



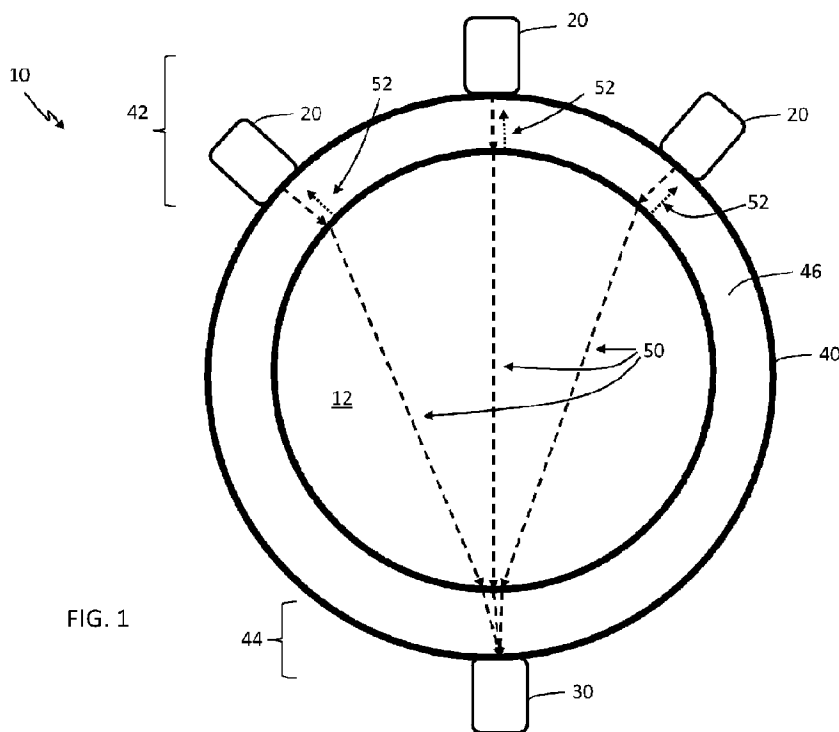
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(54) **Titre : AMELIORATION DE SIGNAL ACOUSTIQUE A TRAJETS MULTIPLES POUR LA DETECTION DE MATERIAUX**
(54) **Title: MULTI-PATH ACOUSTIC SIGNAL IMPROVEMENT FOR MATERIAL DETECTION**



(57) **Abrégé/Abstract:**

A multi-path acoustic signal apparatus, system, and apparatus for use in material detection are provided. The apparatus has a plurality of acoustic sensors positioned along a first portion of a fluid container. At least one acoustic signal is transmitted into the fluid container by each of the plurality of acoustic sensors. At least one additional acoustic sensor is positioned along a second portion of the fluid container, wherein the second portion is substantially opposite the first portion. The at least one additional acoustic sensor receives at least a portion of the acoustic signals from the plurality of acoustic sensors. A reflected acoustic signal is generated from an impedance barrier between the fluid container and a fluid therein. A characteristic of a material of the fluid container and/or the fluid therein are determined.

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Abstract:

A multi-path acoustic signal apparatus, system, and apparatus for use in material detection are provided. The apparatus has a plurality of acoustic sensors positioned along a first portion of a fluid container. At least one acoustic signal is transmitted into the fluid container by each of the plurality of acoustic sensors. At least one additional acoustic sensor is positioned along a second portion of the fluid container, wherein the second portion is substantially opposite the first portion. The at least one additional acoustic sensor receives at least a portion of the acoustic signals from the plurality of acoustic sensors. A reflected acoustic signal is generated from an impedance barrier between the fluid container and a fluid therein. A characteristic of a material of the fluid container and/or the fluid therein are determined.

MULTI-PATH ACOUSTIC SIGNAL IMPROVEMENT FOR MATERIAL DETECTION

The present disclosure is generally related to acoustic signals and more particularly
5 is related to multi-path acoustic signal improvements for material detection.

Many materials that are transported through pipes have significant acoustic
impedance difference with material that the pipe sidewall is formed from. For example,
fluids, liquids, and other viscous materials have a significant acoustic impedance
difference relative to pipes or pipelines formed from metals, such as cast iron, steel,
10 aluminum, or the like. Similarly, materials stored in containers, especially metal
containers such as oil and gas storage tanks, have characteristically big differences with the
material that the container wall is formed from.

With regards to the oil and gas industry specifically, steel is the material often used
for pipelines. A steel pipe carrying crude oil has an acoustic impedance barrier which
15 reflects approximately 88% of the energy of the acoustic wave back into the pipe wall
depending on the temperature. Only approximately 12 % from the energy of the incident
wave is transmitted into the crude oil itself. In a similar example, when a cast iron pipe is
used to transport water, the amount of the reflected energy is approximately 98.30311%
from the incidence wave energy. Due to this reflection of the acoustic wave energy,
20 pipelines and containers with larger sizes often present a challenge for nondestructive
analysis since most of the initial signal is lost just crossing the sidewall of the pipe or
container containing the fluid.

Thus, a heretofore unaddressed need exists in the industry to address the
aforementioned deficiencies and inadequacies.

25 Embodiments of the present disclosure provide a multi-path acoustic signal system,
apparatus, and related methods for use in material detection. Briefly described, in
architecture, one embodiment of the apparatus, among others, can be implemented as
follows. The apparatus has a plurality of acoustic sensors positioned along a first portion of
a fluid container. At least one acoustic signal is transmitted into the fluid container by each
30 of the plurality of acoustic sensors. At least one additional acoustic sensor is positioned

along a second portion of the fluid container, wherein the second portion is substantially opposite the first portion. The at least one additional acoustic sensor receives at least a portion of the acoustic signals from the plurality of acoustic sensors. A reflected acoustic signal is generated from an impedance barrier between the fluid container and a fluid
5 therein. A characteristic of a material of the fluid container and/or the fluid therein are determined.

The present disclosure can also be viewed as providing methods of detecting a material within a fluid container. In this regard, one embodiment of such a method, among others, can be broadly summarized by the following steps: transmitting at least one
10 acoustic signal from each of a plurality of acoustic sensors positioned along a first portion of the fluid container; receiving, with at least one additional acoustic sensor positioned along a second portion of the fluid container, the at least one transmitted acoustic signal, wherein the second portion is substantially opposite the first portion of the fluid container; and determining, based on the at least one received acoustic signal, a composition of the
15 material within the fluid container.

Other systems, methods, features, and advantages of the present disclosure will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present
20 disclosure, and be protected by the accompanying claims.

Many aspects of the disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding
25 parts throughout the several views.

FIG. 1 is a diagrammatical illustration of a multi-path acoustic signal apparatus, in accordance with a first exemplary embodiment of the present disclosure.

FIG. 2 is a diagrammatical illustration of a variation of the multi-path acoustic signal apparatus of FIG. 1, in accordance with the first exemplary embodiment of the
30 present disclosure.

FIG. 3 is a side-view, diagrammatical illustration of a variation of the multi-path acoustic signal apparatus of FIG. 1, in accordance with the first exemplary embodiment of the present disclosure.

FIG. 4 is a diagrammatical illustration of the multi-path acoustic signal apparatus of FIG. 1 in communication with a computer processor, in accordance with the first exemplary embodiment of the present disclosure.

FIG. 5 is a flow chart illustrating a method of detecting a material within a fluid container, in accordance with the first exemplary embodiment of the present disclosure.

To improve upon the use of acoustic signals for the detection of materials in fluid-holding pipes, pipelines, containers, or other structures, a multi-path acoustic signal apparatus 10 is provided. In particular, it has been discovered that using a shear wave through the sidewall of a container holding a material will increase the amount of acoustic energy that is transmitted into the material within the container. In one example, the increase of acoustic energy exceeded 21%. However, the acoustic shear waves are generated with smaller initial energy. Accordingly, to increase the energy of the initial signal, and therefore the effective signal received at a receiving acoustic sensor which is positioned across the container, it is possible to use multiple signals from multiple acoustic sensors that are directed towards the same location on the other side of the container.

FIG. 1 is a diagrammatical illustration of the multi-path acoustic signal apparatus 10, in accordance with a first exemplary embodiment of the present disclosure. The multi-path acoustic signal apparatus 10, which may be referred to simply as 'apparatus 10' includes a plurality of acoustic sensors 20 positioned along a first portion 42 of a fluid container 40, such as a pipeline, as shown in FIG. 1. Any plural number of the acoustic sensors 20 or transducers may be used, and the acoustic sensors 20 may be positioned along a single side or location of the container 40. For instance, in FIG. 1, the acoustic sensors 20 are positioned along a first portion 42 of the container 40, which generally includes a finite area of radial curvature of the container 40, or a portion encompassing less than the entire circumference or perimeter of the fluid container 40. In one example, the first portion 42 may extend to no more than half of the circumference or perimeter of the

fluid container 40. For containers 40 that have planar or substantially planar sidewalls, the acoustic sensors 20 may be positioned on a single sidewall or a portion thereof.

At least one acoustic signal 50 is transmitted by each of the acoustic sensors 20 into the fluid container 40, and into a material 12 within the container 40. To aid in clarity of disclosure, the apparatus 10 is described herein relative to a container 40 that is a pipe or pipeline which carries a fluid oil or gas product, but the apparatus 10 can be used in other fields with other containers, such as those holding or transporting water, chemicals, or other materials. The acoustic signal 50 that is transmitted travels through the sidewall 46 of the container 40, through the interior of the container 40 and through any material 12 therein, and through the sidewall 46 of the container 40 on a substantially opposite side of the container 40 from the locations of the acoustic sensors 20. When the signal 50 passes through the sidewall 46 for the second time, it is received within at least one additional acoustic sensor 30, which is positioned along a second portion 44 of the fluid container 40.

As shown in FIG. 1, the second portion 44 of the container 40 may be substantially opposite the first portion 42, such that as the signal 50 is transmitted between the sensors 20, 30, it travels through the interior of the container 40. In one example, the second portion 44 may include any portion of or position along the circumference of the fluid container 40. In another example, the second portion 44 may be less than the entire circumference of the fluid container 40. In another example, the second portion 44 may be the portion of the circumference that is not the first portion 42. In another example, at least a portion of the first and second portions 42, 44 may overlap. The sensors 20, 30 are located on the exterior surface of the container 40 and may be positioned in a location to account for the transmission angle of the signal 50 from the acoustic sensor 20 and changes in crossing the impedance barrier between the material forming the container 40 and the material 12 within the container. In one example, the sensors 20, 30 may be in direct contact with the container 40. In another example, a couplant material may be used between the sensors 20, 30 and the container 40 to ensure proper transfer of the acoustic signals 50. During the installation of the apparatus 10, locations of each acoustic sensor 20, 30 may be determined depending on the geometry of the container, *e.g.*, cylindrical pipe, cylindrical tank, cuboid tank, etc., the material which is used to form the sidewall 46 of the

container 40, and the material 12 or materials inside the container 40. In one example, the acoustic sensors 20 may be positioned at equal distances, one from another, such that the adjacent sensors 20 are spaced apart evenly. In another example, the acoustic sensors 20 may be separated and spaced apart from each other at different distances, one from
5 another. In another example, the acoustic sensors 20 may be positioned at desired angular positions, for instance, at 0° , 15° , 30° , 45° , 60° , or any desired angle. In another example, the acoustic sensors 20 may be separated according to desired angular increments, such as increments of 5° , 10° , 15° , and so on. The angular placement of the acoustic sensors 20 may be determined relative to an orientation of the at least one additional acoustic sensor
10 30 or to an axis extending through a cross-section of the fluid container 40.

In one example, at least one acoustic sensor 20 may be directly opposite the at least one additional acoustic sensor 30. In other words, at least one acoustic sensor 20 may be positioned directly opposite the additional acoustic sensor 30 relative to the fluid container 40. An acoustic signal 50 transmitted from the acoustic sensor 20 may propagate through
15 an entire diameter or internal length of the fluid container 40, depending on the geometry. The acoustic signal 50 may propagate through a center or central area of the interior of the fluid container 40. Other acoustic sensors 20 may be positioned so that the acoustic signals 50 transmitted from those sensors 20 may have traveled shorter distances than the entire diameter or internal length of the fluid container 40 to reach the additional acoustic
20 sensor 30.

In one example, the plurality of acoustic sensors 20 and the at least one additional acoustic sensor 30 may be positioned so that the transmitted acoustic signals 50 travel through a distance of at least half of a diameter of the fluid container 12. For instance, one acoustic sensor 20 may be positioned at an angle of 0° relative to the additional acoustic
25 sensor 30. Subsequent acoustic sensors 20 may be positioned at larger angles relative to the additional acoustic sensor 30, but not closer than half the circumference or interior length of the fluid container 12.

At least one additional acoustic sensor 30 receives at least a portion of the acoustic signals 50 from the acoustic sensors 20 transmitting the signals 50. Due to the impedance
30 barrier between the materials of the container 40 and the material 12 therein, a reflected

acoustic signal is generated. This reflected acoustic signal may be received at the acoustic sensors 20 or it may dissipate, thereby leaving the portion of the original acoustic signal 50. From the acoustic signal 50 received at the acoustic sensor 30, and/or the reflected signals, and commonly a combination thereof, it is possible to analyze the signals to
5 identify a characteristic of the material forming a sidewall 46 of the fluid container 40 and/or the fluid 12 or other material within the container 40.

FIG. 2 is a diagrammatical illustration of a variation of the multi-path acoustic signal apparatus 10 of FIG. 1, in accordance with the first exemplary embodiment of the present disclosure. It is noted that the receiving sensor 30 can be configured as a single
10 sensor 30, as depicted in FIG. 1, or as multiple acoustic sensors 30, as depicted in FIG. 2, which illustrates a variation of the multi-path acoustic signal apparatus of FIG. 1. Additionally, as shown in FIG. 2, the acoustic sensors 30 may be configured as a sensor array which are mounted together on an array structure 32, and/or they may be movable in position, as indicated by arrows 34. An array of acoustic sensors 30 may increase the
15 accuracy of the measurement of the incidence angles, which may in turn increase the accuracy of measured impedance. This may allow direct measurement of material density as an independent parameter using only the measured time of flight and the angle of transmission of shear wave signals after crossing one or more impedance barriers.

The movable acoustic sensor 30 which receives the signal 50 can be moved in a
20 variety of directions and positions. For example, it can be moved along a plane tangential to the cylindrical shape and sidewall of the container 40. For containers 40 which have other shapes, such as cuboid, the acoustic sensor 30 may only need to be moved in a planar direction on one side of the container 40. This movement of the acoustic sensor 40 can catch signals 50 that reflect geometrically outside of the baseline acoustic sensor 30
25 location, e.g., as depicted in FIG. 1. This may be especially important for situations where there is a change of temperature or change of fluid composition of the material 12 inside the container 40. In one example, at least one of the acoustic sensors 30 may remain stationary. For instance, a central acoustic sensor 30 may remain in a fixed position, while other acoustic sensors 30 move about the fluid container 40. In another example, one or
30 more acoustic sensors 30 may remain stationary at a first measurement time, but may move

at or in order to acquire a subsequent measurement. It should be understood that any combination of stationary, moveable, and periodically moving sensors 30 is within the scope of the subject disclosure.

In one example, moving the acoustic sensor 30 may allow for the measurement and
5 tracking of fluid material density changes or temperature changes, or any other material property changes within the volume of the material.

It may be possible to use a laser interferometer design in operation with the movable acoustic sensor 30, which may include an acoustic peak detector, similar to that used in radio signal transmission, where electromagnetic wave receivers change
10 frequencies to find signals peak due to fading, which may be due to the fact that the carrier frequency may be modified but the frequency encoding is the same.

It is noted that the number of acoustic sensors 20 on the signal 50 transmission side can be determined from various factors, including the condition of the fluid material 12 inside the container 40, a movement or flow of the material 12 within the container, and/or
15 a need for increased signal strength. It is also noted that the acoustic sensors 20 which transmit the signal 50 may be capable of moving position and/or rotating, as indicated by arrows 22, 24 in FIG. 2. For example, the acoustic sensors 20 may be capable of rotating or moving in a plane tangential to the surface of the container 40. This ability of the transmitting acoustic sensors 20 to change position or rotate allows for the signal
20 transmission to compensate for any changing conditions in the material 12, and to control or steer the desired path of the signal 50.

The type of acoustic signal 50 transmitted from the acoustic sensors 20 through the sidewall 46 of the container 40 may include shear waves and/or longitudinal waves, since the incidence angles can be set to match the conditions of the apparatus 10, the container
25 40, and/or the material 12 therein. The frequency of the acoustic signal 50 may be any suitable acoustic frequency or combination of frequencies within the acoustic spectrum, including subsonic, sonic, and ultrasonic frequencies. The frequencies used may be determined based on the composition of the fluid container 40, the expected fluid material 12, or a combination thereof.

The acoustic sensors 30 sensing the material composition of the sidewall 46 of the container 40 may receive the first echo 52 when processing the signal from the acoustic sensors 20 transmitting the signal 50, as shown in FIG. 1. Then, the remaining signal 50 penetrates the inner surface of the sidewall 46 of the container. At this point, the reflections from this impedance barrier can be processed to determine the type of material 12 within the container 40. The use of additional acoustic sensors 20 which transmit additional signals 50 in additional pathways act to increase the signal fidelity and improve the accuracy of the apparatus 10.

Turning to FIG. 3, it is a side-view, diagrammatical illustration of a variation of the multi-path acoustic signal apparatus 10 of FIG. 1, in accordance with the first exemplary embodiment of the present disclosure. In particular, FIG. 3 illustrates the apparatus in use with a fluid material 12 which flows or moves through a container 40, such as a pipeline. When the fluid material 12 is flowing through the container 40, the acoustic sensors 20, 30 sensing the signals 50 can be added in two or more dimensions or positions along the direction of the flow of the fluid material 12, *e.g.*, in a perpendicular direction of the flow of the fluid material 12. This allows the apparatus to determine the flow of the fluid material 12 and additional parameters of the fluid material 12, such as the type of material, the density of the material, or other characteristics. As shown in FIG. 3, one group of acoustic sensors 20, 30 is positioned near one side of the container 40 while a second group of sensors 20, 30 are positioned towards a different side of the container 40. Each group includes sending sensors 20 and the acoustic sensor 30 or sensors which receive the signal 50.

With respect to the apparatus 10 in FIGS. 1-3, the signals 50 transmitted may be phase synchronized since it may be necessary to combine their amplitudes in the receiving sensor 30 before processing of the signal 50. It is possible to use the wave physical properties to amplify the signal 50, such as by superimposing multiple waves 50 over time. While adding multiple signals 50 that measure the same parameters, the noise from the multiple signals 50 stays the same as for single transducer 20 due to the random characteristic of the noise. Attenuation is most affected by this process since this parameter is most sensitive to the material parameters. Additionally, acoustic wave absorption as well

as speed of sound may be compensated for temperature, and as such, a temperature sensor 60 may be used to identify the temperature of the fluid material 12. The temperature sensor 60 may be in communication with the fluid material 12 either directly, or in indirect thermal communication in order to determine the temperature of the fluid material 12. In one example, the temperature sensor 60 may determine the temperature of the fluid container 40.

Furthermore, the wave absorption may be measured at different frequencies. Different frequencies can be used in certain cases, where the material acoustic attenuation allows for receiving of different signals 50 with each individual signal 50 using a separate frequency or range of frequencies. In this way, the signals 50 may not need to be synchronized and it may be possible to measure multiple points of the absorption vs. frequency curve at the same time periodically.

Additionally, it is noted that time of flight measurements may be taken, and additional processing may be used since each path of the signal 50 may have a different time of flight. In the case when each signal path is using different frequencies, the time of flight may be measured separately.

In operation, the apparatus 10 may be calibrated during assembly or before use. In one example, calibration may include mounting an acoustic sensor 20 to the exterior of the fluid container 40 along the first portion 42. The at least one additional acoustic sensor 30 may be mounted along the second portion 44. The additional acoustic sensor 30 may be moved about the fluid container 40 until a maximum signal point is found, which may be used to determine a first path of the signal between the acoustic sensors 20, 30. More acoustic sensors 20 may be mounted to the outside of the fluid container 40 at different locations along the first portion 42. The acoustic sensors 20 may be moved until a maximum signal point between the sensors 20 and the additional acoustic sensor 30 is found. This may allow the apparatus 10 to better operate within larger fluid containers 40.

FIG. 4 is a diagrammatical illustration of the multi-path acoustic signal apparatus 10 of FIG. 1 in communication with a computer processor 80, in accordance with the first exemplary embodiment of the present disclosure. The apparatus 10 may be understood with reference to FIGS. 1-3, above; however, for clarity of illustration, not all of the

reference characters have been shown. The acoustic sensors 20, 30 may be in electrical communication over at least one network 70 with a computer processor 80. The at least one network 70 may include any suitable network systems, including wired data connections and wireless data connections, e.g., LAN, intranet, Internet, Wi-Fi®, Bluetooth®, NFC, radio, or any other type of network connection. The computer processor 80 may include any type and number of processors, including stationary processors, mobile processors, mobile devices, processor arrays, cloud processing networks, and the like. The computer processor 80 may include any components required for operation, including a power source, computer-readable memory, network communications, and the like.

Data from the acoustic sensors 20, 30 may be communicated to the computer processor 80 along the at least one network 70. Communicated data may include data from the plurality of acoustic sensors 20 positioned along the first portion 42 of the fluid container 40, such as characteristic information about any acoustic signals transmitted, and received data from any reflected acoustic signals received by the acoustic sensors 20. Communicated data may further include data from the at least one additional acoustic sensor 30 positioned along the second portion 44 of the fluid container 40, such as received data from the transmitted acoustic signals 50 received by the additional acoustic sensor 30. The communicated data may be analyzed to determine composition and other material characteristics of the material 12 within the fluid container 40.

FIG. 5 is a flow chart 500 illustrating a method of detecting a material within a fluid container, in accordance with the first exemplary embodiment of the present disclosure. It should be noted that any process descriptions or blocks in flow charts should be understood as representing modules, segments, portions of code, or steps that include one or more instructions for implementing specific logical functions in the process, and alternate implementations are included within the scope of the present disclosure in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present disclosure.

Step 510 includes transmitting at least one acoustic signal from each of a plurality of acoustic sensors positioned along a first portion of the fluid container. In one example, at least one of the transmitted acoustic signals may differ from another transmitted acoustic signal in one or more ways. For instance, at least one transmitted acoustic signal may have a frequency different from another. At least one transmitted acoustic signal may have a pulse length or transmission length different from another. For example, one signal may include a shorter pulse, while another may include a long pulse. In one example, one transmitted acoustic signal may be continuous, while another is not. At least one transmitted acoustic signal may have a periodic or patterned transmission. In another example, one or more transmitted acoustic signals may have the same frequency, pulse length, or periodic or patterned transmission.

In one example, at least one of the transmitted acoustic signals may propagate through the fluid container in a direction different from another acoustic signal. For instance, the plurality of acoustic sensors may be positioned at different angular locations on the fluid container, but may each be oriented toward the same point. Put another way, all of the acoustic sensors may be located at different positions within a plane extending through the fluid container.

In one example, a phase of the transmitted acoustic signals may be synchronized between the signals such that periodic maxima and minima in the amplitude of the signals occur at the same time. This may allow the transmitted signals to be constructively or destructively interfered with one another.

Step 520 includes receiving, with at least one additional acoustic sensor positioned along a second portion of the fluid container, the at least one transmitted acoustic signal, wherein the second portion is substantially opposite the first portion of the fluid container. In one example, at least one of the transmitted acoustic signals may travel through the entire diameter of the fluid container. In another example, at least one of the transmitted acoustic signals may travel through less than the entire diameter of the fluid container.

Step 530 includes determining, based on the at least one received acoustic signal, a composition of the material within the fluid container.

Step 540 includes receiving, with at least one of the plurality of acoustic sensors positioned along the first portion of the fluid container, at least one reflected acoustic signal generated from an impedance barrier between the fluid container and the material.

5 Step 550 includes determining, based on the at least one received acoustic signal and the at least one reflected acoustic signal, a composition of the material within the fluid container. In one example, a temperature sensor may be used to determine a temperature of the material, the fluid container, or both. The determined temperature or temperatures may be used to determine the composition or other characteristics of the material within the fluid container.

10 It should be emphasized that the above-described embodiments of the present disclosure, particularly, any “preferred” embodiments, are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) of the disclosure without departing substantially from the spirit and
15 principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and the present disclosure and protected by the following claim.

CLAIMS

What is claimed is:

1. A multi-path acoustic signal apparatus for use in material detection, the apparatus comprising:
 - 5 a plurality of acoustic sensors positioned along a first portion of a fluid container;
 - at least one acoustic signal transmitted into the fluid container by each of the plurality of acoustic sensors;
 - at least one additional acoustic sensor positioned along a second portion of the fluid container, wherein the second portion is substantially opposite the first portion, and wherein the at least one additional acoustic sensor receives at least a portion of the acoustic signals from the plurality of acoustic sensors; and
 - 10 a reflected acoustic signal generated from an impedance barrier between the fluid container and a fluid therein, and wherein a characteristic of a material of the fluid container and/or the fluid therein are determined.
- 15 2. The multi-path acoustic signal apparatus of claim 1, wherein:
 - at least one of the plurality of acoustic sensors is positioned directly opposite the at least one additional acoustic sensor;
 - the plurality of acoustic sensors are evenly spaced apart from one another; or
 - 20 the plurality of acoustic sensors are spaced apart from one another at different distances.
3. The multi-path acoustic signal apparatus of claims 1 or 2, wherein at least one of the plurality of acoustic sensors is rotatable within a plane tangential to a surface of the fluid container.
- 25 4. The multi-path acoustic signal apparatus of claims 1, 2, or 3, wherein the plurality of acoustic sensors and the at least one additional acoustic sensor are positioned so that the transmitted acoustic signals travel through a distance of at least half a diameter of the fluid container.

5. The multi-path acoustic signal apparatus of claims 1, 2, 3, or 4, wherein at least one transmitted acoustic signal travels through a distance of an entire diameter of the fluid container.

6. The multi-path acoustic signal apparatus of claims 1, 2, 3, 4, or 5, wherein
5 the first portion extends no more than half of a perimeter of the fluid container.

7. The multi-path acoustic signal apparatus of claims 1, 2, 3, 4, 5, or 6, wherein the at least one additional acoustic sensor is movable along a plane tangential to a sidewall of the fluid container.

8. The multi-path acoustic signal apparatus of claims 1, 2, 3, 4, 5, 6, or 7,
10 wherein the at least one additional acoustic sensor comprises an array of sensors.

9. The multi-path acoustic signal apparatus of claim 8, wherein the sensors in the array are movable about an exterior sidewall of the fluid container.

10. The multi-path acoustic signal apparatus of claims 1, 2, 3, 4, 5, 6, 7, 8, or 9, further comprising a temperature sensor in communication with the material.

11. A method for detecting a material within a fluid container, comprising the
15 following steps:

transmitting at least one acoustic signal from each of a plurality of acoustic sensors positioned along a first portion of the fluid container;

receiving, with at least one additional acoustic sensor positioned along a
20 second portion of the fluid container, the at least one transmitted acoustic signal, wherein the second portion is substantially opposite the first portion of the fluid container; and

determining, based on the at least one received acoustic signal, a composition of the material within the fluid container.

12. The method of claim 11, further comprising the steps of:

receiving, with at least one of the plurality of acoustic sensors positioned along the first portion of the fluid container, at least one reflected acoustic signal generated from an impedance barrier between the fluid container and the material; and

determining, based on the at least one received acoustic signal and the at least one reflected acoustic signal, a composition of the material within the fluid container.

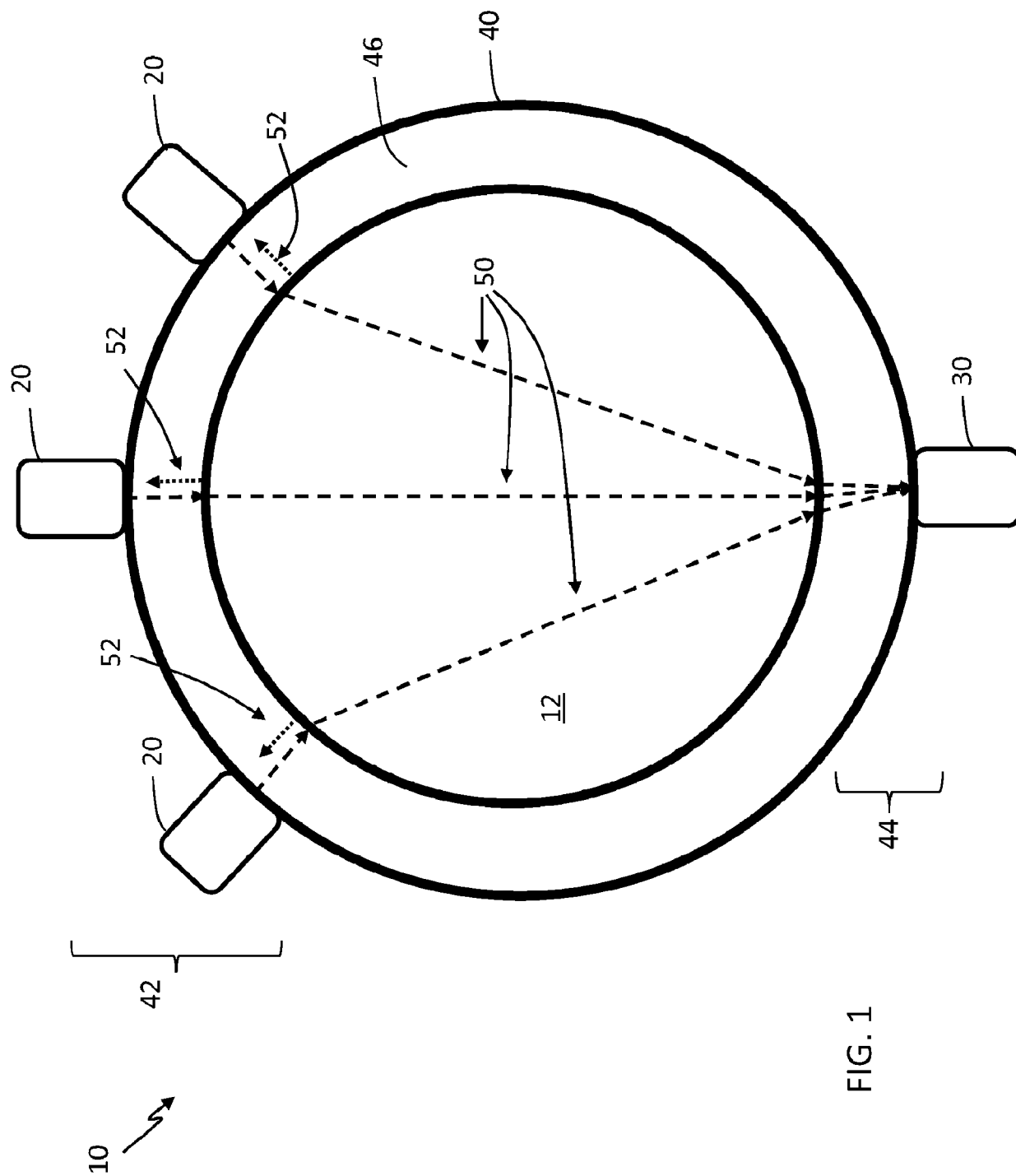
13. The method of claims 11 or 12, wherein:

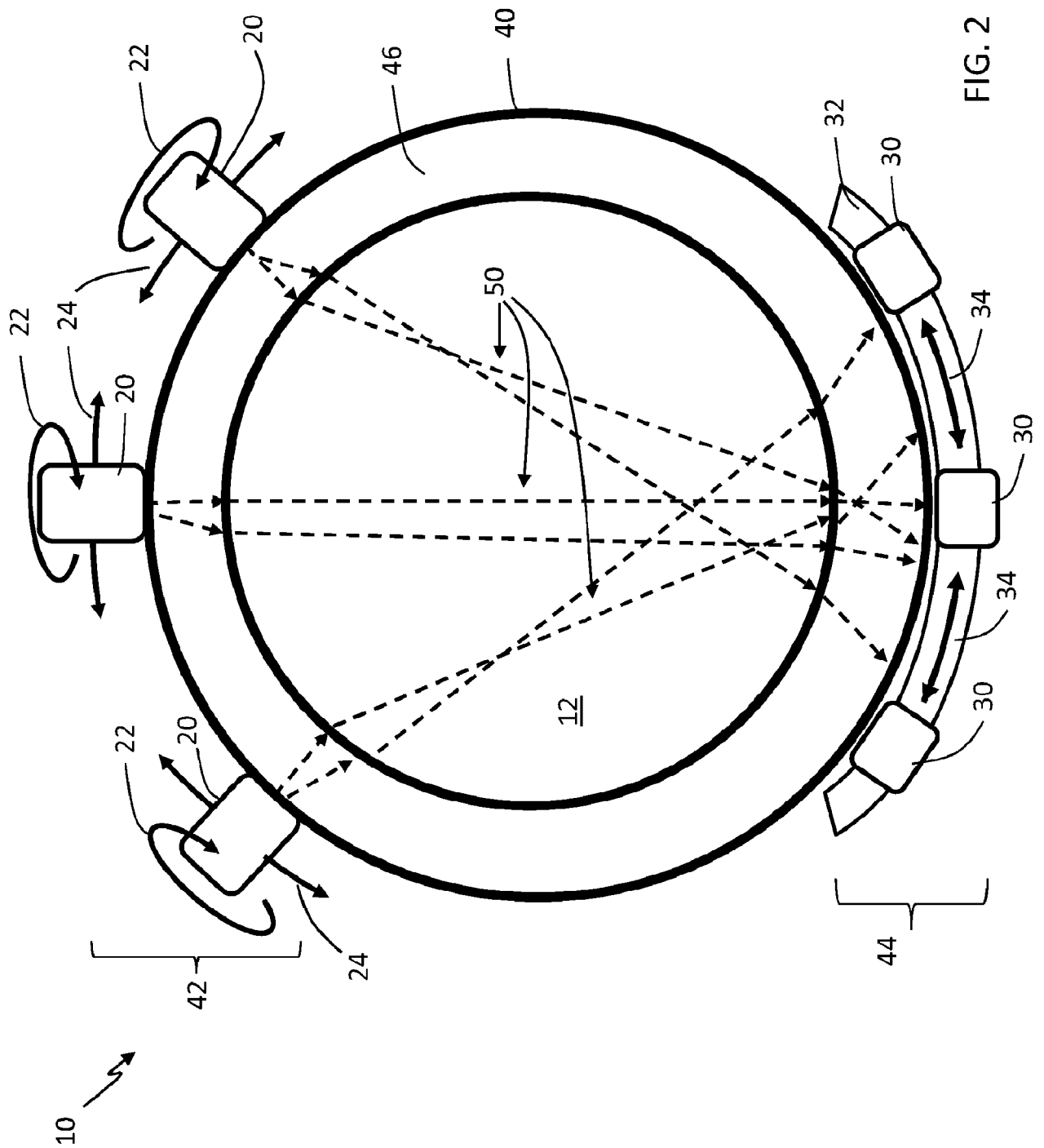
- 5 at least one of the transmitted acoustic signals has a frequency different from another transmitted acoustic signal;
- at least one of the transmitted acoustic signals has a pulse length different from another transmitted acoustic signal;
- at least one of the transmitted acoustic signals has a propagation direction through the fluid container different from another transmitted acoustic signal; or
- 10 at least one of the transmitted acoustic signals travels through a distance of a diameter of the fluid container

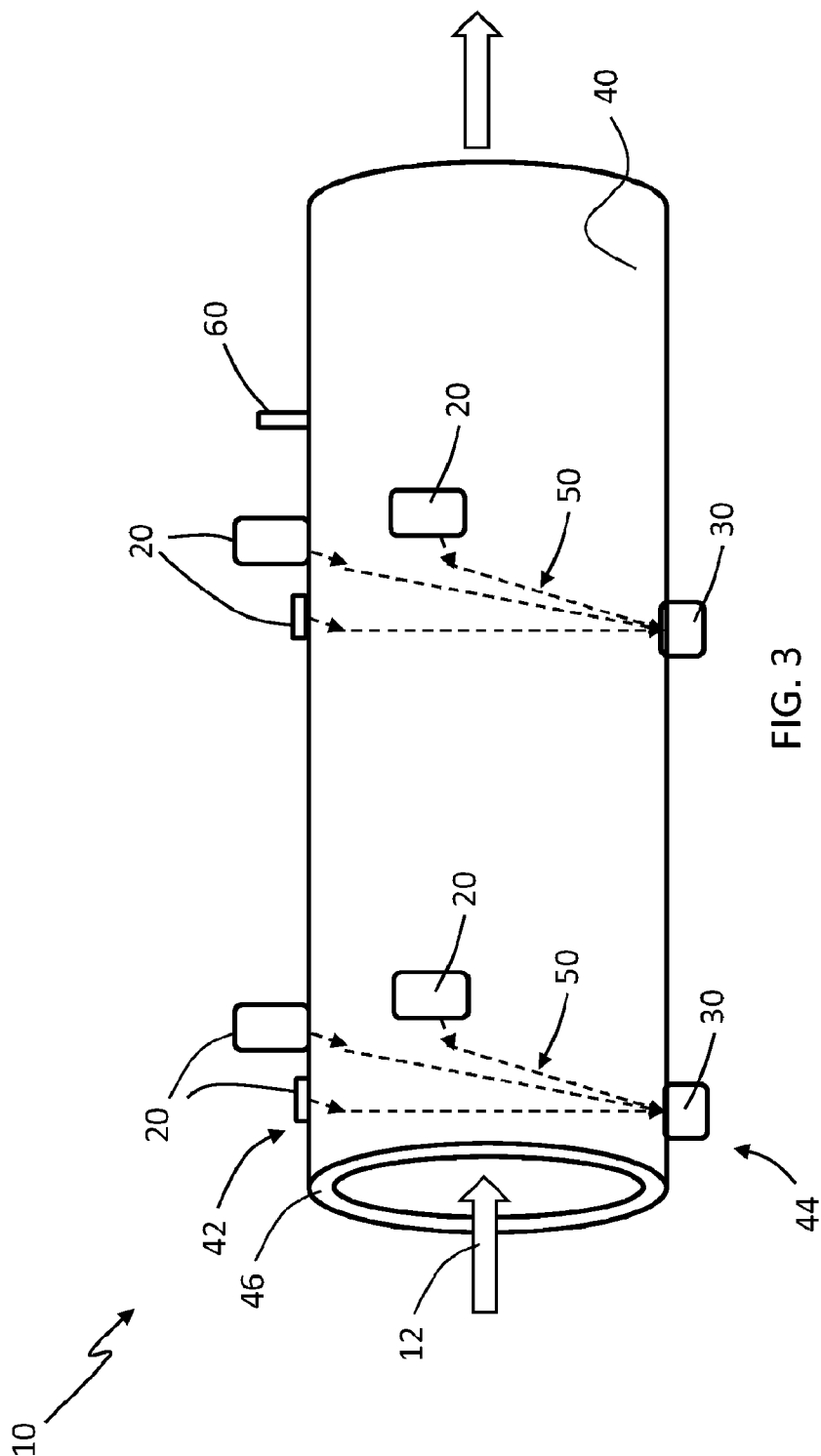
14. The method of claims 11, 12, or 13, wherein a phase of at least two of the transmitted acoustic signals is synchronized between the signals.

15. The method of claims 11, 12, 13, or 14, further comprising the step of receiving, with a temperature sensor in communication with the material, a temperature of the material, wherein the determination of the composition of the material is made based at least partially on the temperature of the material.

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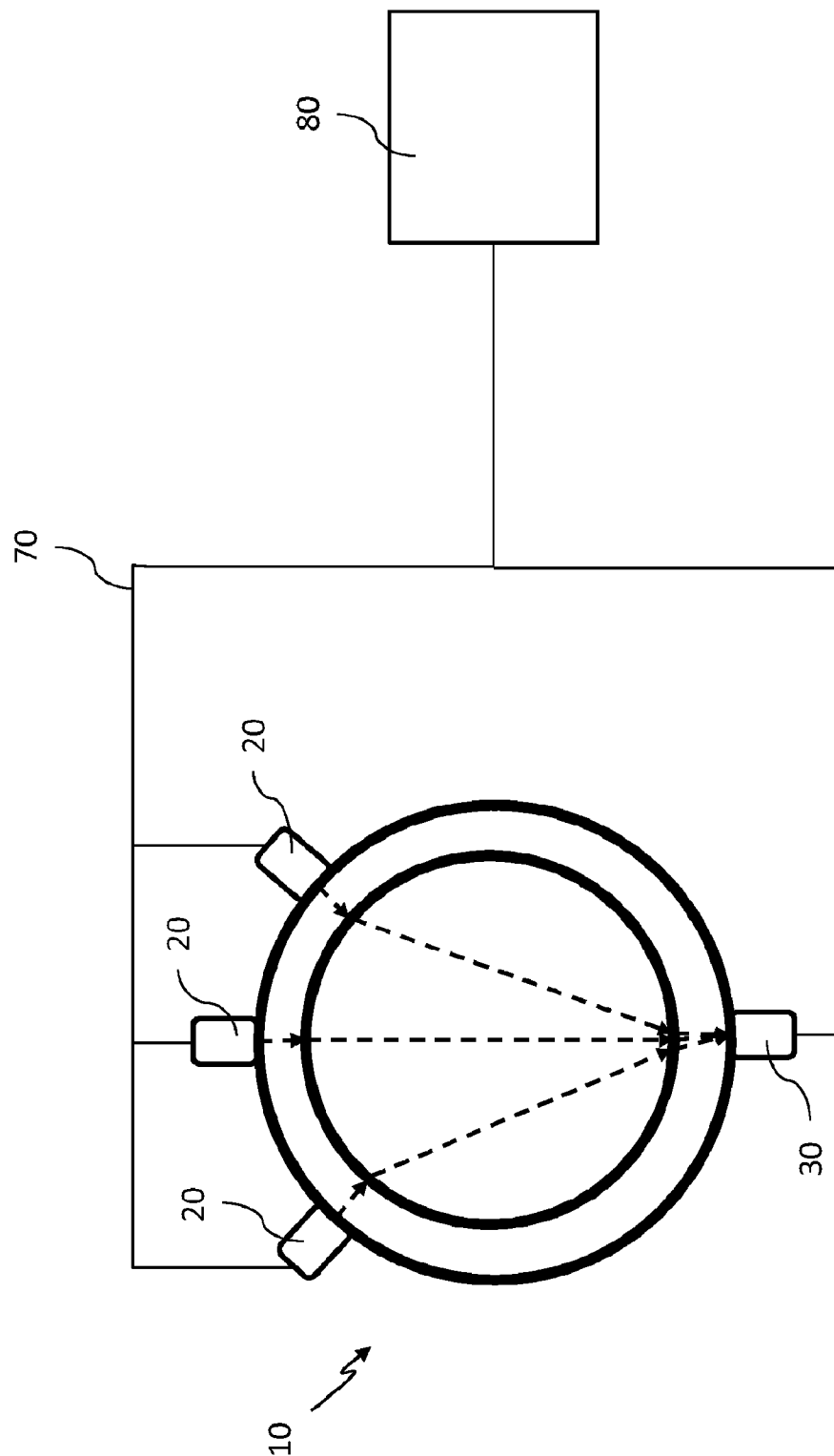


FIG. 4

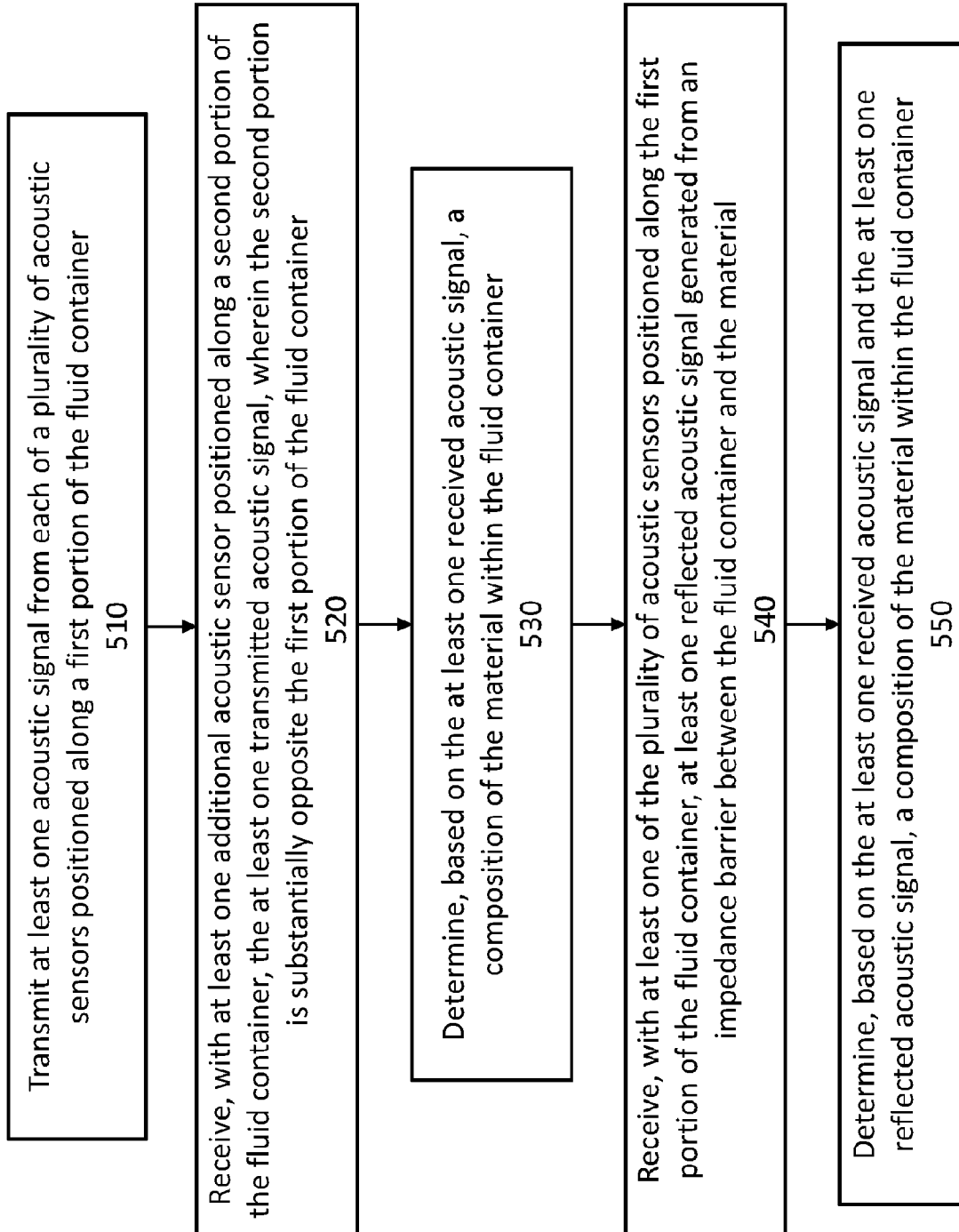
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FIG. 5

