DISPLAY DEVICE WITH TIME-MULTIPLEXED LED LIGHT SOURCE

A display device (100) has a time-multiplexed light source (110, 200) including at least two light emitting diode (LED) devices (210, 220) that operate sequentially, and a light combiner (230, 630, 830) that outputs light from the LED devices (210, 220), the light having a first polarization when a first one of the LED devices (210) is turned on, and having a second polarization (220) when a second one of the LED devices is turned on; and a light modulator (122) that receives the light from the light combiner (230, 630, 830). The light modulator (122) is driven to white when the first LED device (210) is turned on, and is driven to black when the second LED device (220) is turned on.
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- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

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DISPLAY DEVICE WITH TIME-MULTIPLEXED LED LIGHT SOURCE

This invention pertains to the field of display devices, and more particularly to light sources for liquid crystal display devices.

A light emitting diode (LED) is commonly used as a light source for some display devices such as a liquid crystal display (LCD) device. LEDs are desirable light sources due to their small size, high reliability, and long life.

Meanwhile, the maximum brightness level is an important characteristic for a display device, and particularly for a projection display device. Projection display devices often display very large images in rooms with a relatively high ambient light level, and in such a case the brightness level of the projection display is a crucial characteristic. Of course, the maximum achievable brightness of a projection display device is governed by the brightness of the light source that is employed.

Accordingly, much research and development effort is underway to increase the brightness level of LEDs to a suitable level for use in projection display devices.

However, it has been discovered that the light output of an LED drops when the LED becomes heated during operation. In US 2003/0218723 A1, this is solved by introducing a non-emission time for each LED by placing the LEDs on a movable section, wherein the LEDs are in an illumination state during a shorter period when in illumination position with respect to the movable section, and in a non-illumination state when in a non-illumination position with respect to the movable section. Thus, the LEDs are not heated to such an extent that the light emission drops significantly. However, a problem with the solution disclosed in US 20031021 8723 A1 is that the movable parts imply a plurality of mechanical constraints. Further, production of mechanically complex moving structures is also a problem.

Accordingly, it would be desirable to provide a display device having a time-multiplexed LED light source. It also would be desirable to provide a light source for a display device employing at least two LED devices that alternatively emit light. It still
further would be desirable to provide such a display and light source which can employ multiple single-color LEDs in each LED device.

In one aspect of the invention, a projection display device comprises a light source, including first and second light emitting diode (LED) devices adapted to alternatively emit light and a polarizing beamsplitter adapted to receive the light from the first LED device at a first light entrance surface, and to receive the light from the second LED device at a second light entrance surface substantially orthogonal to the first light entrance surface, and to output a portion of the light from the first LED device having a first polarization when the first LED device is turned on, and to output a portion of the light from the second LED device having a second polarization when the second LED device is turned on; a liquid crystal display device having a plurality of pixels adapted to receive the light output from the polarizing beamsplitter and to modulate the polarization of the received light; and a driving circuit adapted to supply data signals to the pixels of the liquid crystal display device when the first LED device is turned on, and further adapted to supply inverted data signals to the pixels of the liquid crystal display device when the second LED device is turned on.

In another aspect of the invention, a display device comprises a light source including at least two light emitting diode (LED) devices adapted to operate sequentially and a light combiner adapted to output light from the plurality of LED devices, the light having a first polarization when a first one of the LED devices is turned on, and having a second polarization when a second one of the LED devices is turned on, and a light modulator adapted to receive the light output from the light combiner and to be driven to white when the first one of the LED devices is turned on, and to be driven to black when the second one of the LED devices is turned on.

FIG. 1 shows a projection display system having a time-multiplexed LED light source;

FIG. 2 shows an exemplary time-multiplexed LED light source that can be employed in the projection display system of FIG. 1;

FIG. 3 shows a first alternative LED device that can be employed in the time-multiplexed LED light source of FIG. 2;

FIG. 4 shows a second alternative LED device that can be employed in the time-multiplexed LED light source of FIG. 2;
FIG. 5 shows a third alternative LED device that can be employed in the time-multiplexed LED light source of FIG. 2;

FIG. 6 shows a first embodiment of a polarization conversion system;

FIG. 7 shows a second embodiment of a polarization conversion system;

FIG. 8 shows an exemplary time-multiplexed LED light source, including a polarization conversion system, that can be employed in the projection display system of FIG. 1.

FIG. 1 shows a projection display system 100, including a time-multiplexed LED light source 110, image generating means 120, and projection optics 130, a controller 140, and a display screen 150.

Advantageously, the time-multiplexed LED light source 110 includes a plurality of LED devices that are arranged to operate sequentially to emit light. The LEDs within the time-multiplexed LED light source 110 are each adapted to operate at a reduced duty cycle, whereby they each emit light having a greater brightness than if the LED was operated continuously (100% duty cycle).

FIG. 2 shows an exemplary embodiment of a time-multiplexed LED light source 200 which may be used in the system 100 of FIG. 1. The light source 200 includes first and second LED devices 210, 220 and a polarizing beamsplitter (PBS) 230 adapted to combine and output the light from the first and second LED devices 210, 220.

Beneficially, each of the LED devices 210, 220 in the embodiment shown in FIG. 2 emits bright white light. In the embodiment shown in FIG. 2, the first and second LED devices 210, 220 each comprise a single white LED. However, the LED devices 210, 220 may instead each comprise a plurality of white LEDs, where all of the LEDs of a given LED device are turned ON and OFF at the same time as each other.

Turning again to FIG. 1, beneficially, the image generation means 120 comprises a light modulator 122 and an analyzer 124. Beneficially, the light modulator 122 is a liquid crystal panel, such as a twisted nematic liquid crystal display (LCD) device. The light modulator 122 comprises a plurality of addressable pixels. The analyzer 124 is a polarizing filter with a polarization direction for light transmission.

The controller 140 includes a driving circuit 142 having pixel address and data driving components for addressing and supplying video data to the pixels of the light
modulator 122 to drive the pixels of the light modulator 122. The controller 140 also includes circuitry to control the light generation of the time-multiplexed LED light source 110. More particularly, the controller 140 provides signals to turn on and off the LEDs in the time-multiplexed LED light source 110 at appropriate times so that they alternate sequentially to emit light, thereby also reducing the operating duty-cycle of each LED and correspondingly increasing the brightness of the light output by each LED.

An operation of the time-multiplexed LED light source 200 will first be explained. The first and second LED devices 210, 220 are arranged to operate alternately to emit light. That is, the first and second LED devices 210, 220 are each switched between an “ON” state and an “OFF” state at a certain frequency with a duty cycle that is approximately 50%. When one of the first and second LED devices 210, 220 is “ON,” then the other is “OFF,” and vice versa. When the first LED device 210 is on, the polarizing beamsplitter 230 receives light from the first LED device 210 at a first light entrance surface 232 and outputs through a light exit surface 236 a portion of the light from the first LED device 210 having a first (e.g., “p”) polarization. Meanwhile, when the second LED device 220 is on, the polarizing beamsplitter 230 receives light from the first LED device 210 at a second light entrance surface 234 and outputs through the light exit surface 236 a portion of the light from the second LED device 220 having a second (e.g., “s”) polarization that is orthogonal to the first (p) polarization. Accordingly, the time-multiplexed LED light source 200 output polarized light that alternates between first (p) and second (s) polarizations that are mutually orthogonal.

Furthermore, in case it is desired to display video at a particular frame rate, it is possible to turn on one of the LED devices 210, 220 during the even frame periods, and to turn on the other of the LED devices 210, 220 during the odd frame periods.

An operation of the display system 100 of FIG. 1 will now be explained with reference to the embodiment of the time-multiplexed LED light source 200 of FIG. 2.

The light source 110 supplies polarized light to the image generation means 120. More particularly, as discussed above with respect to FIG. 2, the light source 110 supplies light having a first (e.g., “p”) polarization when the first LED device is “ON,” and supplies light having a second (e.g., “s”) polarization when the second LED device is “ON.”

In operation, the light modulator 122 receives the polarized light from the light source 100. The pixels of the light modulator 122 selectively change the polarization of
the light received from the light source 110 to thereby modulate the light with a desired image. When the light modulator 122 is a twisted nematic LCD, then in the case where no pixel or video data voltage is supplied to a pixel, then the pixel rotates, or changes, the polarization of the light received at that pixel by 90 degrees. On the other hand, when a video or pixel data voltage is applied to a pixel of the twisted nematic LCD light modulator 122, then the rotation or change of the polarization of the light at that pixel is suppressed.

Meanwhile, the polarization direction for light transmission of the analyzer 124 is the same as either the first (p) polarization or the orthogonal second (s) polarization of the light from the light source 110. For example, when the polarization direction of the analyzer 124 is the first (p) polarization, then the analyzer 124 passes therethrough to the projection optics 130 light having the first (p) polarization, while rejecting light having the orthogonal second (s) polarization of light from the light source 110.

In the discussion to follow, it is assumed that the polarization direction of the analyzer 124 is the second (s) polarization.

As noted above, during the time intervals when the first LED device 210 is on, the light output to the light modulator 122 from the light source 110 has the first (e.g., “p”) polarization. During these time intervals, if no video or pixel data voltage is applied to a pixel, the pixel will rotate, or change, the polarization of the received light having the first (p) polarization by 90 degrees such that it exits the light modulator 122 having the orthogonal second (s) polarization. Accordingly, light from the pixel having no video or pixel data voltage applied thereto passes through the analyzer 124 having the second (s) polarization to be provided to the projection optics 130. On the other hand, if a video or pixel data voltage is applied to a pixel, then the rotation or change of the polarization of the light having the first (p) polarization is suppressed at that pixel. In that case, light from the pixel having a video or pixel data voltage applied thereto is blocked or rejected by the analyzer 124 having the second (s) polarization such that the pixel will appear dark or black in the display. This mode of operating the light modulator 122 is referred to as “driving to black” or “normally white” mode.

Meanwhile, during time intervals when the second LED device 220 is on, the light output to the light modulator 122 from the light source 110 has the second (e.g., “s”) polarization. During these time intervals, if no video or pixel data voltage is applied to a pixel, the pixel will rotate, or change, the polarization of the received light having the
second (s) polarization by 90 degrees such that it exits the light modulator 122 having the orthogonal first (p) polarization. Accordingly, light from the pixel having no video or pixel data voltage applied thereto is blocked by the analyzer 124 having the second (s) polarization from being transmitted to the projection optics 130 such that the pixel will appear dark or black in the display. On the other hand, if a video or pixel data voltage is applied to a pixel, then the rotation or change of the polarization of the light having the second (s) polarization is suppressed at that pixel. Accordingly, light from the pixel having a video or pixel data voltage applied thereto passes through the analyzer 124 having the second (s) polarization to be provided to the projection optics 130. This mode of operating the light modulator 122 is referred to as “driving to white” or “normally black” mode.

In short, the light modulator 122 is controlled to be driven to black (operates in a normally white mode), when the first LED device 210 is turned on, and is controlled to be driven to white (operates in a normally black mode), when the second LED device 220 is turned on.

The controller 140 controls light generation of the light source 110 and image generation of the image generating means 120 to be properly synchronized. More specifically, when the controller 140 turns on an LED of the first LED device 210, the driving circuit 142 of the controller 140 supplies video data signals to the pixels of the light modulator 122 having a “normal” polarity to drive the light modulator 120 to black.

Meanwhile, when the controller 140 turns on an LED of the second LED device 220, the driving circuit 142 of the controller 140 inverts the video data signals, and supplies the inverted video data signals having the “inverted” polarity to the pixels of the light modulator 122 to drive the light modulator 120 to white.

Furthermore, the controller 140 can control sequential color divided image generation, where first (e.g., red), second (e.g., green), and third (e.g., blue) images are generated sequentially, and displayed rapidly, such that a viewer experiences a full-color image. To that end, FIG. 3 shows a first alternative LED device 300 that can be employed for the first and second LED devices 210, 220 in the time-multiplexed LED light source of FIG. 2 to allow sequential color divided image generation.

The LED device 300 includes first (e.g., red), second (e.g., green), and third (e.g., blue) LEDs 310, 320 and 330, and first and second dichroic filters 325 and 335. The light
generated by each of the three LEDs 310, 320 and 330 is recombined by means of the
dichroic filters 325 and 335. These filters are commonly used in projectors and have the
property to transmit one part of the visible spectrum while reflecting the complementary
part.

The embodiment of the LED device 300 of FIG. 3 can easily be extended to more
than three primary colors. In particular, to obtain white light, it is especially advantageous
to combine the light of a single red LED, a single blue LED, and two LEDs emitting light
in the green part of the spectrum. The spectrum of both green LEDs should not overlap too
much in order to be able to combine their light by means of a dichroic filter.

FIG. 4 shows a second alternative LED device 400 that employs more than three
colored LEDs 410, 420, 430 and 440 to obtain white light. Beneficially, LEDs 430 and
440 both emit green colored light.

FIG. 5 shows a third alternative LED device 500 that can be employed for the first
and second LED devices 210, 220 in the time-multiplexed LED light source of FIG. 2.
The device 500 employs a dichroic cube 510 to combine the light from the three LEDs
310, 320 and 330.

In the light source 200 of FIG. 2, approximately half of the light from each LED
device 210, 220 is lost as it passes through the PBS 230 such that it does not reach the
output of the light source 200. More specifically, when the first LED device 210 is on,
then the s-polarized light of the first LED device 210 is reflected by the PBS 230 and does
not reach the light exit surface 236 of the PBS 230. Similarly, when the second LED
device 220 is on, then the p-polarized light of the second LED device 220 is not reflected
by the PBS 230 and does not reach the light exit surface 236 of the PBS 230.

FIG. 6 shows a polarization conversion system (PCS) 600, for directing all light in
one direction, with a uniform polarization. The PCS 600 comprises a PBS 630, a light
coupling element 660, and a half-wave retarder 680. An operation of the PCS 600 will
now be explained. When first LED device 210 is turned on, it emits unpolarized light to
the PBS 630, which transmits p-polarized light to an output (light exit surface 636), and
reflects the s-polarized light to the light coupling element 660. The light coupling element
660 reflects the s-polarized light to the half-wave retarder 680, which converts the light to
the p-polarization. Thus, all light from the first LED device 210 is output as p-polarized
light. Meanwhile, when second LED device 220 is turned on, it emits unpolarized light to
the PBS 630, which reflects s-polarized light to an output and transmits the p-polarized light to the light coupling element 660. The light coupling element 660 reflects the p-polarized light to the half-wave retarder 680, which converts the light to the s-polarization. Thus, all light from the second LED device 220 is output as s-polarized light.

FIG. 7 shows a second embodiment of a PCS 700 for directing all light in one direction, with a uniform polarization. The PCS 700 comprises a PBS 730, a light coupling element 760, and a half-wave retarder 780. When first LED device 210 is turned on, it emits unpolarized light to the PBS 730, which transmits s-polarized light to the retarder 780 and reflects the p-polarized light to the light coupling element 760. The light coupling element 760 reflects the p-polarized light to the output. The retarder 780 converts the s-polarized light to the p-polarization. Thus, all light from the first LED device 210 is output as p-polarized light. Meanwhile, when second LED device 220 is turned on, it emits unpolarized light to the PBS 730, which reflects p-polarized light to the retarder 780 and transmits the s-polarized light to the light coupling element 760. The light coupling element 760 reflects the s-polarized light to the output. The retarder 780 converts the p-polarized light to the s-polarization. Thus, all light from the second LED device 220 is output as s-polarized light.

A polarization conversion system structure can also be used in any of the LED devices of FIGs. 3-5.

FIG. 8 shows an embodiment of a light source 800 that includes a polarization conversion system 830. The light source 800 is similar to the light source 200 of FIG. 2, except the PBS 230 of FIG. 2 has been replaced by the PCS 830 of FIG. 8. That is, instead of (or in addition to) including one or more PCS’s in each of the LED devices 810 and 820, light from the two LED devices 810, 820 is combined by the PCS 830. The operation of the light source 800 is otherwise the same as the operation of the light source 2000 which has been explained in detail above.

While preferred embodiments are disclosed herein, many variations are possible which remain within the concept and scope of the invention. For example, the arrangement shown in FIG. 2 and described above can also be used in three-panel display systems where each panel produces modulated light having a different color (e.g., red, green, and blue). In that case, the arrangement shown in FIG. 2 can be applied to each individual panel of the display system, and the light transmitted by the panels can be recombined by means of
a dichroic cube similar to the one shown in FIG. 5 before being applied to the projection optics 130. Such variations would become clear to one of ordinary skill in the art after inspection of the specification, drawings and claims herein. The invention therefore is not to be restricted except within the spirit and scope of the appended claims.
CLAIMS:

1. A projection display device comprising:
   a light source (110, 200), comprising,
   first and second light emitting diode (LED) devices (210, 220) adapted to
   alternatively emit light, and
   a polarizing beamsplitter (230, 630, 830) adapted receive the light from the
   first LED device (210) at a first light entrance surface (232), and to receive the light from
   the second LED device (220) at a second light entrance surface (234) substantially
   orthogonal to the first light entrance surface (232), and to output a portion of the light from
   the first LED device (210) having a first polarization when the first LED device (210) is
   turned on, and to output a portion of the light from the second LED device (220) having a
   second polarization when the second LED device (220) is turned on;
   a liquid crystal display device (122) having a plurality of pixels adapted to receive
   the light output from the polarizing beamsplitter (230, 630, 830) and to modulate the
   polarization of the received light; and
   a driving circuit (142) adapted to supply data signals to the pixels of the liquid
   crystal display device (122) when the first LED device (210) is turned on, and further
   adapted to supply inverted data signals to the pixels of the liquid crystal display device
   (122) when the second LED device (220) is turned on.

2. The display device (100) of claim 1, wherein the liquid crystal device (122) is
   driven to black when the first LED device (210) is turned on and is driven to white when
   the second LED device (220) is turned on.

3. The display device (100) of claim 1, wherein each of the first and second LED
   devices (210, 220) comprises a plurality of LEDs that each emit white light.

4. The display device (100) of claim 1, wherein each of the first and second LED
   devices (210, 220, 300, 400, 500) comprises:
   a first LED (310, 410) adapted to emit a first colored light;
a second LED (320, 420) adapted to emit a second colored light; and
a third LED (330, 430) adapted to emit a third colored light.

5. The display device (100) of claim 1, wherein each of the first and second LED devices (210, 220, 400) further comprises a fourth LED (440) adapted to emit the third colored light.

6. The display device of claim 2, wherein each of the first and second LED devices (210, 220) further comprises
a first dichroic filter (325) adapted to receive the first colored light and the second colored light and to output combined first and second colored light; and
a second dichroic filter (335) adapted to receive the combined first and second colored light, and to receive the third colored light, and to output combined first, second, and third colored light.

7. The display device (100) of claim 1, further comprising:
a light coupling element (660) adapted to receive from the polarizing beamsplitter (630) a second portion of the light from the first LED device (210) having the second polarization when the first LED device (210) is turned on, and a second portion of the light from the second LED device (220) having the first polarization when the second LED device (220) is turned on, to output the second portion of the light from the first LED device (210) when the first LED device (210) is turned on and to output the second portion of the light from the second LED device (220) when the second LED device (220) is turned on; and
a half-wave retarder (680) adapted to receive from the light coupling element (660) the second portion of the light from the first LED device (210) when the first LED device (210) is turned on, to convert the second portion of the light from the first LED device (210) to have the first polarization, and to output to the liquid crystal device (122) the second portion of the light from the first LED device (210) having the first polarization, and further adapted to receive from the light coupling element (660) the second portion of the light from the second LED device (220) when the second LED device (220) is turned on, to convert the second portion of the light from the second LED device (220) to have the
second polarization, and to output to the liquid crystal device (122) the second portion of the light from the second LED device (220) having the second polarization.

8. The display device (100) of claim 1, further comprising an analyzer (124) is adapted to transmit therethrough light having the first polarization and to reject light having the second polarization.

9. A display device (100), comprising:
a light source (110, 200), comprising,
at least two light emitting diode (LED) devices (210, 220) adapted to operate sequentially, and
a light combiner (230, 630, 830) adapted to output light from the LED devices (210, 220), the light having a first polarization when a first one of the LED devices (210) is turned on, and having a second polarization (220) when a second one of the LED devices is turned on; and
a light modulator (122) adapted to receive the light output from the light combiner (230, 630, 830) and to be driven to white when the first one of the LED devices (210) is turned on, and to be driven to black when the second one of the LED devices (220) is turned on.

10. The display device of claim 9, wherein the light combiner (230) is a polarizing beamsplitter.

11. The display device of claim 9, wherein the light combiner (630, 830) comprises a polarization conversion system.

12. The display device of claim 9, wherein each of the LED devices (210, 220) includes a LED that emits white light.

13. The display device of claim 9, wherein each of the LED devices (210, 220) includes a plurality of LEDs that each emit white light.
14. The display device of claim 9, wherein each of the LED devices (210, 220, 300, 400, 500) comprises:
   a first LED (310, 410) that emits light having a first color;
   a second LED (320, 420) that emits light having a second color;
   a third LED (330, 430) that emits light having a third color.

15. The display device of claim 14, wherein each of the first and second LED devices (210, 220) further comprises
   a first dichroic filter (325) adapted to receive the first colored light and the second colored light and to output combined first and second colored light; and
   a second dichroic filter (335) adapted to receive the combined first and second colored light, and to receive the third colored light, and to output combined first, second, and third colored light.

16. The display device (100) of claim 14, wherein each of the first and second LED devices (210, 220, 400) further comprises a fourth LED (440) adapted to emit the third colored light.

17. The display device (100) of claim 9, further comprising an analyzer (124) is adapted to transmit therethrough light having the first polarization and to reject light having the second polarization.

18. A display device comprising:
    three optical processing systems each adapted to produce modulated light having a different color, each optical system comprising,
    a light source (110, 200), including,
    at least two light emitting diode (LED) devices (210, 220) adapted to operate sequentially, and
    a light combiner (230, 630, 830) adapted to output light from the LED devices (210, 220), the light having a first polarization when a first one of the LED devices (210) is turned on, and having a second polarization (220) when a second one of the LED devices is turned on, and
a light modulator (122) adapted to receive the light output from the light combiner (230, 630, 830) and to be driven to white when the first one of the LED devices (210) is turned on, and to be driven to black when the second one of the LED devices (220) is turned on; and

a dichroic cube adapted to combine the modulated light from each of the three optical systems.
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

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According to International Patent Classification (IPC) or to both national classifications and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>US 6 224 216 B1 (PARKER FRED ET AL) 1 May 2001 (2001-05-01) 7</td>
<td>1-6,8-18</td>
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<td>Y</td>
<td>abstract column 3, line 66 - column 8, line 63; figure 2 1-8,10, 11,17,18</td>
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:

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**A** document member of the same patent family

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Name and mailing address of the ISA

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<td>&quot;LIQUID CRYSTAL DISPLAY THREE PANEL PROJECTOR USING THREE PRIMARY COLORS LIGHT EMITTING DIODE LIGHT SOURCES&quot; IBM TECHNICAL DISCLOSURE BULLETIN, IBM CORP. NEW YORK, US, vol. 40, no. 4, April 1997 (1997-04), pages 201-205, XP000728313 ISSN: 0018-8689 the whole document page 201 - page 203; figures 1-3</td>
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