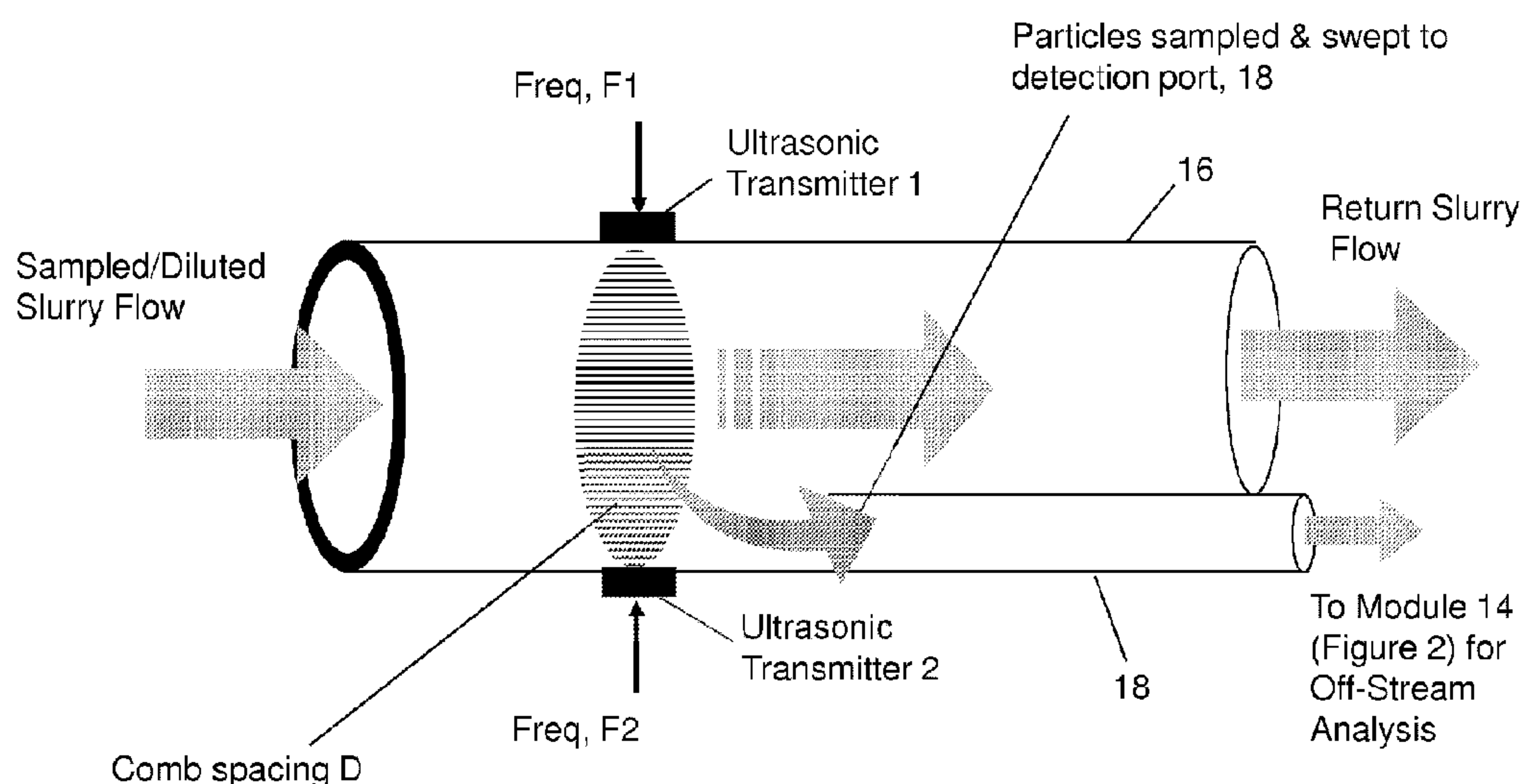




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(54) **Titre : DETECTION DE LA TAILLE OU DE LA REPARTITION GRANULOMETRIQUE DE PARTICULES AU MOYEN D'ONDES
ACOUSTIQUES STATIONNAIRES**
(54) **Title: ACOUSTIC STANDING WAVE PARTICLE SIZE OR DISTRIBUTION DETECTION**



Apparatus or Arrangement No. 1: Swept Acoustic Comb Filter

(57) **Abrégé/Abstract:**

Apparatus features an acoustic comb filter module configured to receive signaling containing information about different frequencies F1 and F2 to create a selected comb spacing D to capture certain particles having a selected size X in a flow stream in a flow pipe, and to provide an acoustic standing wave via ultrasonic excitation based at least partly on the two different frequencies F1 and F2 to create the selected comb spacing D to capture the certain particles having the selected size X in the flow stream in the flow pipe. The apparatus may also include a particle size or distribution determination module configured to receive the certain particles for off-stream analysis via a detection port that forms part of the flow pipe and determine the particle size or distribution of the certain particles in the flow stream in the flow pipe.

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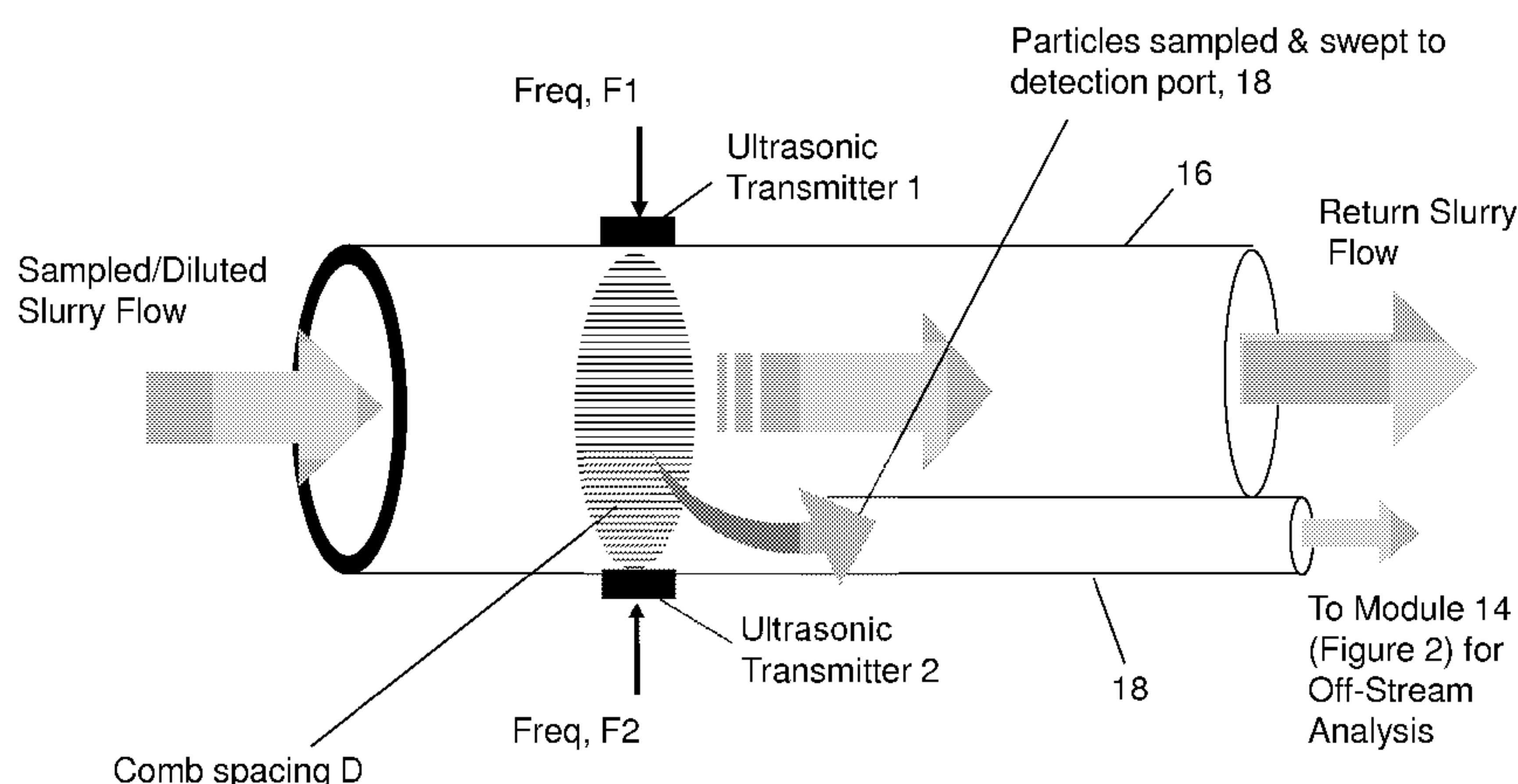


Fig. 3b: Apparatus or Arrangement No. 1: Swept Acoustic Comb Filter

(57) **Abstract:** Apparatus features an acoustic comb filter module configured to receive signaling containing information about different frequencies F1 and F2 to create a selected comb spacing D to capture certain particles having a selected size X in a flow stream in a flow pipe, and to provide an acoustic standing wave via ultrasonic excitation based at least partly on the two different frequencies F1 and F2 to create the selected comb spacing D to capture the certain particles having the selected size X in the flow stream in the flow pipe. The apparatus may also include a particle size or distribution determination module configured to receive the certain particles for off-stream analysis via a detection port that forms part of the flow pipe and determine the particle size or distribution of the certain particles in the flow stream in the flow pipe.

ACOUSTIC STANDING WAVE PARTICLE SIZE OR DISTRIBUTION DETECTION

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Background of the Invention

1. Technical Field

This invention relates generally to a method and apparatus for particle size or
10 distribution detection in a flow stream in a flow pipe using acoustic standing waves.

2. Description of Related Art

Prior art techniques are known that use a single frequency F to excite the
standing wave. The standing wave results due to the counter propagating acoustic
15 fields across the flow pipe: the first off the transducer directly, the other off the
acoustic reflector. The periodicity, or comb spacing, D, of the nodes of the standing
wave is a function of the frequency F, the speed of sound in the fluid (cf):

$$D = cf / 2F$$

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This produces an acoustic comb filter that can trap particles flowing in the fluid. The
retention forces depend on the peak acoustic pressure, the particle size, and the
periodicity D.

As particles are captured in this comb, drag forces will ultimately overcome the retention forces, and the particles will be released into the flow. If the flow is slow enough (as in prior art), the agglomeration of particles will result in them either lifting out of the flow (buoyant), or dropping in the flow due to gravity.

5 One problem with this approach is that if the flow is strong, the drag forces increase, and particles are only held/trapped momentarily until the drag forces exceed the retention forces. The particles are then swept forward with the flow and no overall filtering action is achieved.

10 In particular, acoustic agglomeration techniques are understood and used for filtering a flow stream, including techniques where a standing wave may be formed in the flow stream by ultrasonic excitation frequencies. FloDesign Sonics, Inc., a company in Wilbraham, MA, has developed configurations using a standing wave for creating and trapping of particulate matter in a flow stream. One known application has been demonstrated in water purification with particulate of about 2% of the flow
15 stream.

20 Figure 1a sets forth known apparatus generally indicated as D1 , showing flow channels, an acoustic transducer, a reflective surface, and a collection pocket, for the harvesting of microalgae through acoustophoretic trapping, as disclosed in U.S. patent publication no. 2011/0278218. In Figure 1a, the direction of the fluid flow is horizontal and the direction of the acoustic field is vertical. As shown, the flow pipe receives produced water that is processed using the acoustophoretic technology so as to provide from the flow pipe purified water. In operation, during the acoustophoretic processing micro-droplets are trapped at nodes of standing waves, such that collected micro-droplets agglomerate

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agglomerate gain buoyancy and float to the surface to be removed. As shown, a piezo crystal is used to make acoustic waves.

Consistent with that disclosed Figure 1a, the known acoustophoretic technology is characterized at least by the following features:

- 5 - It employs an acoustic radiation force,
- It is based on a fixed frequency or frequency sweep operation,
- It uses an acoustic standing wave that contains 100s of wavelengths,
- It is a resonance based operation,
- It provides the ability to trap and translate pollutants without any moving
- 10 parts (i.e. a "Filterless" filter), and
- It uses buoyancy and gravitational settling for collection and separation.

Consistent with that disclosed in paragraph [0062] of the aforementioned U.S. patent publication no. 2011/0278218, Figure 1b shows a photo of a device generally indicated as D2 capable of processing 3 gallons/min of emulsified oil-water, and

15 includes an upper device D2' and a lower device D2". The emulsion flows in at the left side (bottom of the device D2', laying on its side); transducers are positioned on the side; and oil is removed from the right side (top of the device D2'). The device D2" shown in the bottom of the photo in Figure 1b is designed for the emulsion to flow in at the left (bottom of the device, laying on its side); there are two separation

20 regions where the oil travels in one and the pure water in the second. In the device D2" shown in the bottom of Figure 1b the emulsion flows in on the left and separate oil and water channels are shown on the right of the device D2".

Figure 1b(1) shows microalgae (10 microns) generally indicated as M being processed by the device D2 shown in Figure 1b, and Figure 1b(2) shows iron-oxide (20 microns) generally indicated as I-O being processed by the device D2 shown in Figure 1b.

The known acoustophoretic technology may be characterized by a trapping
5 efficiency for high-particulate slurry flow that is low. In view of this, there is a need in the industry to provide a better way for trapping high-particulate slurry flow, e.g., by leveraging the known acoustophoretic technology using alternative configurations according to the present invention. Moreover, there is a need in the industry to provide a better way for detecting particle size or distribution in a flow stream in a
10 flow pipe, e.g., using acoustic standing waves.

Summary of the Invention

The present invention provides particle size or distribution detection techniques using acoustic standing wave technology.

15 In its broadest sense, the present invention provides new and unique apparatus featuring an acoustic comb filter module configured to receive signalling containing information about different frequencies F1 and F2 to create a selected comb spacing D to capture certain particles having a selected size X in a flow stream in a flow pipe, and provide an acoustic standing wave via excitation based at
20 least partly on the two different frequencies F1 and F2 to create the selected comb spacing D to capture the certain particles having the selected size X in the flow stream in the flow pipe. The signalling may be received, e.g., from a processor or controller, including signalling in response to a graphical user interface being provided by a user controlling the apparatus.

According to some embodiments, and by way of example, the present invention may take the form of apparatus featuring the acoustic comb filter module in combination with a particle size or distribution determination module that may be configured to determine the particle size or distribution of the certain particles in the
5 flow stream in the flow pipe, e.g., used for, or forming part of, off-stream analysis,.

The particle size or distribution determination module may be configured to receive the certain particles for off-stream analysis via a detection port that forms part of the flow pipe.

According to some embodiments, the apparatus may also include the flow
10 pipe configured to provide the flow stream having particles with different sizes, including the combination of the flow pipe including the detection port configured to provide the certain particles having the selected size X in the flow stream from the flow pipe for the off-stream analysis.

The flow stream may include, or takes the form of, a slurry flow, including a
15 sampled/diluted slurry flow.

The acoustic comb filter module may be programmable to provide different acoustic standing waves at different frequencies to create different selected comb spacings to capture different certain particles having different selected sizes in the flow stream in the flow pipe.

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Swept Acoustic Comb Filter

According to some embodiments of the present invention, the acoustic comb filter module may include, or take the form of, a swept acoustic comb filter configured to provide a swept acoustic standing wave set up via ultrasonic excitation
25 based at least partly on the two different frequencies F1 and F2.

The swept acoustic comb filter may be configured to provide the sweep of the acoustic standing wave based at least partly on the transit time across the flow stream being less than the capture time of the certain particles.

5 The swept acoustic comb filter may be configured with a first ultrasonic transmitter to provide a first acoustic signal at a first frequency F1 and with a second ultrasonic transmitter to provide a second acoustic signal at a second frequency F2.

The swept acoustic comb filter may be configured to be swept, e.g., at frequency F1-F2 "fringes" per second.

10 The swept acoustic comb filter may be configured to capture and sweep the certain particles lower in the flow stream.

In effect, a standing wave can be achieved by directly passing two counter propagating acoustic waves across the flow pipe, using opposing acoustic transducers. (with no acoustic reflector). If the frequencies of excitation of these two transducers is identical, e.g. F, then a standing wave is formed as in the prior art
15 technique set forth above.

However, if the excitation is based on the two different frequencies F1 and F2, then the 'standing wave' becomes a "Quasi-Standing Wave", as it is swept across the flow tube at a rate of F1-F2, according to some embodiments of the present invention.

20 The comb spacing, D, is still related to the frequency F, but now F is the average of F1+F2 (e.g. $F=(F1+F2)/2$).

As there may be hundreds of 'nodes' in the acoustic comb across the flow pipe, the rate at which the acoustic "comb" sweeps can be adjusted via the frequency difference $F_1 - F_2$. For a 100 Hz frequency difference, the comb will translate across the flow stream at a 100 nodes per second (up, or down depending on whether the frequency difference is positive or negative).

Particles captured in the flow stream are now translated across the pipe cross-section and moved to the edge of the pipe. If this is accomplished before the drag forces overcome the retention forces (the 'capture time'), the captured particles can be swept to the side of the flow pipe, and released into a side-stream port/pipe.

This new swept acoustic standing wave technique has a number of potential applications:

1) If the comb periodicity is set such that all particles above size X are captured by the swept acoustic comb to the side port/pipe, then particulate matter in the flow can be filtered out effectively and disposed.

2) As in application no. 1, but the particles are extracted on a periodic 'sampling' basis and the particles extracted are sent for further particle-size analysis, such as sieving, laser diffraction, etc.

3) By adjusting the comb periodicity, the particles sizes selected and drawn from the tube can be altered, and thus the particle size distribution can be assessed through sampling the flow at a series of difference average frequencies, F . In this case, at the highest frequencies, all particles are sampled and swept out of the flow, whereas at lower frequencies, only the larger particles are effectively trapped by the acoustic comb and swept to the side port. By analyzing the mass of particles captured in a given time interval for a range of frequencies F , the particle distribution can be inferred.

Sub-carrier Modulated Acoustic Comb Filter

Alternatively, according to some embodiments of the present invention, the acoustic comb filter module may include, or take the form of, a sub-carrier modulated acoustic comb filter configured to provide a modulated standing wave set
5 up via ultrasonic excitation based at least partly on the two frequencies $F1$ and $F2$ with a comb spacing nominally D and with acoustic signals at ω , oscillated at $\omega/2\pi$, and scattered off particulates in the flow stream.

The sub-carrier modulated acoustic comb filter may be configured with a first ultrasonic transmitter to provide a first acoustic signal at a first frequency $F1$ and with
10 a second ultrasonic transmitter to provide a second acoustic signal at a second frequency $F2$, e.g., where $F2 = F1 + \Delta F1 \sin(\omega t)$ and is swept at $\omega/2\pi$.

The apparatus may also include low frequency (LF) acoustic receivers configured in the flow pipe configured to receive the acoustic signals.

In effect, using the 'opposing acoustic transponder' configuration of the swept
15 acoustic standing wave technique set forth above, if the excitation is based on two different frequencies $F1$ and $F2$, where $F2 = F1 + \Delta F \sin(\omega t)$, then the 'standing wave' becomes again a "Quasi-Standing Wave", as it is swept back and forth in an oscillatory manner across the flow (i.e., not in one direction as in the swept case).

The comb spacing, D , is still related to the frequency F , but now F is the
20 average of $F1+F2$ (e.g. $F=(F1+F2)/2$).

The rate of oscillation is given by $\omega/2\pi$, and the amplitude of the oscillation depends on ΔF : e.g., if ΔF is 10 Hz, then the comb will oscillate back and forth about some nominal point by ± 10 nodes at a frequency of $\omega/2\pi$.

Particles in the flow stream small enough to be captured by the acoustic comb are now translated in an oscillatory fashion across the pipe cross-section. The motion of these trapped particles create acoustic pressure fields, and consequently, the modulated particles generate radiated acoustic signatures which can be
5 detected by low frequency acoustic receivers around the pipe.

The detected signals will be at harmonics of the 'sub-carrier' frequency $\omega/2\pi$.

As the particle sizes captured is dependent on the nominal frequency F_1 (as this determines the comb spacing), changing the comb spacing will alter the degree of particle capture and thus the amplitude of the acoustic signal emitted at the
10 modulation frequency $\omega/2\pi$.

This sub-carrier modulation acoustic standing wave technique has the potential applications for particle size determination, as follows:

If the comb periodicity is set such that no particles are captured by the modulated acoustic comb, then there will be no radiated LF acoustic signal.

15 If the comb periodicity is set such that all particles above size X_1 are captured by the modulated acoustic comb, then there will be a radiated LF acoustic signal of amplitude A_1 .

If the comb periodicity is set such that all particles above size X_2 are captured by the modulated acoustic comb, then there will be a radiated LF acoustic signal of
20 amplitude A_2 .

This is repeated for a series of periodicities X_j and A_j , until substantially all particles are captured.

The increase in amplitude $A_1, A_2, A_3, \dots, A_n$ maps out the cumulative particle size distribution in the flow.

25

The Method

According to some embodiments, the present invention may take the form of a method comprising steps for providing with an acoustic comb filter module an acoustic standing wave via excitation based at least partly on two different
5 frequencies F1 and F2 to create a selected comb spacing D to capture certain particles having a selected size X in a flow stream in a flow pipe; and determining with a particle size or distribution determination module the particle size or distribution of the certain particles in the flow stream.

According to some embodiments of the present invention, the method may
10 include one or more of the features set forth above and herein.

The Combination of the Flow Pipe and Acoustic Comb Filter Module

According to some embodiments, the present invention may take the form of apparatus featuring a flow pipe in combination with an acoustic comb filter module.
15 The flow pipe may be configured to provide a flow stream having particles with different sizes. The acoustic comb filter module may be configured to provide an acoustic standing wave via excitation based at least partly on two different frequencies F1 and F2 to create a selected comb spacing D to capture certain particles having a selected size X in the flow stream in the flow pipe.

20 According to some embodiments of the present invention, the combination of the flow pipe and acoustic comb filter module may include one or more of the features set forth above and herein.

In effect, the present invention aims to leverage known acoustic standing wave technology in the area of particle size/distribution determination, e.g., of a flow
25 stream in a flow pipe.

Brief Description of the Drawing

Referring now to the drawing, which are not necessarily drawn to scale, the foregoing and other features and advantages of the present invention will be more fully understood from the following detailed description of illustrative embodiments, taken in conjunction with the accompanying drawing in which like elements are numbered alike:

Figure 1a is a diagram of acoustic standing wave technology used for filtering that is known in the art.

Figure 1b is a diagram of acoustic standing wave technology used for filtering that is known in the art.

Figure 1b(1) is a photograph of microalgae (10 microns) subjected to the acoustic standing wave technology used for filtering in Figure 1b that is known in the art.

Figure 1b(2) is a photograph of Iron-Oxide (20 microns) subjected to the acoustic standing wave technology used for filtering in Figure 1b that is known in the art.

Figure 2 is a block diagram of apparatus according to some embodiments of the present invention.

Figure 3a is a diagram of a technique for capturing particles using a swept acoustic comb filter technique, according to some embodiments of the present invention.

Figure 3b is a diagram of apparatus or arrangement for implementing the technique for capturing particles using the swept acoustic comb filter technique, according to some embodiments of the present invention.

Figure 4a is a diagram of a technique for capturing particles using a sub-carrier modulated acoustic comb filter technique, according to some embodiments of the present invention.

Figure 4b is a diagram of apparatus or arrangement for implementing the technique for capturing particles using the sub-carrier modulated acoustic comb filter technique, according to some embodiments of the present invention.

Detailed Description of the Invention

Figure 2

According to some embodiments, and by way of example, Figure 2 shows the present invention in the form of apparatus 10 featuring an acoustic comb filter module 12. In Figure 2, the acoustic comb filter module 12 is shown in combination with a particle size or distribution determination module 14 for off-stream analysis, according to some embodiments of the present invention.

The acoustic comb filter module 12 may be configured to receive signalling containing information about different frequencies F1 and F2 to create a selected comb spacing D to capture certain particles having a selected size X in a flow stream in a flow pipe 16, and to provide an acoustic standing wave via excitation based at least partly on the two different frequencies F1 and F2 to create the selected comb spacing D to capture the certain particles having the selected size X in the flow stream in the flow pipe 16 (see Figures 3b and 4b).

The particle size or distribution determination module 14 may be configured to determine the particle size or distribution of the certain particles in the flow stream in the flow pipe, e.g., using or forming part of off-stream analysis.

Figure 3a and 3b: Swept Acoustic Comb Filter

Consistent with that described herein, the acoustic comb filter module 12 may include, or take the form of, a swept acoustic filter using a technique where a standing wave is formed by flow insonification in a slurry flow so that particles in a slurry flow stream are captured and swept lower (depicted by the three arrows) in the slurry flow stream as generally depicted in Figures 3a and 3b. In this technique, e.g., the swept standing wave may be set up via ultrasonic excitation based at least partly on the two frequencies F1 and F2, and the comb spacing D may be set to capture the particle having size X. The sweep of the standing wave is based at least partly on the transit time across the slurry flow being less than the capture time of the certain particles.

Figure 3b shows an embodiment where the swept acoustic comb filter may be configured with, or take the form of, a first ultrasonic transmitter 1 to provide a first acoustic signal at a first frequency F1 and a second ultrasonic transmitter 2 to provide a second acoustic signal at a second frequency F2, so as to provide the swept acoustic standing wave having the comb spacing D set up via the ultrasonic excitation based at least partly on the two different frequencies F1 and F2.

Transmitters like elements 1 and 2, including transmitters in the form of ultrasonic transmitters, are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind thereof either now known or later developed in the future. Moreover, based on that disclosed in the instant patent application, a person skilled in the art without undue experimentation would be able to implement or configure the first ultrasonic transmitter 1 and the second ultrasonic transmitter 2 to provide the swept acoustic standing wave via excitation based at least partly on

the two different frequencies F1 and F2 to create the selected comb spacing D to capture the certain particles having the selected size X in the flow stream in the flow pipe 16 (see Figure 3b).

In Figure 3b, the swept acoustic comb filter may be configured to be swept, e.g., at frequency F1-F2 "fringes" per second, although the scope of the invention is intended to include other sweeping frequencies. The swept acoustic comb filter may also be configured to provide the sweep of the acoustic standing wave based at least partly on the transit time across the flow stream being less than the capture time of the certain particles. In Figure 3b, the slurry flow is shown by way of example in the form of a sampled/diluted slurry flow, although the scope of the invention is intended to include other types or kind of flow streams or slurry flows either now known or later developed in the future. In other words, the scope of the invention is not intended to be limited to the type or kind of flow stream being processed.

In Figure 3b, the flow pipe 16 may be configured with a detection port 18. In operation, the particle size or distribution determination module 14 (Figure 2) may be configured to receive the certain particles via the detection port 18 (Figure 3b) that forms part of the flow pipe 16. The flow pipe 16 is also configured to provide return flow for subsequent processing in a manner that does not form part of the underlying invention.

Figure 4a and 4b: Sub-carrier Modulated Acoustic Comb Filter

According to some embodiments of the present invention, the acoustic comb filter module may include, or take the form of, a sub-carrier modulated acoustic comb filter using a technique where a modulated standing wave is set up via

ultrasonic excitation based at least partly on the two frequencies $F1$ and $F2$ with a comb spacing nominally D , with acoustic signals at ω , oscillated at $\omega/2\pi$, and scattered off particulates in the bulk slurry or flow stream, as generally depicted in Figures 4a and 4b. In Figure 4a, the acoustic signals are indicated as $as1$, $as2$, $as3$ 5 directed towards the particles in flow in the bulk slurry or flow.

Figure 4b shows an embodiment where the sub-carrier modulated acoustic comb filter may be configured with, or take the form of, with a first ultrasonic transmitter 1' to provide a first acoustic signal at a first frequency $F1$ and with a second ultrasonic transmitter 2' to provide a second acoustic signal at a second 10 frequency $F2$, e.g., where $F2 = F1 + \Delta F1 \sin(\omega t)$, and is swept at $\omega/2\pi$. Consistent with that stated above, transmitters like elements 1' and 2', including transmitters in the form of ultrasonic transmitters, are known in the art, and the scope of the invention is not intended to be limited to any particular type or kind thereof either now known or later developed in the future. Moreover, based on that disclosed in 15 the instant patent application, a person skilled in the art without undue experimentation would be able to implement or configure the first ultrasonic transmitter 1' and the second ultrasonic transmitter 2' to provide the modulated acoustic standing wave with the acoustic signals at ω , oscillated at $\omega/2\pi$, and scattered off the particulates in the bulk slurry or flow stream to create the selected 20 comb spacing nominally D to capture the certain particles having the selected size X in the flow stream in the flow pipe 16 (see Figure 4b).

In Figure 4b, the apparatus may also include low frequency (LF) acoustic receivers generally indicated as 20 configured in the flow pipe 16 configured to receive the acoustic signals $as1$, $as2$, $as3$ (Figure 4a).

The Module 12 or 14

By way of example, and consistent with that described herein, the functionality of the modules 12 or 14 in Figure 2 may be implemented in whole or in part using hardware, software, firmware, or a combination thereof, although the scope of the invention is not intended to be limited to any particular embodiment thereof. The acoustic comb filter module 12 may be configured with a controller or processor for providing one or control or processor signals, e.g. to the ultrasonic transmitters in Figures 3b and 4b. In a typical software implementation, the signal processor would be one or more microprocessor-based architectures having a microprocessor, a random access memory (RAM), a read only memory (ROM), input/output devices and control, data and address buses connecting the same. A person skilled in the art would be able to program such a microprocessor-based implementation to perform the functionality set forth in the module 12 or 14, such as for controlling the operation of the ultrasonic transmitters in Figures 3b and 4b, or for determining the size or distribution of the certain particles in the flow stream, as well as other functionality described herein without undue experimentation. The scope of the invention is not intended to be limited to any particular implementation using technology now known or later developed in the future. Moreover, the scope of the invention is intended to include the signal processor being a stand alone module, as shown, or in the combination with other circuitry for implementing another module.

Applications

The scope of the invention is described in relation to processing slurry. However, the scope of the invention is intended to include other types or kinds of applications either now known or later developed in the future, e.g., including a
5 processing other types or kinds of process flows.

The Scope of the Invention

It should be further appreciated that any of the features, characteristics, alternatives or modifications described regarding a particular embodiment herein
10 may also be applied, used, or incorporated with any other embodiment described herein. In addition, it is contemplated that, while the embodiments described herein are useful for homogeneous flows, the embodiments described herein can also be used for dispersive flows having dispersive properties (e.g., stratified flow). Although the invention has been described and illustrated with respect to exemplary
15 embodiments thereof, the foregoing and various other additions and omissions may be made therein and thereto without departing from the spirit and scope of the present invention.

What is claimed is:

1. Apparatus comprising:

an acoustic comb filter module having first and second opposing acoustic transducers configured on opposite sides of a flow pipe having a flow stream, and being configured to:

receive signaling containing information about different frequencies F1 and F2 to create a selected comb spacing D to capture and sweep certain particles having a selected size X lower in the flow stream in the flow pipe, and

provide using the first and second opposing acoustic transducers an acoustic standing wave across a cross-section of the flow pipe via excitation based at least partly on the two different frequencies F1 and F2 to create the selected comb spacing D to capture and sweep the certain particles having the selected size X lower in the flow stream in the flow pipe, a first opposing acoustic transducer configured to provide a first acoustic standing wave at a first frequency F1, and a second opposing acoustic transducer configured to provide a second acoustic standing wave at a second and different frequency F2 than the first frequency F1.

2. Apparatus according to claim 1, wherein the apparatus further comprises a particle size or distribution determination module configured to receive the certain particles and determine the particle size or distribution of the certain particles in the flow stream in the flow pipe.

3. Apparatus according to claim 1, wherein the apparatus further comprises the flow pipe configured to provide the flow stream having particles with different sizes.

4. Apparatus according to claim 3, wherein the flow pipe comprises a detection port configured to provide the certain particles having the selected size X captured and swept lower in the flow stream from the flow pipe for off-stream analysis.

5. Apparatus according to claim 1, wherein the flow stream is a slurry flow, including a sampled/diluted slurry flow.

6. Apparatus according to claim 1, wherein the acoustic comb filter module comprises a swept acoustic comb filter configured to provide a swept acoustic standing wave set up via ultrasonic excitation based at least partly on the two different frequencies F1 and F2.

7. Apparatus according to claim 6, wherein the swept acoustic comb filter is configured to provide the sweep of the acoustic standing wave based at least partly on a transit time across the flow stream being less than a capture time of the certain particles.

8. Apparatus according to claim 6, wherein the swept acoustic comb filter is configured with a first ultrasonic transmitter to provide a first acoustic signal at the first frequency F1 and configured with a second ultrasonic transmitter to provide a second acoustic signal at the second frequency F2.

9. Apparatus according to claim 8, wherein the swept acoustic comb filter is configured to be swept at frequency F1-F2 "fringes" per second.

10. Apparatus according to claim 6, wherein the swept acoustic comb filter is configured to capture and sweep the certain particles lower in the flow stream.

11. Apparatus according to claim 1, wherein the acoustic comb filter module comprises a sub-carrier modulated acoustic comb filter configured to provide a modulated standing wave set up via ultrasonic excitation based at least partly on the two frequencies $F1$ and $F2$ with a comb spacing nominally D and with acoustic signals at ω , oscillated at $\omega/2\pi$, and scattered off particulates in the flow stream.

12. Apparatus according to claim 11, wherein the sub-carrier modulated acoustic comb filter is configured with a first ultrasonic transmitter to provide a first acoustic signal at a first frequency $F1$ and with a second ultrasonic transmitter to provide a second acoustic signal at a second frequency $F2$, where $F2 = F1 + \Delta F1 \sin(\omega t)$, and is swept at $\omega/2\pi$.

13. Apparatus according to claim 11, wherein the apparatus further comprises low frequency (LF) acoustic receivers configured in the flow pipe.

14. Apparatus according to claim 1, wherein the acoustic comb filter module is programmable to provide different acoustic standing waves at different frequencies to create different selected comb spacings to capture different certain particles having different selected sizes in the flow stream in the flow pipe.

15. Apparatus according to claim 1, wherein the acoustic comb filter module is configured to receive the signalling from a processor or controller, via a graphical user interface.

16. Apparatus according to claim 1, wherein the acoustic standing wave is a “quasi-standing wave” that takes the form of an acoustic comb swept across the flow pipe at a rate of $F1-F2$.

17. Apparatus according to claim 1, wherein the selected comb spacing D is based at least partly on the average of $F1+F2$, where $F=(F1+F2)/2$.

18. Apparatus according to claim 17, wherein the acoustic comb is swept across the flow pipe as the rate can be adjusted via a frequency difference $F1-F2$.

19. Apparatus according to claim 17, wherein the acoustic comb filter module is configured to set a comb periodicity so that all particles above the selected particle size X are captured by the acoustic comb and swept to a side port/pipe, so as to filter out particulate matter in the flow stream.

20. Apparatus according to claim 17, wherein the acoustic comb filter module is configured to extract the certain particles on a periodic ‘sampling’ basis to be sent for further particle-size analysis, including by sieving or laser diffraction.

21. Apparatus according to claim 17, wherein the acoustic comb filter module is configured to adjust a comb periodicity, so that the particles sizes selected and drawn from the flow pipe can be altered.

22. Apparatus according to claim 2, wherein the particle size or distribution determination module is configured to assess the particle size distribution through sampling the flow stream at a series of difference average frequencies, F , including where at the highest frequencies, all particles are sampled and swept out of the flow pipe, whereas at lower frequencies, only the larger particles are effectively trapped by the acoustic comb and swept to a side detection port.

23. Apparatus according to claim 2, wherein the particle size or distribution determination module is configured to analyze the mass of particles captured in a given time interval for a range of frequencies F and infer the particle distribution.

24. Apparatus according to claim 2, wherein the acoustic comb filter module is configured to base the excitation on the two different frequencies $F1$ and $F2$, where $F2 = F1 + \Delta F \sin(\omega t)$, so the acoustic standing wave is a “quasi-standing wave” that is swept back and forth in an oscillatory manner across the flow stream.

25. Apparatus according to claim 24, wherein the comb spacing D is related to the frequency F , where F is the average of $F1+F2$ or where $F=(F1+F2)/2$.

26. Apparatus according to claim 24, wherein the rate of oscillation is given by $\omega/2\pi$, and the amplitude of the oscillation depends on ΔF .

27. Apparatus according to claim 24, wherein the acoustic comb filter module is configured to translate the certain particles in the flow stream small enough to be captured by the acoustic comb in an oscillatory fashion across the cross-section of the flow pipe, including where the motion of these trapped particles creates acoustic pressure fields, and consequently, modulated particles generate radiated acoustic signatures which can be detected by low frequency acoustic receivers arranged around the flow pipe.

28. Apparatus according to claim 27, wherein detected signals received by the low frequency acoustic receivers will be at harmonics of a sub-carrier frequency $\omega/2\pi$.

29. Apparatus according to claim 27, wherein the particle sizes captured are dependent on the nominal frequency F_1 , so that changing the comb spacing will alter a degree of particle capture and thus an amplitude of the acoustic signal emitted at the modulation frequency $\omega/2\pi$.

30. Apparatus according to claim 27, wherein the acoustic comb filter module is configured to operate the apparatus as follows:

if the comb periodicity is set such that no particles are captured by the modulated acoustic comb, then there will be no radiated LF acoustic signal;

if the comb periodicity is set such that all particles above size X_1 are captured by the modulated acoustic comb, then there will be a radiated LF acoustic signal of amplitude A_1 ;

if the comb periodicity is set such that all particles above size X_2 are captured by the modulated acoustic comb, then there will be a radiated LF acoustic signal of amplitude A_2 ; and

this is repeated for a series of periodicities X_j and A_j , until substantially all particles are captured, where the increase in amplitude $A_1, A_2, A_3, \dots, A_n$ maps out a cumulative particle size distribution in the flow.

31. A method comprising:

providing, with an acoustic comb filter module having first and second opposing acoustic transducers configured on opposite sides of a flow pipe having a flow stream, an acoustic standing wave via excitation based at least partly on two different frequencies F_1 and F_2 to create a selected comb spacing D across a cross-section of the flow pipe to capture and sweep certain particles having a selected size X in the flow stream in the flow pipe, the acoustic standing wave including a first acoustic standing wave at a first frequency F_1 provided by a first opposing acoustic transducer, and also including a second acoustic standing wave at a second and different frequency F_2 than the first frequency F_1 and provided by a second opposing acoustic transducer; and

determining, with a particle size or distribution determination module, the particle size or distribution of the certain particles captured and swept lower in the flow stream.

32. A method according to claim 31, wherein the method comprises providing via a detection port in the flow pipe the certain particles having the selected size X in the flow stream from the flow pipe for off-stream analysis.

33. A method according to claim 31, wherein the flow stream is a slurry flow, including a sampled/diluted slurry flow.

34. A method according to claim 31, wherein the method comprises providing with a swept acoustic comb filter a swept acoustic standing wave set up via ultrasonic excitation based at least partly on the two different frequencies F1 and F2.

35. A method according to claim 34, wherein the method comprises providing the sweep of the acoustic standing wave based at least partly on a transit time across the flow stream being less than a capture time of the certain particles.

36. A method according to claim 34, wherein the method comprises providing with a first ultrasonic transmitter that forms part of the swept acoustic comb filter a first acoustic signal at the first frequency F1, and providing with a second ultrasonic transmitter that forms part of the swept acoustic comb filter a second acoustic signal at the second frequency F2.

37. A method according to claim 36, wherein the method comprises sweeping the swept acoustic comb filter at frequency F1-F2 "fringes" per second.

38. A method according to claim 34, wherein the method comprises capturing and sweeping with the swept acoustic comb filter the certain particles lower in the flow stream.

39. A method according to claim 31, wherein the method comprises providing with a sub-carrier modulated acoustic comb filter a modulated standing wave set up via

ultrasonic excitation based at least partly on the two frequencies F1 and F2 with a comb spacing nominally D and with acoustic signals at ω , oscillated at $\omega/2\pi$, and scattered off particulates in the flow stream.

40. A method according to claim 39, wherein the method comprises providing with a first ultrasonic transmitter that forms part of the sub-carrier modulated acoustic comb filter a first acoustic signal at the first frequency F1, and providing with a second ultrasonic transmitter that forms part of the sub-carrier modulated acoustic comb filter a second acoustic signal at the second frequency F2, where $F2 = F1 + \Delta F1 \sin(\omega t)$, and is swept at $\omega/2\pi$.

41. A method according to claim 39, wherein the method comprises configuring the flow pipe with low frequency (LF) acoustic receivers.

42. Apparatus according to claim 1, wherein the flow pipe has a longitudinal axis; and the first and second opposing acoustic transducers configured on the opposite sides of the flow pipe provide the acoustic standing wave across the cross-section of the flow pipe perpendicular to the longitudinal axis.

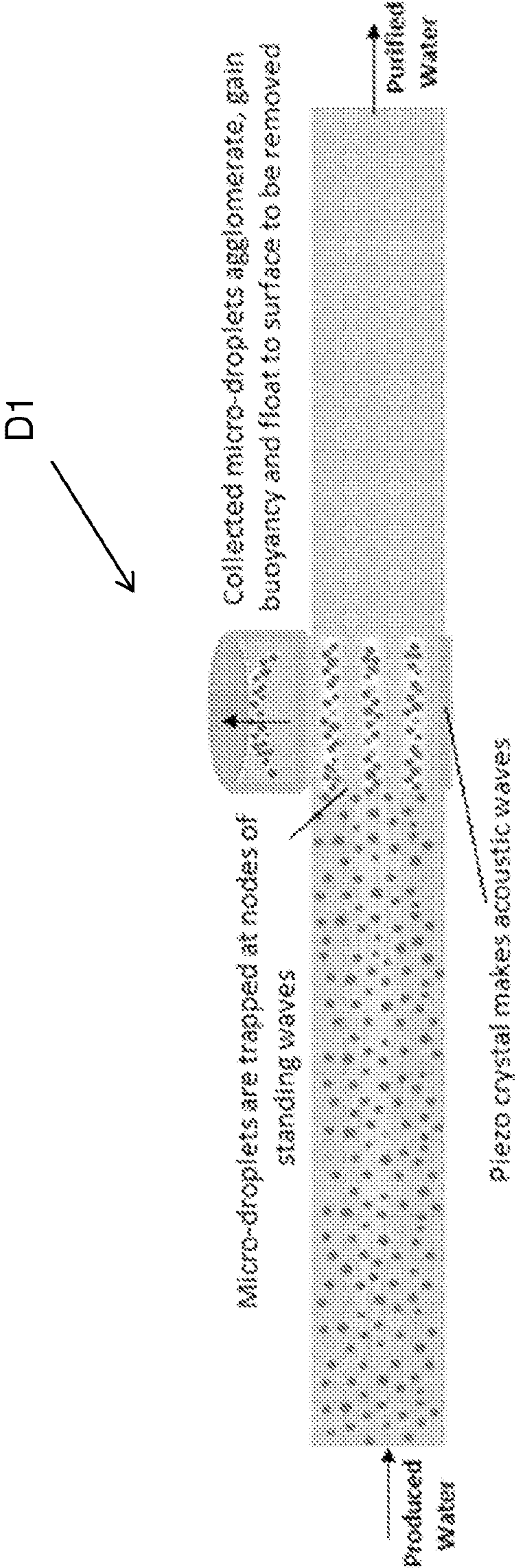


Fig. 1a: Prior Art Design

Fig. 1b: Prior Art Design is Demonstrated

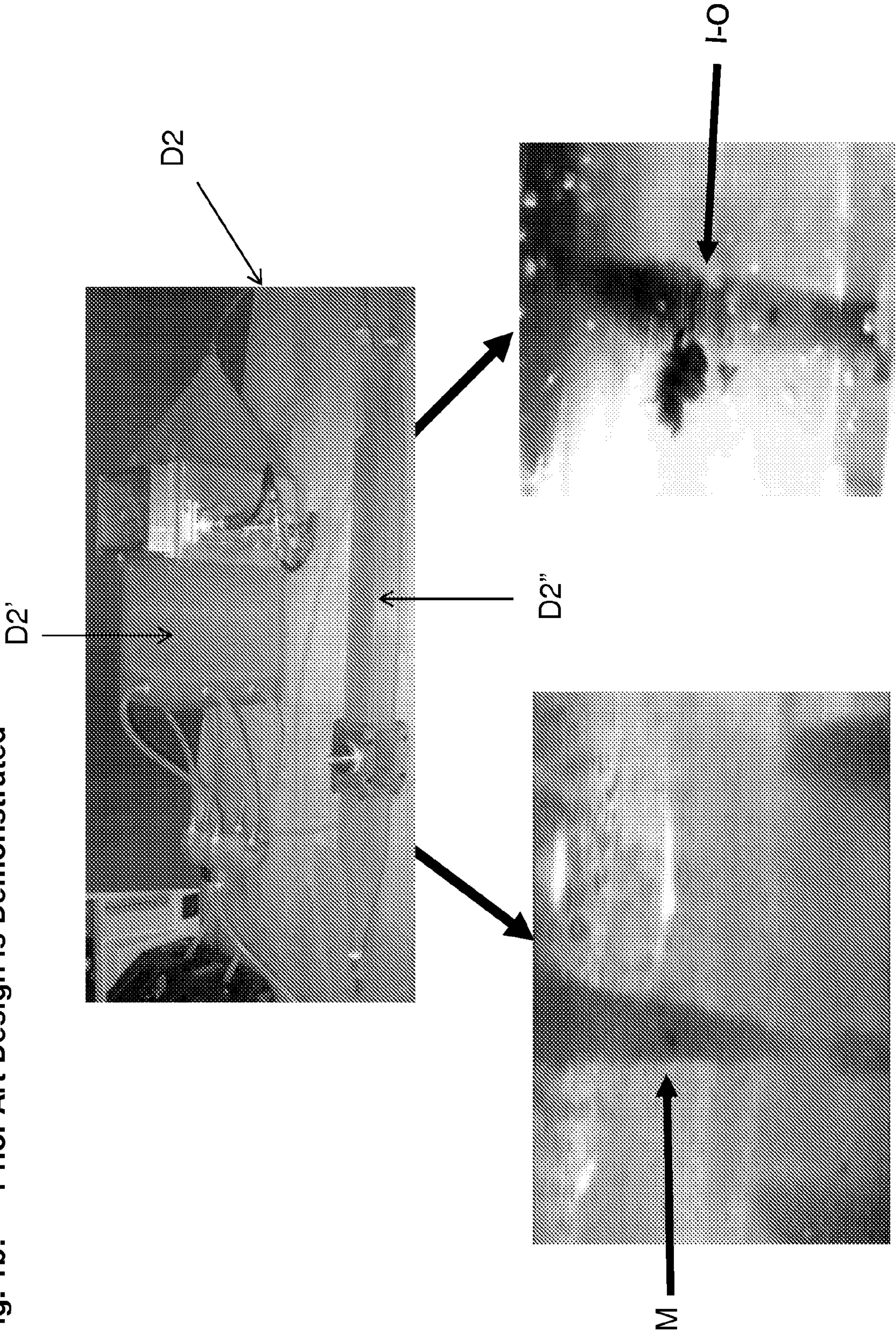


Fig. 1b (2) Iron-Oxide (20 μm)
(Prior Art)

Fig. 1b (1) Microalgae (10 μm)
(Prior Art)

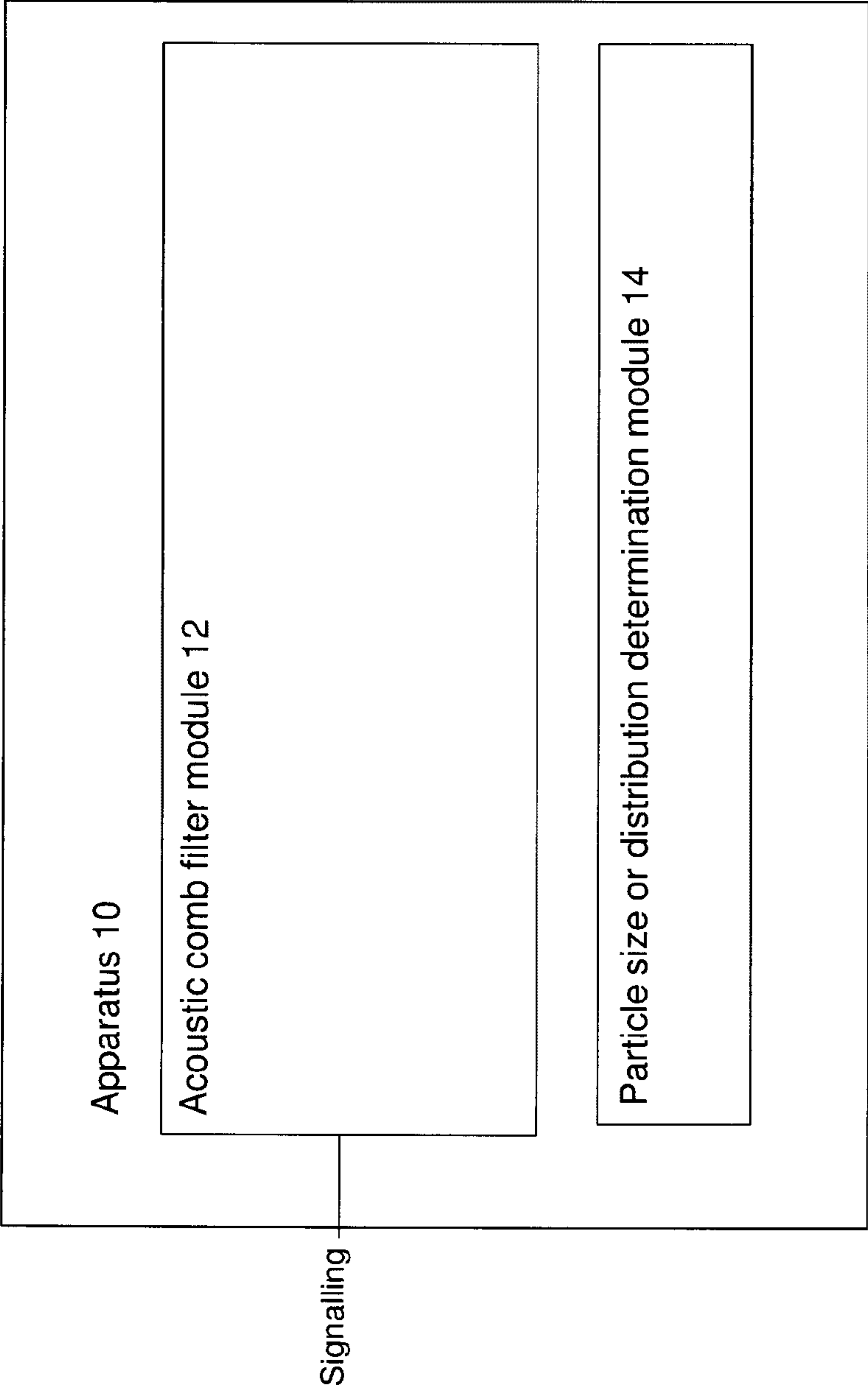


Fig. 2

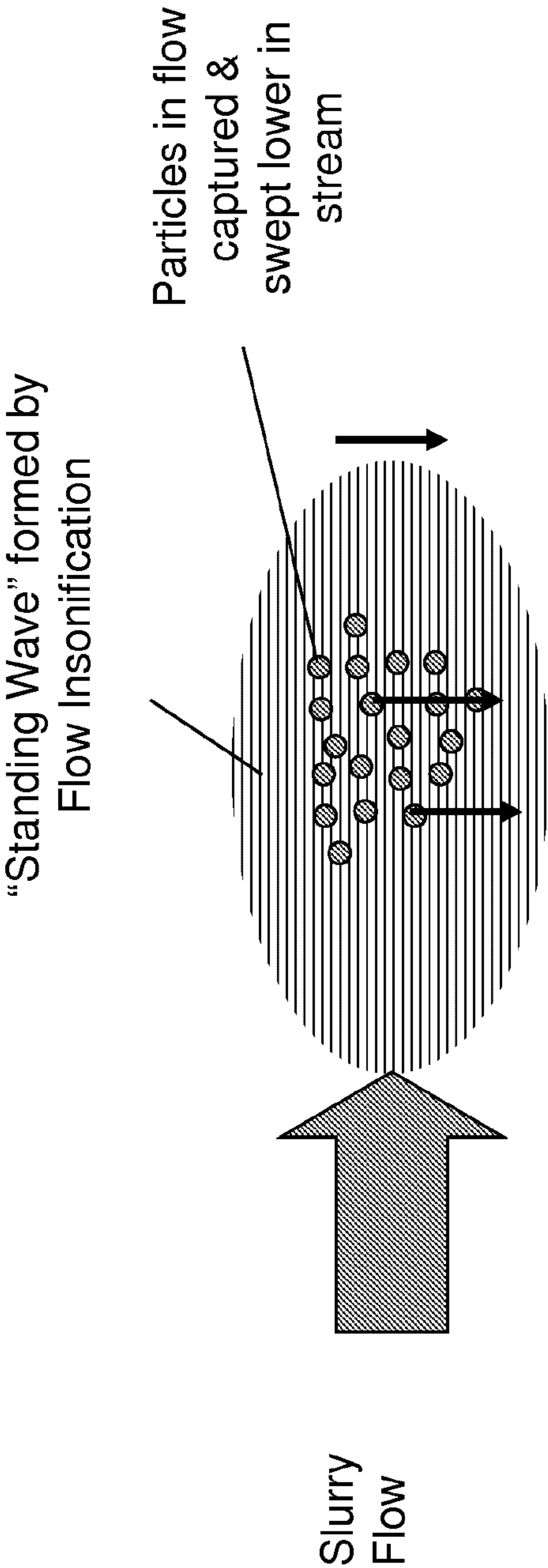


Fig. 3a: Swept Acoustic Comb Filter

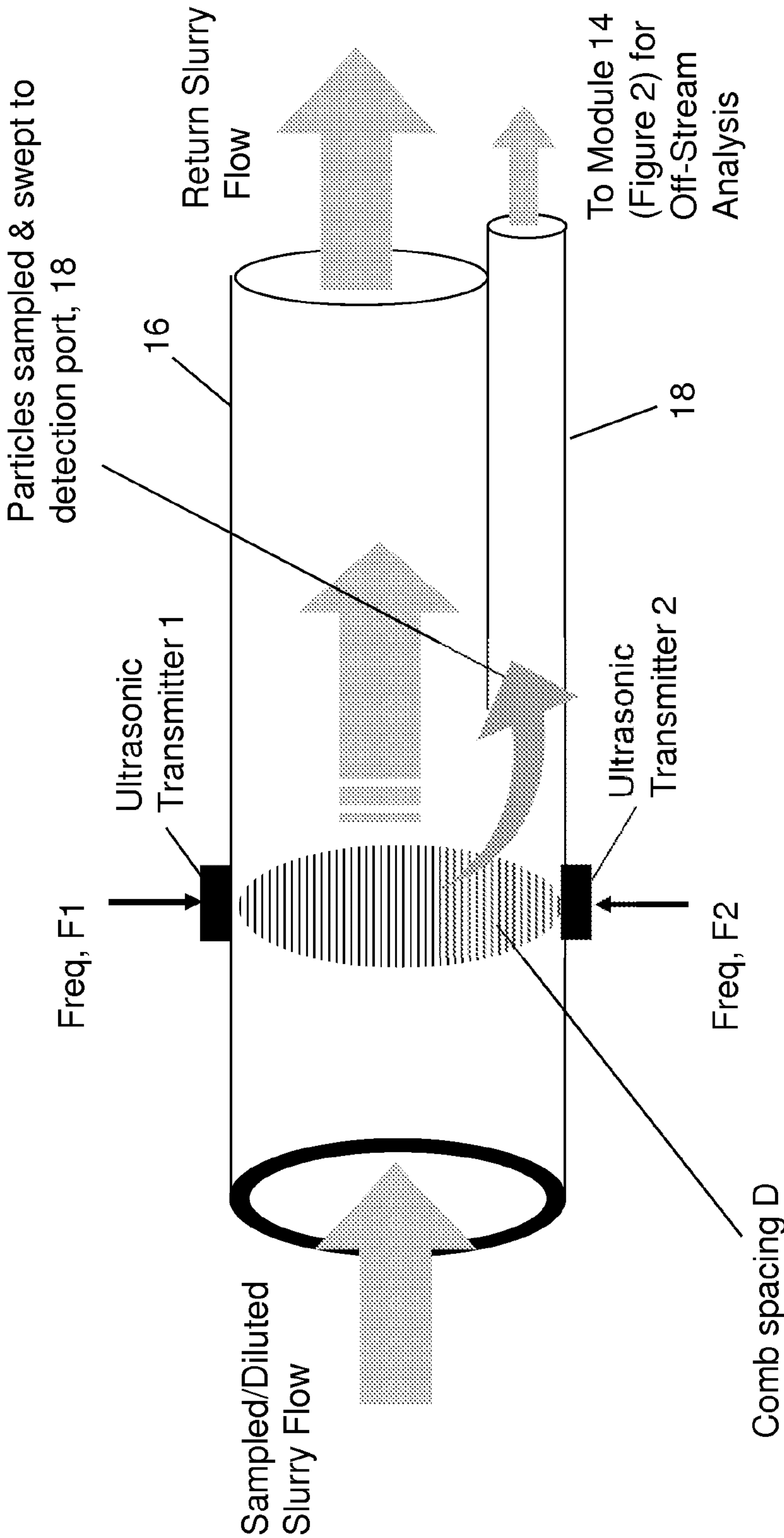


Fig. 3b: Apparatus or Arrangement No. 1: Swept Acoustic Comb Filter

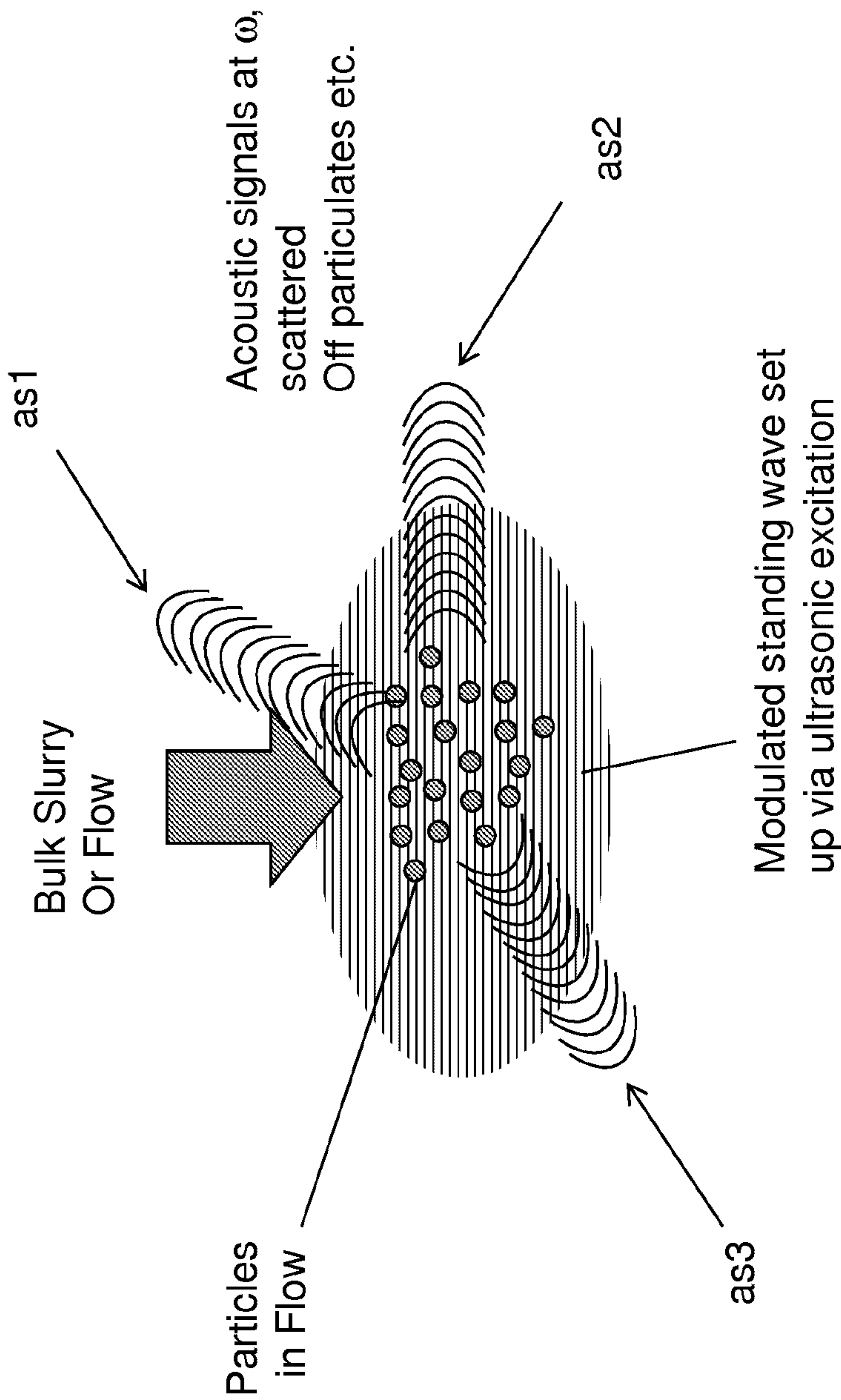


Fig. 4a: Sub-carrier Modulated Acoustic Comb Filter

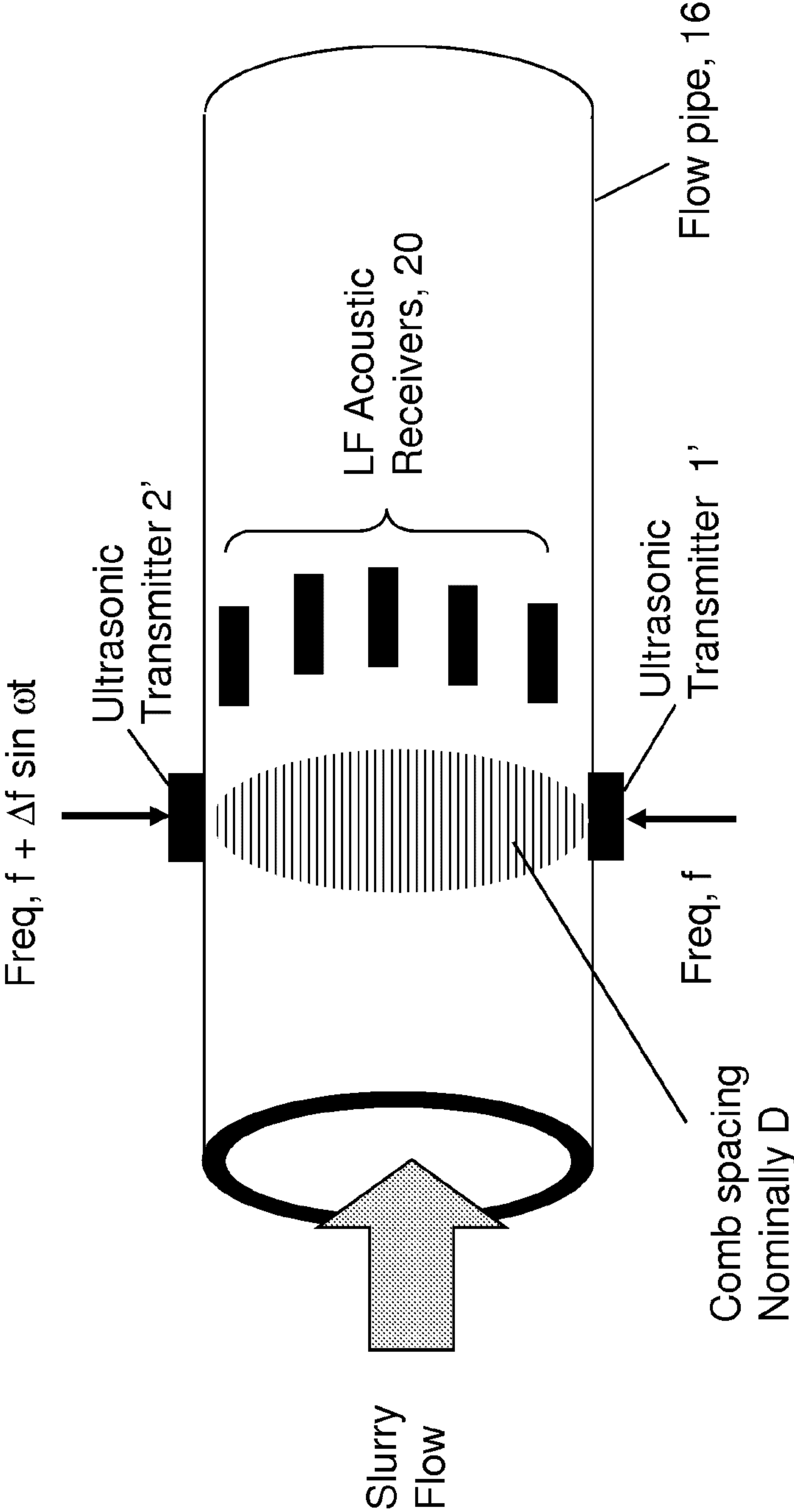
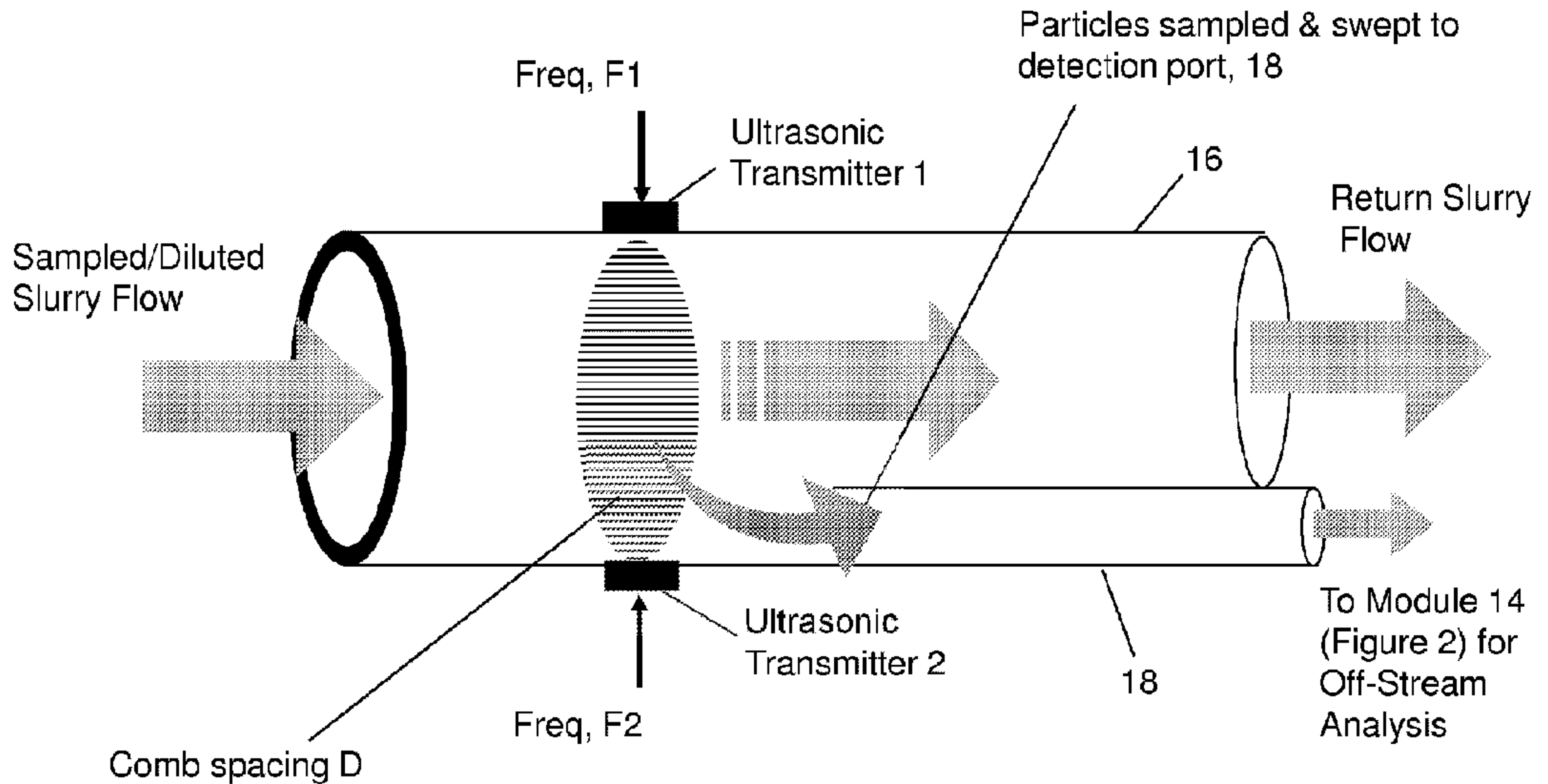


Fig. 4b: Apparatus Arrangement No. 2: Sub-carrier Modulated Acoustic Comb Filter



Apparatus or Arrangement No. 1: Swept Acoustic Comb Filter