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Dalby et al.

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(54) **OPTICAL FLUID ANALYZER**

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§ 371 (c)(1),
(2) Date: **Aug. 22, 2019**

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PCT Pub. Date: **Aug. 30, 2018**

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G01N 21/64 (2006.01)
G01N 21/27 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G01N 21/276*** (2013.01); ***E21B 49/081*** (2013.01); ***E21B 49/10*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC E21B 49/081; E21B 49/10; G01J 3/0218; G01J 3/0297; G01J 3/10; G01J 3/12; G01J 3/14; G01J 3/42; G01J 3/4406; G01J 2003/1213; G01J 2003/1221; G01J 2003/1234; G01J 2003/1282; G01J 2003/2869; G01N 21/05; G01N 21/276; G01N 21/359; G01N 21/43; G01N 21/552; G01N 21/645; G01N 33/2823; G01N 2021/1734; G01N 2021/6471
See application file for complete search history.

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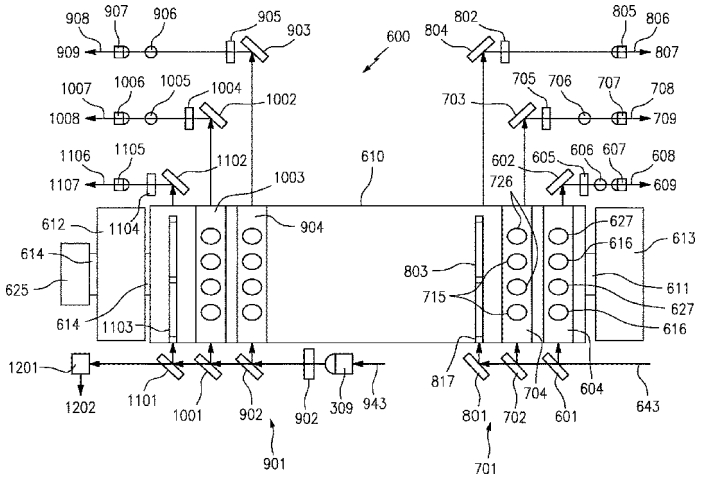
(74) *Attorney, Agent, or Firm* — Matthew J Patterson

(57) **ABSTRACT**

Apparatus and methods for performing optical analyses in a harsh environment are disclosed. Some of the systems and methods of the present disclosure include fluorescence, absorption, and reflectance detection using a drum spectrometer. Other systems and methods of the present disclosure include a measurement channel and a parallel reference channel concurrently filtering optical signals.

20 Claims, 13 Drawing Sheets



(51) **Int. Cl.**

G01N 33/28	(2006.01)
E21B 49/08	(2006.01)
E21B 49/10	(2006.01)
G01J 3/10	(2006.01)
G01J 3/14	(2006.01)
G01J 3/12	(2006.01)
G01N 21/17	(2006.01)
G01N 21/552	(2014.01)
G01N 21/43	(2006.01)
G01J 3/02	(2006.01)

(52) **U.S. Cl.**

CPC . ***G01J 3/10*** (2013.01); ***G01J 3/12*** (2013.01); ***G01J 3/14*** (2013.01); ***G01N 21/645*** (2013.01); ***G01N 33/2823*** (2013.01); *G01J 3/0218* (2013.01); *G01J 2003/1213* (2013.01); *G01N 21/43* (2013.01); *G01N 21/552* (2013.01); *G01N 2021/1734* (2013.01); *G01N 2021/6471* (2013.01)

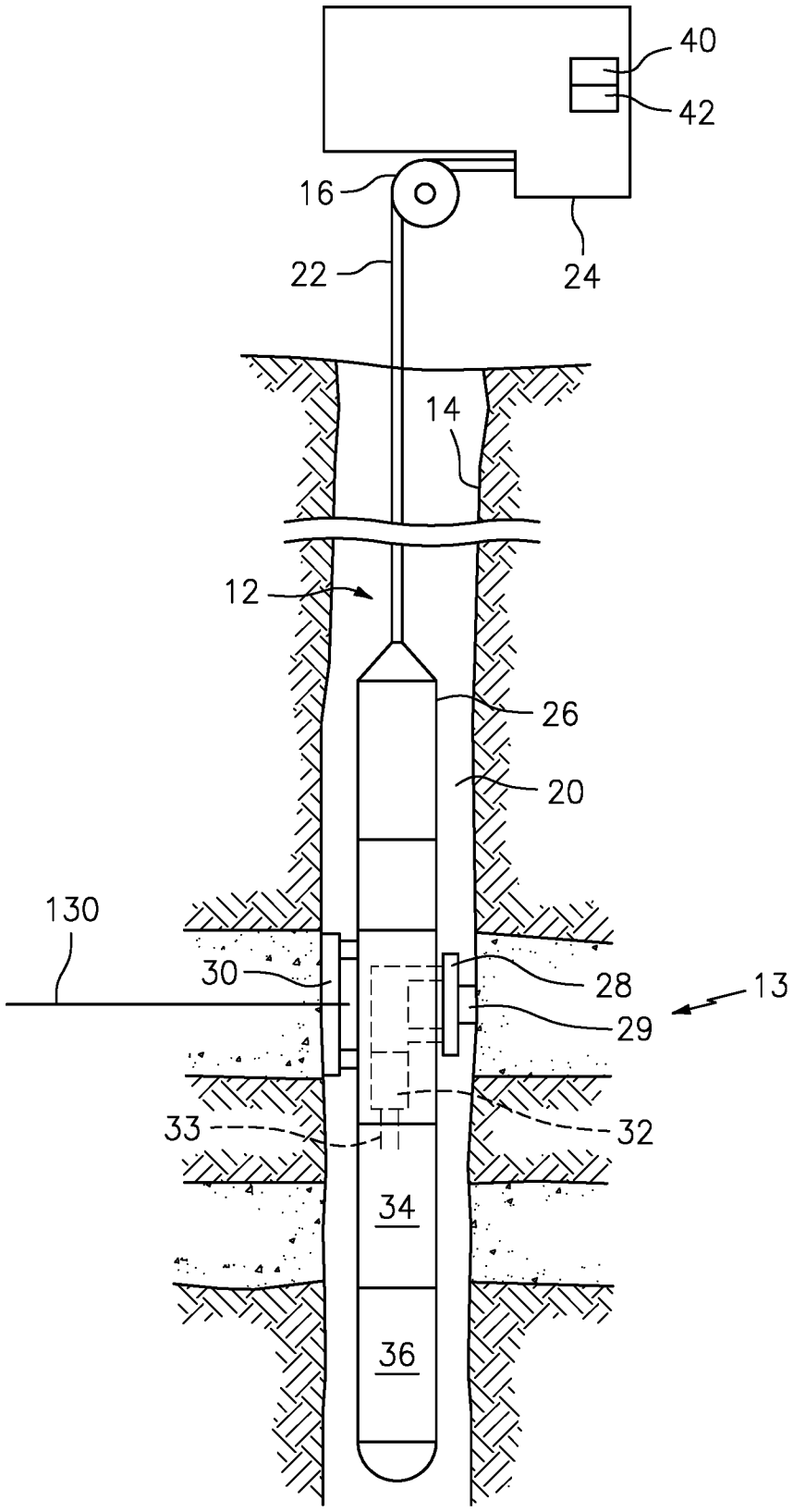


FIG. 1

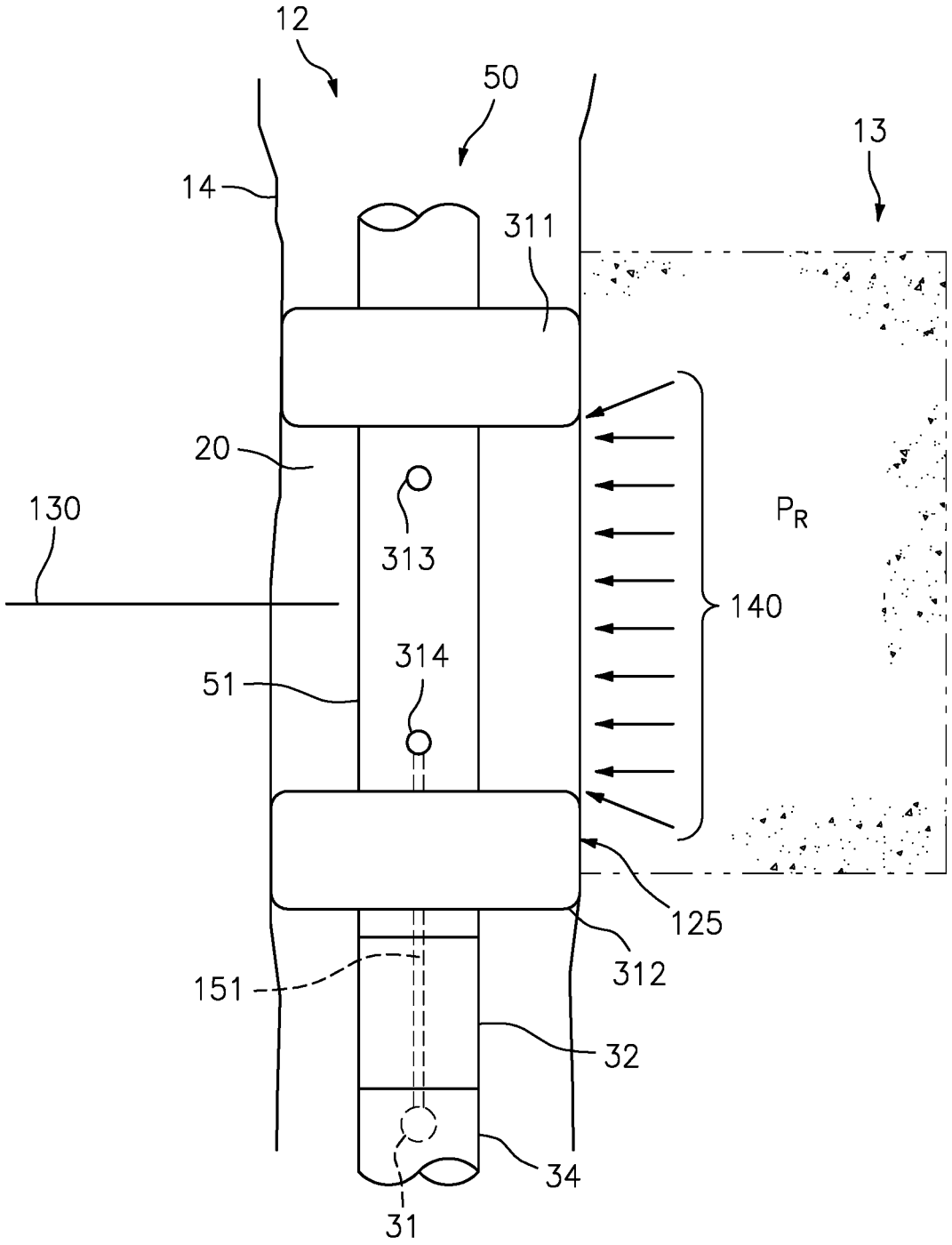


FIG. 2

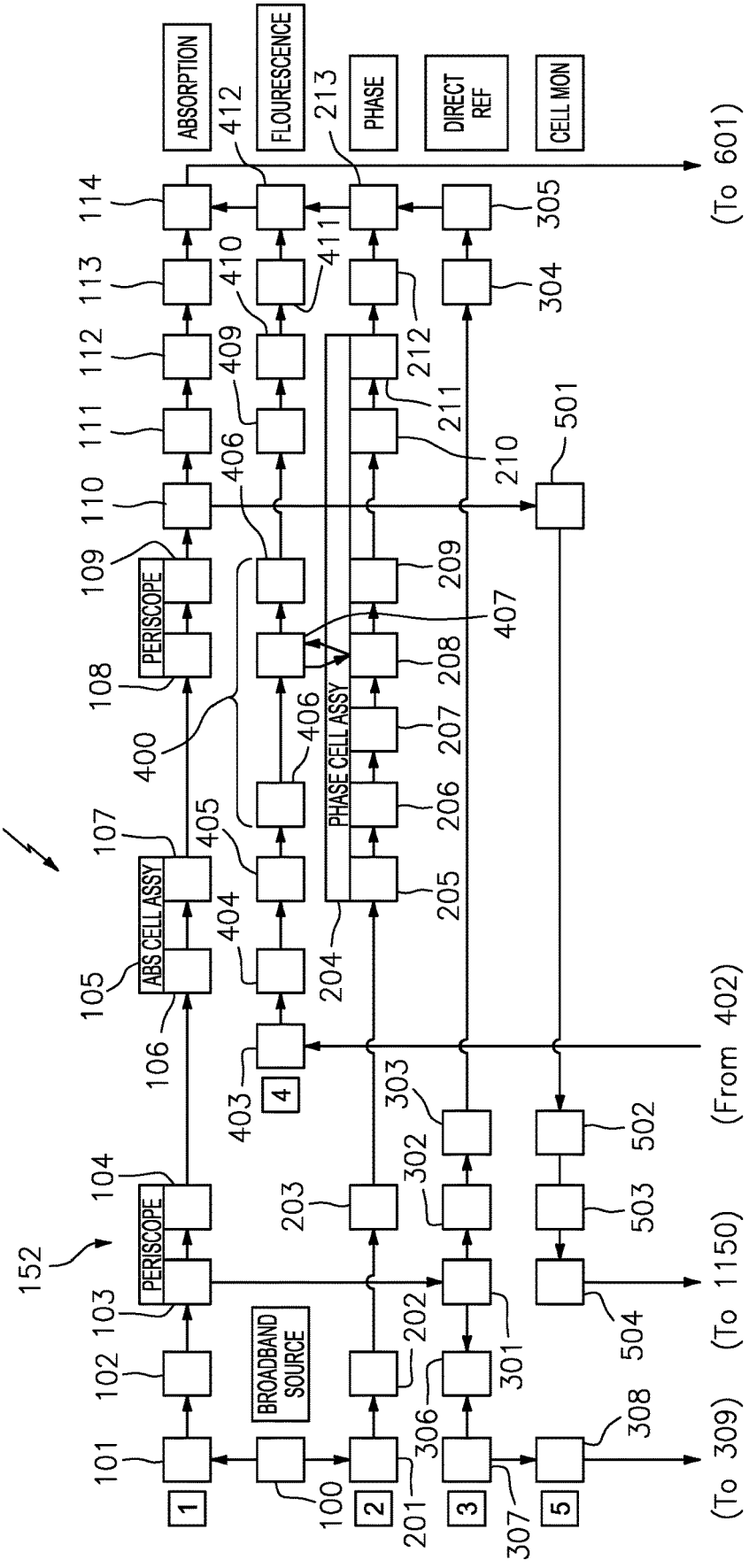

ABSORPTION
FLOURESCENCE
PHASE
DIRECT REF
CELL MON
PERISCOPE
ABS CELL ASSY
PHASE CELL ASSY
BROADBAND SOURCE
(To 601)
(From 402)
(To 1150)
(To 309)
32
152
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
201
202
203
204
205
206
207
208
209
210
211
212
213
301
302
303
304
305
306
307
308
400
403
404
405
406
407
409
410
411
412
501
502
503
504
1
2
3
4
5

FIG. 3

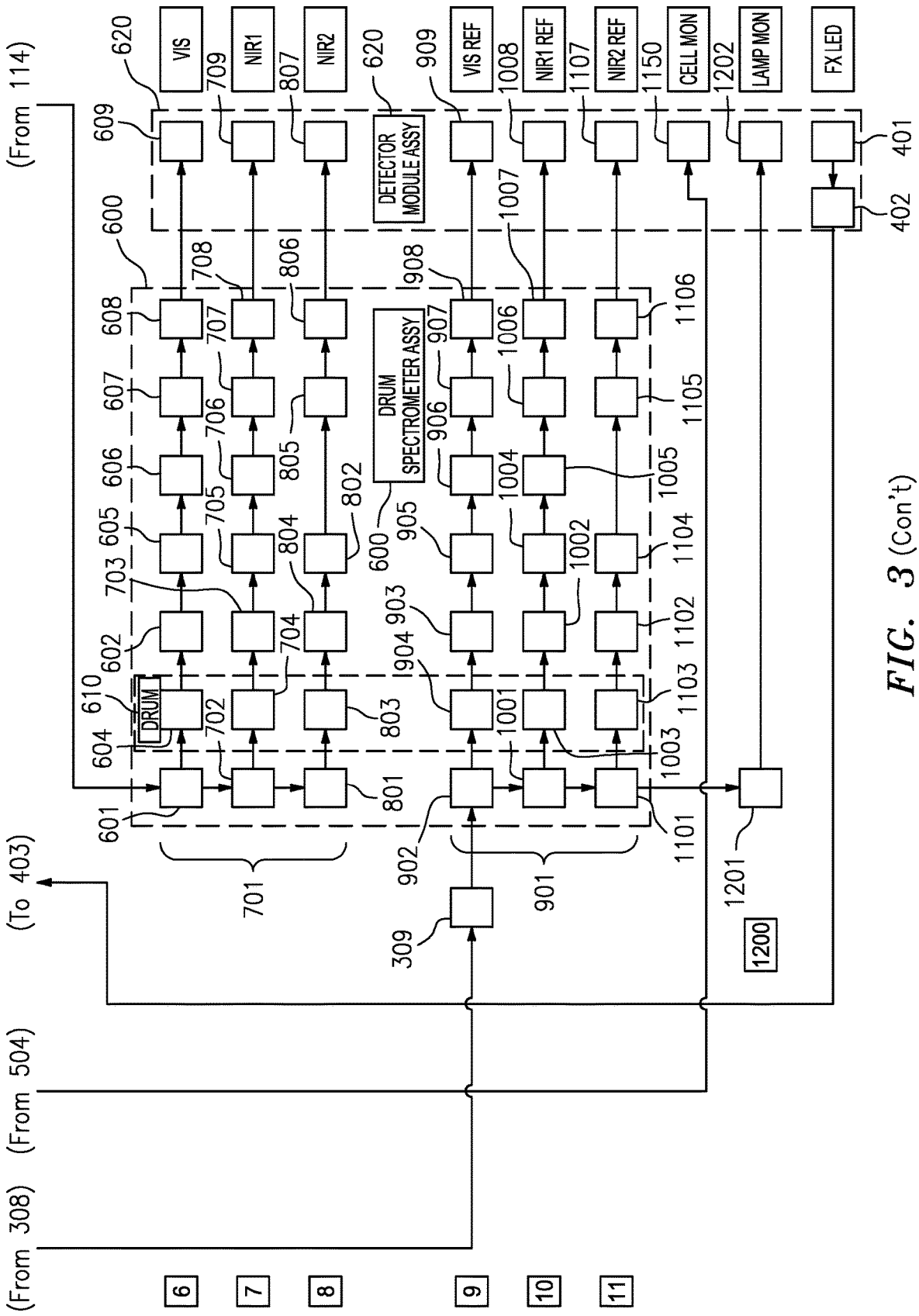

(From 114)
(To 403)
(From 504)
(From 308)
VIS
NIR1
NIR2
DETECTOR MODULE ASSY
VIS REF
NIR1 REF
NIR2 REF
CELL MON
LAMP MON
FX LED
DRUM
DRUM SPECTROMETER ASSY
1200
6
7
8
9
10
11

FIG. 3 (Con't)

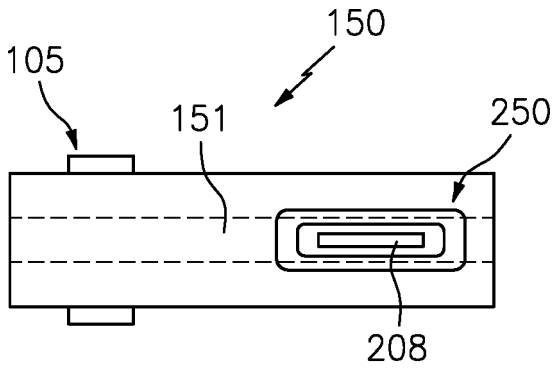


FIG. 4

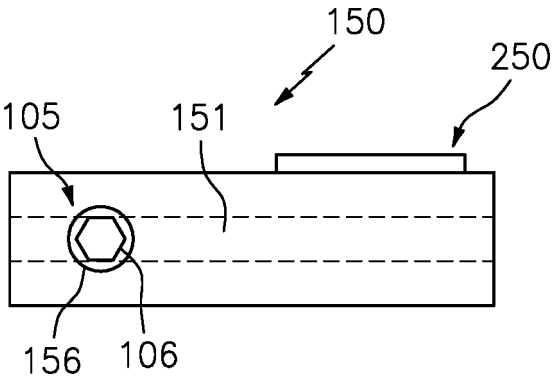


FIG. 5

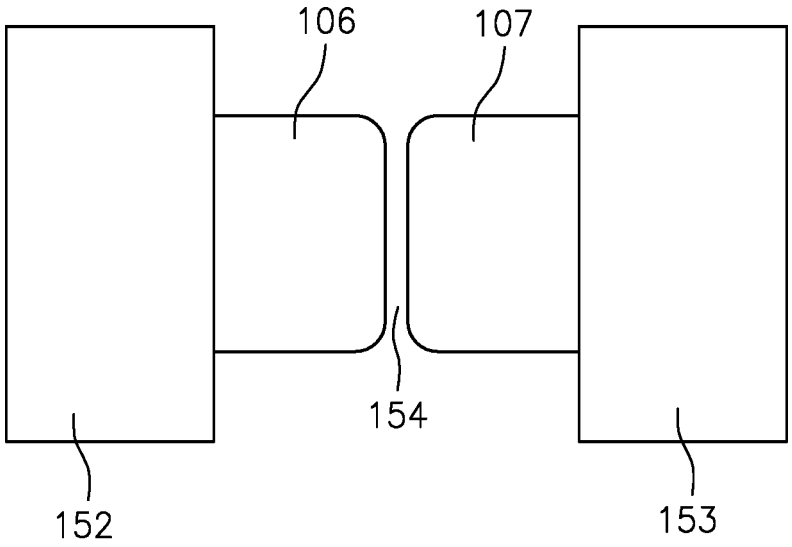

106
107
154
152
153

FIG. 6

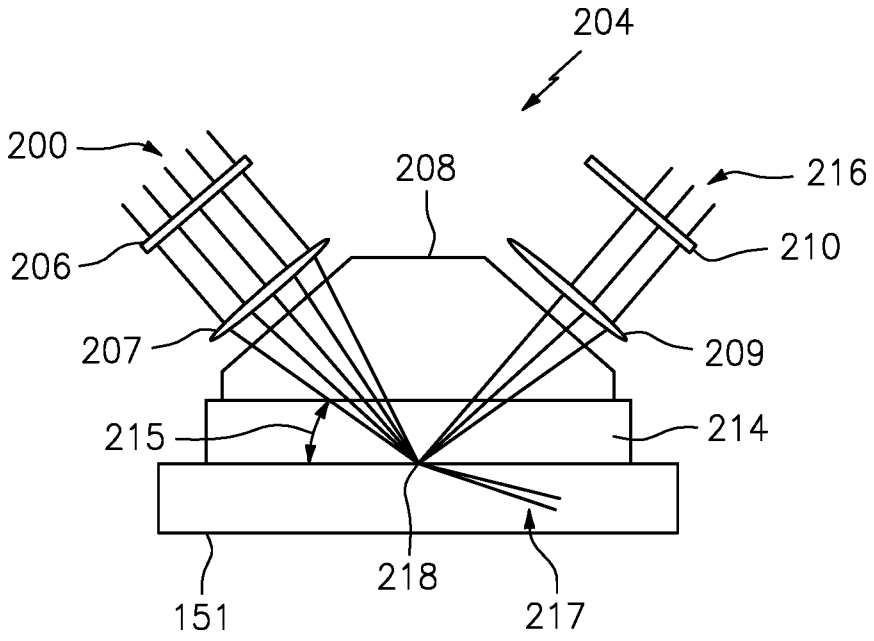

204
200
208
216
206
210
207
209
215
214
218
151
217

FIG. 7

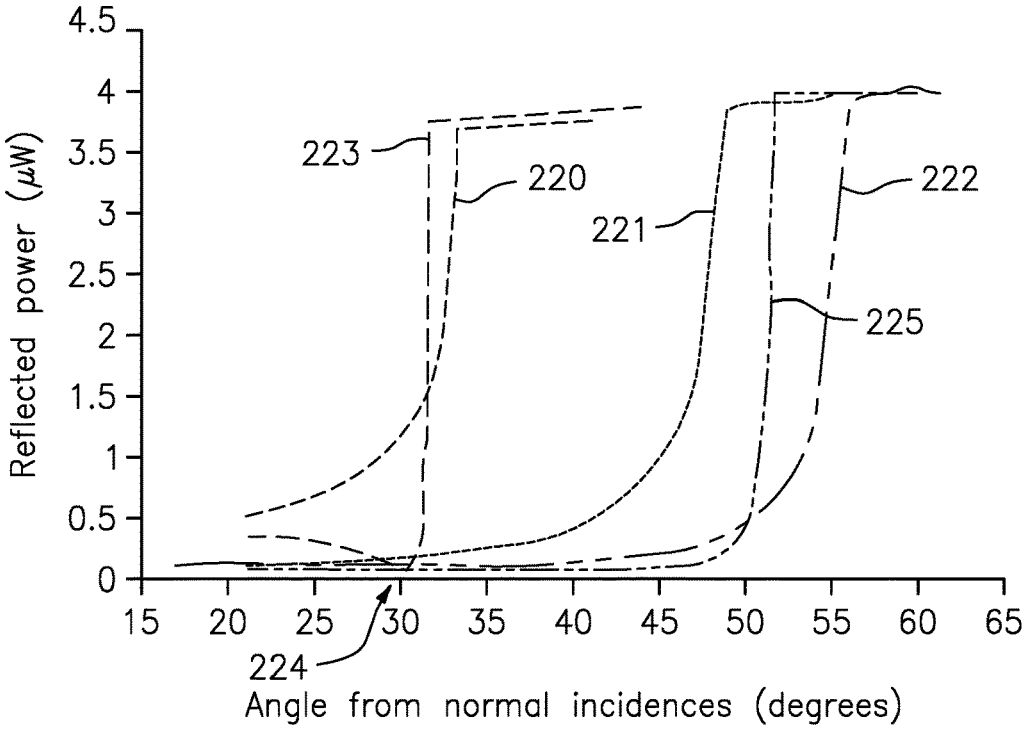

4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Reflected power (μW)
223
220
221
222
225
224
15
20
25
30
35
40
45
50
55
60
65
Angle from normal incidences (degrees)

FIG. 8

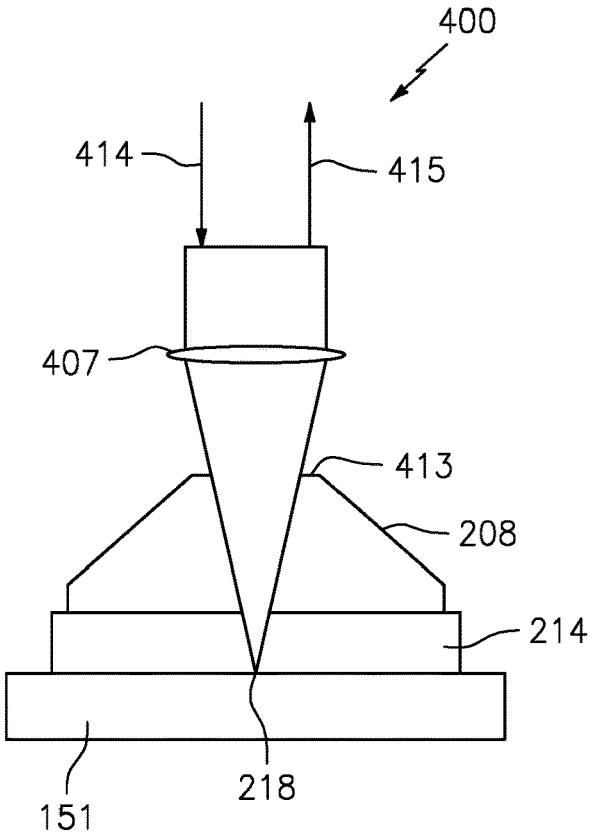

400
414
415
407
413
208
214
218
151

FIG. 9

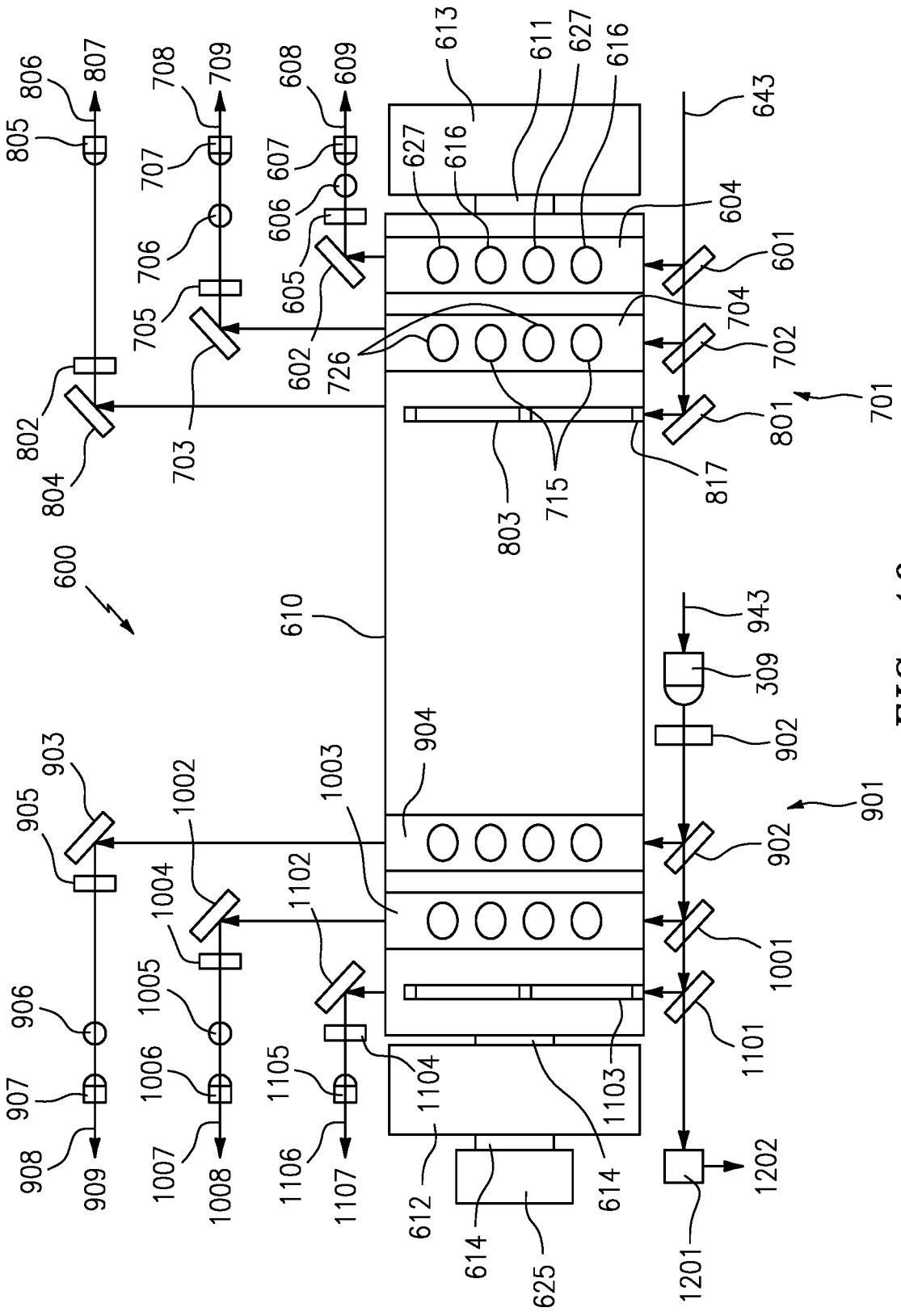
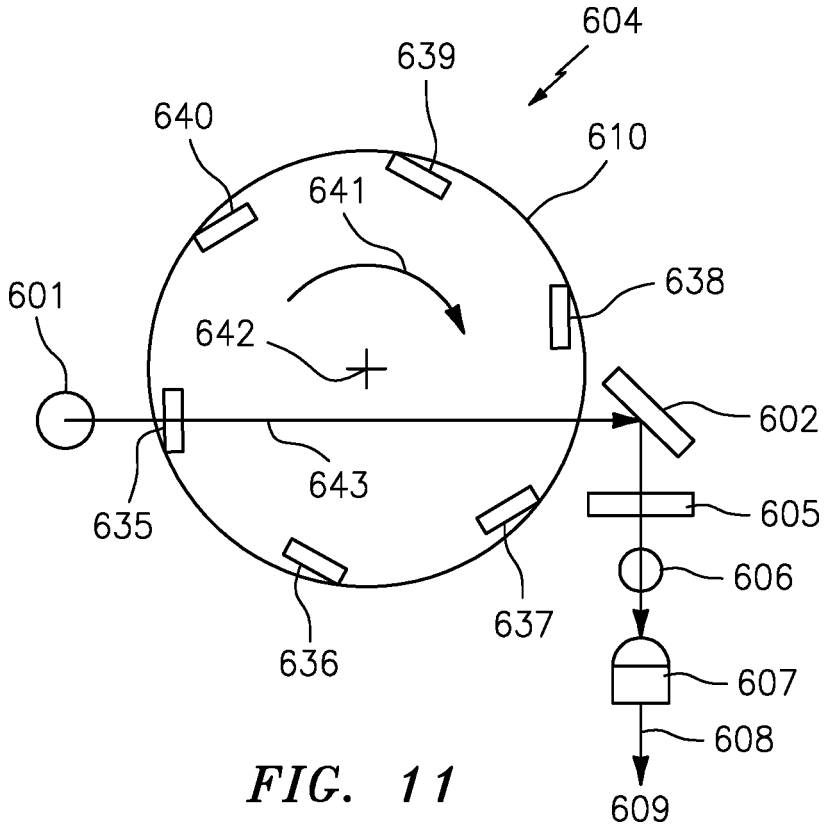

600
610
613
611
627
616
643
604
601
704
702
701
801
817
803
715
602
726
703
802
804
805
806
807
708
709
707
706
705
608
609
607
606
605
943
309
902
901
904
903
905
1002
1003
1004
1102
1005
1006
1105
1104
1103
1101
1001
1202
1201
906
907
908
909
1007
1008
1106
1107
612
614
625

FIG. 10


604
639
640
610
641
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601
642
602
643
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606
637
636
607
608
609

FIG. 11

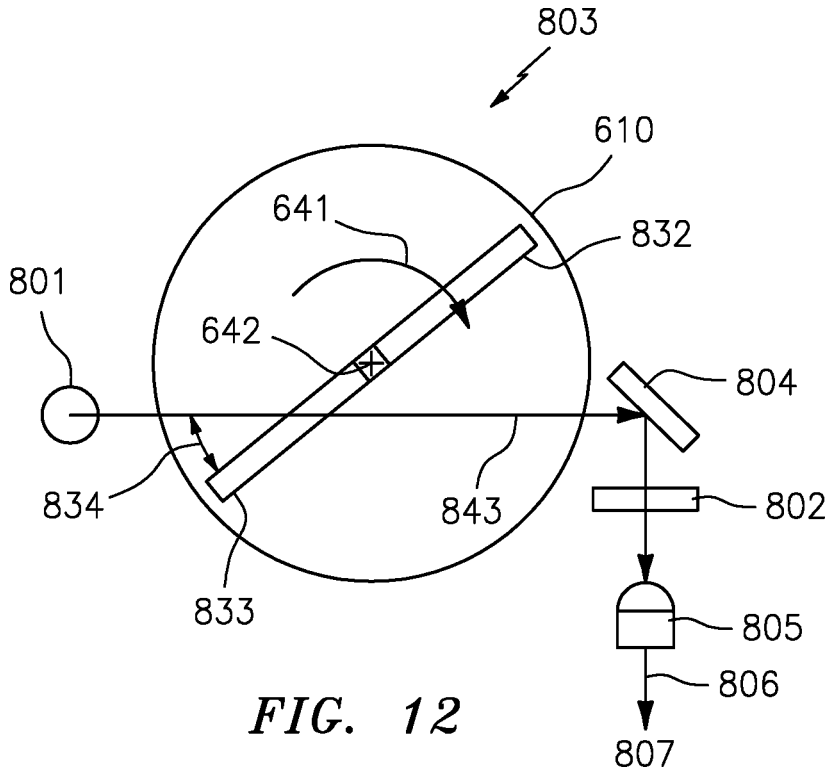
803
610
641
832
801
642
804
834
843
802
833
805
806
807

FIG. 12

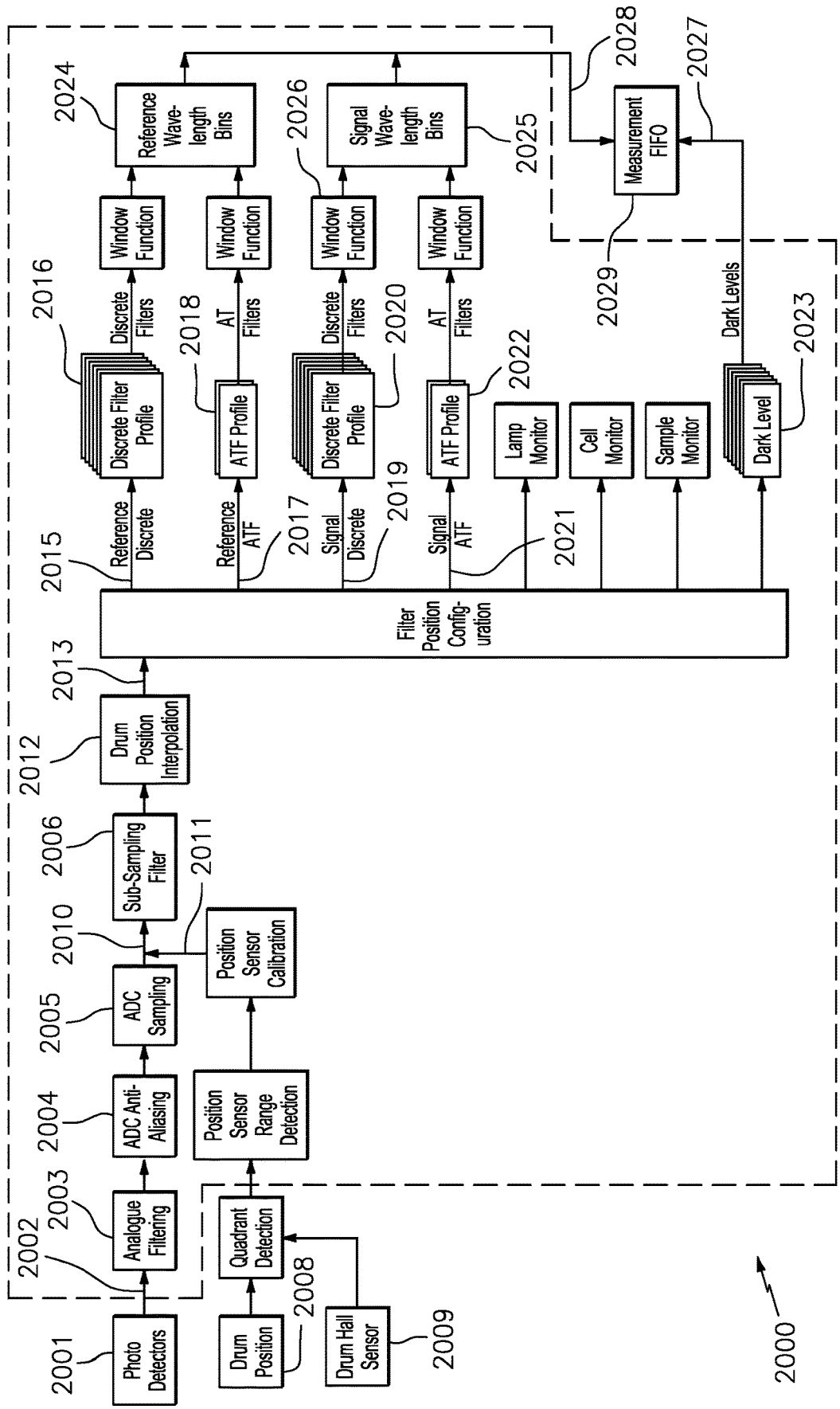
2000
2001
Photo Detectors
2002
2003
Analogue Filtering
2004
ADC Anti-Aliasing
2005
ADC Sampling
2006
Sub-Sampling Filter
2008
Drum Position
2009
Drum Hall Sensor
2010
2011
Position Sensor Calibration
Position Sensor Range Detection
Quadrant Detection
2012
Drum Position Interpolation
2013
Filter Position Config-uration
2015
Reference Discrete
Reference ATF
Signal Discrete
Signal ATF
2016
Discrete Filter Profile
2017
2018
ATF Profile
2019
2020
Discrete Filter Profile
2021
2022
ATF Profile
Lamp Monitor
Cell Monitor
Sample Monitor
Dark Level
2023
Dark Levels
Discrete Filters
AT Filters
Discrete Filters
AT Filters
Window Function
Window Function
Window Function
Window Function
2024
Reference Wave-length Bins
2025
2026
Signal Wave-length Bins
2027
Measurement FIFO
2028
2029

FIG. 13

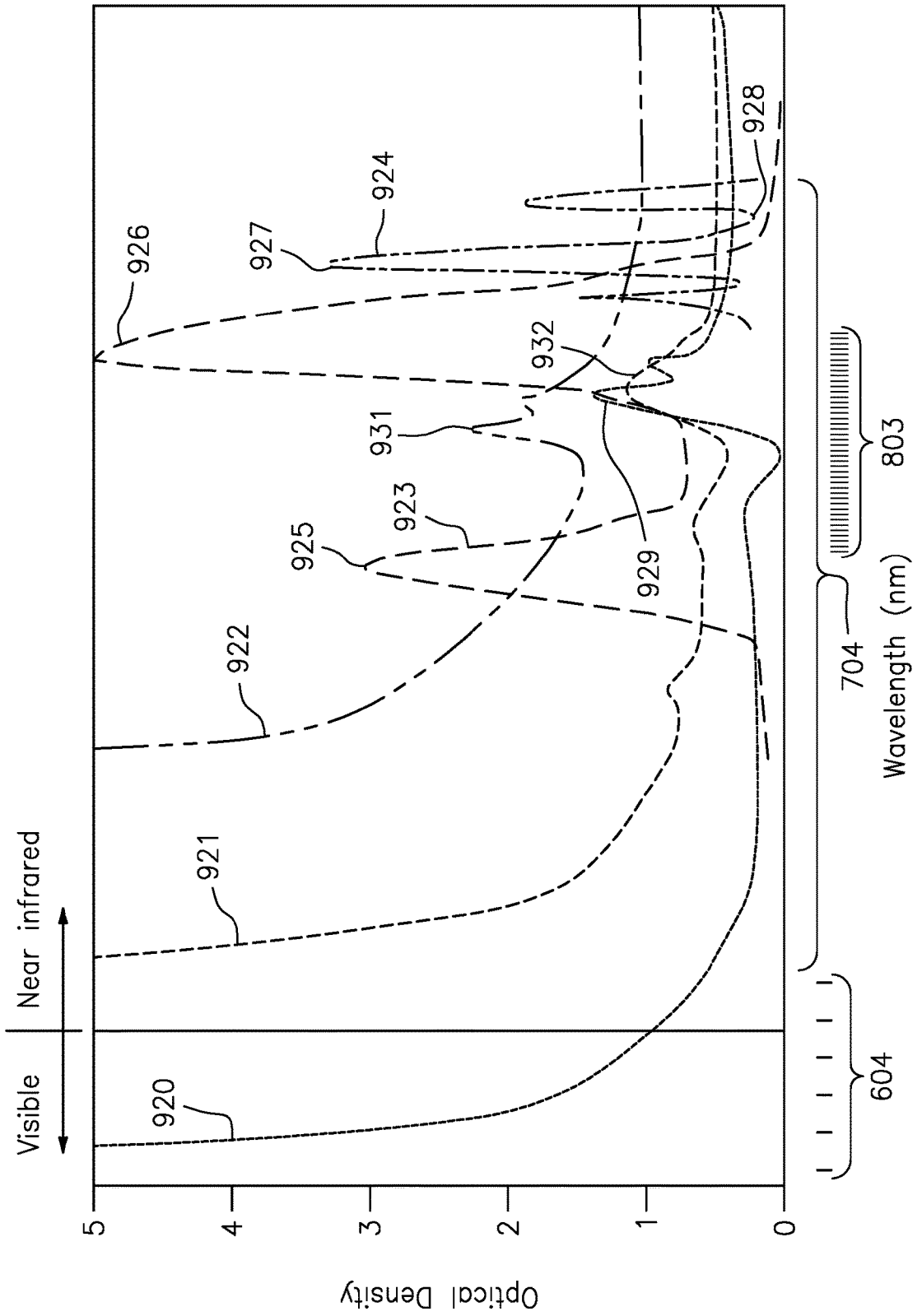
Optical Density
5
4
3
2
1
0
Visible
Near infrared
920
921
922
923
924
925
926
927
928
929
931
932
604
704
Wavelength (nm)
803

FIG. 14

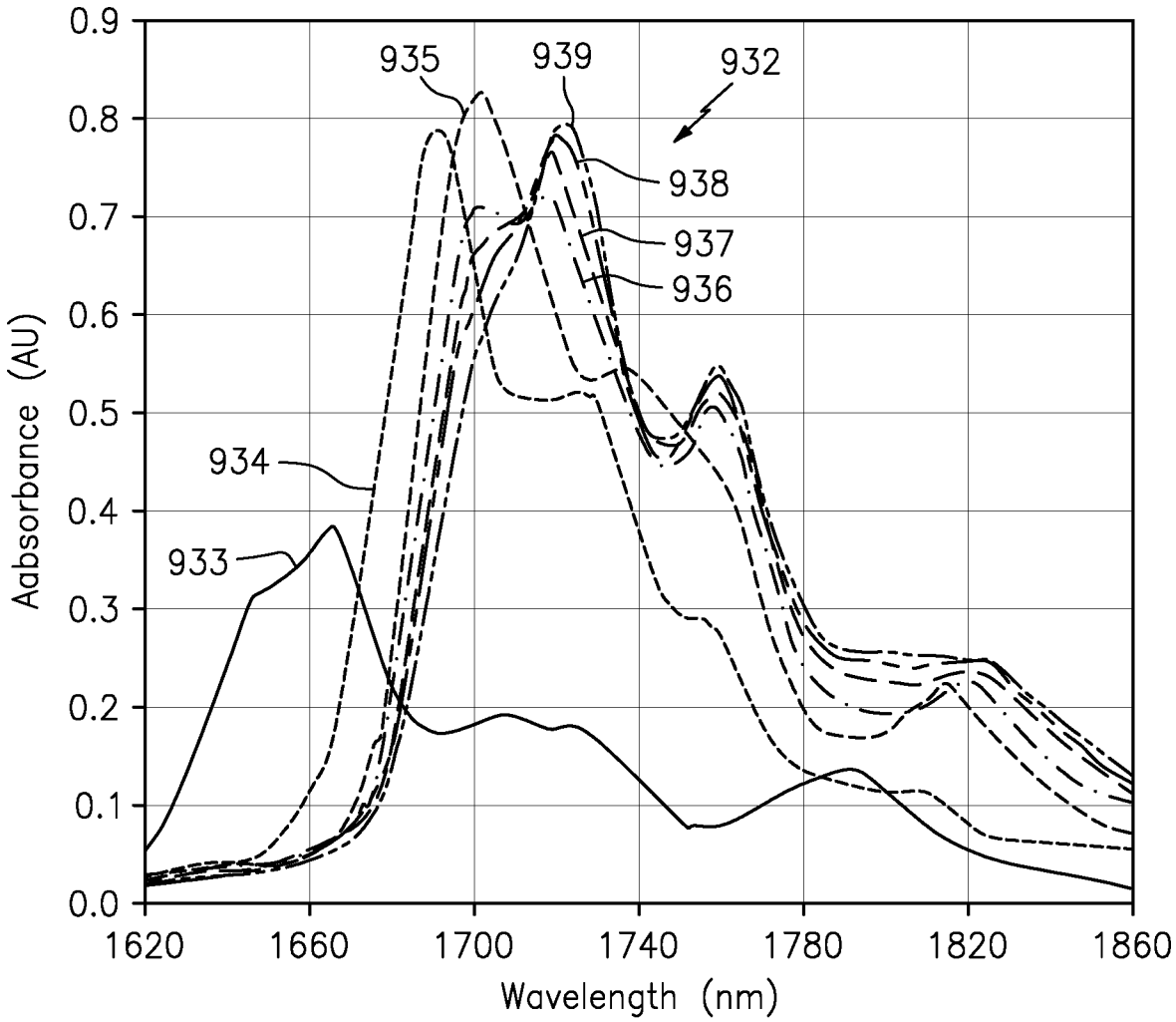
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Aabsorbance (AU)
1620
1660
1700
1740
1780
1820
1860
Wavelength (nm)
935
939
932
938
937
936
934
933

FIG. 15

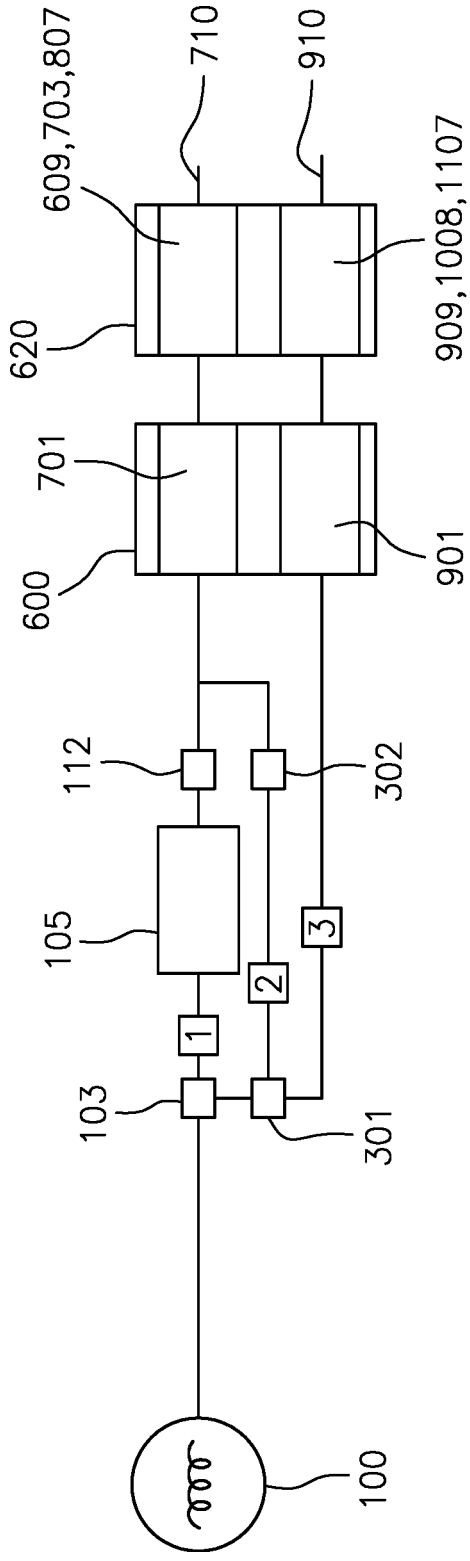
609,703,807
710
910
909,1008,1107
620
701
901
600
112
302
105
3
2
1
103
301
100

FIG. 16

OPTICAL FLUID ANALYZER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 62/463,357 filed 24 Feb. 2017. The disclosure of the application above is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

Embodiments of the present disclosure generally relate to tools and techniques for performing analyses and characterization of substances within harsh environments. More particularly, the present disclosure relates to tools for performing in-situ analyses and characterization of substances utilizing optically based modules.

Description of the Related Art

Optical analyzers are used to characterize substances in many areas of art. The typical optical analyzer can comprise a spectrometer and is suitable for use in a controlled environment, such as a laboratory. There are a myriad of applications for optical analyzers for use in a harsh environment such as the nuclear and chemical processing, and oil and gas industries. Such harsh environments may have high temperatures and pressures and may also include caustic, volatile, or other materials that are harmful to electronics.

In the oil and gas industry, as an example of a harsh environment, wireline formation testing tools are well known in the prior art in providing permeability, mobility, sampling, and other information that can be inferenced therefrom about the reservoir. It is known that companies involved in the production of hydrocarbons strive to produce as much of the reserves within any given formation as possible. At the beginning of the life cycle of a well, wireline formation testers are used to determine many factors that predict how the well will perform. Later in the life cycle of a well, the production rate will taper off for many known and unknown reasons such as water break through, decreased porosity, mobility, and permeability among others.

Wireline formation testers of the prior art have included various testing modules to provide physical fluid property measurements, in-situ, for fluids in the borehole and the reservoir. These prior art methods have included resistivity measurements, pressure-volume measurements, nuclear magnetic resonance, and optical based sensors, among others. Early on, optical based sensors were primarily used to provide quantitative information about the oil-water fraction in wells drilled with water based mud and to distinguish between drilling mud and production fluid in wells drilled with oil-based muds. These measurements were done to determine when the flow line in a testing tool was sufficiently clear of invading fluids to obtain a sample representative of the reservoir. Other early optics-based measurements of the prior art include a bubble point detector and was also aimed at controlling the quality for sampling.

Downhole fluorescence sensors are also known in the prior art which typically comprise a narrow (or single) band source and multiple detectors usually in the visible light range. Some production fluids do fluoresce in the presence of such light and in some instances, such fluorescence sensor

can distinguish oil-based drilling mud from naturally occurring production fluids. Other uses of fluorescence sensors include bubble point detection and phase detection.

Prior art optical analyzers included spectrometers to measure the absorption and/or the reflection of broadband light. Refraction spectrometers direct light through a window and onto the fluid within a flow line at a known angle of incidence. The refraction spectrometers typically use detectors to measure the intensity of the reflected light at different angles of incidence to determine the phase of the fluid flowing in the flow line. Such refraction spectrometers are sometimes referred to as "gas flags" because they are primarily used to determine the presence of gas bubbles in the flow line. An example of a refraction-type spectrometer is disclosed in U.S. Pat. No. 5,201,220 to Mullins, the disclosure of which is included herein in its entirety.

Absorption spectrometers of the prior art use detectors, or detector and filter pairs, which are selected based on a particular wavelength of interest and they measure the amount of light that the fluid within the flow line absorbs at the preselected wavelengths. The broadband light source can include wavelengths from the ultraviolet range (100-400 nm), the visible light range (400 nm to 800 nm) and the near infrared range (up to 2200 nm). Each such detector or filter and detector pair is commonly referred to as a channel. Fluids within the flow absorb light based on two phenomena: electronic absorption at shorter wavelengths and molecular absorption at longer wavelengths. At the shorter wavelengths, the fluids may absorb the light based primarily on color and convert the absorbed light to emitted light and heat. At longer wavelengths (lower frequencies), the light causes vibrations at the molecular bond level and local peaks of absorption occur at certain natural frequencies of these bonds. Absorption spectrometers of the prior art are useful in distinguishing between, and sometimes quantifying, water, oil, and drilling mud in a mixture of fluids. As discussed above, the channels are selected to provide information on the fluids that are predicted to be encountered. For instance, it is known that oil generally has a strong peak at about 1725 nm and water generally has two peaks, one at about 1445 nm and one at 1930 nm. The greater the number of channels that a spectrometer has the more complete a spectrum of the fluid mixture it can provide. Because of the size and availability of filters and the space limitations of downhole tools, prior art spectrometers typically have between eight and 20 channels. The limited number of channels may allow a spectrometer to distinguish between fluid types in the flow line but they do not have the spectral resolution to distinguish between different fluids of the same type. For instance, two production fluids coming from different reservoirs will have slightly different spectra. Typically, and as discussed above, samples of production fluids are taken from different locations within a borehole using wireline formation tools and the samples are analyzed using laboratory spectrometers to provide a continuous spectrum of the fluid thereby producing a fingerprint of the production fluid. Fingerprinting of the production samples allows users to determine whether there is more than one reserve along the borehole and whether there is connectivity between the reserves.

Therefore, there exists a need for providing in-situ, real time information related to fluid characterization in a harsh environment in the form of a comprehensive optical-based fluid analyzer.

SUMMARY OF THE INVENTION

In accordance with some aspects of the present disclosure, methods and systems related to an optical analyzer are presented.

It is an aspect of the present disclosure to provide an apparatus deployable in a harsh environment for fluid analysis having an electromagnetic source generating an optical signal across a spectrum of wavelengths, a source splitter optically coupled to the source and splitting the optical signal into a parallel reference channel and a measurement channel, where the measurement channel includes a test cell and wherein the optical signal of the measurement channel interacts with a fluid sample in the test cell, and at least one adjustable filter assembly having a plurality of filters mounted thereon, the plurality of filters including a parallel reference set of filters and a measurement set of filters, filtering the parallel reference channel with the parallel reference set of filters and filtering the measurement channel with the measurement set of filters and the at least one adjustable assembly adjustable to change which of the parallel reference set of filters filter the parallel reference channel and which of the measurement set of filters filter the measurement channels. The apparatus further includes at least one drive operable to move the at least one adjustable assembly, a control device electrically coupled to the at least one drive, the control device controlling movement of the at least one adjustable assembly; and a detection unit comprising a parallel reference set of detectors and a measurement set of detectors, the parallel reference detectors detecting the parallel reference channel after filtering with the parallel reference set of filters, and the measurement set of detectors detecting the measurement channel filtering with the measurement set of filters.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this disclosure and are therefore not to be considered limiting of its scope, for the disclosure may admit to other equally effective embodiments.

FIG. **1** is a schematic representation of an exemplary formation tester for analyzing downhole formation fluids in accordance with certain aspects of the present disclosure.

FIG. **2** is a schematic representation of an exemplary formation tester for analyzing downhole formation fluids in accordance with certain aspects of the present disclosure.

FIG. **3** is a schematic representation of the light paths for various optical components of an optical fluid analyzer in accordance with certain aspects of the present disclosure.

FIG. **4** is a top view of an optical chassis of an optical fluid analyzer in accordance with certain aspects of the present disclosure.

FIG. **5** is a side view of an optical chassis of an optical fluid analyzer in accordance with certain aspects of the present disclosure.

FIG. **6** is a view of a pair of windows of an absorption cell in accordance with certain aspects of the present disclosure.

FIG. **7** is a schematic representation of a reflectance cell in accordance with certain aspects of the present disclosure.

FIG. **8** is a graphical representation of the reflectance of various fluids in accordance with certain aspects of the present disclosure.

FIG. **9** is a schematic representation of fluorescence cell in accordance with certain aspects of the present disclosure.

FIG. **10** is a top view of a drum spectrometer in accordance with certain aspects of the present disclosure.

FIG. **11** is a schematic representation of a discrete filter assembly in accordance with certain aspects of the present disclosure.

FIG. **12** is a schematic representation of an angle-tuned filter assembly in accordance with certain aspects of the present disclosure.

FIG. **13** is a flow chart of a control system in accordance with an embodiment of the present disclosure.

FIG. **14** is a graphical representation of the spectral output for various fluids of an optical fluid analyzer in accordance with certain aspects of the present disclosure.

FIG. **15** is a graphical representation of an example of spectral output for pure hydrocarbons.

FIG. **16** is a schematic representation of the light paths for various optical components of an optical fluid analyzer in accordance with certain aspects of the present disclosure.

DETAILED DESCRIPTION

The present disclosure is an optical fluid analyzer (OFA), and, when combined with equipment in a harsh environment, it can be utilized to analyze and characterize substances in the harsh environment.

For example, and without limiting the scope of the present disclosure to any area of art, when an OFA of the present disclosure is combined into a formation dynamic testing (FDT) tool, it can be utilized for analyzing and characterizing formation fluids in a downhole environment. Various embodiments of an OFA in accordance with the present disclosure include at least one optical sensor assembly for determining at least one property of a fluid from a hydrocarbon-producing well. As will be described more fully herein after, the OFA of the present disclosure may include a plurality of test cells including an absorption cell assembly, a fluorescence cell assembly, a fluid reflectance assembly, and may further include a spectrometer assembly, as well as various references and monitoring assemblies. The absorption cell may advantageously provide a spectrum of absorption levels versus intensity of light absorbed by the fluid and provide information allowing the identification of various constituents in a mixture of fluids that comprise the formation fluid. The fluorescence cell may, in addition to providing for identifying the bubble point of the formation fluid, sometimes provide information allowing for the identification between drilling mud (filtrate) and formation production fluid. The reflectance cell provides information important to the presence of gas within the formation fluid as well as identifying the presence of condensate, determining between rich gas and lean gas. In some embodiments of the present disclosure, multiple optical sensor assemblies may advantageously be combined together. The present disclosure may also include a cooling system capable of providing cooling to the OFA module **32** after a predetermined temperature is reached to maintain portions of the analyzer within a predetermined operating range to ensure adequate signal-to-noise ratio, accuracy, and reliability of the various components.

Examples of Tools for Monitoring, Analyzing and Characterizing Downhole Fluids

With reference to FIG. **1**, there is shown an embodiment of a wireline formation tester **20** deployed within a well **12** drilled into formation **13**. In operation, wireline formation tester **20** is deployed into well **12** via wireline cable **22** over pulley **16**. As is well known in the art, wireline cable **22** includes electrical conductors for powering the tool, data

communication conductors, as well as tensile members for supporting the weight of the testing tool. The borehole typically contains various mixtures of fluids and gases wherein the mixture varies by depth, age of the well, and various other factors. The well is shown as an open hole, however, the present disclosure is not limited to open hole wells and could, for instance, be used within a cased hole well.

Still referring to FIG. **1**, an embodiment of a formation tester **20** of the present disclosure is shown wherein the tool is deployed in a well **12** and includes various modules as will be described in more detail herein below. The wireline cable **22** can be a multi-conductor that carries electrical power and data to and from power and processing unit **24** located at the surface. The power and processing unit includes the capability to control the various modules included in the formation tester **20**. In addition, power and processing unit **24** includes a processor **40**, in the form of a computer and the like, for processing the electrical signals from the tool into information concerning the analysis and characterization of the downhole fluids as well storage medium **42**. In this particular embodiment, the formation tester **20** includes a clamping mechanism **30** that is urged against the borehole wall **14** by pistons to stabilize the formation tester against the borehole wall **14**. The formation tester includes a probe assembly **28** having a mechanism to urge the probe pad against borehole wall **14** with sufficient force to releasably fix the formation tester in place at preselected test position **130**. The probe assembly **28** and the clamping mechanism **30** are configured so that the formation tool does not rotate or wobble in the preselected downhole position. The probe pad further seals the formation **13** from the wellbore **12** in the area of contact with borehole wall **14**. The snorkel **29** of probe assembly **28** seals against, and can penetrate, the borehole wall **14** and any mudcake that may exist adjacent thereto and enters the formation **13**. The snorkel **29** is in hydraulic communication with pump out module **36** wherein the pump is mounted (not shown) within the formation tester housing **26** wherein a flowline presents reservoir fluid to OFA module **32** for monitoring and analysis as will be more fully described herein below. Although the order of OFA module **32** and modules **34** and **36** are as shown, it is within the scope of the present disclosure that OFA module **32** may be mounted within other modules and in other configurations, such as above the probe assembly **28**, without departing from the scope of the present disclosure. The probe assembly **28** may also include a guard ring (not shown), which may comprise a loop that encircles the ring, and is hydraulically coupled to a pump. An exemplary embodiment of a focused guard probe is disclosed in U.S. Pat. No. 6,301,959 ('959) to Hrametz. The pump out module **36** moves fluids from formation **13** through OFA module **32** for analysis as will be more fully explained herein below.

Another embodiment of the present disclosure further includes formation testing tool **50** shown in FIG. **2** wherein the tool is deployed in well **12** and includes a pair of spaced apart straddle packers **311**, **312**. In this particular embodiment, the straddle packer pair **311**, **312** are positioned about one meter apart and seal against tool housing **51** and are inflated to seal against borehole wall **14** as is known in the industry to stabilize the formation tester within the wellbore **12**. The pump **31**, shown within module **34** pumps fluid from formation **13** into one or both of inlet **314** and inlet **313** and through OFA module **32** and through flow line **151**. As discussed herein with respect to FIG. **1**, the specific order and the orientation of OFA module **32** and other modules does not depart from the present disclosure. Reservoir fluids are analyzed as pump **31** moves fluids from formation **13** through OFA module **32** as will be more fully explained herein below. OFA module **32** will be discussed generally herein below and with reference to the embodiment shown in FIG. **1** but such description applies to the embodiment of OFA module **32** shown in FIG. **2**.

Example Light Paths for an Optical Fluid Analyzer

With reference to FIG. **3**, the logical flow of light paths for various optical assemblies of an OFA module **32** in accordance with an embodiment of the present disclosure will be described. In the embodiment shown, OFA module **32** functionally includes absorption spectroscopy, fluid reflectance spectroscopy, and fluorescence spectroscopy. The various mirrors, splitters, and other elements known in the art described herein are needed to route the light through the embodiments described, wherein different types and arrangements of optical elements may be used in other embodiments without departing from the scope of the present disclosure. OFA module **32** includes a broadband light source **100** for the spectrometer, as will be described more fully herein below. Light source **100** may advantageously comprise a halogen light bulb with a black body temperature of about 2900 K and in certain embodiments of the present disclosure the light source remains energized during the entire measurement sequence at the preselected depth of test position **130** (FIG. **1**). Following light path **1** in FIG. **3**, directed at absorption spectroscopy, light from source **100** is directed by mirror **101** to a relay lens **102** and in this particular embodiment, into a beam splitter **103**. It should be appreciated by those skilled in the art that the beam splitter, as well as other components described herein, should comprise broadband, low loss or lossless qualities to preserve the intensity and spectrum of the light emitted by source **100**. A portion of the light is directed into a beam splitter **301**, which further divides the light between the parallel reference filter assembly **901**, a portion of which goes to the lamp monitor detector **1202**, and toward the direct reference/measurement filter assembly channel set **701** as will be described herein after. The remainder of the light from source **100** is directed by mirror **104** to absorption cell **105** having windows **106** and **107** defining a gap between them accommodating a flow stream. The operation and arrangement of physical components of the absorption cell will be described in more detail herein after. Some of the light may be absorbed in the cell and the remainder is directed to mirrors **108** and **109** and onto beam splitter **110** wherein a portion is directed to cell monitoring light path **5**, which will be described in more depth herein after. The remainder of the light is directed to relay lens **111** and directed on shutter **112**. Shutter **112** may comprise a solenoid bi-stable shutter, suitable for operation at elevated temperature. Shutter **112** is actuated (opened) every time an absorption measurement is required. The shutter is closed every time a dark measurement, a fluid reflectance, or a direct reference measurement is performed. In an embodiment of the present disclosure, the actuation duration is about 30 ms.

Light emitted from shutter **112** is relayed by lens **113**, directed to beam splitter **114**, and directed, along with light from other assemblies, to the measurement set of channels **701** of the drum spectrometer assembly **600**.

Still referring to FIG. **3** and following light path **2**, directed at fluid reflectance detection, light from broadband source **100** is directed to mirror **201** and onto relay lens **202** wherein it is directed onto shutter **203**. Shutter **203** is actuated (opened) every time a fluid reflectance measure-

ment is required. It is closed every time a dark measurement, an absorption measurement, or a direct reference measurement is performed. The actuation duration is about 30 milliseconds. Light from shutter **203** is directed to reflectance cell **204** wherein the reflectance cell comprises mirror **205**, polarizer **206**, cylindrical lens **207**, prism **208**, a second cylindrical lens **209**, a linear variable filter **210** and mirror **211**. The operation and arrangement of physical components of the reflectance cell will be described in more detail herein after. The polarizer **206** may comprise a p-polarizer or an s-polarizer. In this particular embodiment, an s-polarizer is shown. The broadband light is focused into a line by cylindrical lens **207** and directed onto an angled surface of prism **208** and becomes incident at the interface between the sapphire window (similar to that described herein above with reference to absorption cell **105**) and the fluid. The converging beam of light covers a range of angles of incidence. Depending on the refractive index of the material in the flow stream (liquid, gas, or mixture), only the rays which have an angle of incidence greater than the critical angle will be reflected. In the embodiment shown in FIG. **3**, the reflected portion of the light exits a second angled surface of the prism **208**, is directed through a second cylindrical lens **209** and onto linear variable filter **210**. As the source is broadband, a linear variable filter **210** (LVF) is used to spectrally encode the reflected angles of the light. The angle of the reflected light is therefore easily determined based on its unique spectral encoding. It should be appreciated by those skilled in the art that the LVF **210** could be placed before the window **106** to encode the angles of incidence with wavelength. Lens **212** directs the encoded light to beam splitter **213** where it is further directed to a spectrometer. Decoding is performed by the spectrometer wherein discrete filters are arranged therein having wavelengths that are able to detect the encoded wavelengths and determine the angle of incidence thereby as will be more fully described herein after.

This particular embodiment of the present disclosure further includes fluorescence spectroscopy including a fluorescence measurement cell **400** (FMC) depicted schematically in light path **4** of FIG. **3**. Light from LED **401** can produce a fluorescence excitation, and in this particular embodiment the LED comprises a blue LED **401** having a wavelength between 457 nm and 463 nm, is injected into a doped 600 μm optical fiber **402** having a numerical aperture of 0.22 and directed to collimating lens **403** and discrete filter **404**. Discrete filter **404** separates the excitation spectrum of the LED from the expected fluorescence spectrum, so that excitation is not mixed with fluorescence light emitted from the flow stream. Mirror **405** directs the light into FMC **400** and, in transmission, dichroic beam splitter **406** directs blue light, the fluorescence excitation, through focusing lens **407**. The embodiment of FMC **400** shown is commonly referred to as epifluorescence and the dichroic beam splitter **406** transmits the excitation light to the sample and simultaneously reflects only the emitted light (reflected fluorescence signal) from the fluid stream back to light path **4**. The fluorescence excitation light is projected through a flat portion of prism **208** and becomes incident at the interface between the sapphire window and the fluid in the flow stream. An emitted fluorescence signal may be emitted back to focusing lens **407** depending on the type of material in the flow stream. The emitted fluorescence signal directed back through focusing lens **407** is passed to dichroic beam splitter **406** where mirror **409** directs the light to discrete filter **410** wherein the filter only allows the emitted fluorescence signal to pass onto beam splitter **412**. The emitted fluorescence signal is further directed to a spectrometer and onto a detector.

Referring now to light path **3** of FIG. **3**, there is shown a portion of the light path for a direct and a parallel reference. The reference paths measure the spectrum of the light source **100** (light bulb) that may affect measurement quality as will be explained in more detail herein below. Among other things, the reference signals are used to normalize the differences between detectors and absorption signals in accordance with an embodiment of the present disclosure. Broadband light from light source **100** is directed from beam splitter **103** and is further directed to beam splitter **301**. A portion of the light, comprising the direct reference, is directed to shutter **302** which is actuated every time a direct reference measurement is required, wherein the direct reference light signal is relayed by lens **303** and directed by mirror **304** to focusing lens **305**, where it is further directed to measurement set of channels **701** of drum spectrometer **600**. Shutter **302** is closed every time a dark measurement, an absorption measurement, or a fluid reflectance measurement is performed. The remainder of the light from beam splitter **301** comprises the parallel reference light and is directed by mirror **306** to a relay lens **307** into a 400 μm optical fiber **308** having a numerical aperture of 0.22 and passes through lens **309**, where it is further directed to parallel reference channels **901** of drum spectrometer **600**.

A cell monitor of the present disclosure is described with reference to light path **5** in FIG. **3**, wherein a portion of the light that is transmitted through absorption cell **105** is directed by beam splitter **110** to mirror **501**, that in turn directs the light to discrete filter **502** and onto lens **503** to direct the light into optical fiber **504**. The cell monitor of light path **5** continuously monitors the overall absorption of light by the fluid in the absorption cell **105** and gives a continuous signal indicative of the gross intensity of light transmitted through the absorption cell. The light transmitted on light path **5** is directed to detector **1150**. Signals sent to the processing unit from detector **1150** are integrated over a given spectral range, determined by the source emission spectrum and filters used. Fast fluctuations of the intensity of the cell monitor signal may indicate the presence of gas bubbles, slugs, contaminants, or a multiphase flow flowing in the flow line. Optical fiber **504** comprises a 600 μm fiber having a numerical aperture of 0.22 which is used to direct the unabsorbed light from absorption cell **105** to detector **1150** of detector module **620**. The detector module **620** will be described in greater detail herein after.

Still referring to FIG. **3**, the OFA module **32** of the present disclosure includes a drum spectrometer assembly **600** to measure the intensity of light at specific wavelengths from the various light paths described herein above. Spectrometer assembly **600** comprises a drum **610** that is rotated during operation, wherein the drum includes discrete optical filter assemblies **604**, **704**, **904**, and **1003** as well as angle tuned filter assemblies **803** and **1103**. As will be described in more detail herein after, the spectrometer **600** comprises two sets of three channels represented schematically in the first measurement set of channels **701** as light paths (channels) **6**, **7** and **8** and the second, parallel reference, set of channels **901** as light paths, or channels, **9**, **10**, and **11**, respectively. In certain embodiments, channel set **701** is spectrally identical to channel set **901**, with the only physical difference in the mirror **801** in channel set **701**, and a beam splitter **1101** in channel set **901**, in which the beam splitter directs a portion of the light to lamp monitor detector **1202** of detector module **620**. The remaining portion of light from beam

splitter **1101** follows a path **11** which is identical to light path **8** of channel set **701**. The six light paths are fixed. As the drum rotates, the light paths are presented to a different discrete filter, each at different wavelengths, and the angle of incidence is swept on the angle tuned filters, in essence, sweeping the transmitted wavelength.

With reference to drum spectrometer assembly **600**, light from the absorption cell **105**, the fluorescence measurement cell **400**, the reflectance cell **204**, and the direct reference signal (of light path **3**) are directed to first set of measurement channels **701** of the drum spectrometer assembly wherein the light is filtered into various spectral ranges and its intensity is measured. The light is first received by dichroic beam splitter **601** and is directed to filter **602** allowing light in the visible and near infrared range, from approximately 380 nm to approximately 875 nm, there through (the remainder of the light is directed toward dichroic beam splitter **702**). The light enters discrete optical filter assembly **604**, which includes six fixed filters at different wavelengths of interest (434 nm, 500 nm, 600 nm, 700 nm, 780 nm and 850 nm) and directs the filtered light by wavelength through mirror pair **605** and **606** to lens **607** which couples the light into optical fiber **608**. The six filters that comprise optical filter assembly **604** are mounted to within drum assembly **600** (FIG. **10**) wherein the light is presented to the different filters as they rotate past the incident light as will be more fully described herein below.

The direct reference signal of light path **3** is used in conjunction with light path **1** to determine the amount of light that is absorbed within the fluid passing through the absorption cell **105**. For example, if the direct reference signal has a value of 250, as determined by detector module **620**, and the absorption signal from light path **1** has a value of 125, as determined by detector module **620**, then the fluid has absorbed 50% of the light, at the considered wavelength. It should be appreciated by those skilled in the art that the amount of absorption at a given wavelength yields information that may aid in the identification of the fluid. An optical fiber directs the light spectra to the detector assembly as will be described more fully herein below.

The light directed from dichroic beam splitter **601** to dichroic beam splitter **702** is directed to filter **703**, allowing light in the infrared and near infrared range, from approximately 910 nm to approximately 1530 nm, and above 1860 nm, there through (the remainder of the light is directed toward mirror **801**). The light enters discrete optical filter assembly **704**, which is similar to discrete optical filter assembly **604** described herein above, which includes six fixed filters at different wavelengths of interest (935 nm, 1080 nm, 1290 nm, (1450 nm or 1930 nm for water (H_2O) measurement), 2013 nm (for carbon dioxide (CO_2) measurement), and 2045 nm (for CO_2 baseline measurement) and directs the filtered light by wavelength through mirror pair **705** and **706** to lens **707**, which couples the light into optical fiber **708**. The optical fiber directs the near infrared light spectra to the detector assembly as will be described more fully herein below.

The light that passes from dichroic beam splitter **702** mainly comprises light having many wavelengths in the near infrared range, from approximately 1530 nm to approximately 1860 nm, and it is directed down light path **8** to mirror **801** and onto filter **802**, wherein light in the wavelength range of about 1530 nm to approximately 1860 nm is allowed to pass there through. The light enters angled tuned filter assembly **803**, which includes two angled tuned filters targeted for capturing hydrocarbon composition measurements between 1550 nm and 1830 nm, the "oil window". The angle tuned filter assembly **803** is mounted within drum spectrometer **600** (FIG. **10**) which sweeps the angle of incidence on the angled filters. In an embodiment of the present disclosure, the angle tuned filters of angle tuned filter assembly **803** comprise a pair of angled tuned filters whose output is measured at 4 nm increments between each measurement. It should be appreciated by those skilled in the art that this particular embodiment of the present disclosure provides for **70** increments between 1550 nm and 1830 nm, with a 10-15 nm resolution, and that such a fine sampling interval yields a highly refined spectral sample in the area of interest. The filtered light is directed through mirror **804** to lens **805** which couples the light into optical fiber **806**. The optical fiber **806** directs the near infrared light spectra to detector **807** of detector assembly **620** as will be described more fully herein below.

With reference to the second set of channels, the parallel reference set **901** of drum spectrometer assembly **600**, broadband light from optical fiber **308** is directed through lens **309** and passed through dichroic beam splitter **902** to filter **903** wherein light having wavelengths in the visible range, from approximately 380 nm to approximately 875 nm, is directed down light path **9** (the remainder of light is directed toward dichroic beam splitter **1001**). The light enters discrete optical filter **904** (identical to **604**), which includes six fixed filters at different wavelengths (434 nm, 500 nm, 600 nm, 700 nm, 780 nm, and 850 nm) used to make color correction normalization and directs the filtered light by wavelength through mirror pair **905** and **906** to lens **907** which couples the light into optical fiber **908**. The optical fiber directs the visible light spectra to the detector assembly **620** as will be described more fully herein below.

The light from dichroic beam splitter **902** is directed to dichroic beam splitter **1001** and to filter **1002** wherein light having wavelengths in the near infrared range, from approximately 910 nm to approximately 1530 nm and beyond 1860 nm, is directed down light path **10** (the remainder of light is directed toward beam splitter **1101**). The light enters discrete optical filter **1003** (identical to **704**), which includes six fixed filters at different wavelengths of interest (935 nm, 1080 nm, 1290 nm, 1450 nm (or 1930 nm), 2013 nm, and 2045 nm) and directs the filtered light by wavelength through mirror pair **1004** and **1005** to filter **1006**, which couples the light into optical fiber **1007**. The optical fiber directs the near infrared light spectra to the detector assembly as will be described more fully herein below.

The light that passes from dichroic beam splitter **1001** is comprised of light having many wavelengths and is directed to filter **1102**, allowing light in the infrared range, from approximately 1530 nm to approximately 1860 nm, to pass there through. The remainder of the light is directed toward lens **1201** and light path **1200**. The light from filter **1102** enters the angled tuned filter assembly **1103** (optically identical to **803**), which includes two angled tuned filters between 1550 nm and 1830 nm, that sweep the angle of incidence to provide hydrocarbon composition measurement normalization. The filtered light is then directed by mirror **1104** to lens **1105**, which couples the light into optical fiber **1106**. The optical fiber directs the near infrared light spectra to the detector assembly as will be described more fully herein below.

Still referring to FIG. **3**, the OFA module **32** of the present disclosure includes a photo detector module assembly **620** to receive output from drum spectrometer **600**. Detector module **620** comprises both silicon (Si) and indium gallium arsenide (InGaAs) photo detectors. Measurement set of detectors **609**, **709**, and **807** receive light that carries infor-

mation about the fluid and reference set of detectors **909**, **1008**, and **1107** receive light that comprise the parallel reference signals. The light in the visible/near infrared (NIR) range from optical fiber **608** is shone onto detector **609**. Detector **609** is a silicon-based detector that converts the light to an electrical signal. Similarly, light from optical fibers **708** and **806** are shone onto detectors **709** and **807**, respectively. Detectors **709** and **807** are both InGaAs detectors that convert the light signals to electrical signals. The light in the visible/NIR range from optical fiber **908** is shone onto detector **909**. Detector **909** is a silicon-based detector that converts the light to an electrical signal. Similarly, light from optical fibers **1007** and **1106** are shone onto detectors **1008** and **1107**, respectively. Detectors **1008** and **1107** are both InGaAs detectors that convert the near infrared light signals to electrical signals. The converted signals are an analogue signal which is proportional to the intensity of the light that fall on them. The analogue signals are communicated to the processing unit in the OFA. It should be appreciated by those skilled in the art that the reference channel and the measurement channel are concurrently filtered through their respective plurality of filters.

A dark measurement is made when all light paths are blocked. It is an advantage of the present disclosure over the prior art in that light source **100** is on continuously and not switched off to make a dark measurement and switched back on again to make a fluid measurement. The switching on and off of a light source can bring stability errors and shorten the life of the source. This may occur in measurement channel set **701** by closing shutters **112**, **203**, and **302** and by further switching LED **401** into the off position. Dark measurements may also be made at points in the rotation of the drum **610** when light falls between filters as they rotate and is not transmitted out of the drum. The dark measurements measures the electrical noise of the detectors when they are not illuminated. The magnitude of the dark signal is subtracted from both the reference and the measurement signal, absorption signals for example, then the absorption signal is normalized (divided) by the reference signal as will be explained more fully herein below. Further signal processing may be applied (placing signals in wavelength bins) and then sent to the ground equipment **24** (FIG. **1**) for display and/or further processing.

Example Monitoring and Measurement Cells of an Optical Fluid Analyzer

The OFA module **32** shown in FIG. **1** includes various optical components that are optically coupled to an optical chassis **150** as is best shown with reference to FIGS. **4** and **5**. Chassis **150** includes a flow line **151** that runs through the chassis and is hydraulically connected to snorkel **29** (FIG. **1**), and is rigidly fixed within wireline formation tester **20** (FIG. **1**), and carries formation fluid there through. Chassis **150** includes an absorption cell **105** and a prism assembly **250** which includes prism **208** (FIG. **3**). With reference to the description directly herein above and FIG. **6**, an example of the absorption cell **105** includes windows **106**, which windows can be comprised of sapphire, and **107** mounted within carriers **152** and **153**, respectively. FIGS. **4** and **5** depict flow line **151** shown in phantom within chassis **150**. When windows **106** and **107** are mounted within absorption cell **105**, a gap **154** of approximately 1-2 mm is formed there between. In the embodiment shown, the window carriers are secured within chassis **150** by hollow screws **156**. It is an important aspect of the present disclosure that the formation fluids maintain their original pressure while the analyses are being performed. To that end, the cross-sectional area of flow line **151** inside of the absorption cell **105**, taking into account the geometries of the chassis **150** and windows **106** and **107**, is matched to that of the remainder of flow line **151** as depicted in FIGS. **4** and **5**. Now referring also to FIG. **3**, broadband light from source **100** is directed into window **106** via efficient angled mirror **108**. There is an optical arrangement, in the form of a periscope solely as a means of directing light into and out of this particular embodiment, of mirror **109** connected to window **107** that receives the light that is transmitted through absorption cell assembly (that which is not absorbed by fluid in the flow line) and transmits that light to drum spectrometer **600**.

The present disclosure also includes a reflectance cell **204** to help determine, for example, the presence of gas, and/or determining the gas-to-oil ratio, within a fluid in flow line **151**. An example of a portion of the reflectance cell assembly, or refraction spectrometer, is shown in FIG. **7** wherein prism **208** is optically connected to sapphire window **214**, which is in fluid contact with fluids in the flow line **151**. Although depicted as separate components in the embodiment shown, prism **208** and sapphire window **214** may also comprise a monolithic structure.

In reflectance cell **204**, light **200** from source **100** (FIG. **3**) is projected through cylindrical lens **207** and into prism **208**. The light **200** passes through sapphire window **214**, where it becomes incident on fluid within flow line **151**. The light becomes incident with the fluid at a low angle of incidence **215** relative to the vertical axis in FIG. **7**. In certain embodiments, the angle of incidence **215** will include a range of angles and may, for example, include angles of incidence **215** from 30 degrees to 50 degrees. Depending on the material in the flow line **151**, some rays of the light **216** are reflected and some rays of the light are refracted **217**. As discussed, reflectance cell **204** may detect the presence of gas within flow line **151**, wherein gas has a refractive index close to 1.0 at the interface between the fluid and the sapphire window. All other liquids of interest will have a refractive index greater than 1. For example, water has a refractive index of approximately 1.3. This effect is best illustrated with reference to FIG. **8** and while still referring to FIG. **7**, wherein the angle of incidence **215** influences the amount of light **217** refracted, and conversely the reflected light **216**, for different fluids comprising gas **220**, water **221**, and oil **222**, based on their respective different refractive indices for s-polarized light. Therefore, for small angles of incidence **215**, more light will be absorbed/refracted **217** into the fluid as shown in FIG. **8**. It is important to note that the curves shown in FIG. **8** are between about 20 degrees and about 60 degrees. When the power of the reflected light **216** approaches a maximum value, one can infer the presence of gas in flow line **151**. The increasing presence of liquid, as opposed to gas, in flow line **151** is indicated as the power of the reflected light **216** drops in intensity with respect to respectively smaller angles of incidence **215**.

Certain embodiments of the reflectance cell **204** of FIG. **7** the present disclosure implement an approach using the Fresnel reflection on the refractive index contrast and angle of incidence **215** to detect gas in flow line **151** using known methods such as those set forth in U.S. Pat. No. 5,167,149, the disclosure of which is incorporated by reference herein in its entirety. Certain embodiments of the present disclosure also utilize the basic properties of Fresnel reflection to discern information about a fluid in a borehole flow stream. However, the present disclosure includes advances over the prior art in that light **216** reflected from the sapphire-fluid interface **218** (FIG. **7**) is further measured and analyzed,

using the same detectors of drum spectrometer assembly **600** as is used in for other measurements, at a range of angles of incidence **215** as will be more fully described herein after. In addition, in the example shown, the polarizer **206** may advantageously comprise an s-polarizer wherein the light is polarized normal to the plane of incidence with the flow line **151** at point of interface **218**. In FIG. **7**, light **200** from broadband light source **100** is directed through s-polarizer **206**, cylindrical lens **207** and prism **208**, and the reflected light **216** is directed through a second cylindrical lens **209** and onto linear variable filter (LVF) **210**. As one skilled in the art can appreciate, linear variable filter **210** is used to encode the reflected rays of light **216** with wavelength versus angular position data. The incident broadband light remains broadband after reflection, but only certain angles are reflected. Each reflected angle will reach the LVF at a different position whereupon only the corresponding specific wavelength of the filter is passed. Hence, each wavelength passed by the filter directly encodes an angle of incidence/reflection. The encoded light is directed to drum spectrometer **600** (FIG. **3**) where the wavelength of the encoded light is detected and the angle can be readily determined. It will be appreciated by those skilled in the art that the approach of the present disclosure provides for greater measurement resolution over that used in the prior art.

As discussed above, and with reference to FIG. **7** and FIG. **8** the line indicating oil **222** shows the theoretical reflectivity at interface **218** between sapphire window **214** and oil, and the line indicating gas **220** shows the theoretical reflected power measurement (reflectivity) at interface **218** between the sapphire and material flowing in the flow line. The reflectivity depends on angle of incidence **215** and the polarization state (p or s) of the incident light. At angles of incidence greater than the critical angle, all light is reflected and none is transmitted into the flow line. At less than the critical angle, some light is transmitted and some light is reflected. An example of the present disclosure uses s-polarized light and an angular range of approximately 35° to 47° and FIG. **8** illustrates how this angular range facilitates differentiation between fluids comprising gas **220**, water **221**, and oil **222**, based on their respective different refractive indices. In alternative embodiments of the present disclosure wherein the polarization state of the light is p-polarized, the differentiation between fluids may be more apparent. With p-polarized light, light is projected parallel to the plane of flow line **151** and there is a particular angle less than the critical angle, known as the Brewster angle and that allows nearly 100% transmission into the flow line. The values for Brewster and critical angles are significantly different between gas and oil and therefore measuring the relative intensity of the reflective power over a range of angles allows for the positive identification of gas. For instance, the reflectivity of gas **223** for p-polarized light passes through the Brewster angle **224** where the reflectivity is nearly zero (fully transmitted) and then makes an abrupt change in reflectivity near the critical angle when compared to the more gradual change of the s-polarized light indicating gas **220**. Similarly, the reflectivity of p-polarized light for oil **225** is nearly all transmitted into the flow line **151** and the slope of the change in reflectivity is much steeper than the s-polarized reflectivity for oil **222**. In other embodiments of the present disclosure, and as discussed herein above, s-polarized light may be used wherein the output may provide a smoother progressive curve allowing for better interpretation.

As discussed herein above with reference to light path **4** in FIG. **3**, the present disclosure may advantageously include fluorescence measurement cell **400** to assist in analyzing and characterizing downhole fluids. With reference to both light path **4** in FIG. **3** and FIG. **9**, the example shown utilizes an epifluorescence approach, a well-known technique where excitation of the fluorophore in a fluid (if present) and detection of the fluorescence are done through the same light path. In the present disclosure, the fluorescence excitation from LED **401**, shown as injected excitation light **414**, is directed through focusing lens **407** and injected into the flat, top, portion **413** of prism **208**, through sapphire window **214** and becomes incident normal (perpendicular) to the fluids in flow line **151** at the point of interface **218**. If the fluid flowing in flow line **151** contains a fluorophore, i.e. is of the type that is able to fluoresce, given the excitation light **414**, the fluorescence signal **415** is captured on the same light path flowing back through focusing lens **407**. Beam splitter **406** and discrete filter **410** are utilized to segregate the two signals before fluorescence signal **415** is directed to drum spectrometer **600**. It should be recognized by those skilled in the art that the prism **208** may be advantageously combined as shown with fluorescence measurement cell **400** and reflectance cell **204**. Prism **204** has no optical effect on the epifluorescence light paths but advantageously saves on having to add a separate window for the fluorescence measurement cell **400**, among other advantages.

The physical configuration of drum spectrometer **600** is best illustrated with reference to FIG. **10**. Drum **610** is attached at either end to shafts **611** and **614** and the shafts are rotatably positioned within bearings **612** and **613**. Coupling **625** is connected to a motor or drive (not shown) and is further coupled to shaft **614**, which in turn is fixed to drum **610**. It should be appreciated by those skilled in the art that the drive may be controlled by a control device electrically coupled to the drive controlling movement of the drum and filter assemblies. Filter assemblies **604**, **704**, **803**, **904**, **1003**, and **1103** are mounted within drum **610** as will be described more fully herein below.

Referring to FIG. **10**, the first set of channels, the measurement channel set **701**, direct light, depicted by light path **643**, from reflectance cell **204** (FIG. **7**), absorption cell **105** (FIG. **4**), fluorescence measurement cell **400** (FIG. **9**), and direct reference (light paths **1**-**4** of FIG. **3**) to drum assembly **600**. The light is directed into input ports **715** of discrete filter assembly **704** and input ports **616** of discrete filter assembly **604**. It should be appreciated that there exists six pairs of input ports **615** and **616**, radially positioned about drum **610**, only two pairs of which can be seen in the figure. Behind each input port **615** and **616** are mounted the individual discrete filters as will be described herein below. In operation, light from light path **643** enters beam splitter **601** and filter **602** and is presented to the discrete filters of discrete filter assembly **604** through input ports **616**. Light that matches any of the bandpass wavelengths of the discrete filters of assembly **604** as they are rotated past beam splitter **601** and filter **602** travels through the drum **610** and exits the drum through output ports **627** and is directed by mirror **605** toward detector **609**. The operation of filter assembly **704** is the same as discrete filter assembly **604** except that the filtered light exits the drum through output ports **627** and is directed to mirror **705** and on to detector **709**. Light path **643** is similarly passed to mirror **801** and filter **802** where it is directed through slot **817** behind which is mounted angle tuned filter assembly **803**. The light is filtered at the various wavelengths described herein above as the incidence angle

of light relative to the angle tuned filter assembly changes as drum **610** rotates. The filtered light exits the drum through an output slot (not shown) radially displaced from slot **817** and is directed by mirror **804** toward detector **807**.

The second set of channels, parallel reference channels **901**, direct light received from a broadband source **100** (FIG. **3**), depicted by light path arrow **943** (light path **9** of FIG. **3**), to drum assembly **600** into input ports behind which are drum filter sets **904** **1003** and into input slot behind which is mounted angle tuned filter assembly **1103**. The operation of parallel reference channels **901** is the same as that stated herein above with reference to the measurement channel set **701** albeit having different specific optical components and detectors. In addition, broadband light from beam splitter **902** is passed to an optical fiber (not shown) and is detected on lamp monitor detector **1202** to monitor the broadband source **100** (FIG. **3**).

Referring now to FIG. **11**, there is shown a schematic representation of discrete filter assembly **604** mounted within drum **610**. In the example shown, and as described herein above, discrete filter assembly **604** includes filter **635** having a band pass wavelength of 434 nm; filter **636** having a passband wavelength of 500 nm; filter **637** having a passband wavelength of 600 nm; filter **638** having a passband wavelength of 700 nm; filter **639** having a passband wavelength of 780 nm; and filter **640** having a passband wavelength of 850 nm all mounted within drum **610**. Drum **610** is rotated in the direction shown by arrow **641** about the center of rotation **642**. Discrete filters **635-640** are mounted within drum **610**, approximately 60 degrees apart, and are positioned orthogonal to the light path depicted by arrow **643** as the drum is rotated. As can be appreciated by those skilled in the art, as drum **610** rotates, each of the six discrete filters **635-640** are positioned in light path **643** in turn. Light that is within the passband wavelength of the individual filter, to the extent that such wavelengths exist in the light path, is passed there through to mirror **605** and mirror **606** and onto detector **609** (FIG. **3**). It should be further appreciated that positioning light path **643** outside (below in the example shown) of the rotational axis of drum **610**, and positioning the filters at 60 degree angles relative to one another, allows for additional filters to be included in discrete filter assembly **604** than might otherwise be possible. It should further be appreciated that while the drum **610** rotates, there will be periods when no light from light path **643** passes through the drum, a "dark" period, and the detector **609** will not receive any light. For conciseness, discrete filter assemblies **704**, **904**, and **1003** of FIG. **10** have the same configuration as **604** depicted in FIG. **11**.

Referring now to FIG. **12**, there is shown a schematic representation of adjustable filter assembly or angle tuned filter assembly **803** mounted within drum **610**. In the example shown, and as described herein above, angle tuned filter pair **832** and **833** are mounted within drum **610**. The drum **610** is rotated in the direction shown by arrow **641** about the center of rotation **642**. The angle tuned filter pair **832** and **833**, are positioned such that as the angle of incidence **834** changes wavelengths of light and are passed from mirror **801** and filter **802** through the angle tuned filter **833** at 4 nm spacing onto mirror **804** and directed to detector **807** (FIG. **3**). It should be further appreciated that positioning light path **843** outside (below in the example shown) of the rotational axis of drum **610** allows for a full sweep of the pair of angle tuned filters **832** and **833**. For conciseness, the angle tuned filter assembly **1103** of FIG. **10** has the exact same configuration as **803** depicted in FIG. **12**.

Example Light and Signal Processing of an Optical Fluid Analyzer

Having described the light paths and associated components of OFA module **32** hereinabove, the processing steps that the signals are subject to in order to produce a meaningful spectrum will now be described with reference to FIG. **13** as well as FIG. **3**. The photo-detectors **2001** of detector module **620** each produce an analogue signal **2002** that is proportional to the intensity of light incident on each respective detector. Analogue signal **2002** is amplified and filtered using any known method by amp/filter **2003** and is then routed to analogue-to-digital converter **2004** (ADC). The ADC sampling process **2005**, as well as other processes described herein, may be controlled by software that may reside on processor **2000**, for example, wherein the processor may be comprised of any known computing device and may further be comprised of more than one processors and may advantageously be located within formation wireline tester **20** and/or located at the surface such as processing unit **24** (FIG. **1**). The ADCs **2004** simultaneously sample eight channels from detectors **609**, **709**, **807**, **909**, **1008**, **1107**, **1150**, and **1202**. The ADCs **2004** may also advantageously include an anti-aliasing digital filter stage.

The processor **2000** filters and sub-samples the signals within sub-sampling filter **2006** from all eight channels in order to further reduce the noise level and to reduce the sample rate down to any desired level. Simultaneously, an encoder **2008**, which can comprise a rotary encoder, sends a signal to the processor indicating the angular position of the rotational portions of drum **610**. In one embodiment of the present disclosure the encoder **2008** measures the angular position of the drum within a 90° quadrant to a resolution of about the equivalent of 0.02° of rotation. A timer (not shown) within the processor **2000** may be used to measure the duty cycle and an additional Hall sensor **2009** mounted within proximity of drum **610** is used to determine the quadrant that the drum is rotating through. The software within the processor **2000** continuously tracks the position of the rotation portions of drum **610** as it rotates with respect to time. In one embodiment of the present disclosure, the filters within drum **610** rotate at a predetermined rate of rotation such that the filters are positioned, with respect to the signals, at a preselected position. It should be appreciated that the rotational speed of the filters could be slowed, stopped, or reversed and restarted to take more data at any certain position of the rotation which would, among other advantages, increase the signal-to-noise ratio.

As each photo-detector ADC sample is taken, the sampled signal **2010** is labeled with the last reported drum position signal **2011** from the encoder **2008**. In certain embodiments, the sampling rates of the drum position and photo-detector signals may not be the same and may not be time synchronized. In this case, the software on the processor **2000** includes drum position interpolation **2012** in order to calculate the drum position for each individual sample. The software may also buffer the samples and then calculates a more accurate rotational drum position using the sample time, the reported drum position and time, as well as the speed and acceleration of the rotational portion of the drum. In some embodiments, signal stream **2013** coming from the photo-detectors comprises eight channels of 32-bit samples, each tagged with the relative rotational drum position sampled at 2 kHz.

The software that reside within processor **2000** may contain the parameters, or profiles, of each of the optical filters mounted rotationally within the drum **610**. It should be appreciated by those skilled in the art that this data includes the center wavelength, the bandwidth, and the angular position of each filter mounted within the drum, some or all of which may be temperature dependent. It should further be appreciated that certain aspects of these parameters may be temperature dependent and that steps must be taken to account for changes due to temperature. In the case of the angle-tuned filters **803** and **1103**, the angle-tuned parameters **2018** also include a fitted curve that is used to determine the pass-band wavelength from the angular position of the filter relative to the incident light. The parallel reference signal **2015** associated with discrete filters **904** are compared with the parallel reference discrete filter parameter profiles **2016**. The parallel reference signals **2017** associated with the angle-tuned filters **1103** are compared with the parallel reference angle-tuned filter parameter profiles **2018**. The sample, or measurement, signals **2019** associated with discrete filters **604** are compared with the measurement discrete filter parameter profiles **2020**. The sample signals **2021** associated with the angle-tuned filters **803** are compared with the measurement angle-tuned filter parameter profiles **2022**. There are additional profiles **2023** used to mark points in the drum's rotation at which the signal can be considered to be dark to perform a dark measurement as will be disclosed in more detail herein below.

In operation, as the drum upon which the filters are mounted rotates, software on the processor **2000** determines which filter the light for each ADC channel is passing through and converts the drum angle into a wavelength. The processor then adds this wavelength information to the signal stream for assignment into its proper wavelength bin as will be more fully described herein after.

The software may also advantageously include a configurable set of wavelength bins, the reference wavelength bins **2024**, and the sample signal wavelength bins **2025**. These bins are comprised of a center wavelength (in nanometers) and a width (in nanometers) of the wavelength. These bins define the wavelengths that will be reported for each spectral measurement. The samples in the signal stream are assigned to one of these bins, depending on their tagged wavelength.

There may be multiple sample signals per wavelength bin **2025**. As the sample signals are added to a particular bin, they are weighted using a configurable windowing function. The windowing function uses a higher weighting for sample signals having a center frequency close to the center of the frequency bin, and a lower weighting for sample signals having a center frequency close to the edge of the bin. For instance, the signals coming from the measurement discrete filter parameter profiles **2020** go through windowing function **2026** before being assigned to any particular bin within sample signal wavelength bins **2025**.

Still referring to FIG. **13**, the measured dark levels **2027** are subtracted from the sample signals, and dependent on the measure type, the ratio between the individual sample signal and respective parallel reference stream is obtained. The resulting spectrum **2028** may be added to measurement first-in-first-out (FIFO) memory **2029**, and may further be processed by processing unit **24** (FIG. **1**).

The electrical control and operation of the present disclosure is now described with reference to the various figures. When the OFA module **32**, or optics module, is powered on, software residing in the module runs a self-test script. The purpose of the self-test is to detect any faults prior to deployment of the tester in a well or in situ as necessary for confidence checking. The OFA module **32** then enters a stand-by mode while the tester is deployed to a first predetermined depth within a wellbore. Cooling may then be switched on if the sensors/detectors temperature reaches a pre-determined threshold during deployment within the wellbore. Prior to taking any measurements, cooling is provided to the detectors to facilitate the detectors reaching the lowest possible temperature while deployed. Once the detectors have reached a stable temperature, the OFA module is taken out of stand-by mode and completely powered up. In wells of relatively low temperature, the cooling may not be required and in other circumstances, less cooling may be used to free power for other purposes, consistent with adequate measurement quality at the time.

Measurements that can be made with the present disclosure, include, but are not limited to, fluorescence, phase, composition, absorption, reflectance, reference, and others. The measurements may be done in a predetermined sequence or ordered manually from the operator at the surface. Not all measurements need to be done at any of the predetermined testing locations. Once a particular measurement is made, for example a fluorescence measurement performed by the fluorescence measurement cell **400** (FIG. **9**), the electrical output from detector **609**, of the detector module **620**, is converted to a digital signal proportional to the intensity of the light hitting the detector module **620**. This signal is sent to a signal processing algorithm within a computing device. Processed or raw data can be sent to the processing unit **24** (FIG. **1**) for further analysis. In certain embodiments, these signals may be sent to FIFO buffers (FIG. **13**) and then sent for further analysis as described with reference to FIG. **10** directly herein above. The OFA module **32** continues to take measurements using other optics sensors (or repeating measurements if desired). The duration of the test depends on many factors including the type of test (fluorescence, reflectance, absorption, etc), the number of times the measurement is made, the type of data desired (running average versus single point), formation conditions and other factors. Once all of the desired measurements are made, the OFA returns to the 'ready' mode. Referring back to FIG. **1**, the formation tester **20** is then positioned in another predetermined location and the sequence of measurements is repeated as desired. Once all of the measurements are made at all of the desired predetermined locations (depths) the OFA module **32** is powered down and the formation tester **20** may be brought to the surface.

Examples of Utilizing Tools for Monitoring, Analyzing and Characterizing Downhole Fluids

The operational aspects of spectrometer assembly **600** (FIG. **10**) with respect to providing downhole fluid property measurements, is best described with reference to FIG. **14**. There is shown an example of the deconvolved theoretical output of a spectrometer of the present disclosure for certain fluids typically found in a downhole environment. The absorption spectrum shown is from light output from absorption cell **105** (FIG. **4**) for various constituents and is displayed as optical density plotted against wavelength for both the visible range and the near infrared range. It should be appreciated by those skilled in the art that the raw output, before being deconvolved, of absorption cell **105** would be the sum of the optical density for all of the constituents in the mixture plotted against wavelength. The use of the present disclosure in the identification of individual constituents within the mixture will be described more fully herein below. In the example shown in FIG. **14**, curve **920** is an

example of a absorption spectrum for an oil-based mud with a decaying portion in the visible range and a peak somewhere around 1700 nm. Curve **921** represents the absorption spectrum for a first reservoir fluid and has various absorption features with corresponding optical densities shown in the 1700 nm range. Curve **922** represents the absorption spectrum for a second reservoir fluid and it also has various absorption features with corresponding optical densities shown in the 1700 nm range. It is known that different oils have variations in their molecular structure that cause them to have different colors and corresponding differences in absorption at the lower frequencies dues to electrical absorption. It is also known that most oils have a strong characteristic absorption peak at about 1725 nm due to molecular vibration absorption of the light because a typical carbon atom will have two hydrogen molecules attached thereto. Curve **923** represents the absorption spectrum for water with well-known significant peaks at 1445 nm and 1930 nm. Curve **924** represents an example of a absorption spectrum for CO_2 with a maximum peak at about 2013 nm and a trough at 2045 nm.

As described herein above, downhole spectrometers of the prior art typically comprise twenty or fewer channels. It is therefore virtually impossible to deconvolve and reproduce the entire spectrum of a fluid as shown in FIG. **14**. Instead, spectrometers of the prior art comprise a discrete filter or channel having a bandpass wavelength along the spectrum corresponding to qualitative measures for identifying the presence (or absence) of a fluid of interest within the tester flow line. For instance, spectrometers of the prior art typically position a channel at about 1445 nm and 1930 nm to detect the presence (or absence) of a water peak and another channel at about 1725 nm to detect the presence or absence of oil. Because of the strong peaks and the wavelength separation between water and oil, these prior art spectrometers make it very easy to differentiate between the fraction of water and the fraction of oil in the tester flow line. For the reasons discussed herein above, spectrometers of the prior art lack the capability to provide better resolution at points along the spectrum to provide more information about the properties of the fluids in the flow line.

Still referring to FIG. **14**, the discrete filters of discrete filter assembly **604** are shown graphically with their approximate wavelength within the visible region and extending into the near infrared. The use of a drum spectrometer of the present disclosure allows for the positioning of six discrete filters, in one embodiment having wavelengths of 434 nm, 500 nm, 600 nm, 700 nm, 780 nm and 850 nm, within this area of interest to accurately detect the presence or absence of a fluid of interest at lower wavelengths. For example, many of the oil-based drilling muds are comprised of synthetic-type oils, which typically lack the aromatic components of naturally occurring hydrocarbons, and will have a higher absorption spectrum at lower wavelengths. The present disclosure has increased resolution at these lower wavelengths and may be useful to accurately monitor the presence of oil-based muds to determine, for example, when the flow line is free of filtrate to enable the taking of a clean sample of hydrocarbons. In addition, because oil-based muds may be recycled and blended, the present disclosure may be able to distinguish between different types of oil-based muds in a mixture and when used with multivariate analysis software, such as software offered by CAMO Software AS, be able to permit quantitative analysis of each in the mixture. In addition, as shown in FIG. **9**, the fluorescence light source comprises a blue LED **401** having a wavelength between 457 nm and 463 nm. It should be appreciated by those skilled in the art that if the fluid in flow line **151** fluoresces, the relatively dense spacing of filters in this wavelength range provides a means of determining oil-based mud filtrate from reservoir hydrocarbons comprised of a light color.

The discrete filters of filter assembly **704** are also shown graphically in FIG. **14** with their approximate wavelength within a wide portion of the near infrared range. The use of a drum spectrometer of the present disclosure allows for the positioning of six discrete filters, in one embodiment having wavelengths of 935 nm, 1080 nm, 1290 nm, 1450 nm, 2013 nm and 2045 nm, within this area of interest to accurately detect the presence or absence of a fluid of interest at this wavelength range. For instance, the filters at wavelengths 935 nm and 1080 nm are important for detecting the presence of a first production fluid **921** at the lower near infrared wavelengths. The filter at 1290 nm is useful for detecting the presence of a second production fluid **922**. The significance of being able to detect the compositional variations between two different production fluids is the ability to determine reservoir connectivity. The two different fluids most likely come from different non-connected compartments within the formation. This type of information is critical in designing the completion, determining economic reserves, and in production planning. The present disclosure enables the positioning of more filters within the near infrared wavelength region than spectrometers of the prior art and therefore enhances the ability to accurately determine compositional information about the fluids within the flow line.

Referring still to FIG. **14**, and still with reference to discrete filter assembly **704**, is the ability of the present disclosure to detect and quantify H_2O present in flow line **151** (FIG. **4**) as depicted by curve **923**. As discussed herein above, H_2O has a characteristic peak **925** at 1450 nm and a second, stronger, peak **926** centered at about 1930 nm. Discrete filter assembly **704** of the present disclosure may include a filter having a center bandwidth of 1450 nm as show in FIG. **14** to monitor characteristic peak **925**, and may also, or alternatively, include a filter having a center bandwidth of 1930 nm to monitor for peak **926**, both associated with the presence of water in flow line **151**.

Also shown in FIG. **14**, with reference to discrete filter assembly **704**, is the ability of the present disclosure to detect and quantify CO_2 present in flow line **151** (FIG. **4**) as depicted by curve **924**. As discussed herein above, CO_2 has a characteristic absorption peak **927** at 2013 nm and a corresponding characteristic trough at 2045 nm. Because water has a peak at 1930 nm, an exemplary embodiment of discrete filter assembly **704** of the present disclosure includes both a filter at 2013 nm and at 2045 nm to confirm the presence of CO_2 in flow line **151**, for example, in the presence of water-based muds. Heretofore, spectrometers have been of limited accuracy at low concentrations of CO_2 and especially so in the presence of water-based drilling fluids. As discussed herein before, the present disclosure enables the positioning of more filters within the near infrared wavelength region than spectrometers of the prior art and therefore enhances the ability to accurately quantify CO_2 within the flow line. Similar to connectivity, the ability to accurately quantify CO_2 directly influences the ability to determine reserves and perform production planning.

Still referring to FIG. **14**, an embodiment of angle-tuned filter assembly **803** is depicted, and as described herein above, the filter assembly, comprises a pair of angled-tuned filters having a 4 nm increment between each measurement as the filters are rotated within drum assembly **600** (FIG. **10**)

relative to stationary light directed therein. It should be appreciated by those skilled in the art, this particular embodiment of the present disclosure provides for **70** measurement increments between 1550 nm and 1830 nm, with a 10-15 nm spectral resolution, and that such a fine sampling interval yields a highly refined spectral resolution in the area of interest. In fact, with such a fine sampling interval, the curves presented in FIG. **14** within this region may be produced with great accuracy without much need for curve fitting techniques. In other words, angle-tuned filter assembly **803** not only reveals the vibrational peaks of the mixture of fluid components within the flow line, the output of the drum spectrometer **600** of the present disclosure can enable the ability to identify subtle differences between the fluids within the wavelength range of 1550 nm and 1830 nm and produce representative curves for each such fluid as will be described more fully herein below. It should be appreciated by those skilled in the art that the present disclosure may also enable the fingerprinting of fluids within the flow line, downhole and in real time. The present disclosure could not be realized utilizing discrete filters of the prior art because even if one could obtain such filters having center bandwidths at 4 nm spacing, it would be virtually impossible to install **70** such filters in a downhole tool.

Still referring to FIG. **14**, and with special attention to the "oil window", or the wavelength range between 1550 nm and 1830 nm, an operational example of the present disclosure is disclosed. Oil-based mud **920** has a vibrational absorption peak at 1745 nm and has a distinctive shape throughout the oil window. First production fluid **921** has a vibrational absorption peak at 1760 nm and has its own distinctive shape throughout the oil window. Similarly, second production fluid **922** has a vibrational absorption peak at 1710 nm and has its own distinctive shape throughout the oil window. The ability to obtain such high spectral resolution within the oil window enables the fingerprinting of oil-based mud indicated by curve **920**, first production fluid **921**, and second production fluid **922**. Although first production fluid **921** and second production fluid **922** are shown on the same spectrograph in FIG. **14**, the fluids may not have been flowing in flow line **151** (FIG. **4**) at the same time and may have been obtained at different downhole testing positions within the wellbore. The fingerprinting information may be stored and used at subsequent downhole testing positions to determine connectivity or compartmentalization of reserves. The fingerprinting information may also be used on subsequent wireline testing in the future to determine changes in the reservoir such as gas to oil ratio (GOR), water fraction, etc, and further assist in production planning such as enhanced oil recovery (EOR) actions. In addition, such fingerprinting information is useful, for example, in determining EOR incremental recovery, and can used in conjunction with the sigma-derived values of downhole fluids as described in co-pending application number WO2017015340, the disclosure of which is incorporated by reference herein in its entirety.

The spectral analysis of the high resolution spectral output of optical fluid analyzer in the oil window of the present disclosure may provide downhole quantitative analysis of a mixture of well fluids utilizing correlations between component partial densities and the spectra. Utilizing a calibration data set based on spectra data for, as an example, pure hydrocarbons C_1-C_7, at least in the hydrocarbon window of wavelengths, as well as mixtures thereof, regression coefficients can be determined for use in various correlation techniques. An example of such a data set **932** is shown graphically for pure hydrocarbons C_1-C_7, **934-939** respectively, in FIG. **15** within the wavelength range of 1620 nm to 1860 nm. As described herein above with reference to FIG. **14**, the optical fluid analyzer of the present disclosure would provide at least 53 measurements in this wavelength range. Various methods may be used for correlating, or deconvolving, the output spectra with the data sets to provide downhole identification and quantitative analysis of the well fluids. Such known techniques include principal component analysis (PCA), principal component regression (PCR), partial least squares regression (PLSR), and least squares estimation (LS), among others. In the field of quantitative chemometrics, PLSR is sometimes preferred because of the way it handles unknowns mixed in with a particular fluid of interest, or target analyte. In the case of using PCA, such technique is based on singular value decomposition, and is useful to determine the number of non-zero singular values, and thus how many unknowns can be independently estimated. Using such techniques, and combinations thereof, it may possible with the present disclosure to quantify the amount of a particular fluid of interest within a mixture of well fluids downhole and in real time.

The optical analyzer of the present disclosure is unique in that it provides a parallel reference signal and a direct reference signal. It is an important aspect of the present disclosure that, unlike prior art optical fluid analyzers, the direct reference signal completely bypasses the testing cell of the analyser. Referring to FIG. **16**, the reference signal aspects of the present disclosure will be described using a simplified version of absorption cell light path **1**, direct reference light path **3** and parallel reference light path **9** of FIG. **3**. As described herein above, broadband light from source **100** is exposed to downhole fluid in absorption cell **105** and a spectrum is produced using the filters in channel set **701** and the output **710** from detectors **609**, **700**, and **807**. This measurement output is produced with shutter **112** in the open position and shutter **302** in the closed position. In one embodiment of the present disclosure, the optical analyzer is operated in a direct reference mode wherein shutter **112** is closed and shutter **302** is open. In direct reference mode, light from source **100** is directed through beam splitters **103** and **301** into light path **3** and into channel set **701** and detectors **609**, **700**, and **807** and the output signal **710** is a pure direct reference signal. The measurement signal output and the direct reference output signal are produced from the same set of filters and detectors and processed through the same analog to digital converters under the same conditions (pressure and temperature) at approximately the same time. The intensity of the light of the measurement signal output is compared to the intensity of the light from the direct reference signal output. In some embodiments, a measurement is made during one rotation of the measurement filter sets **701** and a direct reference is made during a subsequent rotation. It should be appreciated by those skilled in the art that by comparing these two reference signal outputs, the time dependent differences as well as the difference between detectors can be normalized as will be described herein below. Still referring to FIG. **16**, the parallel reference aspects of the present disclosure are explained. As described herein above, the filters of channel set **701** and **901** are selected to be as close to identical as possible as are the detector pairs of detector module **620**. In addition to pressure and temperature effects on the optical components that comprise a downhole analyzer, which may be changing relatively slowly, other factors may exist that change more rapidly that may produce deleterious effects on the accuracy of the output of such analyzers. One such factor is the

temporal changes, or flickering, in source **100**. In one embodiment of the present disclosure, with shutter **112** closed and shutter **302** open, the output **710** is the direct reference signal and this may be compared to the parallel reference output **910** at the same time. In doing so, the spectral intensity differences caused by temporal changes in the source **100** can be normalized as will be described more fully herein below. It should be further appreciated that with shutter **112** open and shutter **302** closed, the output **710** is a measurement output, or spectrum, and that output may be compared to parallel reference output signal **910**. As discussed, the output made during a dark measurement period is indicative the noise of the detector. The normalization of the measurement signal by using the parallel and direct reference signals can be accomplished using the following relationship:

$$meas\lambda_{corr}(t') = \frac{(meas\lambda(t') - dark_1)}{(pref\lambda(t') - dark_2)} \times \frac{(pref\lambda(t'') - dark_2)}{(meas\lambda(t'') - dark_1)} \quad \text{(Equation 1)}$$

Wherein:

$meas\lambda_{corr}(t')$ is the corrected measurement output at wavelength λ, at time equals t';

$meas\lambda(t')$ is the raw measurement output at wavelength λ produced at **710** at time equals t';

$dark_1$ is the averaged detector output produced at **710** during dark periods;

$pref\lambda(t')$ is the parallel reference output at wavelength λ produced at **910** at time equals t';

$dark_2$ is the averaged detector output produced at **910** during dark periods;

$pref\lambda(t'')$ is the parallel reference output at wavelength λ produced at **910** at time equals t''; and

$meas\lambda(t'')$ is raw measurement at wavelength λ produced via the direct path at **710** at time equals t''.

Time t'' is preferably close enough to time t' that the apparatus temperature is similar.

The normalization of the measurement signal of optical fluid analyzer of the present disclosure may be shown by examples utilizing Equation 1 with reference to Table 1. For convenience, the dark signals are taken as zero without altering the generality of Equation 1, and the source intensity is taken as constant with time.

The cell contents in this example absorb 50% at the two wavelengths but the source intensity differs at these wavelengths. The parallel detector at wavelength λ_2 has 92% of the sensitivity of the detector at wavelength λ_1, due to manufacturing variation.

When the data in Table 1 is inserted into Equation 1, the corrected readings at each wavelength are 0.5, corresponding to the cell absorption of 50%. This example shows how both the spectral variation in the source, and detector variations can be compensated.

TABLE 1

Wavelength		λ_1	λ_2
Source Intensity		1.0	0.9
Cell absorption factor		50%	50%
Cell output Intensity		0.5	0.45
Measurement Signal at 710	$meas\lambda(t')$	0.5	0.45
Reference Signal at 910	$pref\lambda(t')$	1.0	0.9*0.92 = 0.83
Reference Signal at 710	$meas\lambda(t'')$	1.0	0.9
Reference Signal at 910	$pref\lambda(t'')$	1.0	0.9*0.92 = 0.83

$$meas\lambda_{1corr}(t') = \frac{(0.5-0)}{(1-0)} \times \frac{(1-0)}{(1-0)} = 0.5 \quad \text{(Equation 1)}$$

$$meas\lambda_{2corr}(t') = \frac{(0.45-0)}{(0.83-0)} \times \frac{(0.83-0)}{(0.9-0)} = 0.5 \quad \text{(Equation 1)}$$

While the foregoing description of the reference channels is relative to the absorption cell **105** (FIG. **4**), it should be appreciated that signal output from the reflectance cell **204** (FIG. **7**) can be similarly normalized using the techniques described herein above.

While the foregoing is directed to only certain embodiments of the present disclosure, certain observations of the breadth of the present disclosure should be made. Wireline, as referred to herein, may be electric wireline including telemetry and power. Wireline may also include wired slickline and wired coil tubing. Embodiments of the present disclosure include pumped-down-the-drill-pipe formation testing where the tools described herein exit through the drill bit. Otherwise heretofore conventional logging while drilling (LWD) that include the present disclosure allow for formation testing and sampling where the drill pipe may be wired for power and telemetry or some other telemetry such as mud pulse or electromagnetic through the earth. Further, commands and data can be stored using battery power, and power can come from a turbine during circulation.

In addition, while the foregoing is directed to only certain embodiments of the present disclosure, it should be appreciated by those skilled in the art that the present disclosure is not limited to any particular embodiment or field of endeavor. Other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. An apparatus for fluid analysis, comprising:

a broadband source configured to produce a broadband light across a spectrum of wavelengths;

a source splitter optically coupled to the broadband source and splitting the broadband light into a parallel reference channel and a measurement channel;

the measurement channel including a test cell wherein the broadband light of the measurement channel is configured to interact with a fluid sample in the test cell;

at least one adjustable filter assembly having a plurality of filters mounted thereon, the plurality of filters including a parallel reference set of filters configured to filter the parallel reference channel and a measurement set of filters configured to filter the measurement channel;

at least one drive operable to move the at least one adjustable filter assembly; and

a detection unit comprising a parallel reference set of detectors detecting the parallel reference channel after filtering with the parallel reference set of filters and a measurement set of detectors detecting the measurement channel after filtering with the measurement set of filters.

2. The apparatus of claim **1**, wherein the plurality of filters comprise any of discrete filters, linear variable filters and angle tuned filters.

3. The apparatus of claim **2**, wherein the at least one adjustable filter assembly comprises a plurality of preselected positions wherein the parallel reference channel and the measurement channel are concurrently filtered at the preselected positions.

4. The apparatus of claim 1, wherein the parallel reference channel includes a beam splitter optically connected to the parallel reference channel splitting the broadband light of the parallel reference channel into a direct reference signal, a pair of shutters having at least one selective orientation configured to block the measurement channel and to permit the direct reference signal to pass to a direct reference channel and on to the measurement set of detectors.

5. The apparatus of claim 4, wherein the direct reference channel bypasses the test cell.

6. The apparatus of claim 1, wherein the test cell comprises any of an absorption cell, a fluorescence cell and a reflectance cell.

7. The apparatus of claim 1, wherein the at least one adjustable filter assembly comprises a drum and the plurality of filters are mounted to an inside surface of the drum.

8. A method for performing fluid analysis, comprising:

generating a broadband light;

splitting the broadband light signal into a parallel reference channel and a measurement channel;

interacting the broadband light signal of the measurement channel with a fluid sample in a test cell;

filtering the broadband light signal from the measurement channel after interacting with the fluid sample through a measurement set of filters and filtering the broadband light signal of the parallel reference channel through a parallel reference set of filters; and

detecting the measurement channel after filtering with the measurement set of filters using a measurement set of detectors to produce a measurement output and further detecting the parallel reference channel after filtering with the parallel reference set of filters using a parallel reference set of detectors to produce a parallel reference output signal.

9. The method of claim 8, wherein the filtering of the broadband light from the measurement channel after interacting with the fluid sample through a measurement set of filters and the filtering the broadband light of the parallel reference channel through a parallel reference set of filters are performed concurrently.

10. The method of claim 8, further including correcting the measurement output using the parallel reference output signal and producing a corrected measurement output.

11. The method of claim 10, further including calculating at least one property of the fluid sample using the corrected measurement output.

12. The method of claim 10, further including producing at least a portion of an optical density spectrum from a plurality of the corrected measurement outputs.

13. The method of claim 8, wherein the test cell comprises an absorption cell, determining a direct reference signal and determining an amount of the broadband light that is absorbed within the fluid sample.

14. The method of claim 8, wherein the test cell comprises a reflectance cell, utilizing the measurement output and determining an incidence angle to detect any of a presence of gas, a presence of condensate, a presence of rich gas, a presence of lean gas, a presence of water, or a gas to oil ratio, in the fluid sample.

15. The method of claim 8, wherein the test cell comprises a fluorescence cell, utilizing the measurement output and determining a fluorescence signal and further detecting a bubble point or a phase of the fluid sample.

16. An optical fluid analyzer comprising:

a broadband light source;

an optical chassis comprising:

a flowline configured to include a fluid sample flowing therethrough;

an absorption cell optically coupled with the flowline; and

a prism assembly optically coupled with the flowline and comprising any of a reflectance cell and a fluorescence measurement cell;

a drum spectrometer assembly comprising a measurement filter assembly and a parallel reference filter assembly;

an absorption cell light path optically coupled to the broadband light source, the absorption cell and the measurement filter assembly;

a light path directed at fluid reflectance optically coupled to the broadband light source, the prism assembly and the measurement filter assembly;

a direct reference light path optically coupled to the broadband light source and the measurement filter assembly;

a fluorescence light path optically coupled to an fluorescence light source, the prism assembly and the measurement filter assembly;

a parallel reference light path optically coupled to the broadband light source and the parallel reference filter assembly;

a cell monitoring light path optically coupled to the absorption cell light path and to a cell monitoring light path detector;

a first discrete filter assembly disposed in the measurement filter assembly and optically coupled to a first detector;

a second discrete filter assembly disposed in the measurement filter assembly and optically coupled to a second detector;

a first angle tuned filter assembly disposed in the measurement filter assembly and optically coupled to a third detector;

a third discrete filter assembly disposed in the measurement filter assembly and optically coupled to a fourth detector;

a fourth discrete filter assembly disposed in the measurement filter assembly and optically coupled to a fifth detector; and

a second angle tuned filter assembly disposed in the measurement filter assembly and optically coupled to a sixth detector.

17. The optical fluid analyzer of claim 16 further comprising:

the first discrete filter assembly and the third discrete filter assembly are comprised of a matching first set of a plurality of discrete filters configured to filter any of the fluorescence light source and the broadband light source after interacting with the fluid sample to pass light in a visible range and a near infrared range;

the second discrete filter assembly the fourth discrete filter assembly are comprised of a matching second set of a plurality of discrete filters configured to filter the broadband light source after interacting with the fluid sample to pass light in the near infrared range; and

the first angle tuned filter assembly and the second angle tuned filter assembly are comprised of a matching a first angle tuned filter and a matching second angle tuned filer and configured to filter the broadband light source after interacting with the fluid sample to pass light in the near infrared range.

18. The optical fluid analyzer of claim 17 further comprising:

wherein the matching first set of a plurality of discrete filters are configured to filter any of the fluorescence light source and the broadband light source after interacting with the fluid sample concurrently;

wherein the matching second set of a plurality of discrete filters are configured to filter the broadband light source after interacting with the fluid sample concurrently; and

wherein the matching a first angle tuned filter and a matching second angle tuned filer are configured to filter the broadband light source after interacting with the fluid sample concurrently.

19. The optical fluid analyzer of claim **18**, wherein:

the first detector is configured to produce a first measurement output;

the second detector is configured to produce output a second measurement output;

the third detector is configured to produce output a third measurement output;

the fourth detector is configured to produce output a fourth parallel reference output signal;

the fifth detector is configured to produce output a fifth parallel reference output signal;

the sixth detector is configured to produce output a sixth parallel reference output signal; and

the optical fluid analyzer further configured to produce a first corrected measurement output using the first measurement output and the fourth parallel reference output signal, to produce a second corrected measurement output using the second measurement output and the fifth parallel reference output signal, and to produce a third corrected measurement output using the third measurement output and the sixth parallel reference output signal.

20. The optical fluid analyzer of claim **16** further comprising:

the cell monitoring light path detector configured to produce a continuous signal indicative of a gross intensity of the broadband light source transmitted through the absorption cell after interacting with the fluid sample.

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