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(54) **Title:** DEVICES AND METHODS FOR SENSING PROPERTIES OF FLUIDS

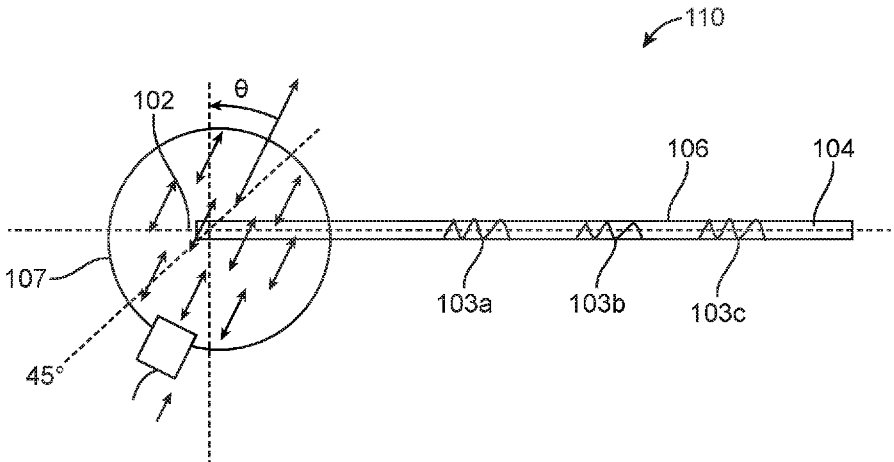

FIG. 1B

(57) **Abstract:** The invention discloses methods for simultaneously measuring various properties of a fluid using a waveguide. The method includes transmitting a plurality of wave modes into the fluid using an ultrasonic shear wave transducer from one end of a waveguide. Further, the wave modes are reflected from the other end of the waveguide. The reflected wave modes are processed simultaneously. The time of flight and the amplitude of the received wave modes are determined. Further, one or more properties of the fluid are measured using determined time of flight and amplitude of the received wave modes. The disclosed method is used to accurately measure the properties of fluid such as level, density, viscosity or flow rate in a short period of time.

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DEVICES AND METHODS FOR SENSING PROPERTIES OF FLUIDS

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to Indian provisional patent application no. 201841043175 dated November 16, 2018 entitled "DEVICE AND METHOD OF SENSING MULTIPLE PROPERTIES OF LIQUIDS", and the complete specification thereof, filed on March 15, 2019, entitled DEVICES AND METHODS OF SENSING PROPERTIES OF FLUIDS.

FIELD OF THE INVENTION

[0002] The disclosure relates generally to measuring devices and in particular to devices and methods for measuring properties of liquids using ultrasound sensing.

DESCRIPTION OF THE RELATED ART

[0003] Acoustic waveguides are used to measure the physical properties (e.g., density, viscosity, level, temperature, etc.) of a fluid flowing or stored in a conduit or vessel. In a typical acoustic waveguide, a transducer assembly launches an acoustic pulse from one end of the waveguide located outside of a sealed conduit while its major portion is submersed into the fluid inside the conduit. The acoustic wave pulse is propagated in either the fundamental flexural, longitudinal or torsional mode along the length of the waveguide. When the wave group contacts the end of the waveguide, or with any cross-sectional change in the waveguide, it is reflected backwards towards the transducer. The transducer receives the reflected wave group and transmits it for further analysis. The speed of the acoustic pulse in the section of the waveguide submersed into the fluid depends on the physical properties of the fluid and therefore can be used to determine those properties.

[0004] Prior art methods measure physical properties of fluids based on noise wave propagation in either one or two fundamental modes in a waveguide. One of the major drawbacks of these techniques is the weak reflection of the wave pulse from the tube's end cut resulting in difficulties in result interpretation. There is therefore a need for improvising the propagation of acoustic waves in a waveguide to obtain accurate measurements by improving the robustness of the reflected wave signal. Apart from these, the wave mode signals are processed individually which leads to increase in time for the extraction of information from those signals.

[0005] US patent application US20180113030A1 proposes a waveguide with distributed sensors that support travelling of ultrasonic wave modes and provide sensing of the physical and chemical properties of the medium surrounding the sensor locations. A method to determine a location of a fluid layer is disclosed in US granted patent US9343055B2 in which an acoustic wave is propagated through the acoustic waveguide and the echoes of the acoustic wave reflected by the waveguide reflectors provides the location of the fluid layer. A method of detecting the level of an aerated fluid is disclosed in US granted patent US9285261B2. US patent application US20160153938A1discloses a method and a system for measuring mechanical properties of a solid material using standard ultrasonic wave modes. Prior art methods do not measure the properties of fluid accurately within a shorter duration of time. The invention discloses a method for measuring the properties of fluid that overcomes some of the drawbacks of existing methods.

SUMMARY OF THE INVENTION

[0006] In various embodiments, provided herein is a method of simultaneously measuring various properties of a fluid using a waveguide having a first end and a second end and a body of substantially uniform cross section therebetween. At least one transducer is affixed to the first end of the waveguide and configured to send acoustic waves and to receive reflected acoustic signals. The method comprises transmitting a plurality of wave modes into the fluid using an ultrasonic shear wave transducer from the first end of a waveguide and receiving the reflected plurality of wave modes from the second end of the waveguide. The reflections may contain information characteristic of the properties of the fluid. Then the plurality of received wave modes are processed simultaneously to determine time of flight and amplitude ratio of the received wave modes. Thereby one or more properties of the fluid are measured using the determined time of flight and amplitude of the received wave modes.

[0007] In various embodiments the plurality of wave modes are selected from longitudinal (L(m,n)), torsional (T(m,n), or flexural (F(m,n)). In some embodiments the transmitting is done at an angle of 45-90° inclination to an axis of the waveguide.

[0008] In some embodiments the one or more properties measured may include viscosity, density, flow rate, level or temperature of the fluid. In some embodiments the properties of the fluid are measured using at least two wave modes.

[0009] In some embodiments the method comprises measuring a first property of the fluid, measuring a second property of the fluid and applying a correction to the first property using the second property measurement. In some embodiments the first property is fluid level and the second property is density, viscosity or temperature of the fluid. In one embodiment the fluid level is measured to an accuracy of 2.5% or better in the range 10-100 mm.

[0010] In various embodiments of the method the second end is provided with an axisymmetric notch, a non-axisymmetric notch, a bend, a polygonal section, or an elliptical section. In various embodiments the method may include measuring the density or viscosity using flexural wave mode, torsional wave mode or both.

[0011] In some embodiments the property measured is density and the second end comprises an elliptical section. In some embodiments the property measured is fluid level and the second end comprises a cylindrical or a flat section. In some embodiments the property measured is flow rate and the second end comprises a cylindrical section.

[0012] In some embodiments the fluid properties are measured using at least two different frequencies.

[0013] This and other aspects are disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The invention has other advantages and features which will be more readily apparent from the following detailed description of the invention and the appended claims, when taken in conjunction with the accompanying drawings, in which:

[0015] FIG. 1A illustrates a system for measuring the properties of fluid.

[0016] FIG. 1B illustrates a configuration of shear transducer with respect to the waveguide.

[0017] FIG. 1C illustrates a waveguide with an excitation transducer and a reception transducer.

[0018] FIG. 1D shows the changes in the cross-section of second end of the waveguide.

[0019] FIG. 2 illustrates a method for measuring the properties of fluid.

[0020] FIG. 3 shows the schematic of the experimental setup for fluid property measurement using a waveguide sensor.

[0021] FIG. 4A, and 4B show reflected A-scan signals in L(0,1), T(0,1) and F(1,1) modes at different fluid levels.

[0022] FIG. 5A shows the change in time of flight (δTOF) of the L(0,1) , T(0,1) and F(1,1) wave modes at different fluid levels.

[0023] FIG. 5B shows the change in peak amplitude of the L(0,1) , T(0,1) and F(1,1) wave modes at different fluid levels.

[0024] FIG. 5C shows validation of liquid level measurement in the 10-100 mm range, illustrating error < 2.5 %.

[0025] FIG. 6A shows the reflected L(0,1), T(0,1) and F(1,1) modes in the A-scan signals observed at different fluid densities.

[0026] FIG. 6B shows comparison between standard and measured values of fluid densities using shift in TOF.

[0027] FIG. 7 shows viscosity measurements using ultrasonic method compared to Cannon standard values at different temperatures.

[0028] FIG. 8A shows experimental setup for intrusive flow measurement.

[0029] FIG. 8B shows L(0,1) , T(0,1) and F(1,1) wave modes in A scan for intrusive flow measurement.

[0030] FIG. 8C shows variation in TOF with flow rate for L, T and F modes.

[0031] FIG. 8D shows change in amplitude with flow rate for L, T and F modes.

[0032] FIG. 8E shows comparison between standard rotameter measurements and ultrasonic measurements using waveguide for different flow rates.

DETAILED DESCRIPTION

[0033] While the invention has been disclosed with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made to adapt to a particular situation or material to the teachings of the invention without departing from its scope.

[0034] Throughout the specification and claims, the following terms take the meanings explicitly associated herein unless the context clearly dictates otherwise. The meaning of "a", "an", and "the" include plural references. The meaning of "in" includes "in" and "on." Referring to the drawings, like numbers indicate like parts throughout the views. Additionally, a reference to the singular includes a reference to the plural unless otherwise stated or inconsistent with the disclosure herein.

[0035] The invention in its various embodiments discloses a system and a method for simultaneously measuring various properties of a fluid using a waveguide. The disclosed method is used to measure the properties of a fluid accurately in a short period of time.

[0036] In various embodiments, provided herein are systems and methods for simultaneously measuring various properties of a fluid. The system **100** as shown in FIG. 1A includes a computing device **101**, an analog to digital converter **103**, an ultrasonic pulser-receiver **105** and a waveguide sensor device **110**. The computing device **101** is configured for data acquisition, processing and calculation of properties of fluid. The analog to digital converter **103** is configured to convert the analog signal to digital signal. The ultrasonic pulser-receiver **105** is configured to generate electric pulses. The pulses generated by pulser-receiver **105** are sent to the device **110**. The device **110** includes a first end **102**, a body **106** and a second end **104**. The body **106** has substantially uniform cross section. The cross section in some embodiments may be circular, square, polygonal or other section. The device **110** includes at least one transducer **107** affixed to the first end **102** of the waveguide. The transducer **107** is configured to convert the electric pulses into acoustic pulses. The transducer **107** is configured to send acoustic waves and to receive reflected acoustic signals.

[0037] In one embodiment, the measurement device **110** may have a shear wave transducer **107** oriented at an angle θ to the axis of the waveguide, as shown in FIG. 1B. In various embodiments, the angle θ may vary between 45-90 degrees with reference to the axis of the waveguide. In various embodiments, the transducer is configured to produce waveforms 103a corresponding to longitudinal L(0,1), 103b corresponding to torsional T(0,1), or flexural F(1,1) modes of vibration simultaneously.

[0038] In one embodiment, device **120** includes one excitation transducer **107-1** and one reception transducer **107-2** as shown in FIG. 1C. In some embodiments, the device **110** includes more than one transducer for transmitting or receiving the signals in more than one frequency zone or wave mode. The zones may include low attenuation, increasing attenuation and high attenuation zones. The second end **104** of the device **110** in some embodiments is provided with a change in cross section. In various embodiments, the change in cross-section may include a circular section **104a**, a flat or polygonal section **104b**, an elliptical section **104c**, a bend **104d**, axisymmetric notch **104e**, or a non-axisymmetric notch **104f**, as shown in FIG.1D. In some embodiments a waveguide with circular cross section and with unchanged cross section at the second end may be used. In some embodiments, the waveguide may have a circular cross section with non-circular second end.

[0039] In various embodiments, the method **200** for simultaneously measuring various properties of a fluid, as shown in FIG. 2 includes the steps of transmitting a plurality of wave modes into the fluid using an ultrasonic shear wave transducer from the first end of a waveguide in step **201**. In some embodiments, the plurality of wave modes are selected from longitudinal (L(m,n)), torsional (T(m,n), or flexural (F(m,n)) modes. In step **202**, the reflected plurality of wave modes are received from the second end of the waveguide. The reflections contain information characteristic of the properties of the fluid. The plurality of received wave modes are processed simultaneously in step **203**. In step **204**, time of flight and amplitude ratio of the received wave modes are determined. In step **205**, one or more properties of the fluid are measured using determined time of flight and amplitude of the received wave modes. In various embodiments, the properties of the fluid are measured simultaneously using at least two wave modes. In some embodiments, the measured one or more properties of the fluid includes viscosity, density, flow rate, level or temperature of the fluid.

[0040] In some embodiments, the method **200** may involve measuring a first property of a fluid such as level, flow etc. and a second property such as temperature, density etc. The method may further involve applying a correction to the first property using the second property. In one embodiment, the simultaneous measurements performed using the method **200** may be fluid level and temperature, and the method may involve correcting the fluid level measurement using density, viscosity or temperature of the fluid. Temperature may be measured by a temperature dependent parameter such as density or viscosity. In one embodiment, the measurement error is less than or equal to 2.5% when measuring change in level between 10-100 mm.

[0041] In some embodiments, the method **200** in step **201** includes transmitting the wave modes at an angle θ of 45-90° inclination to an axis of the waveguide. In another embodiment, the transmitting is done at an angle of 90° and the property measured is a level of fluid.

[0042] In some embodiments, the density and viscosity are measured using flexural wave and torsional wave modes. In one embodiment, the flow rate is measured using longitudinal wave mode and the fluid level is measured using flexural wave mode. In various embodiments the temperature of a fluid may be measured using density or viscosity as primary measurement.

[0043] In some embodiments the method **200** may be used to measure flow rate. The waveguide may be employed for flow measurement using the same experimental setup as shown in FIG. 1A. In some embodiments a circular waveguide with circular end may be used and the second end of the waveguide may be placed in the flowing fluid. The tranducer orientation may be 45° to the axis of the waveguide to generate all three L, T and F wave modes. The method may further involve detecting drop in amplitude of the reflected signals, in all three wave modes shift in TOF in F(1,1) with increasing flow rate. The method may detect flow rate with error of 2% or less.

[0044] The methods disclosed here may be used to measure the physical properties of fluids. The disclosed methods may also be used to determine gradients in the properties of the fluid. The distributed physical properties of fluid may also be determined using the methods. Further, the methods disclosed here provide redundancy to improve accuracy in measurements of the fluid level/rheology. The methods have wide applications for example, inside critical enclosures of processing industries where access to other types of sensors is difficult.

EXAMPLES

[0045] Example 1: Method for measuring fluid level

[0046] The experiment was conducted for the determination of fluid level in (a) water and (b) castor oil using thin wire like waveguide sensor. The cross section was uniformly cylindrical without a change in cross section at the end. The schematic of the experimental setup is shown in FIG. 3. Initially, the A-scan signal was obtained for air medium or zero water level(0-cm) as shown in FIG. 4A. Subsequently, the fluid (water) was filled gently in the cylindrical container at increments of 10 mm. The A-scan signals were acquired at each 10 mm interval while filling 90 mm depth of water in the test container are shown in FIG. 4B.

[0047] The sensor was placed inside a beaker and corresponding level scale were used for verification of level measurement. The change in δTOF's and amplitude for the L(0,1),T(0,1) and F(1,1) wave modes at different fluid levels are shown in FIG. 5A and FIG. 5B respectively. As shown in FIG.5A, due to the dispersive nature of the F(1,1) mode, the δTOF's values are relatively higher in flexural wave mode as compared to the torsional and longitudinal wave modes. The time of flight indicates the fluid level. As shown in FIG. 5A, the time of flight is proportional to the fluid level. As shown in FIG. 5B, the amplitude ratio of flexural wave mode decreases with increase in fluid level. There is no substantial drop in the amplitude ratio of torsional and longitudinal wave mode, when the fluid to be measured is water whereas there is significant drop in the amplitude ratio of torsional and longitudinal wave mode, when the fluid to be measured is oil.

[0048] Multiple trials were conducted to validate the repeatability of this technique. The level Measurement experiments were repeated for non-viscous fluid and the obtained shift in peak frequency and δTOF at different fluid levels of F(1,1) are shown in FIG. 5C. The data of FIG. 5C was found to be consistent and repeatable with an error percentage less than 2.5 %.

[0049] It was observed that the flexural wave mode F(1,1) was much more sensitive to the surrounding fluid as compared to the longitudinal L(0,1) and torsional T(0,1) wave modes on viscous and non-viscous fluids. L(0,1) is much more sensitive in water (non-viscous) level measurement compared to T(0,1), while T(0,1) is much more sensitive in oil (viscous) level measurement compared to L(0,1).

[0050] Example 2: Measurement of density

[0051] For measuring density, the experimental setup as shown in FIG. 3 was used to transmit/ receive the signal, and temperature was recorded with a thermocouple. The obtained A-scan signals are shown in FIG.6A. This experiment was chosen to validate the inverse model for density prediction. An circular waveguide with non-circular elliptical end was used. Fluid samples with density from 800 kg/m^3 (kerosene) to 1200 kg/m^3 were used. Above 1000 kg/m^3, the density variation was achieved by adding salt to water. The centre frequency of the tone burst signal was selected to be 500 kHz. The effect of density was measured by tracking the change in TOF of T(0,1) (i.e TOF changes with density changes) and temperature effects were tracked by monitoring the change in TOF of L(0,1) signal. The waveguide measured density values were compared with the standard values as shown in FIG. 6B. Based on the results the waveguide measurement are closely in agreement with the standard value

[0052] Example 3: Measurement of viscosity

[0053] For measuring viscosity, the same equipment as in FIG. 3 was used, with thermocouple for temperature measurement. Experiments were carried out using F(1,1) wave mode on Cannon viscosity standards from room temperature to 48 °C. The dynamic viscosity was measured using a uniformly cylindrical waveguide and compared with the standard values. The effect of viscosity was measured by tracking the change in amplitude and also calculating the reflection coefficient of the reflected L(0,1) wave mode. Also the effect of temperature was monitored by tracking the change in TOF of the other wavemode, as shown in FIG. 7. Based on the results it was observed that the waveguide measurement are closely in agreement with the standard values.

[0054] Example 4: Intrusive Flow Measurement

[0055] The waveguide was employed for flow measurement using the same experimental setup as shown in FIG. 8A. A circular waveguide with circular end was selected for this experiment and the waveguide was placed inside the pipeline. The tranducer was oriented at 45° to the axis of the waveguide to generate all three wave modes. The centre frequency of the tone burst signal was 500 kHz. The flow was gradually varied in the range 0-2LPM and the flow was measured using a rotameter. The obtained A-scan signals are shown in FIG. 8B. Significant drop in amplitude of the reflected signals in all three wave modes and shift in TOF is observed in F(1,1) wave mode compared to L(0,1) and T(0,1), with increasing flow rate, as illustrated in FIG. 8C and 8D. The comparison of rotameter vs. waveguide measurement shows that the waveguide measurements are closely in agreement with the standard values.

WE CLAIM:

1. A method of measuring various properties of a fluid using a waveguide having a first end and a second end and a body of substantially uniform cross section therebetween, at least one transducer affixed to the first end of the waveguide configured to send acoustic waves and to receive reflected acoustic signals, comprising:

a. transmitting a plurality of wave modes into the fluid using an ultrasonic shear wave transducer from the first end of a waveguide;

b. receiving the reflected plurality of wave modes from the second end of the waveguide, wherein the reflections contain information characteristic of the properties of the fluid;

c. processing simultaneously the plurality of received wave modes;

d. determining time of flight and amplitude ratio of the received wave modes; and

e. measuring one or more properties of the fluid using determined time of flight and amplitude of the received wave modes.

2. The method as claimed in claim 1, wherein the plurality of wave modes are selected from longitudinal (L(m,n)), torsional (T(m,n), flexural (F(m,n)).

3. The method as claimed in claim 1, wherein the transmitting is done at an angle of 45-90° inclination to an axis of the waveguide.

4. The method as claimed in claim 1, wherein the one or more properties measured include viscosity, density, flow rate, level or temperature of the fluid.

5. The method as claimed in claim 1, wherein the properties of the fluid are measured using at least two wave modes.

6. The method as claimed in claim 1, comprising measuring a first property of the fluid, measuring a second property of the fluid and applying a correction to the first property using the second property measurement.

7. The method as claimed in claim 6, wherein the first property is fluid level and the second property is density, viscosity or temperature of the fluid.

8. The method as claimed in claim 7, wherein the fluid level is measured to an accuracy of 2.5% or better in the range 10-100 mm.

9. The method as claimed in claim 1, wherein the second end is provided with an axisymmetric notch, a non-axisymmetric notch, a bend, a polygonal section, or an elliptical section.

10. The method as claimed in claim 4, wherein the method comprises measuring the density or viscosity using flexural wave mode, torsional wave mode or both.

11. The method of claim 9, wherein the second end comprises an elliptical section and the property measured is density.

12. The method of claim 9, wherein the second end comprises a cylindrical or a flat section and the property measured is fluid level.

13. The method of claim 9, wherein the second end comprises a cylindrical section and the property measured is flow rate of the fluid.

14. The method as claimed in claim 1, wherein the fluid properties are measured using at least two different frequencies.

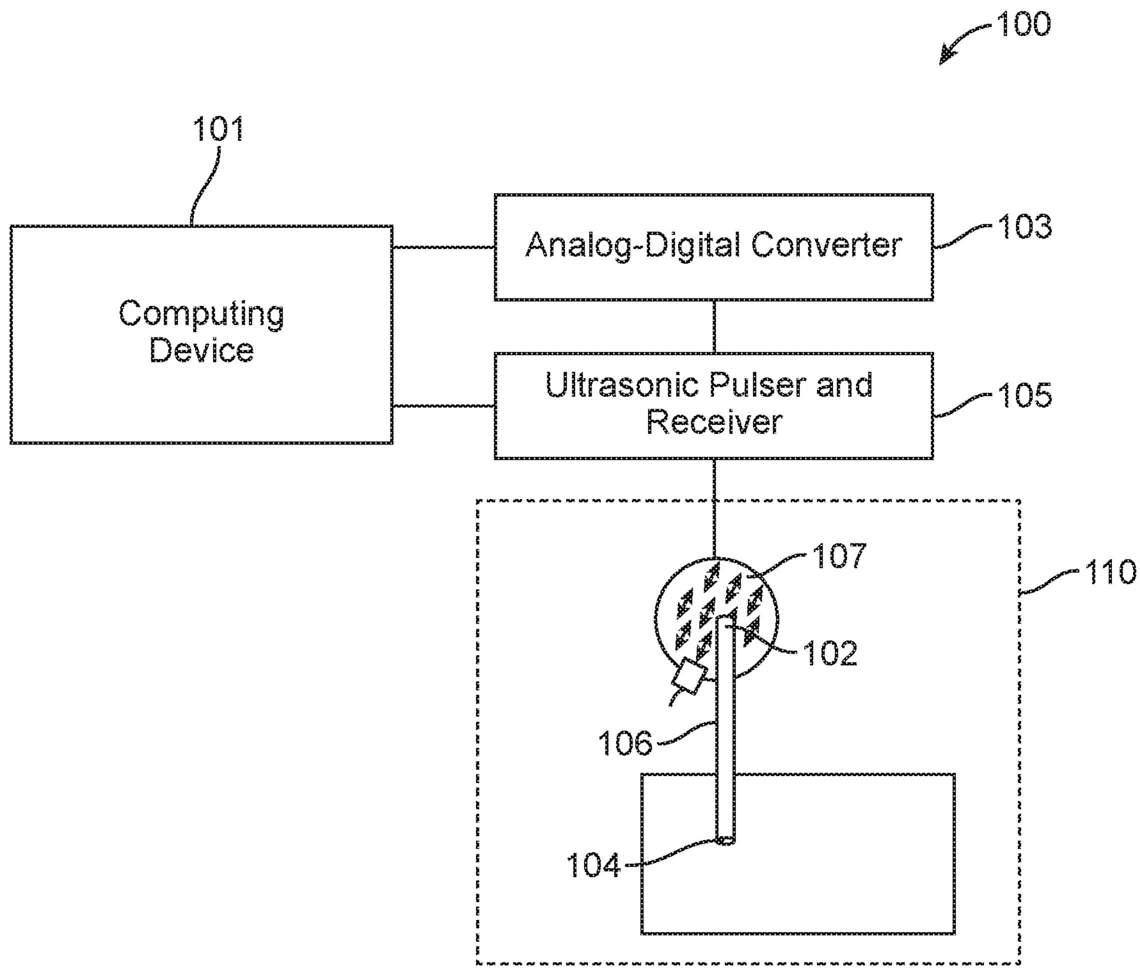

100
101
Computing Device
Analog-Digital Converter
103
Ultrasonic Pulser and Receiver
105
107
110
102
106
104

FIG. 1A

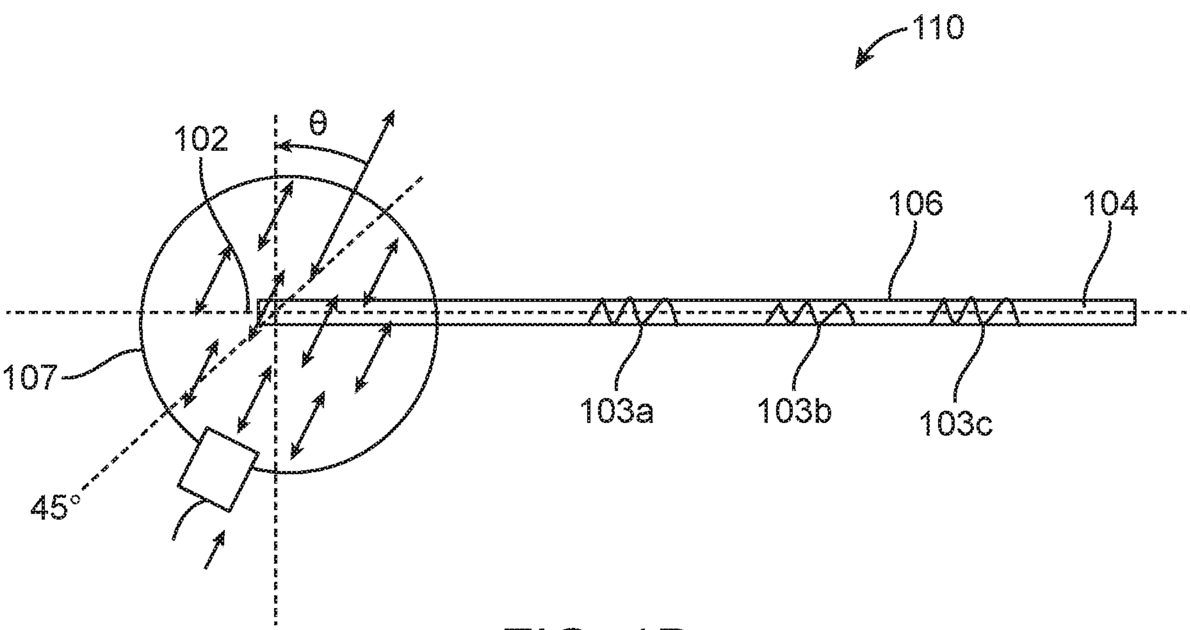

110
θ
102
106
104
107
103a
103b
103c
45°

FIG. 1B

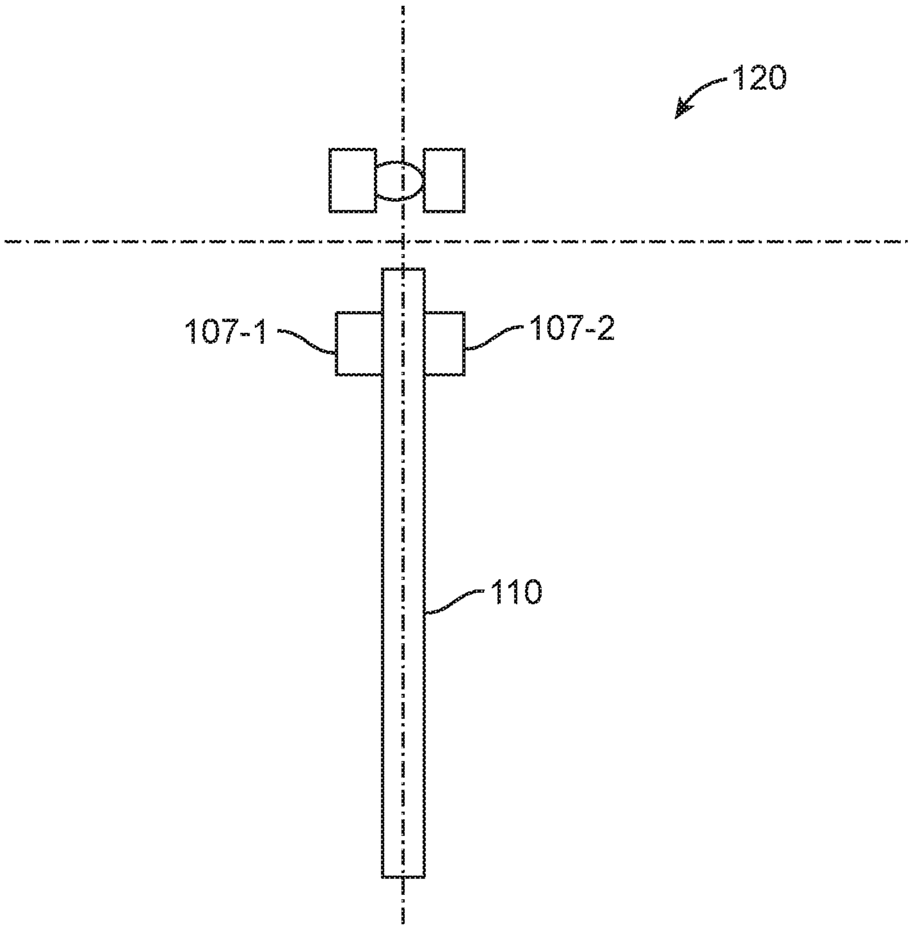


FIG. 1C

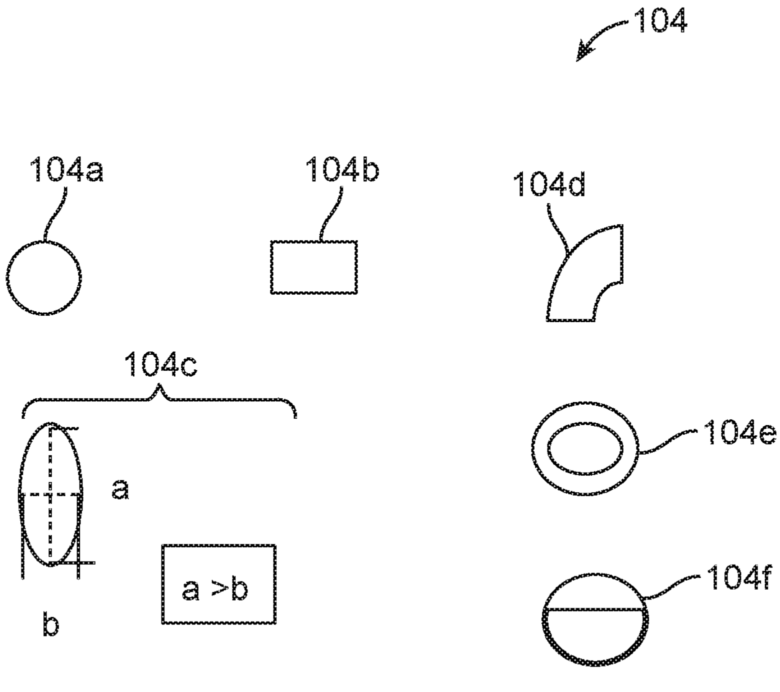


FIG. 1D

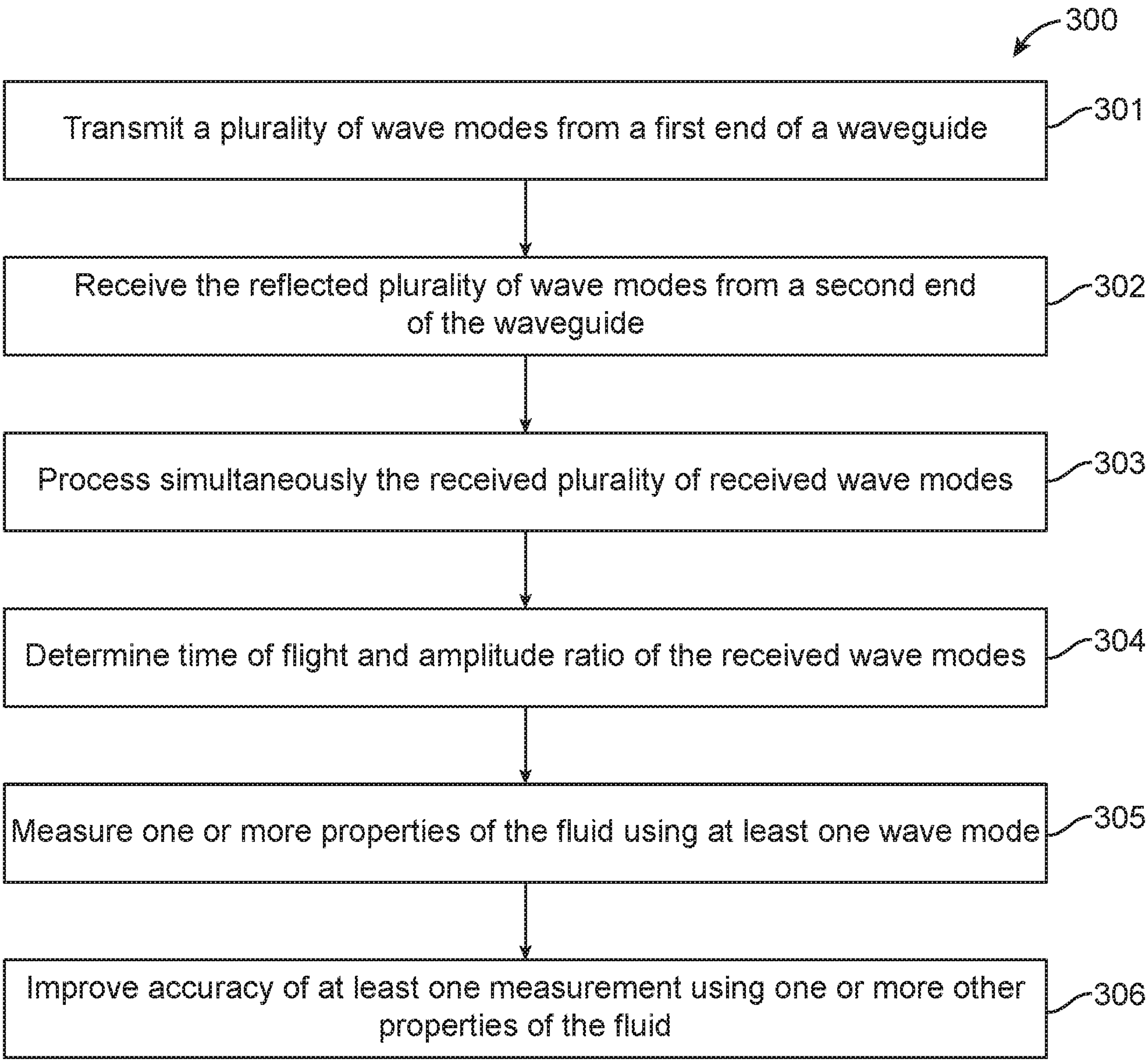

300
Transmit a plurality of wave modes from a first end of a waveguide
301
Receive the reflected plurality of wave modes from a second end of the waveguide
302
Process simultaneously the received plurality of received wave modes
303
Determine time of flight and amplitude ratio of the received wave modes
304
Measure one or more properties of the fluid using at least one wave mode
305
Improve accuracy of at least one measurement using one or more other properties of the fluid
306

FIG. 2

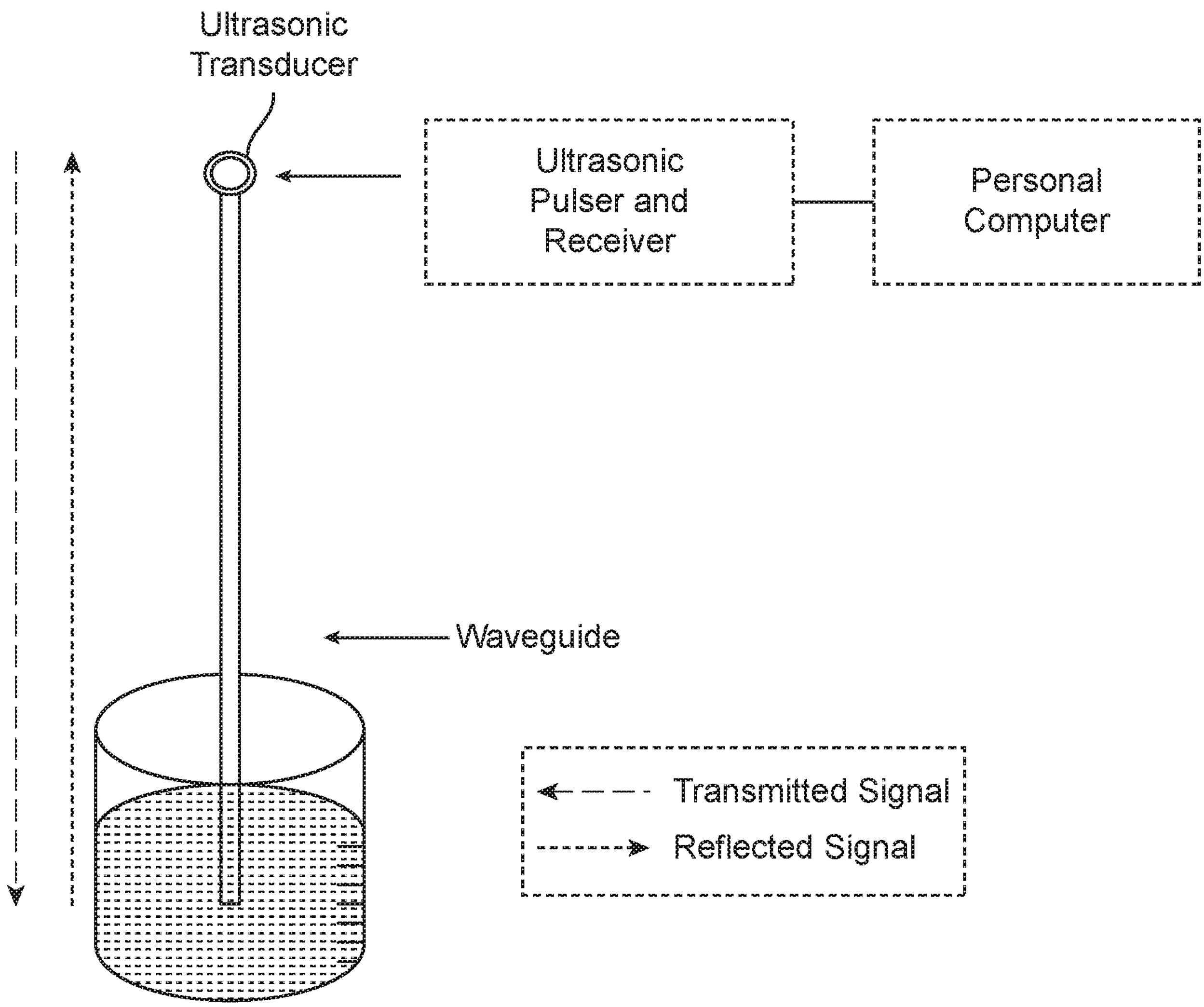

Ultrasonic
Transducer
Ultrasonic
Pulser and
Receiver
Personal
Computer
Waveguide
Transmitted Signal
Reflected Signal

FIG. 3

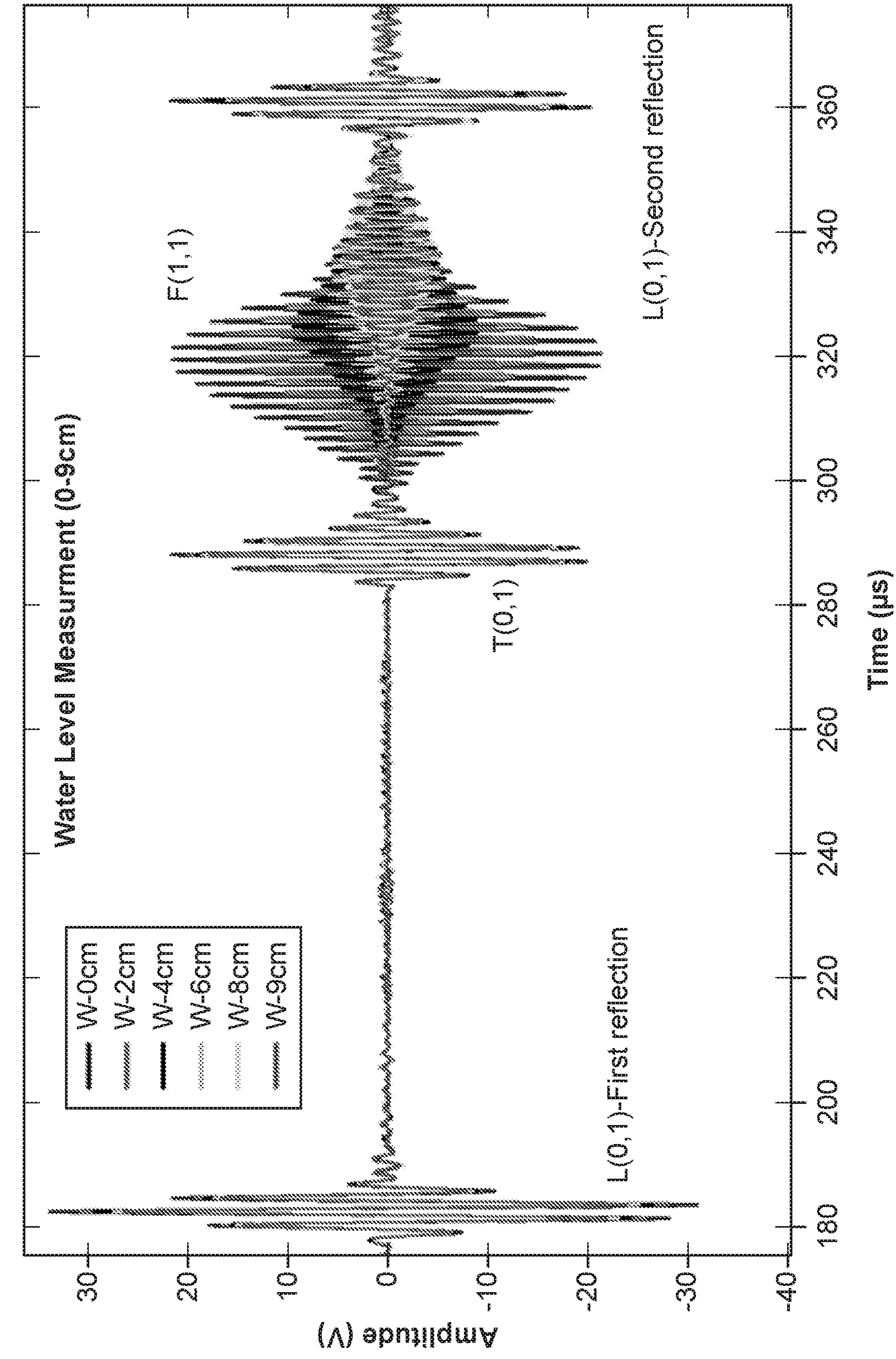

Water Level Measurment (0-9cm)
W-0cm
W-2cm
W-4cm
W-6cm
W-8cm
W-9cm
L(0,1)-First reflection
T(0,1)
F(1,1)
L(0,1)-Second reflection
Amplitude (V)
Time (µs)
30
20
10
0
-10
-20
-30
-40
180
200
220
240
260
280
300
320
340
360

FIG. 4A

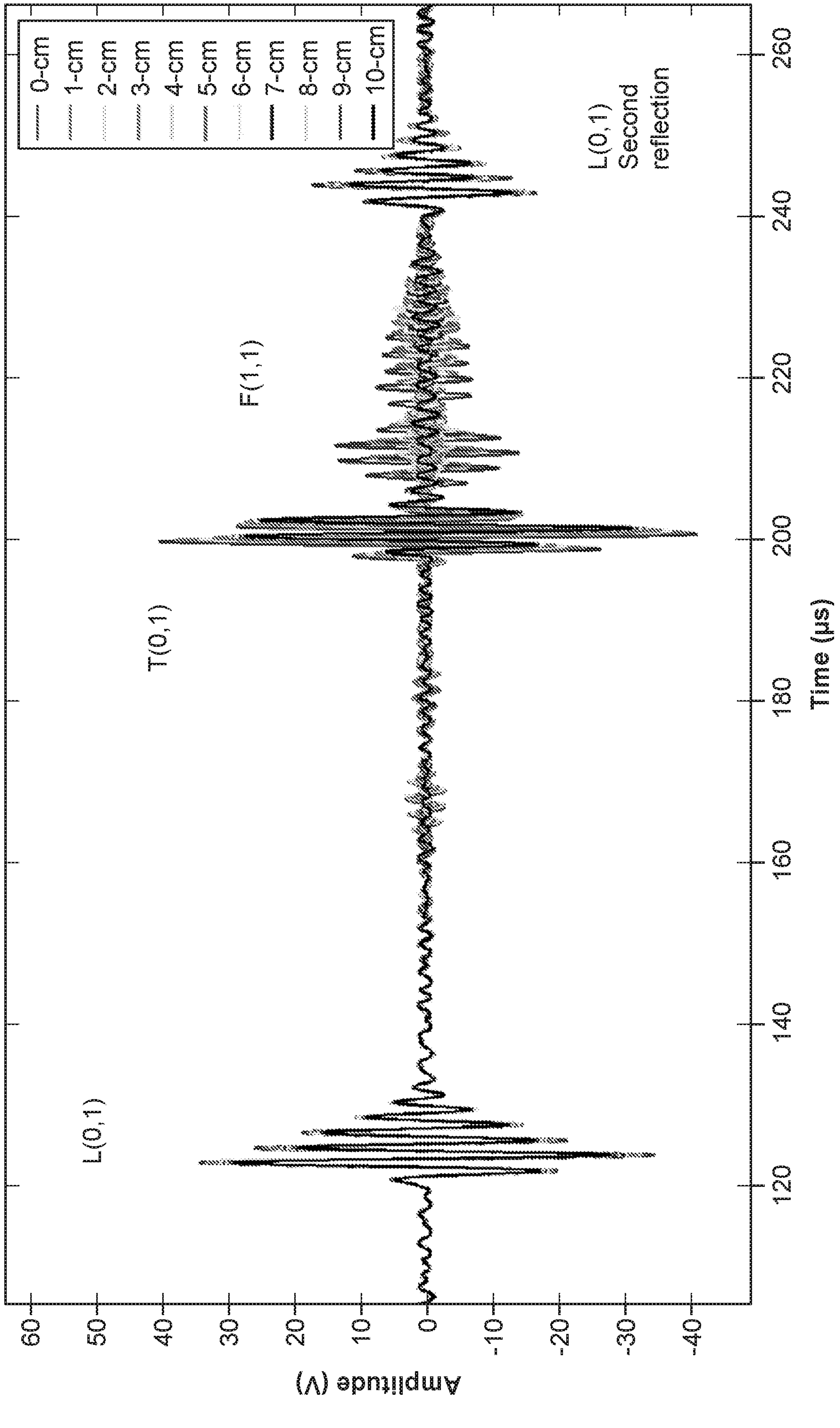

0-cm
1-cm
2-cm
3-cm
4-cm
5-cm
6-cm
7-cm
8-cm
9-cm
10-cm
L(0,1)
T(0,1)
F(1,1)
L(0,1) Second reflection
Amplitude (V)
Time (µs)
60
50
40
30
20
10
0
-10
-20
-30
-40
120
140
160
180
200
220
240
260

FIG. 4B

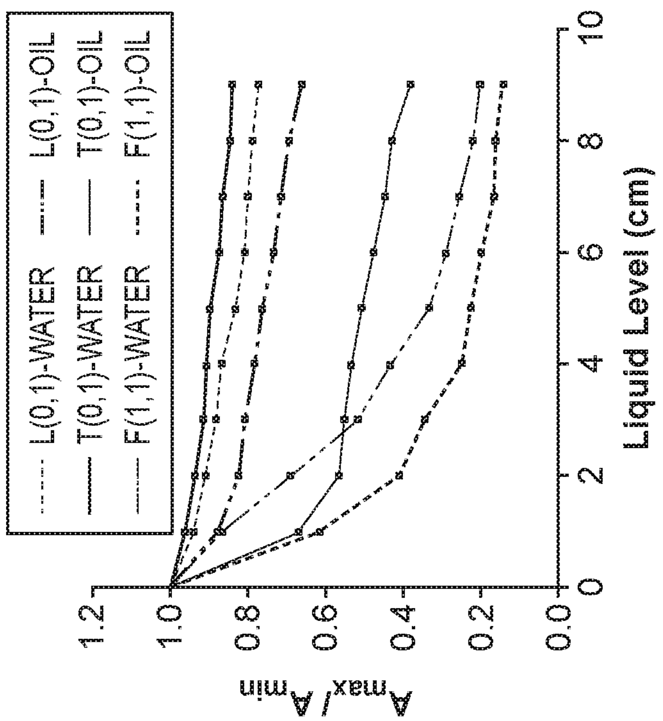


FIG. 5B

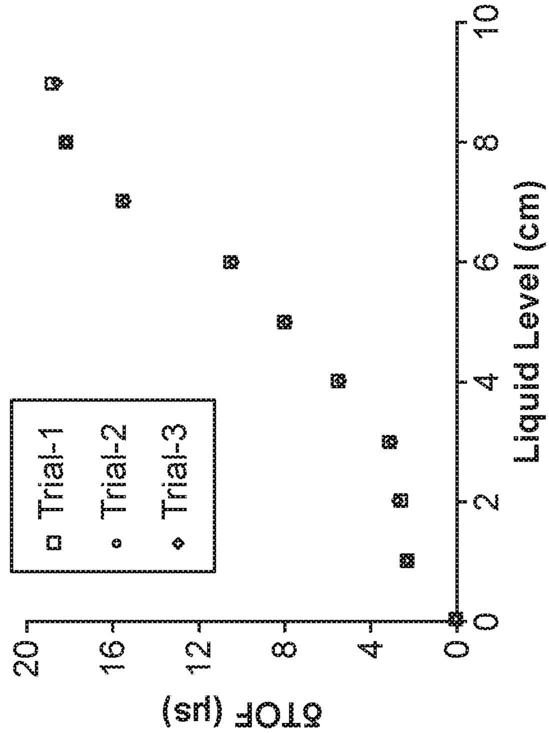


FIG. 5C

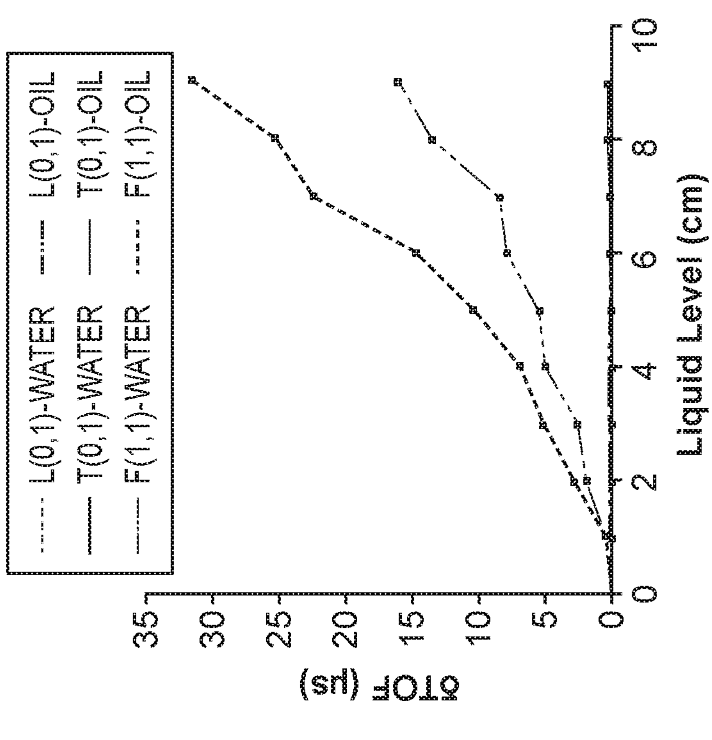


FIG. 5A

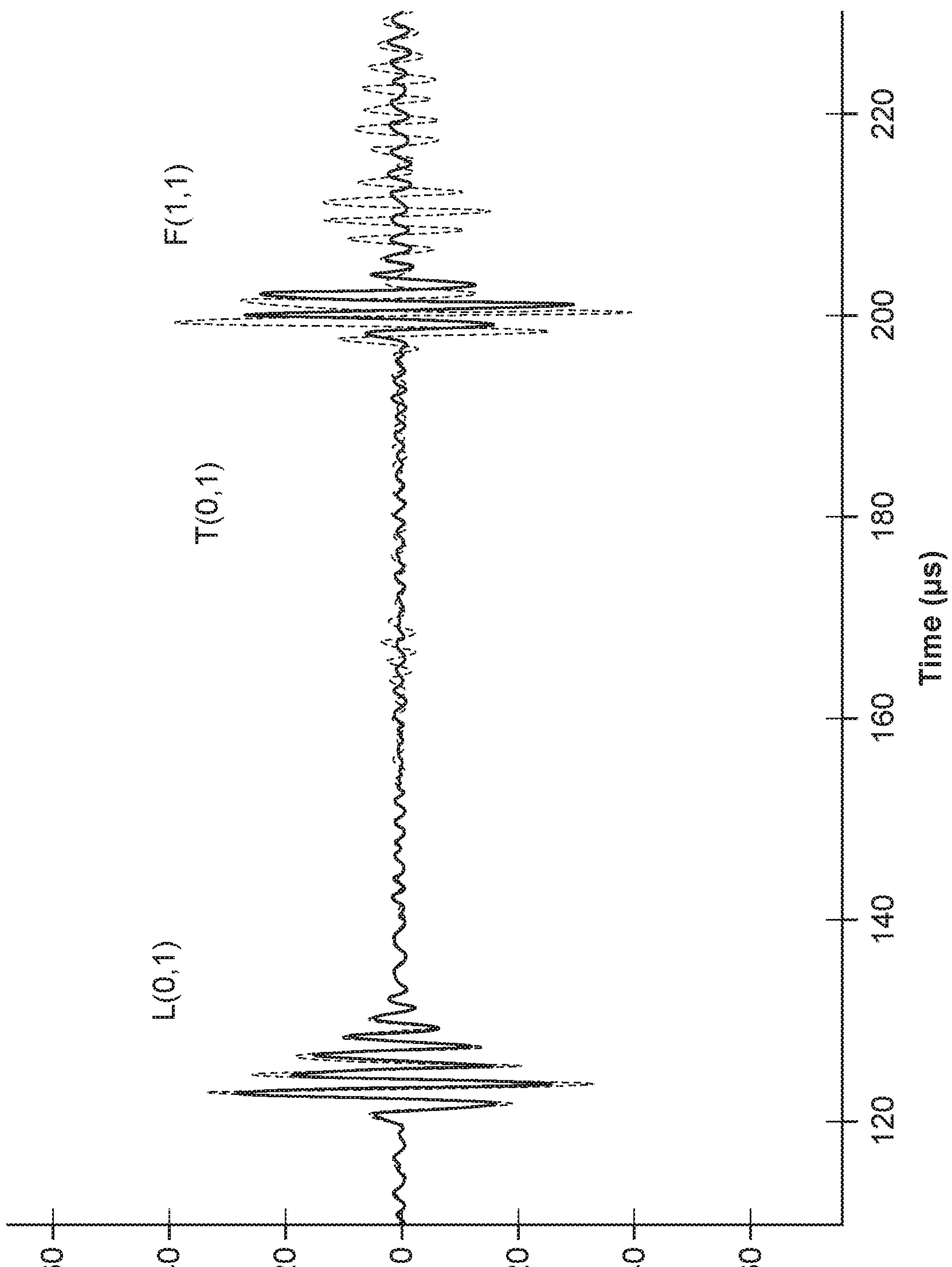

L(0,1)
T(0,1)
F(1,1)
Amplitude (V)
60
40
20
0
-20
-40
-60
120
140
160
180
200
220
Time (µs)

FIG. 6A

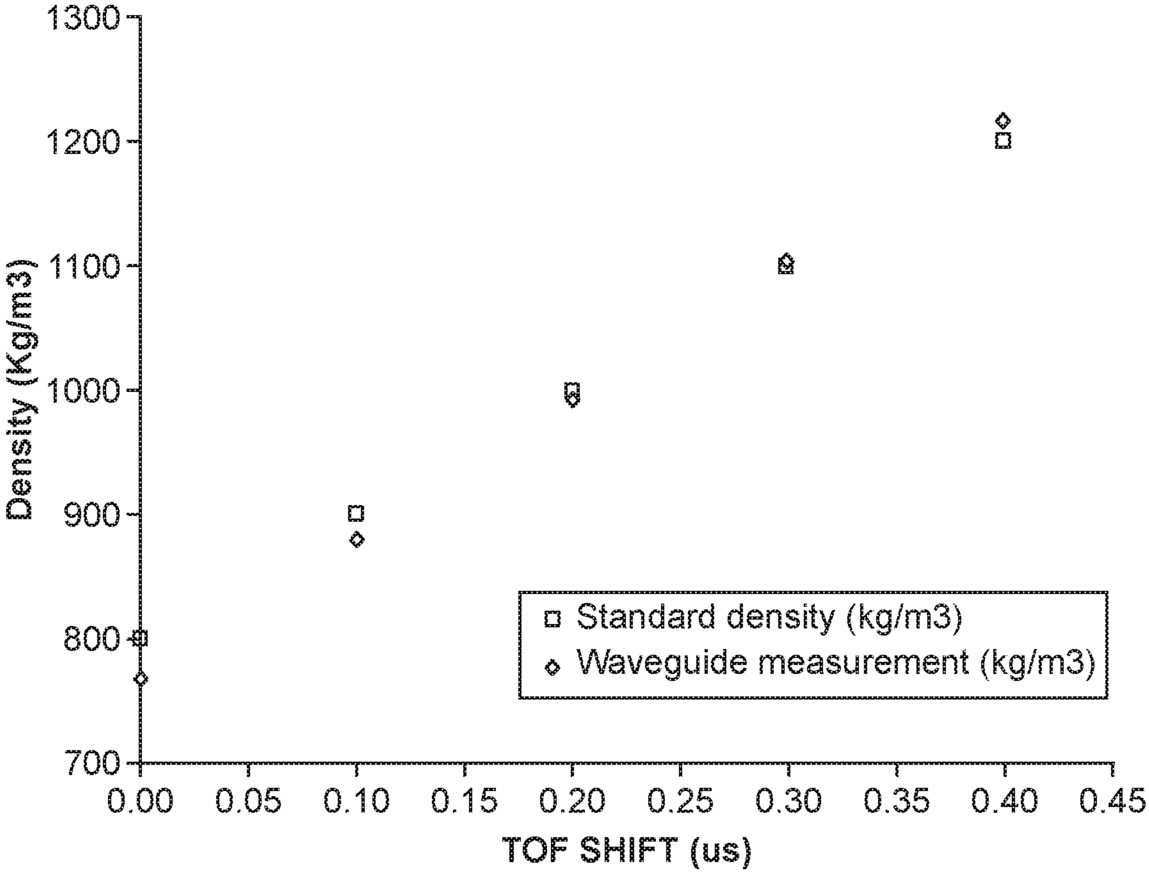

1300
1200
1100
1000
900
800
700
Density (Kg/m3)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
TOF SHIFT (us)
Standard density (kg/m3)
Waveguide measurement (kg/m3)

FIG. 6B

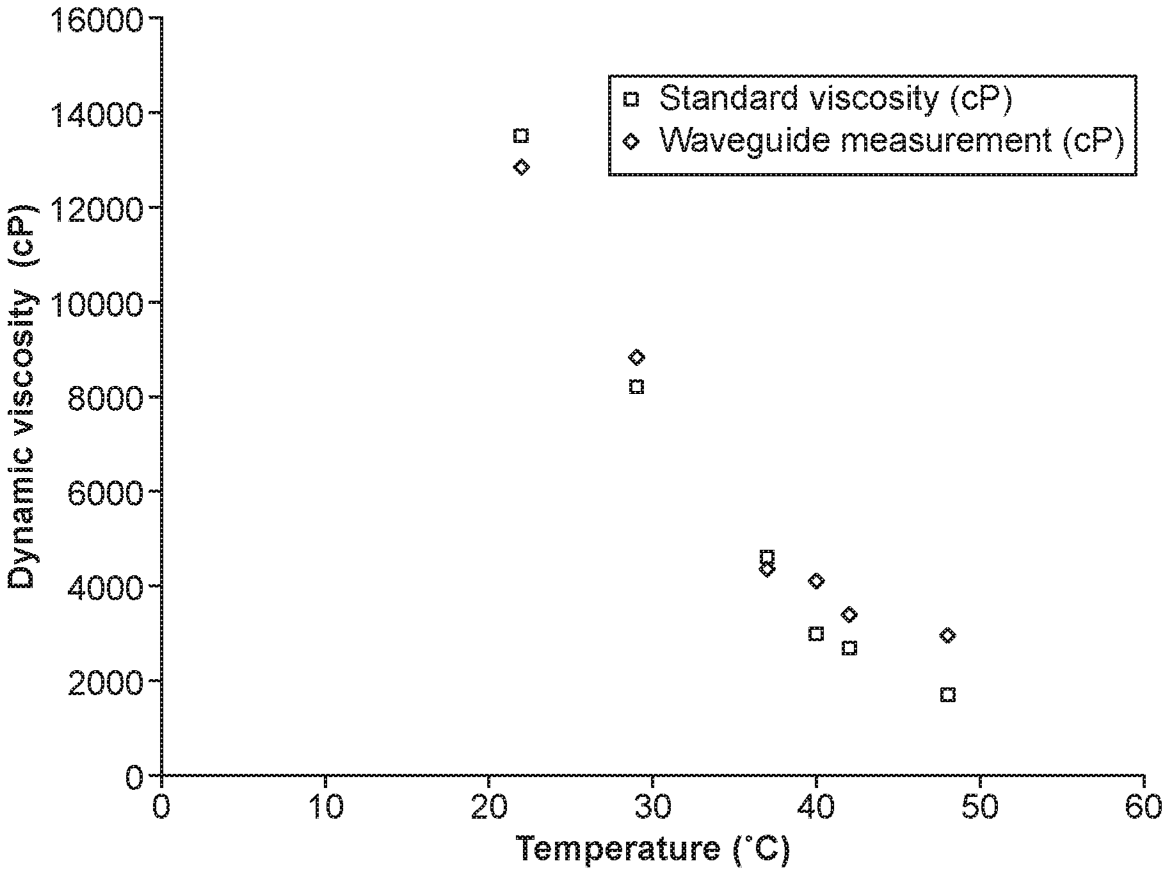

16000
14000
12000
10000
8000
6000
4000
2000
0
Dynamic viscosity (cP)
0
10
20
30
40
50
60
Temperature (˚C)
Standard viscosity (cP)
Waveguide measurement (cP)

FIG. 7

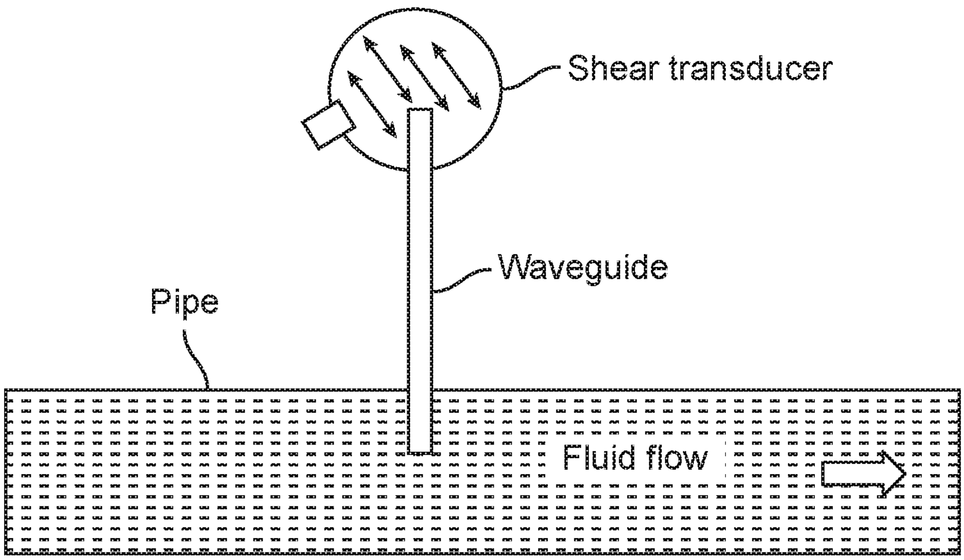

Shear transducer
Waveguide
Pipe
Fluid flow

FIG. 8A

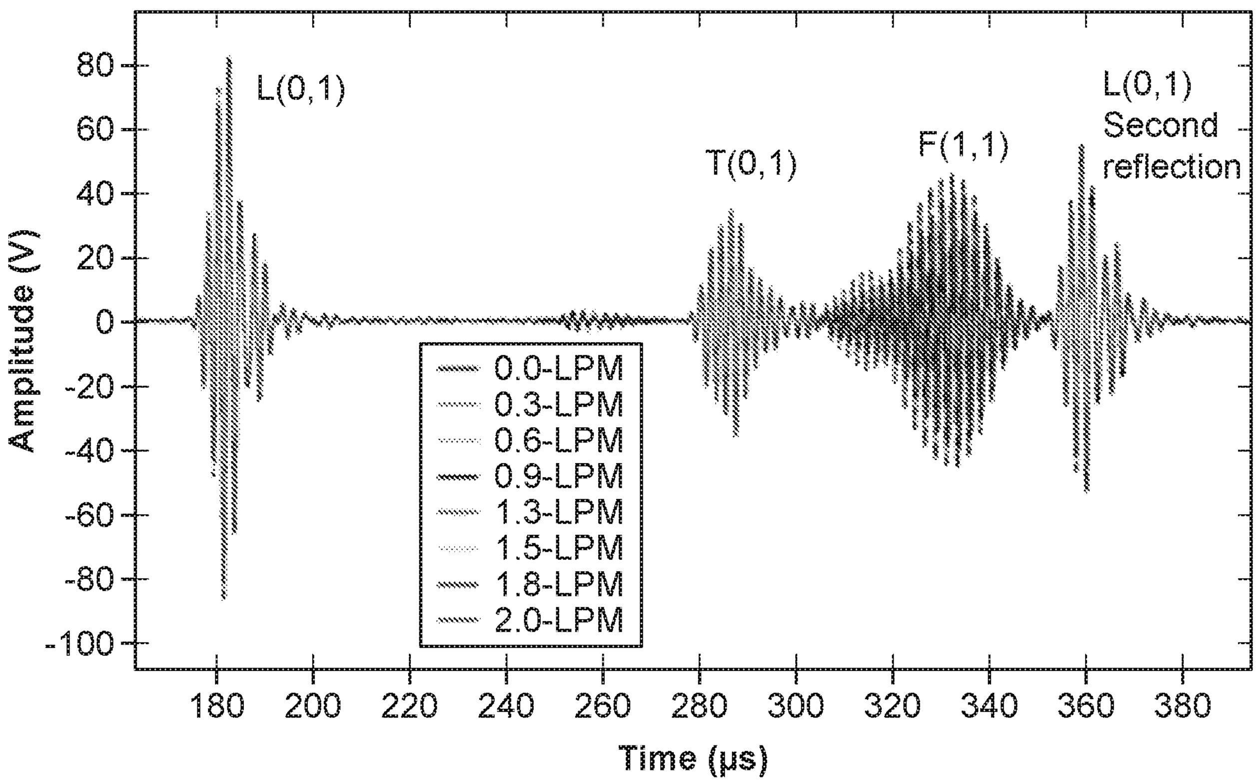

L(0,1)
T(0,1)
F(1,1)
L(0,1)
Second
reflection
0.0-LPM
0.3-LPM
0.6-LPM
0.9-LPM
1.3-LPM
1.5-LPM
1.8-LPM
2.0-LPM
Amplitude (V)
Time (μs)
80
60
40
20
0
-20
-40
-60
-80
-100
180
200
220
240
260
280
300
320
340
360
380

FIG. 8B

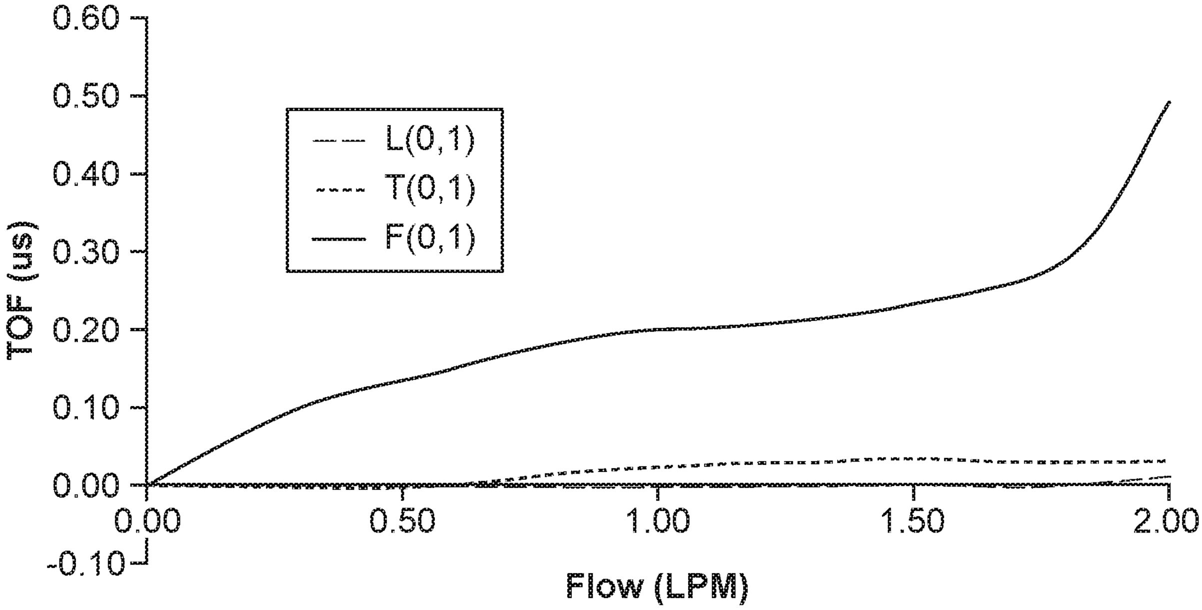

0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
TOF (us)
L(0,1)
T(0,1)
F(0,1)
0.00
0.50
1.00
1.50
2.00
Flow (LPM)

FIG. 8C

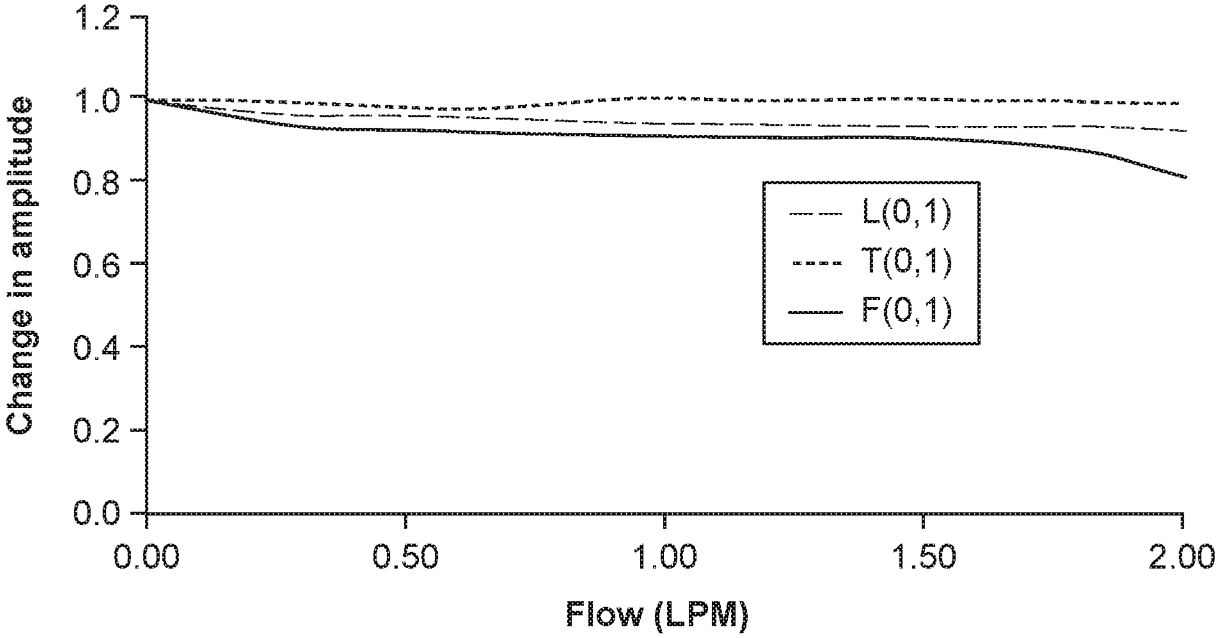
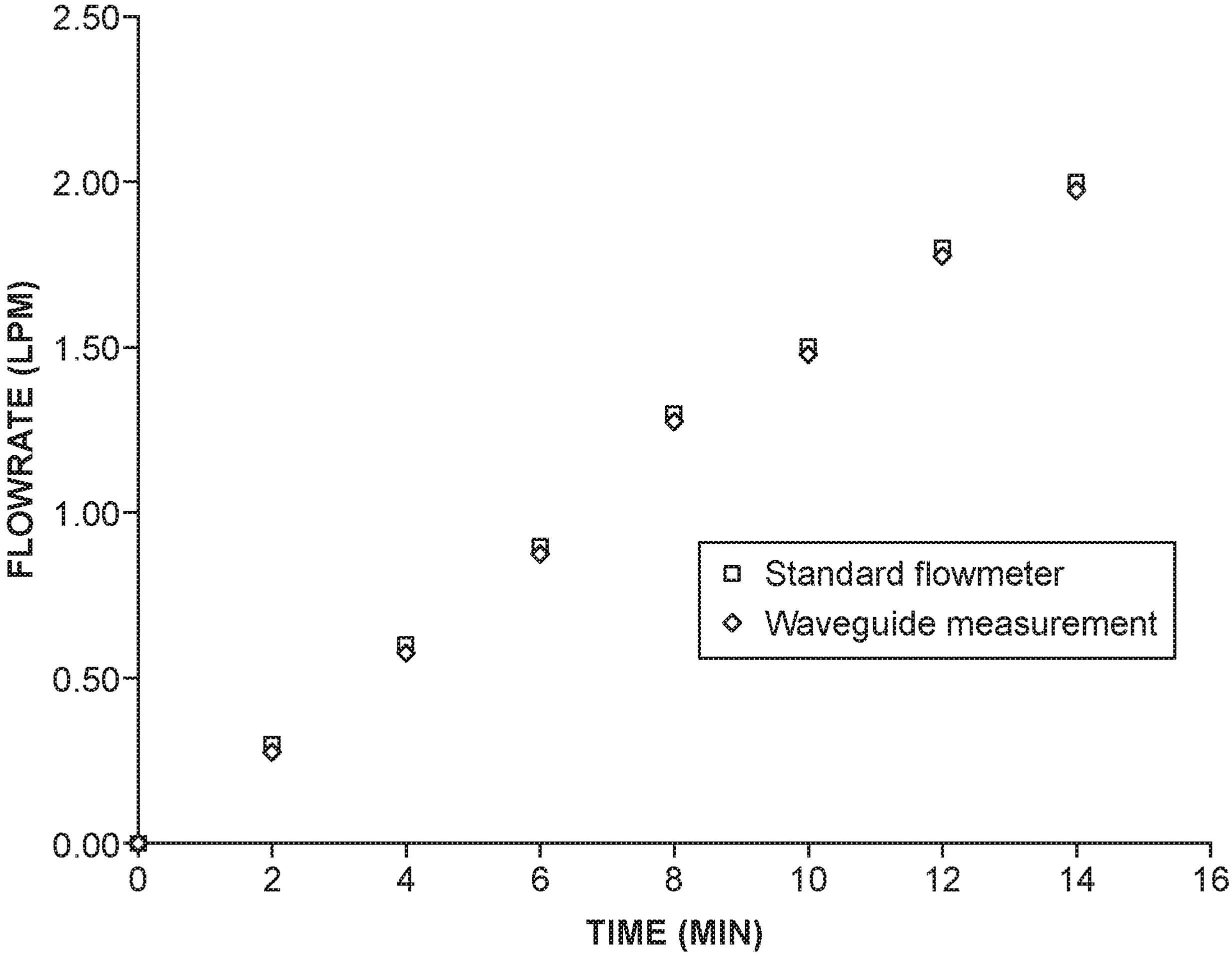

1.2
1.0
0.8
0.6
0.4
0.2
0.0
Change in amplitude
L(0,1)
T(0,1)
F(0,1)
0.00
0.50
1.00
1.50
2.00
Flow (LPM)

FIG. 8D



2.50
2.00
1.50
1.00
0.50
0.00
FLOWRATE (LPM)
0
2
4
6
8
10
12
14
16
TIME (MIN)
Standard flowmeter
Waveguide measurement

FIG. 8E

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2019/050795

A. CLASSIFICATION OF SUBJECT MATTER
G01N29/07,G01F1/66,G01K11/24 Version=2020.01

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01N, G01F, G01K

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

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

DATABASES: TotalPatent One, IPO Internal Database
KEYWORDS: Ultrasonic transducer wave-guide time amplitude

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/0153938 A1 (INDIAN INSTITUTE OF TECHNOLOGY MADRAS) 02 JUNE 2016 (02/06/2016) Abstract;Figs.1A-1D, 2-4, 9;Claims 1, 8-14;Paragraphs [0038,0042 0044,0045, 0048,0053-0055 0060, 0064]	1-14
X	US 2014/0331785 A1 (GENERAL ELECTRIC COMPANY) 13 NOVEMBER 2014 (13/11/2014) Abstract; Figs.1-4;Claims 1,7-10;Paragraphs [0018, 0023-0027]	1-14
X	"Fluid bulk velocity and attenuation measurements in non-Newtonian liquids using a dipstick sensor" Measurement Science and Technology 23 DECEMBER 2005 (23/12/2005) Abstract; Figs.1, 6(a), 7;pages 264-269	1-14
X	US 9297789 B2 (MATERIALS AND SENSORS TECHNOLOGIES, INC.) 29 MARCH 2016 (29/03/2016) Abstract;Figs.1,2, 4, 8A-8E, 9A-9D, 10A-10D, 21, 27-30;Claims 1-6; col.1 line 55-line 65,col.9, line 25-col.10 line 35, col.13,line 20-col.14,	1-14

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14-02-2020	14-02-2020

Name and mailing address of the ISA/	Authorized officer
Indian Patent Office Plot No.32, Sector 14,Dwarka,New Delhi-110075 Facsimile No.	Sadigama Mahesh Telephone No. +91-1125300200

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2019/050795

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	line 10, col.20 line 10-line 40	

Citation	Pub.Date	Family	Pub.Date
US 2016/0153938 A1	02-06-2016	WO 2015008299 A2	22-01-2015
US 2014/0331785 A1	13-11-2014	WO 2014182402 A1	13-11-2014
US 9297789 B2	29-03-2016	WO 2009152143 A1	17-12-2009