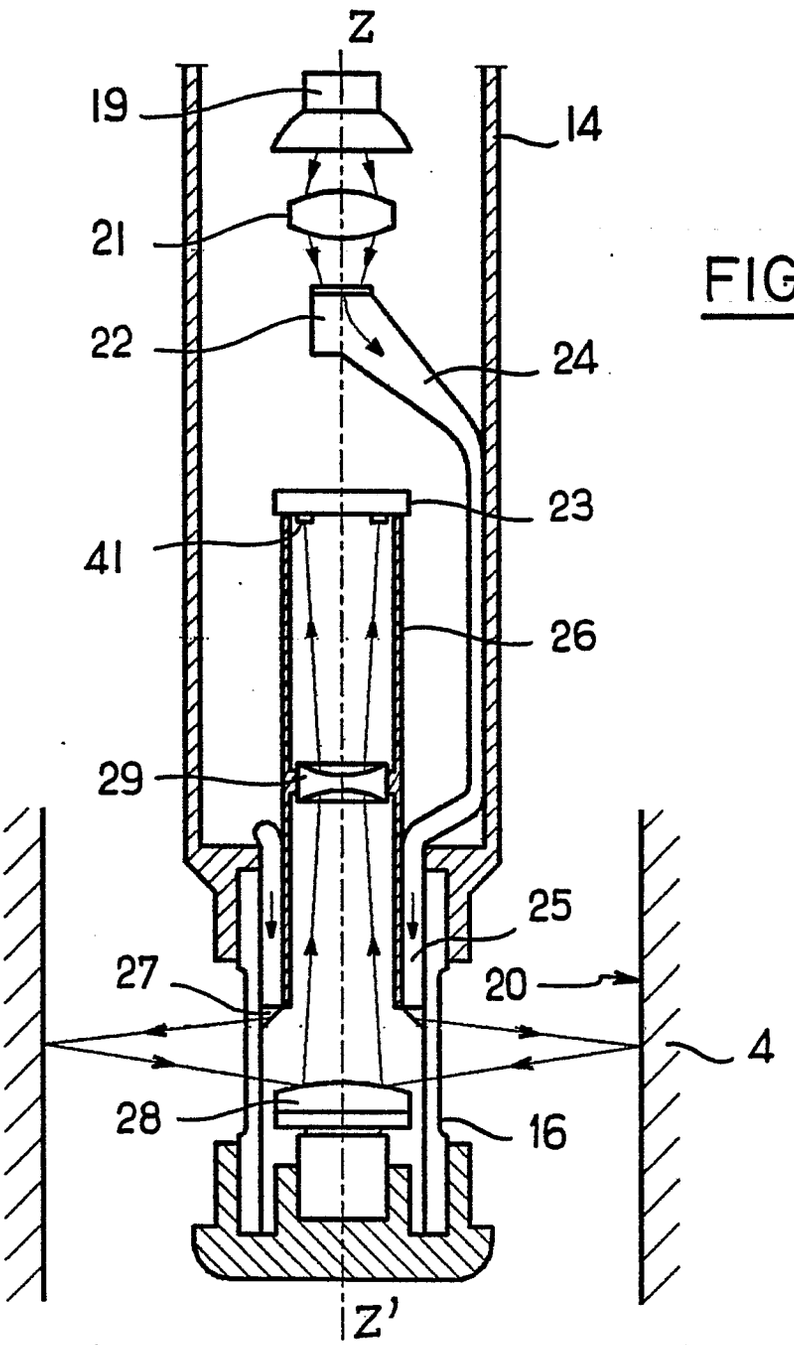


FIG_2

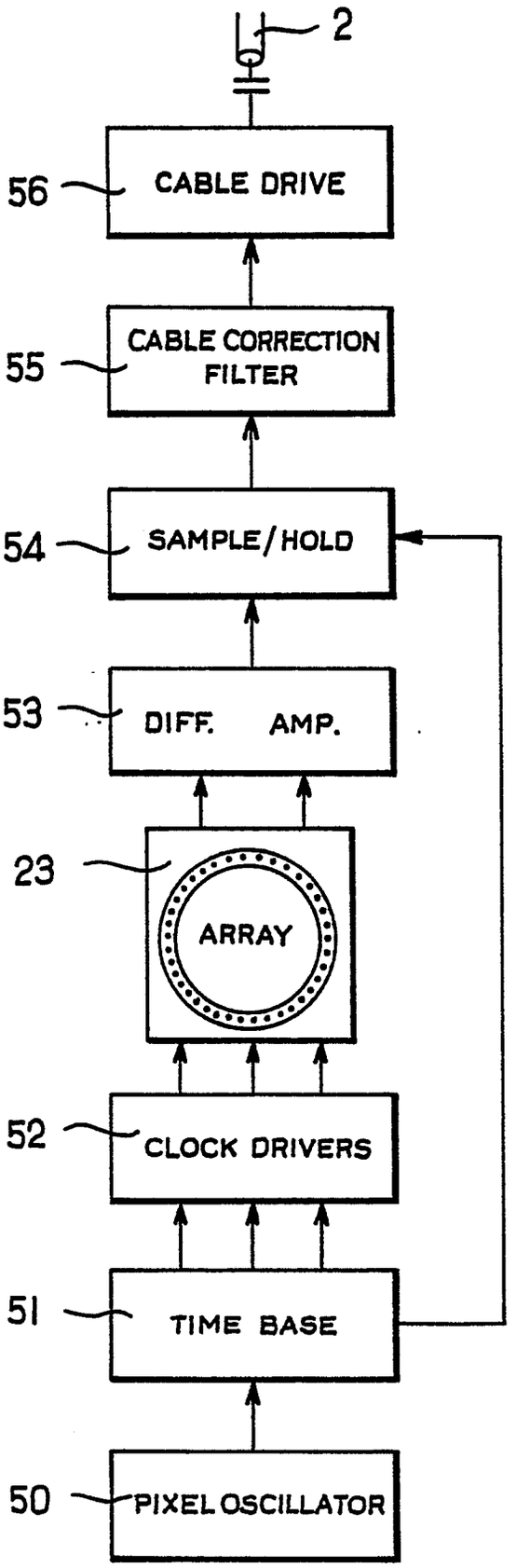

2
56
CABLE DRIVE
55
CABLE CORRECTION FILTER
54
SAMPLE/HOLD
53
DIFF. AMP.
23
ARRAY
52
CLOCK DRIVERS
51
TIME BASE
50
PIXEL OSCILLATOR

FIG_4

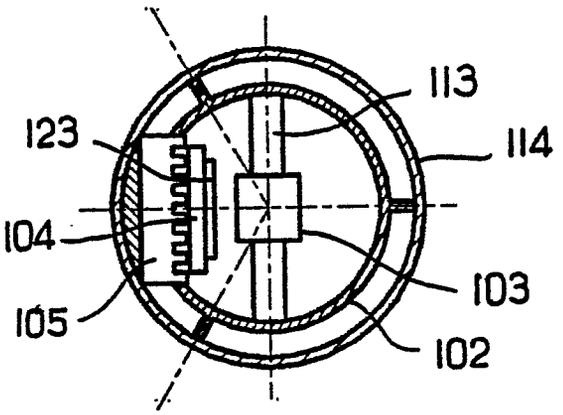
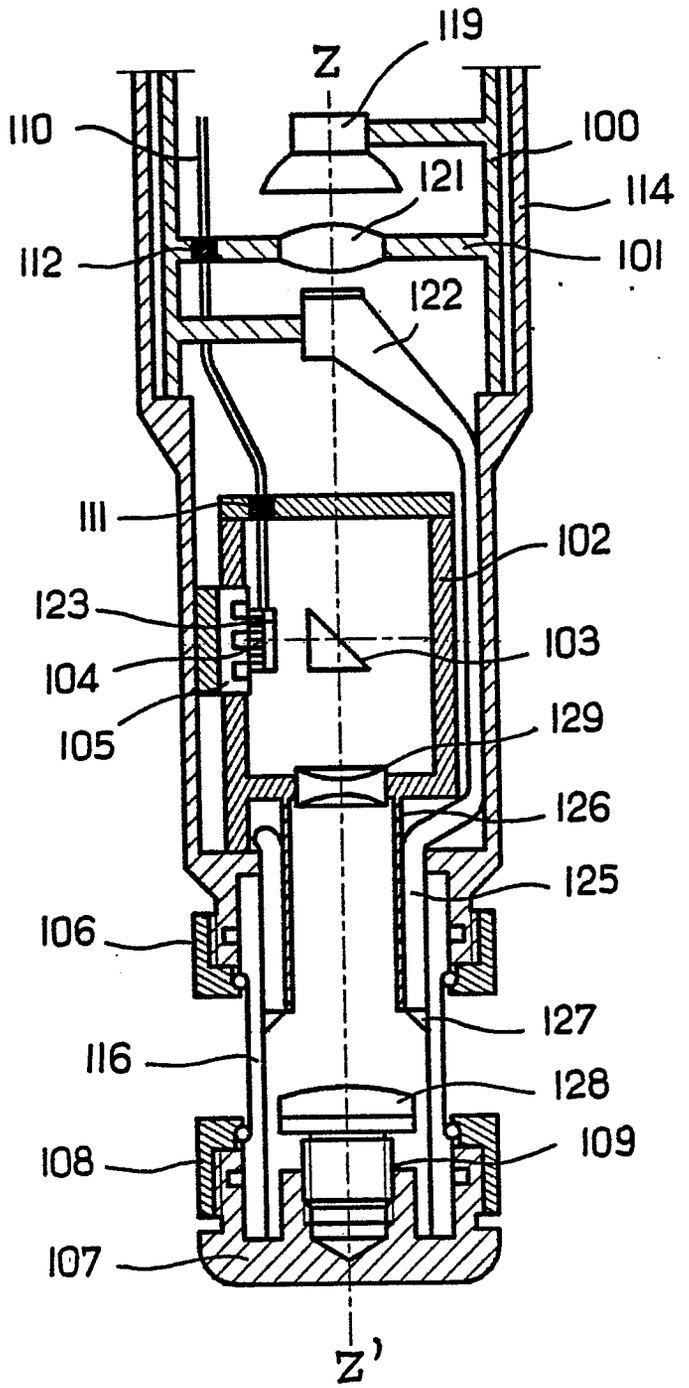

113
123
114
104
103
105
102

FIG_6


119
Z
110
100
121
114
112
101
122
111
102
123
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104
105
129
126
125
106
127
116
128
108
109
107
Z'

FIG_5

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 86 40 2369

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	GB-A-2 047 882 (DIFFRACTO LTD.) * Pages 2,3,13,14; figures 1,17 *	1,3,4,6	H 04 N 7/18
A	DE-A-3 213 652 (SCHÄFTER + KIRCHHOFF) * Pages 16-20; figures 1,2 *	1,2	
A	US-A-3 974 330 (B. ASKOWITH et al.) * Columns 5-7; figures 2a-2d *	1	
A,D	US-A-2 912 495 (J. MOON et al.) * Columns 4-6 *	1	
A	US-A-4 317 632 (V. ORPHAN et al.) * Columns 2,3 *	1,2	TECHNICAL FIELDS SEARCHED (Int. Cl.4) E 21 B 47/00 H 04 N 7/18 G 02 B 23/24
A	DE-A-2 104 095 (ELTRO GmbH) * Pages 4,5 *	5	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25-06-1987	BOEHM CH.E.D.

CATEGORY OF CITED DOCUMENTS

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