



- (51) International Patent Classification:
G01N 15/06 (2006.01)
- (21) International Application Number:
PCT/GB2015/051681
- (22) International Filing Date:
9 June 2015 (09.06.2015)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
1410283.4 10 June 2014 (10.06.2014) GB
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: SENSING METHODS AND APPARATUS

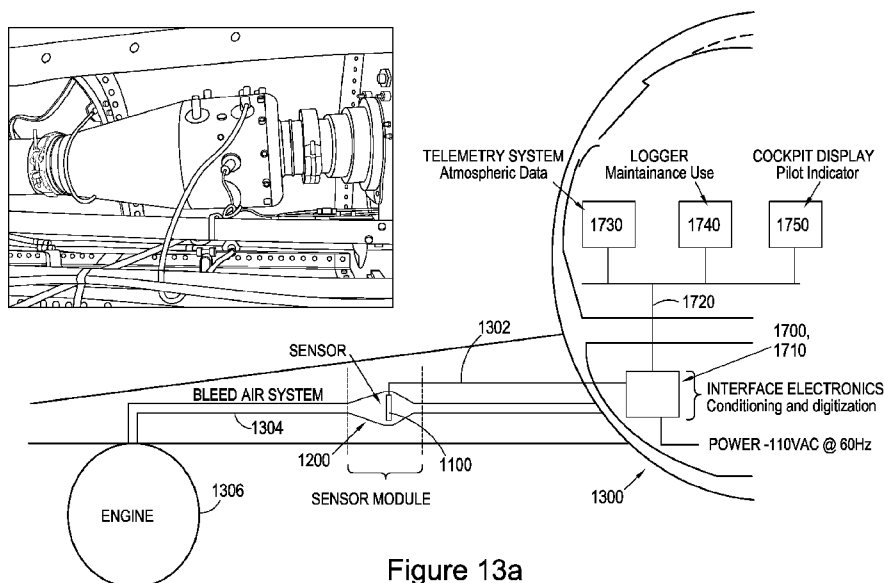


Figure 13a

(57) Abstract: We describe a particulate sensor for an aircraft, the sensor comprising: a duct for carrying an air flow bearing particulates to be sensed; an electrically conductive mesh or grid, mounted on an insulating support in said air flow; and sensor electronics, coupled to said electrically conductive mesh or grid, configured to detect a signal on said electrically conductive mesh or grid from charged particulates in said air flow flowing through said electrically conductive mesh or grid.

Sensing Methods and Apparatus

FIELD

- 5 This invention relates to particulate sensors for aircraft, in particular but not exclusively for sensing volcanic ash.

BACKGROUND

- 10 Volcanic ash can damage aircraft engines and lead to engine failure/stall. More particularly an ash cloud can erode compression blades, plug cooling circuits, and accumulate on turbine nozzles via melting and re-solidification. Other effects of ash include contamination of oil and air conditioning systems, erosion of flow path hardware and piping, and various deposits.

- 15 An ash cloud typically contains different shaped and sized particles and the composition depends upon the volcano and upon distance from the eruption. Typically ash comprises pumice, glassy shards and sharp edged fragments of minerals and rocks. The (equivalent) diameter of particles ranges from less than 1 μ m to several
20 hundred micrometres; at distances greater than 1000 kilometres from the source the diameter drops to less than 10s of μ m, and the IVATF (International Volcanic Ash Task Force) suggest that test powders should comprise particles with diameters in the range 10-100 μ m. This is the size that is expected away from the source (aircraft typically do not fly near the source).

- 25 Figures 1a and 1b show SEM images of volcanic ash from Eyjafjallajokull (Iceland) and Montserrat (West Indies) respectively. Measurements of the 2010 Eyjafjallajokull eruption indicate that the volcanic ash particle size is less than 300 μ m. Measured in Germany the ash cloud particle size distribution was bimodal with peaks at 300nm and
30 2 μ m; this is typical.

- Although there is a particular need for sensing volcanic ash, it would also be useful to sense other particulates in airflows within an aircraft, in particular aviation fluids such as oil, cleaning fluids, de-icing fluids, and hydraulic fluids.

- 35

General background prior art relating to particle sensing can be found in WO2011/151462, WO2010/088049, EP2,256,472A, DE4008348 A1, SU1312449 A2 and WO84/04390 A1. More particularly, we have previously described a volcanic ash sensor for an aircraft in WO2013/017894. This described a 'Christmas tree' type sensor having a generally conical shape with a surface which is stepped or ribbed in order to provide a turbulent air flow. The aim was to increase the probability of charged particle capture, in particular by flow separation in the air flow over the device. In broad terms the aim was for particles to be trapped in the gullies, swirl around and attach to the metal. Figure 2 shows an example of the sensor 100 described in WO'894, comprising a cone-shaped copper coil 106a on a metal support 106b.

The inventors have since carried out extensive further testing of a range of different configurations of sensor. As previously understood, the particulates, for example volcanic ash particles, in an airflow are generally charged. The charge can arise in a range of different ways, for example as a result of particle-particle interaction, particle-wall interaction, particle-air interaction and/or as a result of an electrical system configured to charge the particles. However the sensor need not capture a particle in order to detect a charge and charges can also be detected, for example, by electrostatic induction when a charged particle passes past the sensor. As a charged particle moves past a conductive surface it induces a charge in the conductor. The induced charge will depend upon the distance to the conductor and the duration of the induced charge will depend upon the speed of the particle and the distance the charged particle traverses across the surface of the conductor. A corresponding current will flow and a voltage will also be induced dependent, in part, on the capacitance of the sensor (which acts as a low pass filter). In addition some particles will impact and attach to the sensor.

It will be appreciated that there are many factors which interact in a complex manner which make theoretical predictions difficult. A thorough experimental program was therefore implemented to test and evaluate a different a range of different sensor topologies.

SUMMARY

According to a first approach there is therefore provided a particulate sensor for an aircraft, for mounting in a duct for carrying an air flow bearing particulates to be sensed, the sensor comprising: a duct for carrying an air flow bearing particulates to be sensed; an electrically conductive mesh or grid, mounted on an insulating support in said air flow; and sensor electronics, coupled to said electrically conductive mesh or grid, configured to detect a signal on said electrically conductive mesh or grid from charged particulates in said air flow flowing through said electrically conductive mesh or grid.

A comparison of different sensor topologies, including a cone, ring, rod, and mesh topology, indicated that for samples of authentic volcanic ash and various aerosols the mesh or grid topology was significantly more sensitive than the others. In some approaches a suitable mesh or grid comprises a mesh of metal, for example stainless steel wire. Preferably the mesh or grid extends substantially completely across the region of the duct in which it is located. No clear results were obtained indicating that any particular grid opening for the mesh is preferred, although there is a general preference that the mesh/grid should not overly obstruct the air flow in the duct. There is also a general need for the grid/mesh to be relatively robust because of the high temperatures and pressures which can be encountered in an air bleed from the compressor stage of a gas turbine. Thus in one preferred embodiment the mesh or grid may comprise a metal plate bearing a plurality of apertures, optionally slots. This can provide a robust sensor and the thickness of the plate can provide some interaction length for the charged particles with the sensor. Thus the apertures or slots in the plate may be longer in the direction of the air flow than perpendicular to the air flow - that is the slots or apertures may be deeper than they are wide (although in other embodiments the reverse may be true depending, for example, on the air flow, back pressure, nature of and sensitivity to the material being sensed and so forth). In embodiments front edges (with a respect to the air flow) of the apertures or slots may be chamfered to reduce the risk of resonance in the air flow and/or mechanical asymmetry may be introduced and/or one or more reinforcing cross-members may be added to the mesh/grid. In general the air speed is high and thus there is naturally a high degree of turbulence.

Conveniently the sensor is located in a flared region of the duct, to reduce the back pressure and maintain good air flow. In embodiments the cross sectional area of the sensor is at least 1.5 times or 2 times the cross sectional area of the duct prior to the flared region. In preferred embodiments the sensor is mounted on an insulated support
5 in a flared housing which is arranged to fit within an air duct. Preferably the housing has an openable fastening at the location of the sensor, for maintenance.

In embodiments the sensor electronics may comprise an electrometer to measure the charge on the sensor, but the skilled person will appreciate that equivalently a current
10 from and/or voltage on the sensor may additionally or alternatively be measured. Suitably an input to the electrometer includes an over-voltage protection circuit, and preferably also a current spike protection circuit. Suitably the sensor electronics provides a variable (controllable) gain; in embodiments the gain of the sensor electronics is extremely high, for example greater than 10^8 , 10^9 or 10^{10} , in
15 embodiments around 10^{11} (that is 10^{-11} coulombs charge would provide a one volt output). Conveniently the sensor is coupled to the electrometer by capacitance compensated-cable to reduce the effect of cable movement and vibration. Where vibration is a significant issue the signal processing electronics may include a vibration sensing element such as an accelerometer and a circuit or signal processing arranged
20 to compensate for or substantially null out the vibration by subtracting a component of the vibration from the sensed signal. The sensor electronics may include a low pass filter stage, in particular with a cut-off (corner) frequency of less than 5 kilohertz, 3 kilohertz, 2 kilohertz or 1 kilohertz. Optionally the bandwidth of the sensor electronics is variable (controllable) so that it may be adjusted depending upon the target
25 substance to be detected for example ash or aerosol. The skilled person will appreciate that signal processing for the sensor may be performed in the analogue and/or digital domain and/or by a programmed signal processor such as a digital signal processor.

30 The signal processing may further determine a charge of the particulates and/or process a waveform of a signal from the mesh or grid sensor to distinguish between particulates of different types. The waveform may optionally be pre-processed, for example by filtering, and may be processed in the time or frequency domain. Additionally or alternatively the signal processing may determine a change in the
35 waveform, or a spectrum of the waveform, over time, and/or classify the waveform into

one of a plurality of classes, and/or analyse a burstiness of the signal (for example by performing an auto-correlation in the time or frequency domain). These techniques may also be used to distinguish between particulates of different types.

5 In some examples of the sensor the sign of the charge on the electrically conductive mesh/grid is determined and it has been established experimentally that the signal polarity can provide information which is useful for distinguishing particulates detected by the sensor – for example compressor wash cleaning liquid has been found to give a signal of a different polarity to de-icing fluid. Thus the sensor electronics may provide
10 an output indicating or dependent upon the polarity of the detected signal, which may be used to distinguish the physical and/or chemical nature of detected particulates. In the case of an aerosol the sign of the charge apparently reflects inherent properties of the aerosol; in the case of volcanic ash the chemical nature/composition can vary substantially between volcanos and thus in principle this could be used to identify the
15 source of the ash.

In some approaches of the sensor the grid/mesh may be divided into two and combined with an electrostatic particle deflection stage to selectively sense positively charged and negatively charged particles within the same air flow. The electrostatic
20 particle deflection stage may comprise, for example, a pair of parallel plates across which a high voltage is applied (typically greater than 0.5 KV). Each of the two portions of the grid/mesh may be connected to a respective input stage of the sensor electronics or a common set of sensor electronics may be time multiplexed to detect the signal on each portion (half) of the grid/mesh. Optionally a particle charging stage
25 may also be incorporated upstream of the sensor (and deflector), but in practise this has not been found to be necessary. Where used such a charging stage may comprise, for example, a mesh connected to a high voltage (greater than 0.5 KV) source or a grid of conductors in which alternate conductors are respectively connected to either a high voltage supply or ground/0V.

30 In some variations the sensor includes signal processing to process the detected signal and provide a warning or alarm output to the pilot. In embodiments this processing comprises integrating the charge detected by the sensor over a time window; typically this may be performed by a suitably programmed general purpose computer or digital
35 signal processor. The integration may integrate the signed charge or the absolute

value of the charge or both; a warning may be generated if the integrated value exceeds a threshold; preferably some hysteresis is also included. In embodiments the warning/alarm may comprise a traffic light signal displaying green, amber and red and depending upon the level of integrated charge detected.

5

There are many places in which a particulate sensor as described above may be located to sense volcanic ash/aerosols in an aircraft. However advantageously the particulate sensor may be located in an air bleed duct or line from a compressor stage of an engine of the aircraft, in particular following a pressure-regulating shut off valve as this provides some restrictions on the environmental limits the sensor must tolerate. Such a pressure-regulating shut off valve (PRSOV) may, for example, be a nacelle PRSOV. Using the air bleed duct or line from a compressor stage of the engine facilitates monitoring volcanic ash entering the engine; in a particularly preferred approach the sensor is located in such an air bleed duct or line supplying air to an air conditioning unit of the aircraft. This further facilitates the sensor detecting aerosols which may end up in the cabin giving rise to a problem, for example a smell, which would need investigation. A particularly preferred location for the sensor is in a location designed for an ozone converter of the aircraft as this typically provides the foregoing advantages and, importantly in addition, locating the sensor here generally results in little or no change in back pressure in the air bleed line. In embodiments, therefore, the sensor may be located in a wing of the aircraft.

The sensor electronics may comprise a front end coupled to the sensor and an interface to a system data bus of the aircraft; optionally some or all of the signal processing may therefore be performed remotely from the front end, for example by an existing processing system in the aircraft. Additionally or alternatively the sensor may provide a signal on the system data bus for a cockpit display system of the aircraft. Any standard interface may be employed to connect the sensor to the aircraft data bus, for example an ARINC (Aeronautical Radio, Incorporated) standard such as ARINC 429 or ARINC 664.7.

In a related approach we describe a method of particulate sensing in an aircraft, the method comprising: mounting an electrically conductive sensor on an electrically insulating support at a location in an air bleed duct or line from a compressor of said engine; and sensing charged particles flowing past said sensor using sensor

electronics coupled to detect a signal on said electrically conductive sensor; wherein said location comprises a location designed for an ozone converter for said aircraft.

In preferred embodiments of the method the sensor is as previously described.

5

In a further related approach there is provided an aircraft, the aircraft including a particulate sensing system comprising: an electrically conductive sensor; and sensor electronics, coupled to said electrically conductive sensor, wherein said sensor electronics are configured to detect a signal on said sensor from charged particles
10 flowing past said sensor; wherein said sensor is mounted on an electrically insulating support at a location in an air bleed duct or line from a compressor of said engine; and wherein said location comprises a location designed for an ozone converter for said aircraft.

15 There is still further provided a method of particulate sensing in an aircraft, the method comprising: mounting an electrically conductive mesh or grid on an insulating support in an air flow duct carrying particulates to be sensed; and detecting a signal on said electrically conductive mesh or grid from charged particulates in an air flow through said electrically conductive mesh or grid.

20

The particulate sensing is preferably used for the aircraft on which the sensing system is mounted but the system may additionally or alternatively be employed for collecting data from a plurality of aircraft in flight so that this data can be combined, for example to map a volcanic ash cloud.

25

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the system will now be further described, by way of
30 example only, with reference to the accompanying figures in which:

Figures 1a and 1b show SEM images of volcanic ash from Eyjafjallajökull (Iceland) and Montserrat (West Indies) respectively;

35 Figure 2 shows an embodiment of a 'Christmas tree' – type volcanic ash sensor;

Figure 3a and 3b show an end view and a vertical cross section view respectively of a particulate sensor according to one example;

- 5 Figure 4 shows a schematic diagram of experimental apparatus used to evaluate alternative sensor topologies;

Figures 5a to 5d show examples of alternative sensor topologies;

- 10 Figures 6a to 6e show signal waveforms from, respectively, a mesh sensor, a rod sensor, a cone sensor, a bauble sensor, and a wedge-shaped sensor;

Figure 7 shows a detected charge – collected mass relationship for a plurality of different measurements made with a plurality of different sensor topologies;

- 15 Figures 8a and 8b show a sensor output signal (upper curve) and cumulative mass flow past the sensor (lower curve) for respective first and second aerosols (DF PLUS and BBTC100);

- 20 Figures 9a and 9b show detected charge against calculated mass flowing past the sensor for the first and second aerosols of Figure 8, for cone, ring, rod and mesh sensor topologies;

- 25 Figures 10a and 10b illustrate comparative sensitivities of different sensor topologies rated relative to a mesh sensor (sensitivity of mesh: sensitivity of other topology) for the aerosols of Figure 8, and a comparison of sensor sensitivity to different aerosol compositions for different sensor topologies;

- 30 Figures 11a and 11b show, respectively, a computer aided design drawing and a photograph of a sensor grid for use in a gas turbine bleed line;

Figures 12a and 12b show, respectively, an exploded view and a closed view of the sensor of Figure 11, in a housing, for insertion into an air bleed duct or line from a gas turbine;

Figures 13a and 13b show, respectively, a location of the sensor of Figures 11 and 12 in an air bleed duct or line (the inset photograph shows a low pressure prototype), and example output signals from a sensor of the type shown in Figures 11 and 12 located as illustrated in Figure 13a;

5

Figure 14 shows example pressure, temperature and mass flow rate curves for an Embraer E190 aircraft from take-off, to a cruise altitude of just under 40,000 feet, then landing, where the curves illustrate parameters of the air bleed duct or line at a location following the nacelle shutoff valve of the aircraft;

10

Figures 15a to 15d show, respectively, a schematic illustration of a particulate sensor including an electro static deflector stage, a diagram illustrating the operating principle of the arrangement of Figure 15a, a graph illustrating the operation of a sensor of the type illustrated in Figure 15a, and a photograph of a sensor of the type illustrated in Figure 15a showing volcanic ash deposited on the positive plate of the deflector stage;

15

Figure 16 shows an example of a particulate sensor including a particulate charging stage;

20

Figure 17 illustrates example sensor electronics for a particulate sensor according to an example implementation; and

Figures 18a and 18b show, respectively, an integration window for the sensor signal processing system of Figure 17, and an example “traffic light” display indicating the presence of detected particulates.

25

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

30

Referring now to figures 3a and 3b, these show a mesh/grid topology particulate sensor 300 according to an example of the device. The sensor is mounted within a duct 302, for example in part of the bleed air pipework of an aircraft, supported by a ring-shaped, electrically insulating mount 304 fabricated, for example, from nylon. An electrical connection 306 is provided to a metal mesh 308 which preferably extends

across all or substantially all of duct 302. In a test embodiment mesh 308 was fabricated from woven stainless steel wire.

5 Figure 4 shows a test rig 400 used for comparative testing of different sensor topologies. Broadly speaking the test rig comprises a plurality of segments of stainless steel tubing connected together to form a wind tunnel. The wind tunnel is driven by a fan 402 provided with a filter 404 on the output side to inhibit release of particles. The apparatus is provided with a port 406 for an anemometer (preferably with a computer inter face or data logging) and a sensor module region 410 to accommodate a sensor
10 under test, such as grid sensor 300. A particle dispensing module 420 is provided at an inlet 408 of the apparatus such that aerated particles are dispersed into the air flow entering the tunnel – thus the inlet 408 may comprise an open-ended section of tubing 408a.

15 Figure 4 illustrates a dispenser module 420 for volcanic ash particulates comprising a Drechsel jar arrangement provided with a connection 422 to a pressurised air supply 424, preferably at relatively low pressure, for example less than 10psi. The aerated ash particles 426 are provided via tubing 428 to the air inlet of apparatus 400. The apparatus of Figure 4 can also be used for testing aerosol particulates. A dispenser
20 dual module for dispensing fine aerosols may comprise a “air gun” of the type typically used for spray painting; this typically operates at a pressure of order 50psi.

Preferably the metal tubing of the apparatus is grounded to avoid static charge building up, and preferably the sensor module region is mounted on a separate support or table
25 412 to other parts of the apparatus, to reduce vibration.

Not all of the particulates which enter the rig pass through the sensor because of interaction and accretion of particles within the rig. Thus preferably the apparatus incorporates a module for measuring the mass of solid or aerosol particulates flowing
30 past the sensor. In the case of solid particulates a filter may be located downstream of the sensor and the changing mass of the filter used to measure the mass flow rate of particulates past the sensor. In the case of aerosols a quartz crystal micro balance may be located in the flow of the sensor module; the mass flow rate can then be determined from the thickness of the deposited aerosol on the QCM crystal, knowing
35 the density of the aerosol.

The sensor module 410 is connected to sensor electronics comprising an electrometer (described later) which measures the movement of charge as a result of the particles moving past (and/or colliding with) the sensor.

5

It is assumed that the detected mass is proportional to the detected charge, and it then follows that:

$$\dot{m}(t) \propto i(t)$$

10

Where $\dot{m}(t)$ is the instantaneous mass flow rate and $i(t)$ is the detected instantaneous current. The mass is related to the integral of this signal over the period of which the mass is dispensed:

$$m = \alpha \int_{t_0}^{t_1} i(t) dt$$

15

where t_0 is the time the dispersion of the mass starts, t_1 is the time the dispersion of the mass stops and α is a proportionality constant relating the mass to the integral. By calculating the integral α can be determined by taking the ratio of the measured mass to that of the calculated integral:

$$\alpha = \frac{m_{meas}}{\int_{t_0}^{t_1} i(t) dt}$$

20

where m_{meas} is the measured mass.

α is a characteristic of the type of sensor and substance under investigation, and can be determined for different sensors and particulates. It can be used to compare different sensors. However, errors arise from the mass measurement techniques, the accretion of particles on the wind tunnel walls and different particle sizes and shapes. For this reason multiple measurements are taken to take an approximate average.

25

Six different sensor topologies were investigated: the Christmas tree or cone topology of Figure 2, the mesh/grid topology of Figure 3, and the four additional topologies

illustrated in Figure 5. These latter comprised, respectively, a rod-shaped sensor, a ring-shaped sensor, a “bauble” sensor, and a range of different wedge-shaped sensors. Thus Figure 5a shows a rod-shaped metal sensor 500 and Figure 5b a ring-shaped metal sensor 502 (other elements like to those of Figure 3 are indicated by like reference numerals). The bauble shaped sensor of Figure 5c comprised a plurality of conductive fins defining a rounded, in particular generally spherical overall shape. Various different wedge-shaped sensors were also fabricated, two of which are illustrated in Figure 5d. These potentially offer less intrusion to the air flow than a mesh sensor and provide a longer conductive path through the sensor, but potentially suffer from poor spatial sensitivity which may give rise to inaccuracies if the air flow is not uniform across the duct. Optionally therefore multiple sensors may be arranged at angular intervals circumferentially within the air duct, for example three sensors at 120 degrees separation. The signals from these sensors may then be combined by signal processing.

The performance of these various different sensor topologies was compared in multiple experiments (the results of any particular experiment show considerable scatter). Examples of the signals from the different topology sensors are shown in Figures 6a to 6e. These show a voltage output from the electrometer electronics when the sensors were tested with volcanic ash from the Montserrat volcano (the apparent differences in polarity of the signals are an artefact of the electronic amplification employed – the detected signals had the same polarity). Thus Figures 6a to 6e show recorded voltage profiles from, respectively, the mesh sensor of Figure 3, the rod sensor of Figure 5, the cone sensor of Figure 2, the bauble sensor of Figure 5 (lower trace, compared with the mesh sensor, upper trace), and a wedge sensor of the type shown in Figure 5 (upper trace; the lower trace shows the mesh sensor, for comparison). From these figures it can be seen that the mesh sensor arrangement of Figure 3 performs better than the bauble sensor and the wedge sensor, although it is more difficult to draw clear conclusions from the single examples of Figures 6a to 6c.

Multiple signals were measured for each sensor topology and the signals were evaluated by calculating the detected charge from the integral of the measured signal, which represents the current generated in response to the particulate mass passing the sensor. The mass flow can be determined as previously described. This enables a mass-charge relationship to be determined for a measurement, and Figure 7 illustrates

a plurality of charge-mass measurements for a range of different sensor topologies and particulates, comparing rod, cone and mesh sensor geometries. The results of Figure 7 show that the cone sensor is slightly more sensitive than the rod sensor and that the mesh sensor is much more sensitive than either of these, albeit there is a substantial spread in the results. (The spread results from a range of uncontrolled parameters including the environmental humidity, the dispensing method, the collection of particles in the filter, interaction of particles with the test rig, non-uniformity of particle size and other effects).

A similar analysis was performed on a range of different aerosols. Aerosols tested included a de-icing fluid (DF PLUS, comprising monopropylene glycol), a cleaning fluid (compressor wash BBTC100; soapy) turbine oil (BP Turbo Oil 2380), and a second compressor wash (Turco 5884; an aromatic hydro carbon mixture used to clean the jet engine gas path).

Figures 8a and 8b show the response to de-icing fluid and compressor wash fluid aerosols respectively, showing the sensor signal in the upper curve and a quartz crystal micro balance signal measuring the mass flow in the lower curve. Although the curves of Figures 8a and 8b show an output voltage of the same polarity, these signals were taken from different amplification stages, one comprising a signal inversion, and thus the detected charge of the aerosols of Figures 8a and 8b are of opposite polarity.

The detected charge polarity of an aerosol or particulate flow past a sensor can help to distinguish one type of particulate from another. The ability of different sensor topologies to distinguish signal polarity was investigated and outline results are shown in the table below. Although not shown in the table, the mesh sensor gave the most distinguishable signal polarity by comparison with the other sensor topologies; all the topologies except for the mesh topology also exhibited substantial stochastic fluctuations in the observed signal:

	Sensor	Cone	Ring	Rod	Mesh
Input	DF PLUS	Negative	Negative	Positive	Negative
polarity	BBTC100	Positive			Positive

Knowing the mass of aerosol which is passed the sensor, and the (integrated) detected charge a charge-mass relationship can be plotted for experimental runs for each of the aerosols and for each of the different sensor topologies. Figures 9a and 9b compare the results for the cone, mesh, rod and ring topologies for de-icing fluid and compressor wash fluid aerosols respectively. It is observed that the collected mass of aerosol is two to three orders of magnitude below the collected mass of volcanic ash in the ash measurements. By fitting a linear relationship with a zero intersect to the data the gradients (α), and hence sensitivity of the different sensor topologies to the aerosols can be compared. The calculated values of the sensor sensitivity (α) are shown below:

Sensor X 10 ⁷	Cone	Ring	Rod	Mesh
DF PLUS	-1.37	-3.70	4.98	-46.2
BBTC100	622	1100	712	3640

By using the sensitivity of the mesh as a reference and using absolute values of the sensitivity (α) the sensor sensitivities to the different fluids can be compared. This is illustrated in Figure 10a, which shows the ratio of the mesh sensor's gradient to that of the other topologies. It can be seen from Figure 10a that the mesh sensor topology is significantly better than the other topologies. Figure 10b shows a ratio of the sensitivity to BBTC100 (wash) to DF-PLUS (de-icer). All the sensors are more sensitive to compressor wash than de-icer, but the mesh sensor exhibits the most uniform response.

The foregoing discussion illustrates the experiments which were performed to compare the various different sensor topologies, and taken collectively, the results of the experiments showed that a mesh/grid topology provides surprising and significant advantages over the other topologies, in particular over the cone topology we have previously described in WO 2013/017894.

Based on these results, a practical embodiment of a mesh/grid sensor topology was developed, as illustrated in Figure 11. Thus Figure 11 shows a sensor grid 1100 comprising a stainless steel metal plate with a plurality of slots 1102. To assist airflow through the grid and inhibit resonance (and thus potential whistling) the leading edges of the grid bars are chamfered. Optionally resonance can be further inhibited by

changing a resonant frequency of the bars by adding a cross bar to provide additional stiffness and/or by changing the illustrated bars to rods. In one embodiment the plate has a thickness of 10mm; the width of a grid bar is 2.5mm and the air space between bars is 5mm; in an example embodiment the plate diameter is approximately 140mm; the plate may be made from grade 316 stainless steel. The plate is provided with insulated mounts 1104, for example comprising ceramic bushes which may be fabricated from Macor (registered trademark). A connection hole is drilled and tapped in the edge of the plate to provide an electrical connection.

Figure 12 illustrates a sensor assembly 1200 including the grid 1100 of Figure 11. The sensor assembly comprises first 1106 and second 1108 duct portions fastened together by a strap 1110 to allow access to the plate 1100 for maintenance. At least the upstream duct portion 1108 is flared so that when the assembly is installed in an aircraft bleed air system the air flow is not substantially impaired. The duct portion 1108 may flare to increase its cross sectional area by a factor of 1.5, 2 or more. An electrical connection assembly 1112 a-d is provided comprising a metal terminal 1112 c which screws into the plate 1100 and an insulated bush 1112a. The terminal assembly 1112 connects to a low triboelectric noise coaxial cable 1302 (Figure 13a) to connect the sensor assembly to the sensor electronics. Preferably the connection is relatively short and the cable is securely fastened to inhibit movement (and hence a detection of noise and vibration).

Figure 13 shows installation of the sensor assembly 1200 in the wing of an aircraft 1300. Location of an ash sensor assembly in the wing is not essential, but is advantageous, facilitating location of a sensor in an air bleed duct or line 1304 from a compressor stage of the engine 1306.

The bleed air system takes compressed air from the aircraft engine and, typically, supplies this to the aircraft air conditioning pack, an airframe de-icing system, cabin, flight compartment and door seal pressurisation systems, and other systems. Broadly speaking air for the sensor may be bled off one of the front fans of an engine, but alternatively air may be bled into the sensor. Two aircraft will be considered, by way of example.

In the Embraer E195 the bleed air pressure and temperature is regulated using a combination of the air from the high pressure ninth stage take off and the low pressure fifth stage take off. Preferably the sensor is located in this bleed after the nacelle shut-off valve, in particular in the manifold within the wing section of the aircraft.

5 Advantageously the sensor is mounted where an ozone converter would otherwise be fitted. In this location the maximum normal operating pressure is around 50psi and the maximum temperature is in the range 230°C – 260°C (depending upon the conditions); the ducting at this location has a three inch diameter. In a Bombardier Q400 aircraft preferably the sensor is similarly located following the nacelle shut-off valve, for
10 example in the P2.2 pipeline (2.5 inch ducting); other pipelines which may be used include P2.7 and P3.0. Again in some preferred embodiments the sensor is mounted where an ozone converter would otherwise be located. In the Bombardier Q400 aircraft the maximum normal operating pressure is around 54psi and the maximum normal operating temperature is around 290°C (depending upon the precise location).
15 Figure 14 shows pressure, temperature, and mass flow rate for both engines (left axis) of an E190 aircraft together with altitude (right hand axis); the parameters are similar for the E195 aircraft. The previously described sensor configuration is suitable for operating in this range of temperatures and pressures. In principle it may even be used in a harsher, unregulated environment, for example before the Nacelle shut-off
20 valve and/or after the precooler. The photo insert in Figure 13a shows a prototype device installed in a preferred location described in the manifold within the wing section; the unit is visible and accessible when the flaps are down.

Figure 13b illustrates test results for a sensor of the type shown in Figures 11 and 12
25 showing the signal from water (A), air only (B), Turco cleaning fluid (C), air only (D), water (E) and air only (F). During the air only sections the system detects the remnants of the injected contaminants; the clipping is due to the large system gain (preferably the sensor electronics includes an adjustable gain stage). Tests of this type validated the practical ruggedized sensor design of Figures 11 and 12.

30 Figure 15 shows a schematic diagram of a particulate sensor 1500 for facilitating distinguishing between positive and negative charged particles. Thus in the arrangement of Figure 15a the sensor stage 1502 comprises a pair of separate mesh or grid sensors 1502a, b and a particular deflection module 1504 upstream of the
35 sensor. In the illustrated example the particle deflector comprises an electro static

deflector, in particular a pair of electrodes 1504a, b, in the example deflector plates, across which is connected a high voltage DC supply 1506. The deflection of particles passing through the deflector stage 1504 depends upon whether the charge of a particle is positive or negative, as explained further below. In alternative approaches
 5 magnetic deflection may be employed, using a magnetic field with a component perpendicular to the air flow, which results in particles moving along a circular trajectory whilst in the magnetic field.

In one embodiment the deflector stage comprises a pair of copper plates, one at 5Kv, the other at zero volts. As shown in Figure 15b, a particle moving with velocity u ,
 10 having mass m and charge q experiences an electrostatic force whilst travelling through the electric field between the plates.

The force will give the particle a velocity u_1 in vacuum when leaving the plates. For a
 15 parallel plate configuration, shown below, the time between the plates is Δt is given by:

$$\Delta t = \frac{L_p}{u}$$

where L_p is the length of the plates. u_1 is given by:

$$u_1 = \frac{F_T}{m} \Delta t = \frac{L_p q E}{mu} = \frac{L_p q V}{amu}$$

where a is the separation between plates. V is the applied voltage and E can be given
 20 as:

$$E = \frac{V}{a}$$

The deflection D_E is then given by:

$$D_E = \frac{u_1}{u} L_E = L_E \tan \theta = \frac{q L_E L_p V}{ma|u|^2}$$

The small deflection between the plates has a parabolic trajectory. The total deflection,
 25 D_P , on exiting the plates is given by:

$$D_p = \frac{qE\Delta t^2}{2m}$$

Thus when a potential is placed across plates 1504a, b charged particles are deflected
 5 preferentially towards either mesh 1502a or mesh 1502b, depending upon their charge
 and the direction of electric field across plates 1504a,b. Each of meshes 1502a,b may
 have separate sensor electronics, in particular a separate electrometer. A ratio may be
 calculated of the integral of the signal from one portion of the mesh to the integral of
 the signal from the other portion of the mesh. Figure 15c shows a box plot of this ratio
 10 for different plate voltages; it can be seen that as the applied voltage increases the
 ratio changes, reflecting increased deflection of the particles. The ratios themselves
 tend to have a large spread; in the plot whiskers are extreme points, red crosses are
 outliers, the red line is the median, the blue block represents 75% and 25% percentiles,
 and the green asterisk represents the mean value. When tested with Montserrat ash
 15 (finer than the Icelandic ash), ash was deposited on the positive deflector plate as
 shown in the photograph of Figure 15d, indicating that these particles are negatively
 charged. In addition, it appears that only small particles adhere to the plate.

It appears from the measurements that in embodiments of this technique more reliable
 20 results are obtained if filtered rather than full spectrum signals are employed when
 calculating the ratio of integrated signals from the portions of the sensor grids/mesh.
 The filter applied may be a low pass filter with a band width of less than 10KHz, 5KHz,
 2KHz, 1KHz or 0.5KHz.

Figure 16 shows an embodiment of a particulate sensor 1600 similar to that illustrated
 in Figure 15 but with the addition of a particle charging stage 1602. The charging stage
 may comprise, for example, a grid or mesh 1604 held at a high voltage, for example
 5Kv or a grid 1606 of wires alternately connected to either zero volts or a high voltage
 such as 5Kv. In principal other geometries may also be employed, for example a
 30 cylindrical or tubular geometry. In principal this arrangement can be employed in a
 similar manner to that previously described with referenced to Figure 15, calculating
 the same ratio as previously described, but calculating the ratio twice, once when the
 charging stage is active and once when it is off. The off or inactive state of the

charging stage can then be used to produce a base line reference at ratio with which the ratio when the charging stage is on can be compared. The result of the comparison can be used for improved sensitivity/selectivity of particulate detection.

5 Figure 17 shows a sensor interface electronics 1700 for use with a mesh/grid sensor as previously described. Thus line 1702 may be connected to signal cable 306 of the sensor of Figure 3 or to terminal 1112 of the sensor of Figure 12; a ground connection forms the other input connection. The input stage, stage 1, of the electronics of Figure 17a preferably also incorporates a pair of over-voltage protection diodes 1704a, b,
10 clamping the input to the supply rails. These diodes should have ultra-low leakage. At stage two of the input electronics comprises a damping circuit (R15, R16, C5) to protect the following stage from any current spikes; a capacitor C6 may optionally be employed to compensate for the input capacitance.

15 The third stage of the input electronics comprises an electrometer circuit constructed around an ultra-low input bias current operational amplifier with a high gain resistance feedback network. In embodiments this stage preferably includes a low pass filter with a cut off frequency of less than 500Hz, 400Hz, 300Hz, 200Hz or 100Hz, for example around 75Hz; this may be implemented in the feedback network as shown. Optionally
20 R17 may be left open circuit. Preferably the input to stage 3 is guarded as shown to reduce leakage currents; a trimmer may be included to adjust for any DC output voltage off sets.

Stages 4 and 7 of the interface electronics comprise filter stages. In embodiments
25 stage 4 provides a passive low pass filter stage with a cut off frequency of around 1Kz, and stage 7 provides an active low pass filter stage. In embodiments the cut off frequency is adjustable in the range 15-330Hz. Stages 5 and 8 comprise signal isolation/output stages. As illustrated stage 5 comprises a pair of buffers, one providing an intermediate output (OUTPUT 1); stage 8 provides a second output
30 (OUTPUT 2) following low pass filter stage 7. Stages 5 and 8 comprise voltage follower stages and help to isolate the output of the previous stage from noise. Stage 6 comprises an adjustable gains stage.

The skilled person will appreciate that the voltage and current protection and stages 4 to 8 are optional, and that the electrometer stage 3 may be implemented in many different ways.

- 5 The analogue electronics of Figure 17 may provide an input to further digital signal processing 1710, for example, comprising a processor controlled by stored program code. This digital signal processing may be used, for example, to provide one or more warning/alarm signals to the cockpit indicating the presence of detected ash and/or aerosol. Additionally or alternatively the digital processing may log data collected from
10 the sensor or sensors and/or combine data from other inputs, for example, a satellite based communication system and/or weather data and/or other data which may indicate where a volcanic ash cloud is located or expected.

The sensor electronics and/or digital signal processor of Figure 17 may communicate
15 with one or more other processing systems on the aircraft, for example, via an aircraft system data bus. Thus, referring back to Figure 13a, the interface electronics 1700, 1710 may communicate over system data bus 1720 with one or more of a telemenatory or atmospheric data system 1730, a data logger/maintenance system 1740, and a cockpit display/pilot indicator system 1750.

20 Since the sensor electronics may provide information which is useful for engine performance monitoring and for determining whether/when engine maintenance may be required, the interface electronics/signal processing may additionally or alternatively communicate with one or more engine performance monitoring/management systems
25 (not shown in Figure 13). Data of this type may be logged and/or used, for example in combination with other engine performance management data, and/or transmitted from the aircraft back to a central data logging/processing centre which processes engine-related data from aircraft.

30 Signal processing applied to a signal from the sensor may comprise, inter alia, determining a mean, integral over time, integral of an absolute value over time, and standard deviation of a sensor signal, in particular from the equations below:

Mean	$\bar{V} = \frac{\int_0^T V(t)dt}{T}$
Integral	$A = \int_0^T V(t)dt$
Absolute Integral	$A' = \int_0^T V(t) dt$
Standard Deviation	$\sigma = \sqrt{\frac{\int_0^T (V(t) - \bar{V})^2 dt}{T}}$

In embodiments such a value may be determined by integrating over time, employing sequential windows onto a data set of length N elements (determined by the sample rate and length of time the data is acquired over). Figure 18a illustrates an example window size defining a set of sequential elements of the acquired data. In embodiments each sequential window overlaps the next by a percentage; the window size may be defined in terms of seconds and the overlap may be defined in terms of percentage of the window size. The example of Figure 18a shows the Nth and Nth+1 windows, each of size 6 elements, indicating the overlap.

The skilled person will appreciate that there are many different ways in which sensor signal data may be processed. Figure 18b illustrates an example of a traffic light-type display 1800 with red 1802, amber 1804 and green 1806 indicators, in the illustrated example for each of two sensor channels A, B. In one embodiment an indicator is activated when the integral of the signal from the channel exceeds a threshold value, in the illustrated example adjustable. Conveniently an indicator has hysteresis so that once an indicator is activated it only deactivates when the integral of the signal decreases below a lower limit associated with that indicator.

20

A system installed in an aircraft including the display of Figure 18b, may be simplified to a single indicator or single indicator per sensor channel showing, for example red/green or red/amber/green in accordance with a level of volcanic ash and/or aerosol and/or any particulate detected by the sensor system.

25

No doubt many other effective alternatives will occur to the skilled person. It will be understood that the invention is not limited to the described embodiments and encompasses modifications apparent to those skilled in the art lying within the spirit and scope of the claims appended hereto.

CLAIMS:

1. A particulate sensor for an aircraft, for mounting in a duct for carrying an air flow bearing particulates to be sensed, the sensor comprising:
 - 5 an electrically conductive mesh or grid, mounted on an insulating support in said air flow; and
 - sensor electronics, coupled to said electrically conductive mesh or grid, configured to detect a signal on said electrically conductive mesh or grid from charged particulates in said air flow flowing through said electrically conductive mesh or grid.
- 10 2. A particulate sensor as claimed in claim 1 wherein said electrically conductive mesh or grid comprises a metal plate having a plurality of apertures, in particular slots.
3. A particulate sensor as claimed in claim 2 wherein said apertures or slots are
15 longer in a direction of said air flow than perpendicular to said air flow.
4. A particulate sensor as claimed in claim 2 or 3 wherein front edges of said apertures or slots are chamfered.
- 20 5. A particulate sensor as claimed in any preceding claim wherein said duct is flared to enlarge in cross-sectional area in the direction of said air flow; and wherein said electrically conductive mesh or grid is located in a region of said enlarged cross-sectional area.
- 25 6. A particulate sensor as claimed in any preceding claim wherein said duct has an openable fastening to enable said electrically conductive mesh or grid to be accessed for maintenance.
7. A particulate sensor as claimed in any preceding claim where said sensor
30 electronics comprise an electrometer.
8. A particulate sensor as claimed in claim 7 further comprising an integrator to integrate a charge sensed by said electrometer and an alarm output to signal when said integrated charge exceeds a threshold level.

9. A particulate sensor as claimed in any preceding claim further comprising a particle deflector stage, prior to said electrically conductive mesh or grid in said air flow, wherein said electrically conductive mesh or grid is divided to selectively sense positively and negatively charged particles.

5

10. An aircraft comprising the particulate sensor of any preceding claim, wherein said particulate sensor is located in an air bleed duct or line from an engine of the aircraft.

10

11. An aircraft as claimed in claim 10 wherein said air bleed duct or line comprises a line supplying air to an air conditioning unit of the aircraft.

15

12. An aircraft as claimed in claim 11 wherein said particulate sensor is installed in a location designed for an ozone converter and/or following a pressure-regulating shut off valve in said air bleed line.

20

13. An aircraft as claimed in claim 10, 11 or 12, wherein said sensor electronics are coupled to a system data bus of said aircraft to provide engine management data and/or aircraft safety data for the aircraft.

25

14. A method of particulate sensing in an aircraft, the method comprising:
mounting an electrically conductive sensor on an electrically insulating support at a location in an air bleed duct or line from a compressor of said engine; and
sensing charged particles flowing past said sensor using sensor electronics coupled to detect a signal on said electrically conductive sensor;
wherein said location comprises a location designed for an ozone converter for said aircraft.

30

15. A method of particulate sensing as claimed in claim 14 wherein said sensing comprises sensing using an electrically conductive mesh or grid for said electrically conductive sensor.

35

16. A method of particulate sensing as claimed in claim 15 further comprising enlarging a cross-sectional area of said air bleed at said location of said sensor by a factor of at least 1.5.

17. An aircraft, the aircraft including a particulate sensing system comprising:
an electrically conductive sensor; and
sensor electronics, coupled to said electrically conductive sensor, wherein said
5 sensor electronics are configured to detect a signal on said sensor from charged
particles flowing past said sensor;
wherein said sensor is mounted on an electrically insulating support at a
location in an air bleed duct or line from a compressor of said engine; and
wherein said location comprises a location designed for an ozone converter for
10 said aircraft.
18. A method of particulate sensing in an aircraft, the method comprising:
mounting an electrically conductive mesh or grid on an insulating support in an
air flow duct carrying particulates to be sensed; and
15 detecting a signal on said electrically conductive mesh or grid from charged
particulates in an air flow through said electrically conductive mesh or grid.
19. A method of sensing the presence of volcanic ash in an aircraft airspace using
the method of claim 18.
20
20. A method of detecting a contaminant in the bleed air system of an aircraft using
the method of claim 18.
21. A sensor, aircraft or method as recited in any preceding claim further configured
25 for processing a signal from said mesh or grid sensor to determine a charge of said
particulates for distinguishing between particulates of different types.
22. A sensor, aircraft or method as recited in any preceding claim further configured
for processing a waveform of a signal from said mesh or grid sensor to distinguish
30 between particulates of different types.

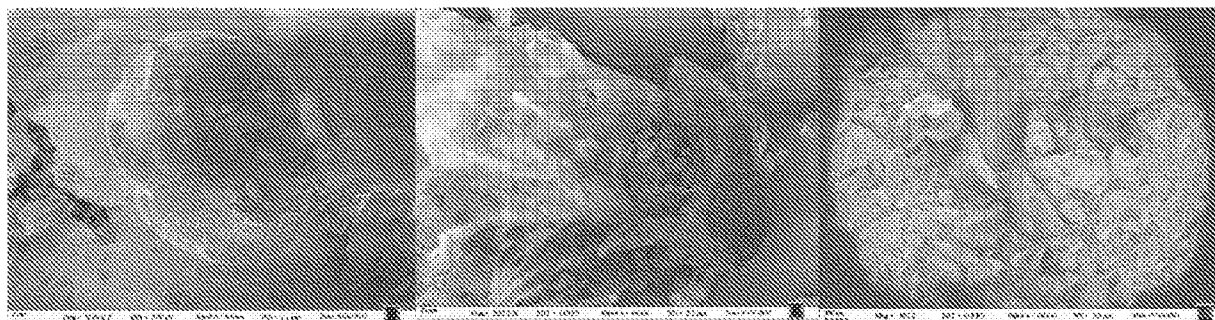


Figure 1a

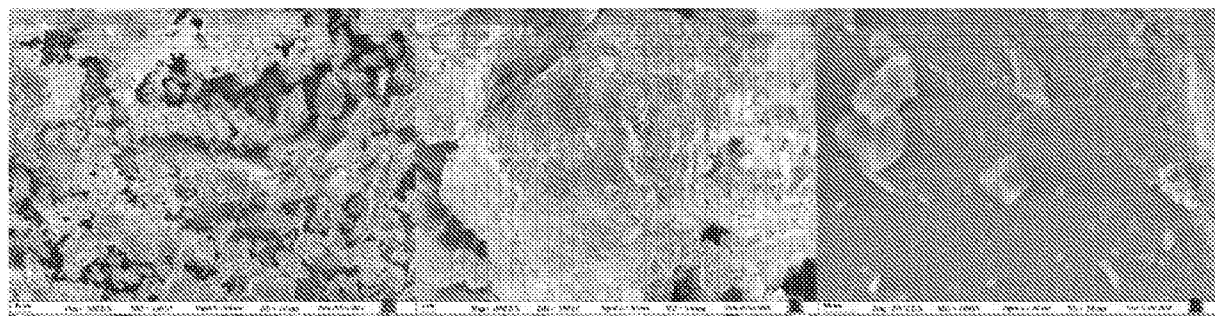


Figure 1b

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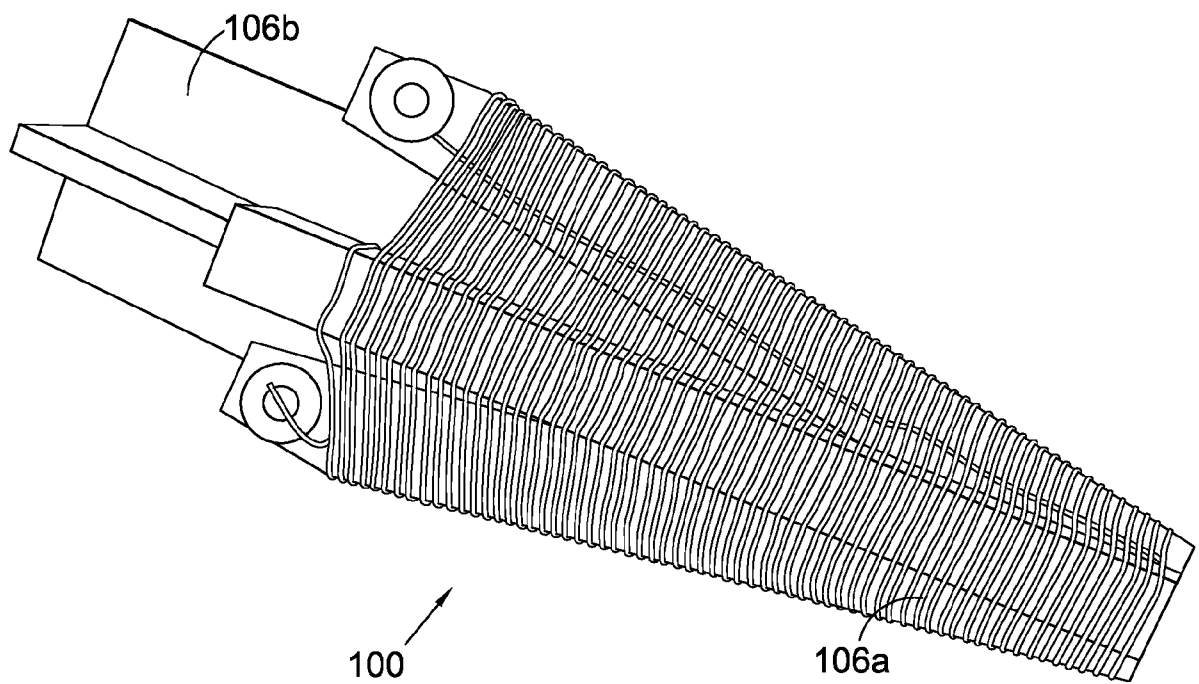
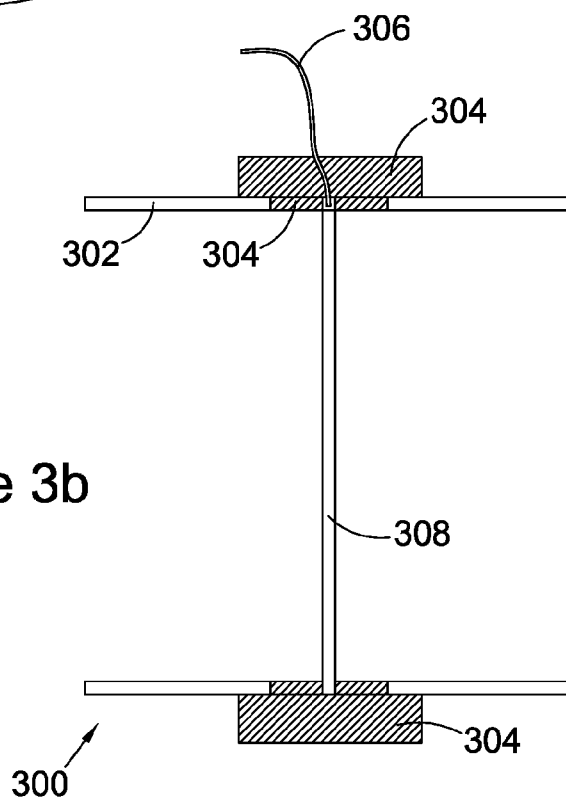
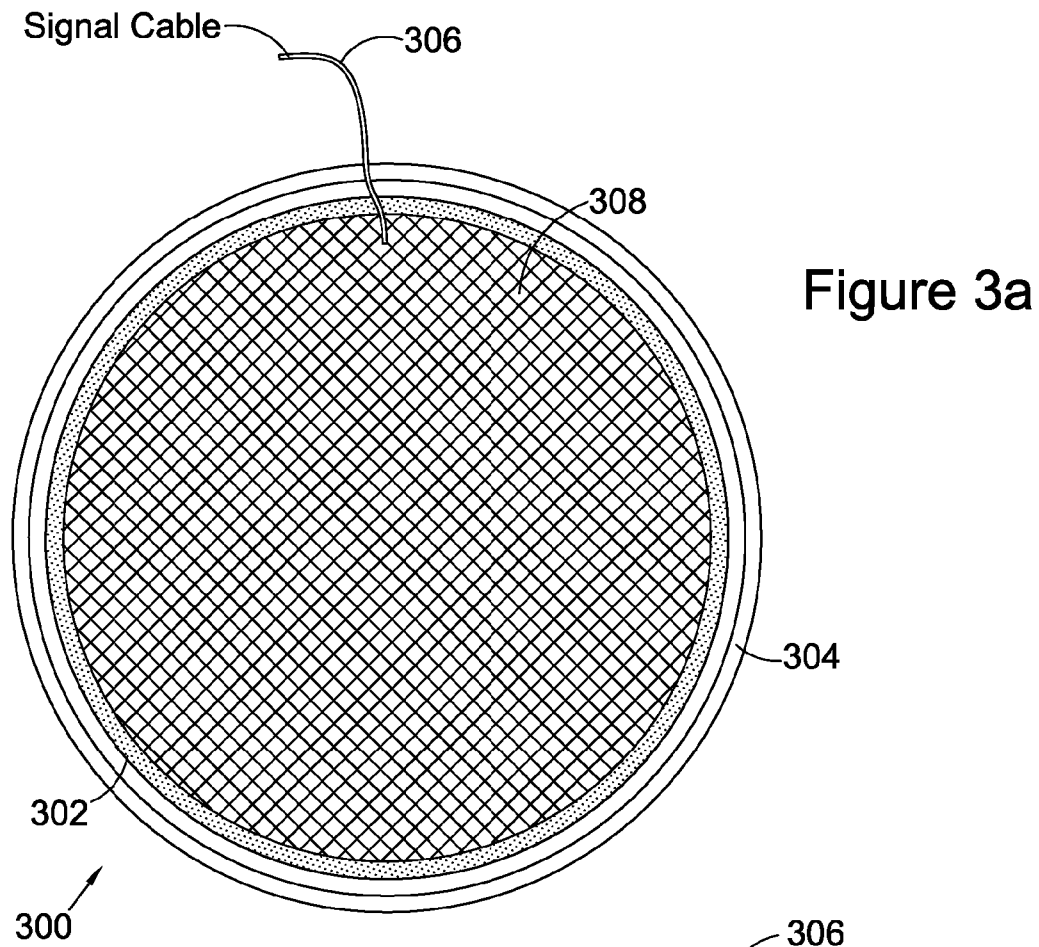


Figure 2

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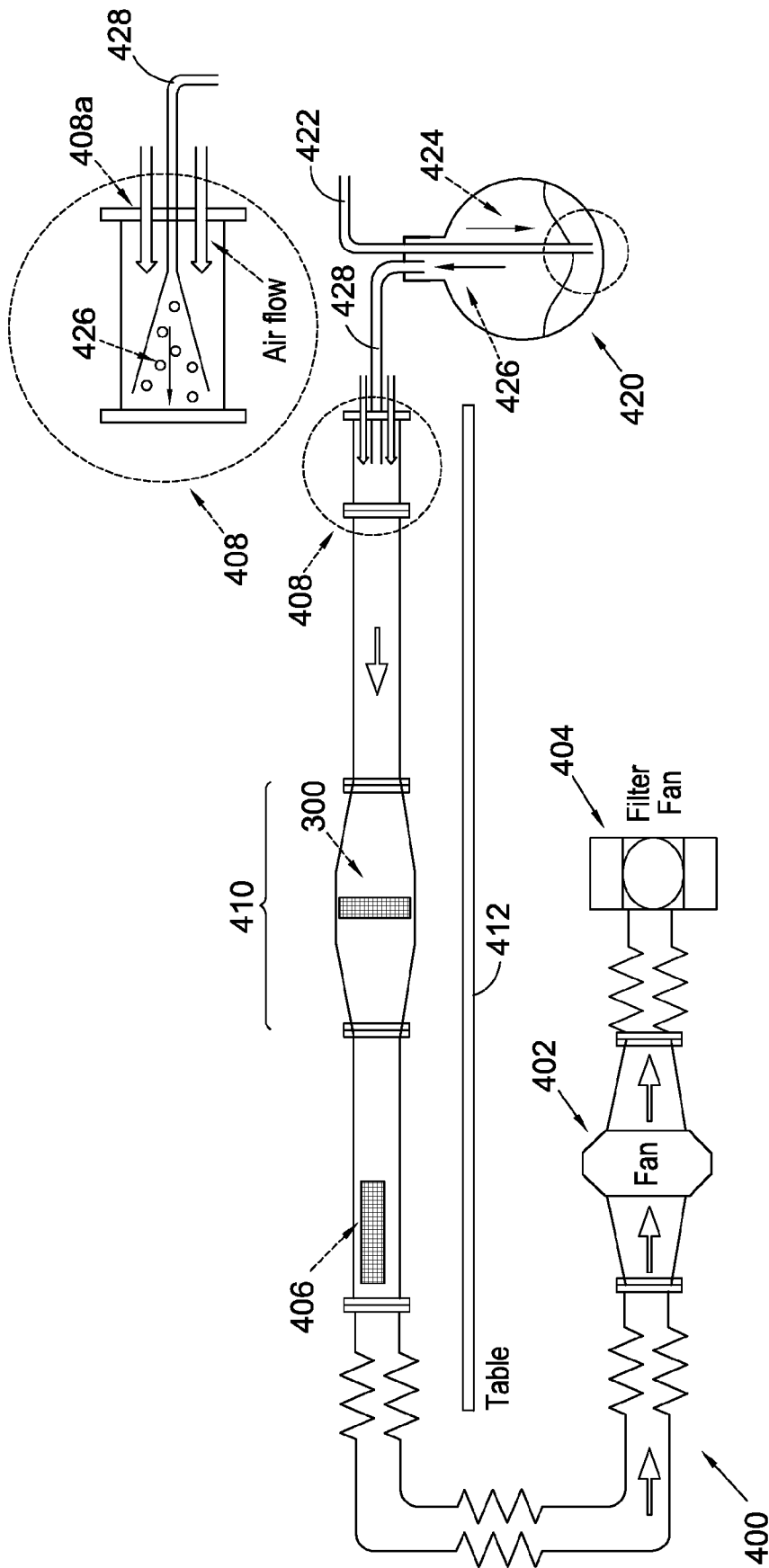


Figure 4

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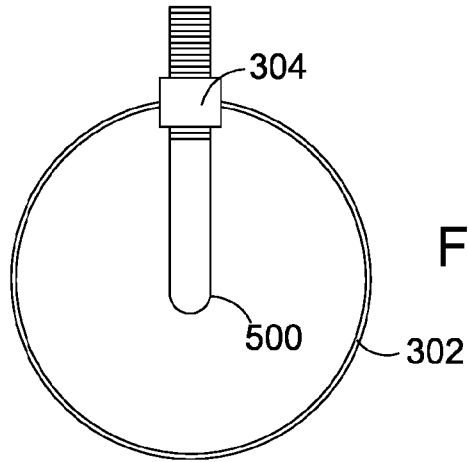


Figure 5a

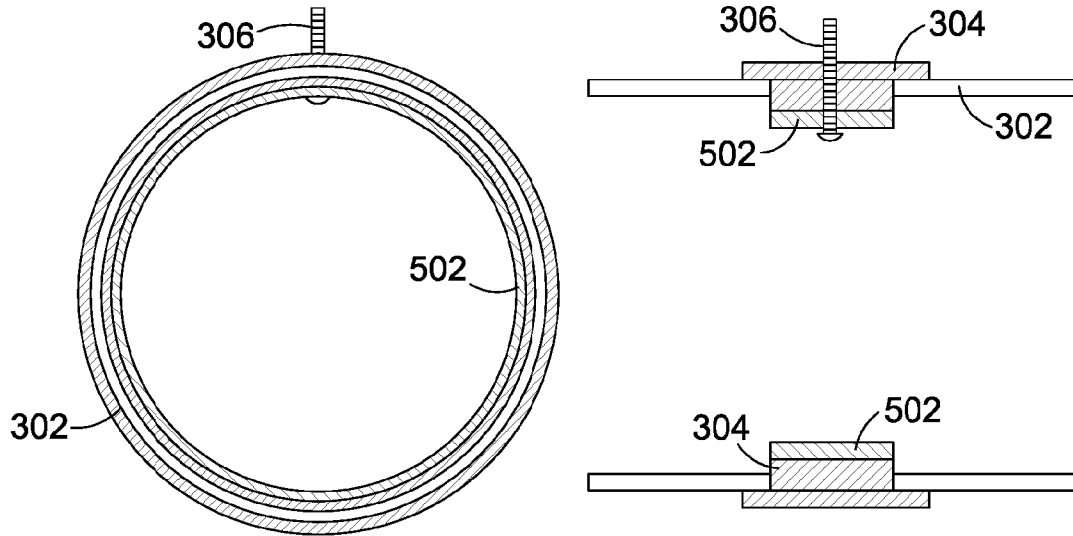


Figure 5b

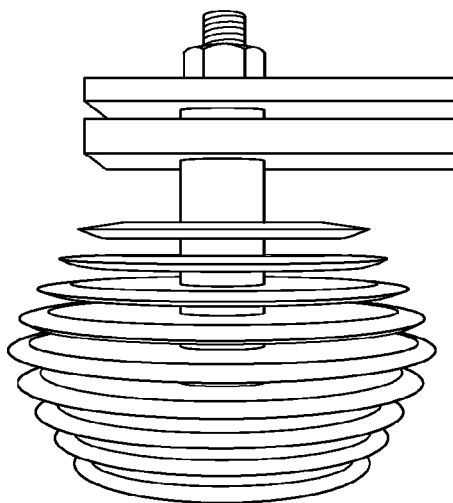


Figure 5c

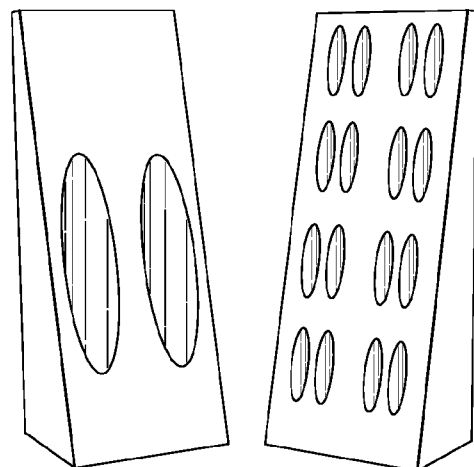


Figure 5d

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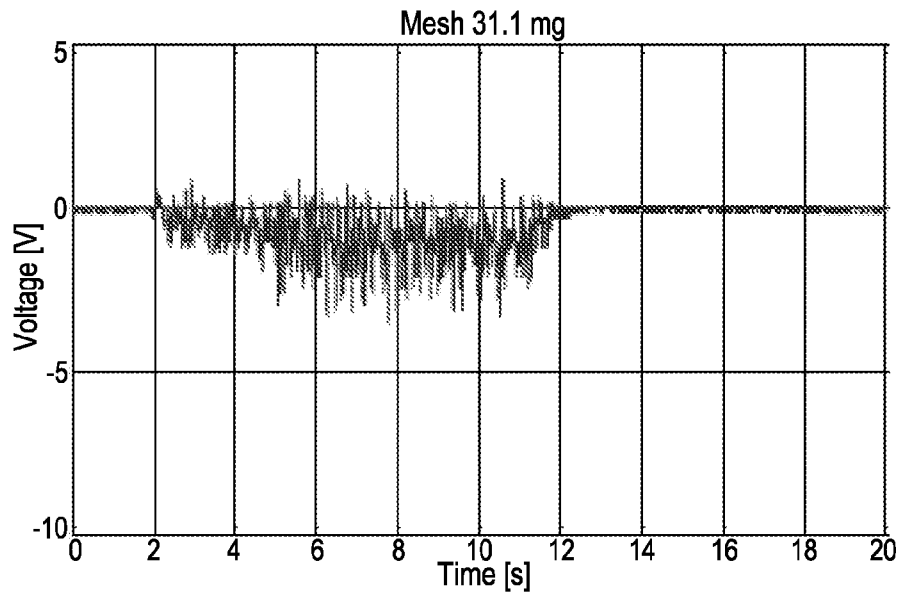


Figure 6a

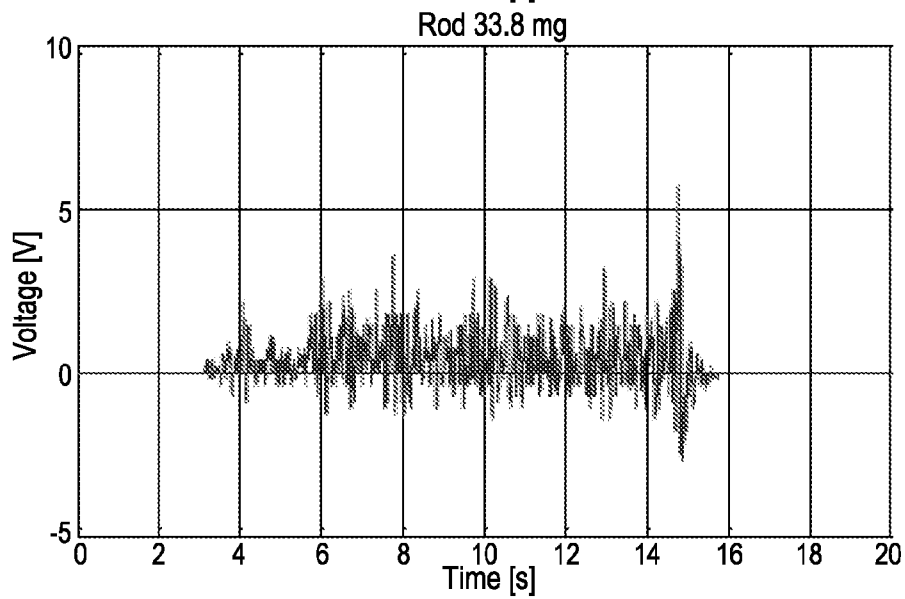


Figure 6b

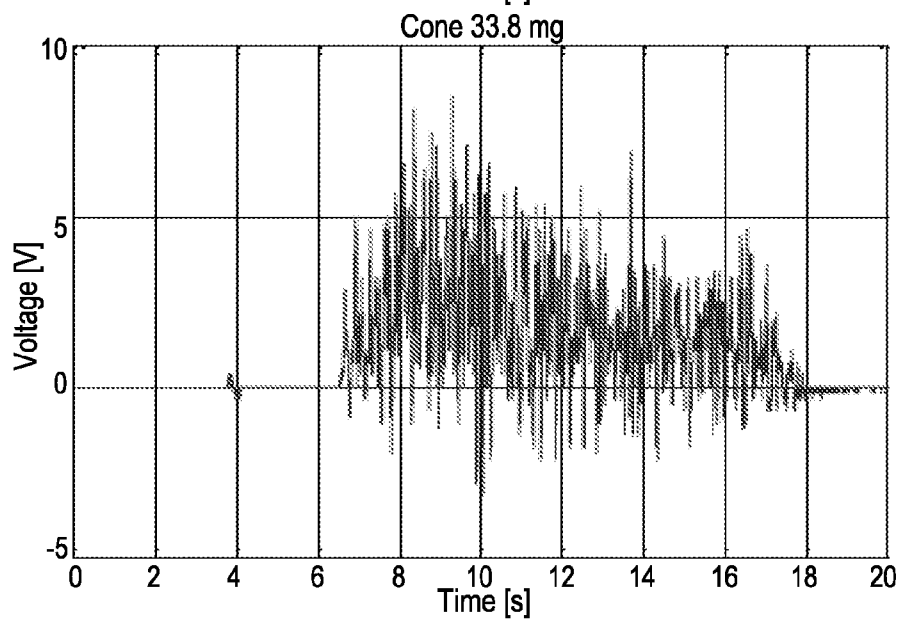


Figure 6c

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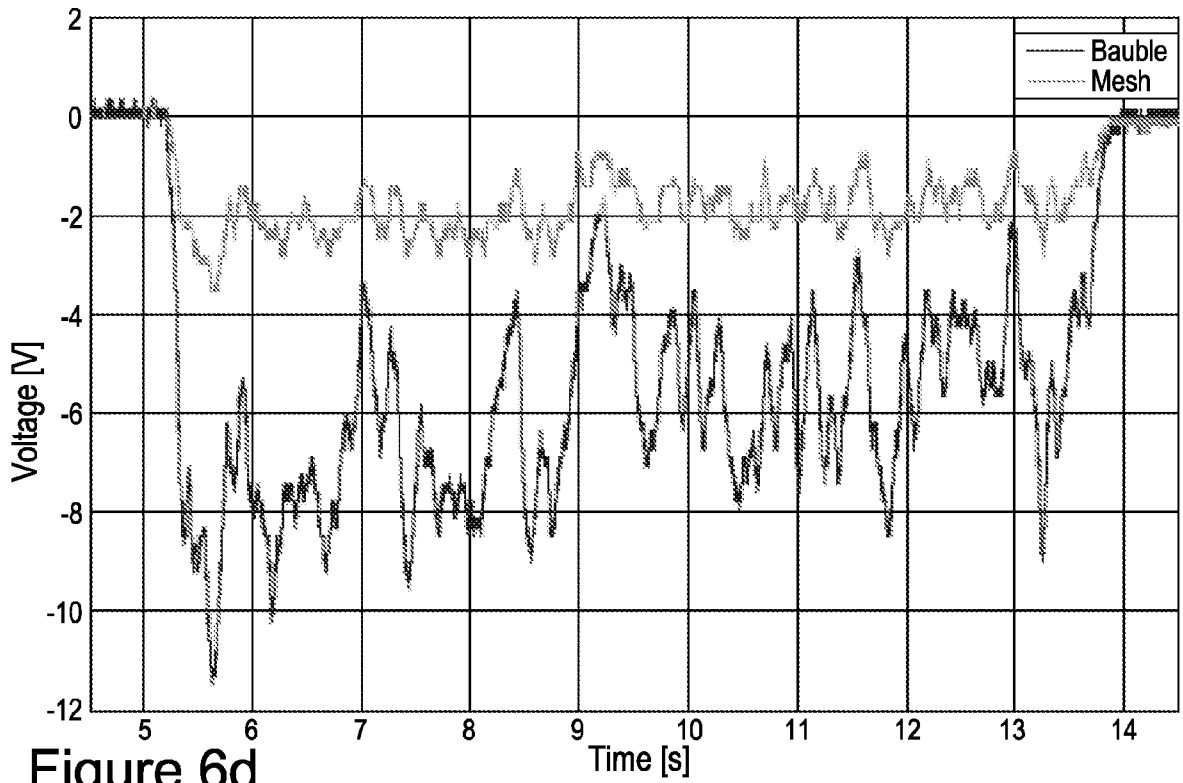


Figure 6d

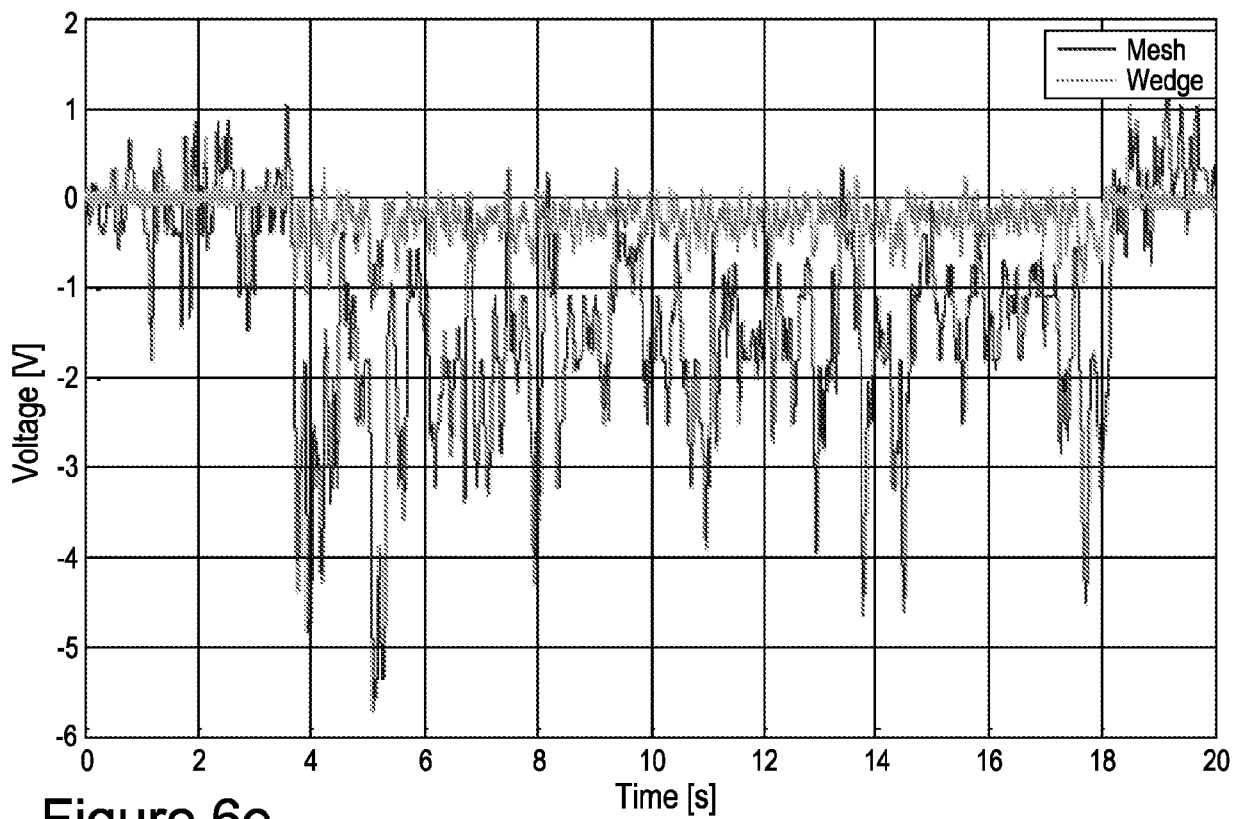


Figure 6e

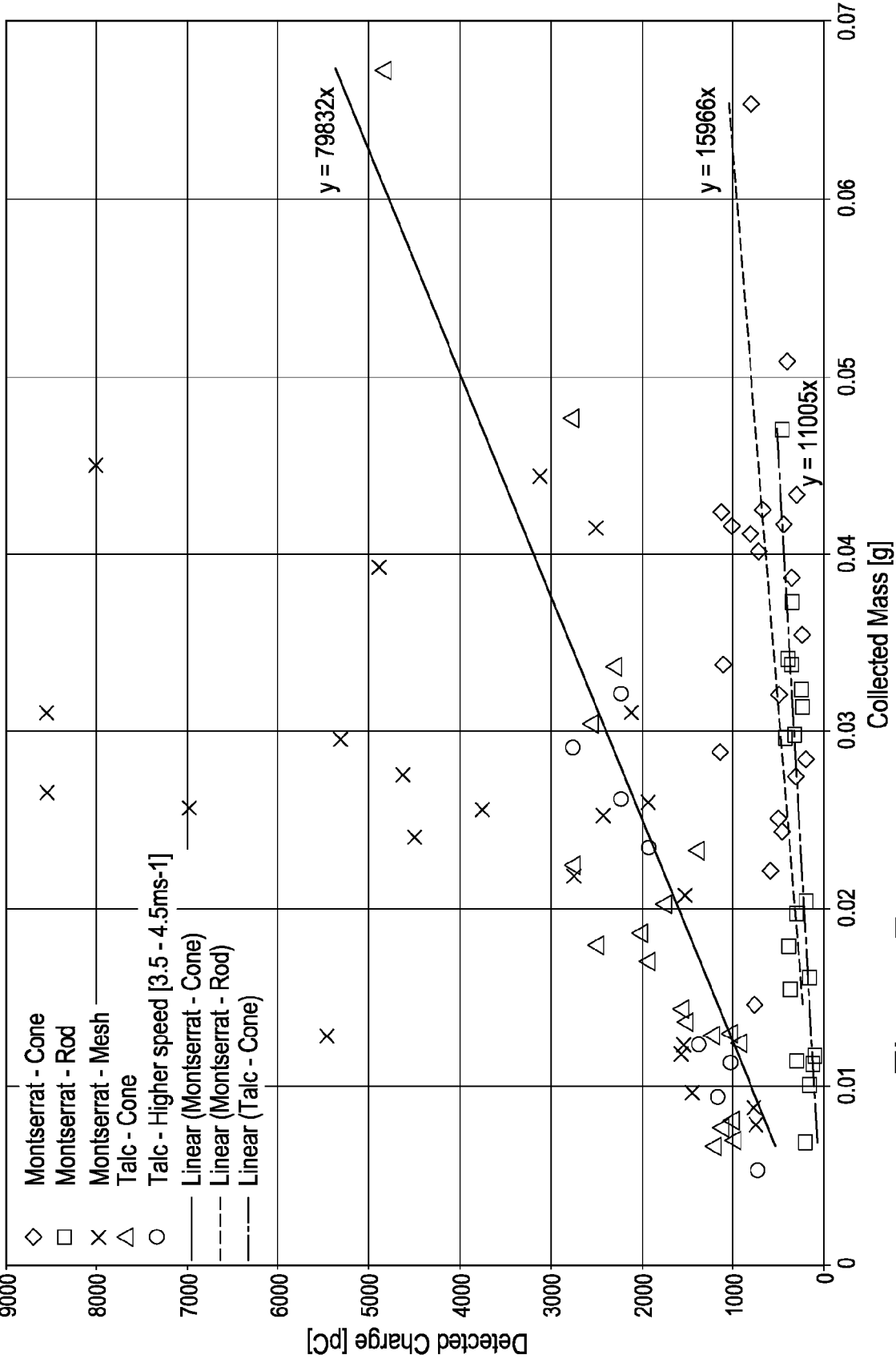


Figure 7

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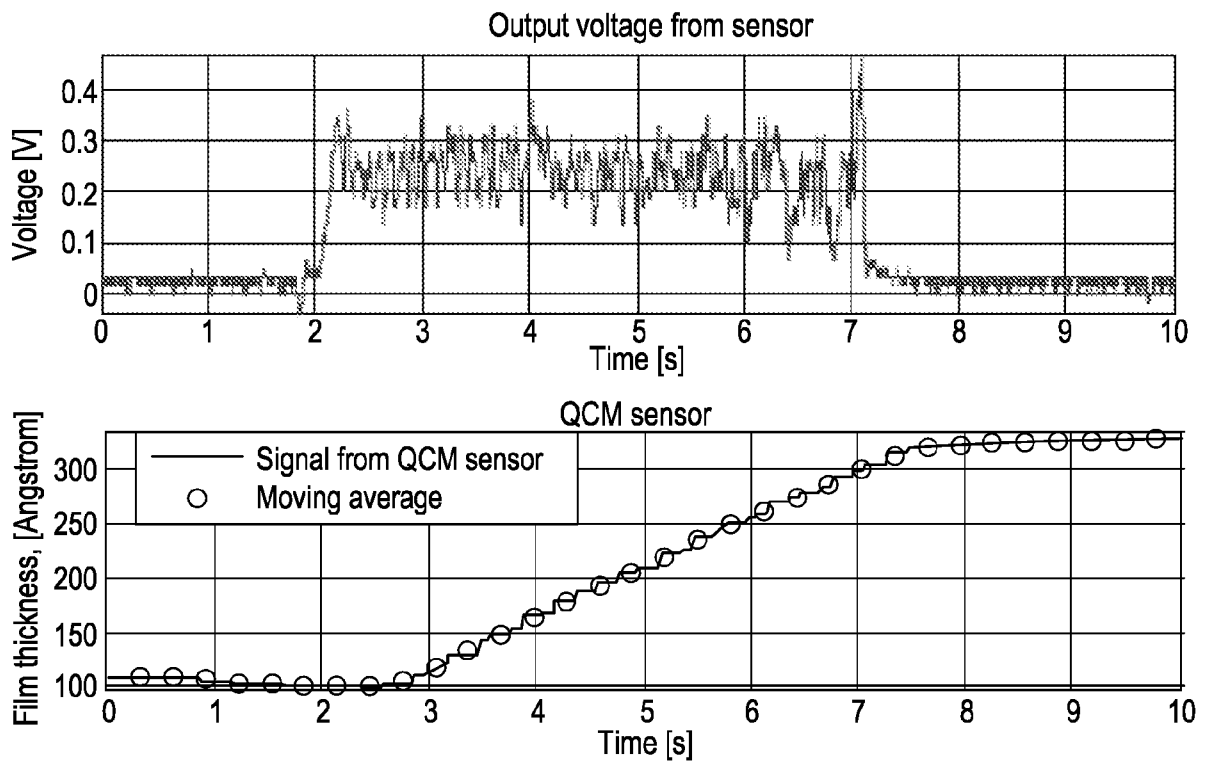


Figure 8a

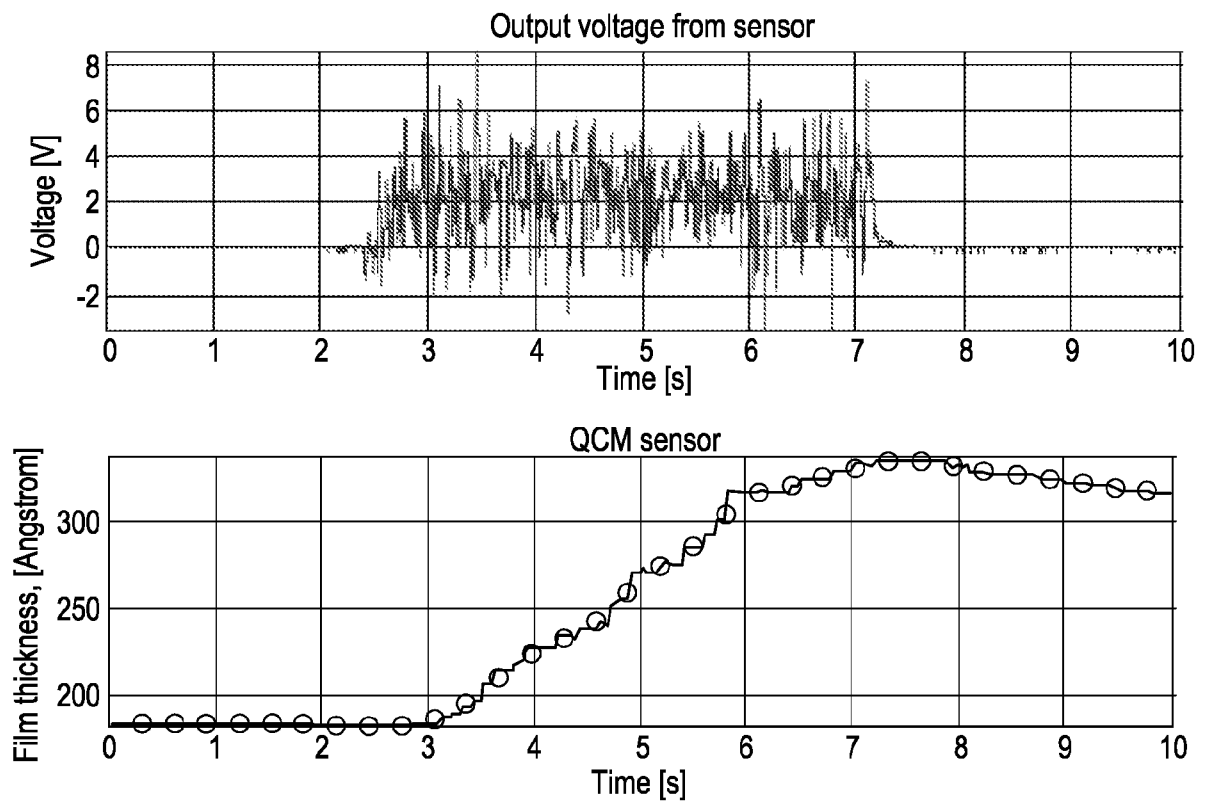


Figure 8b

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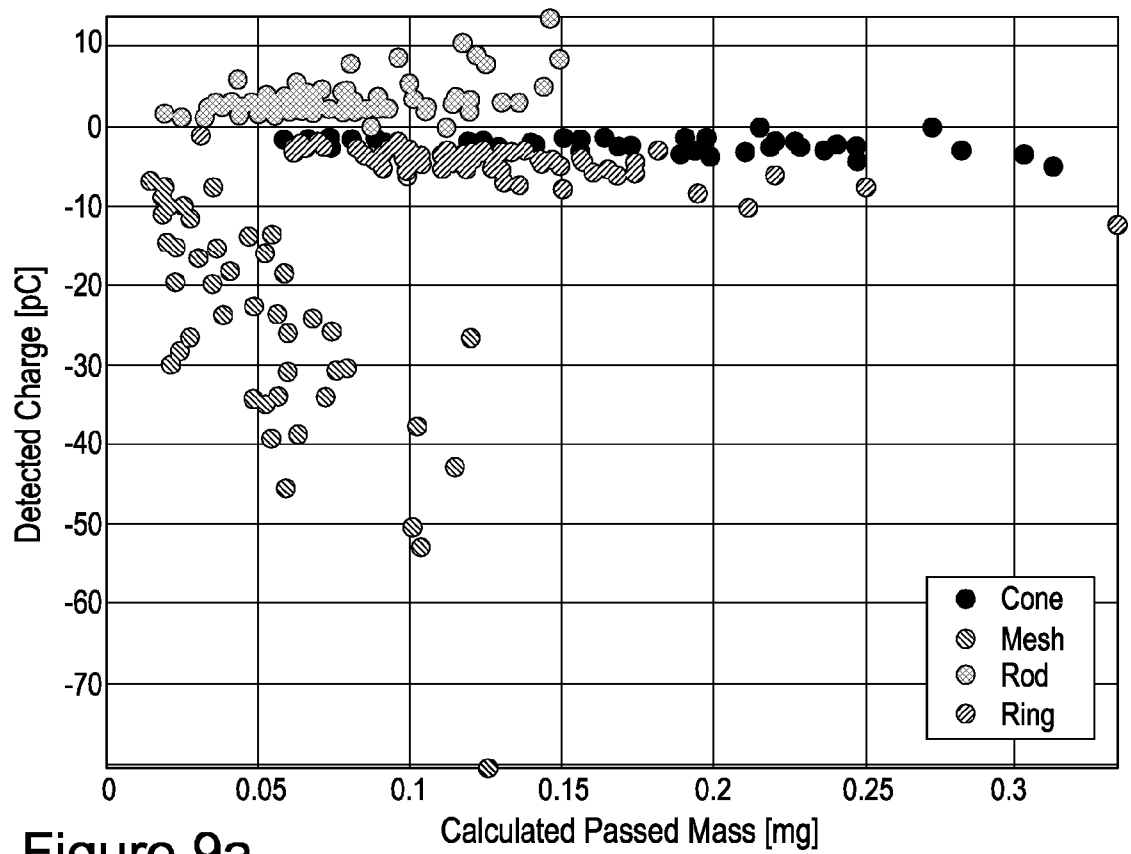


Figure 9a

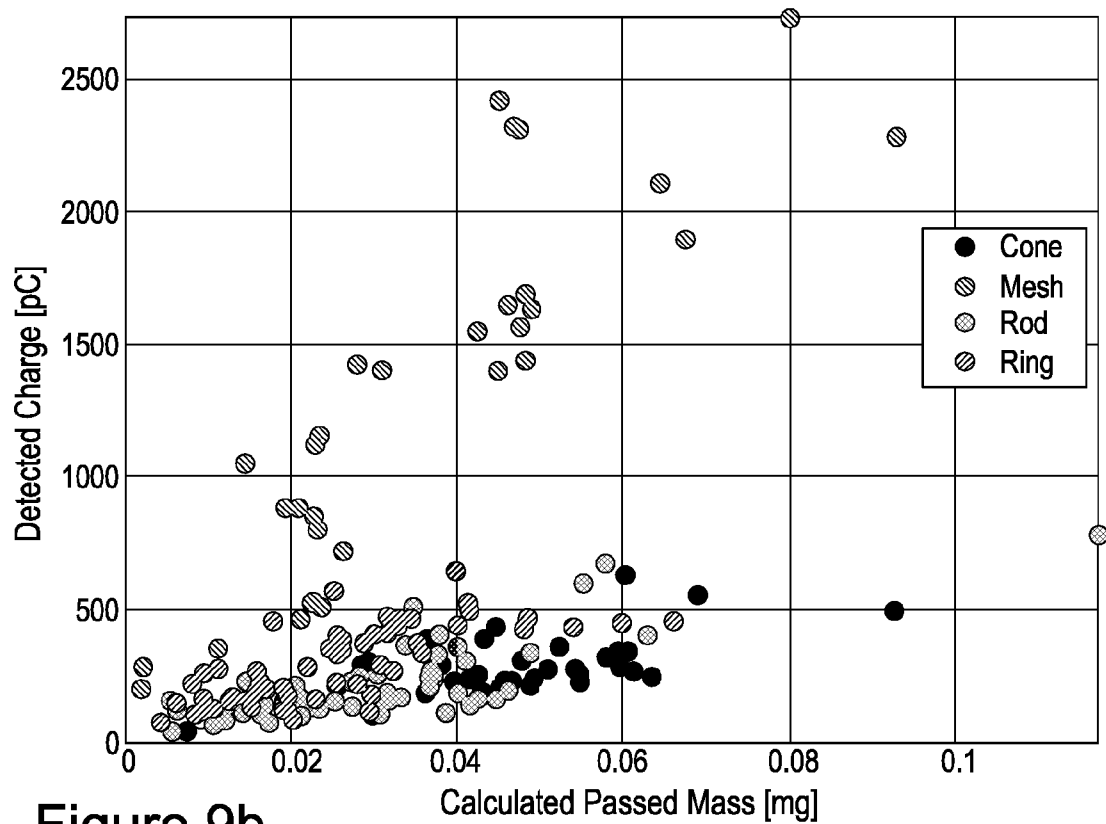


Figure 9b

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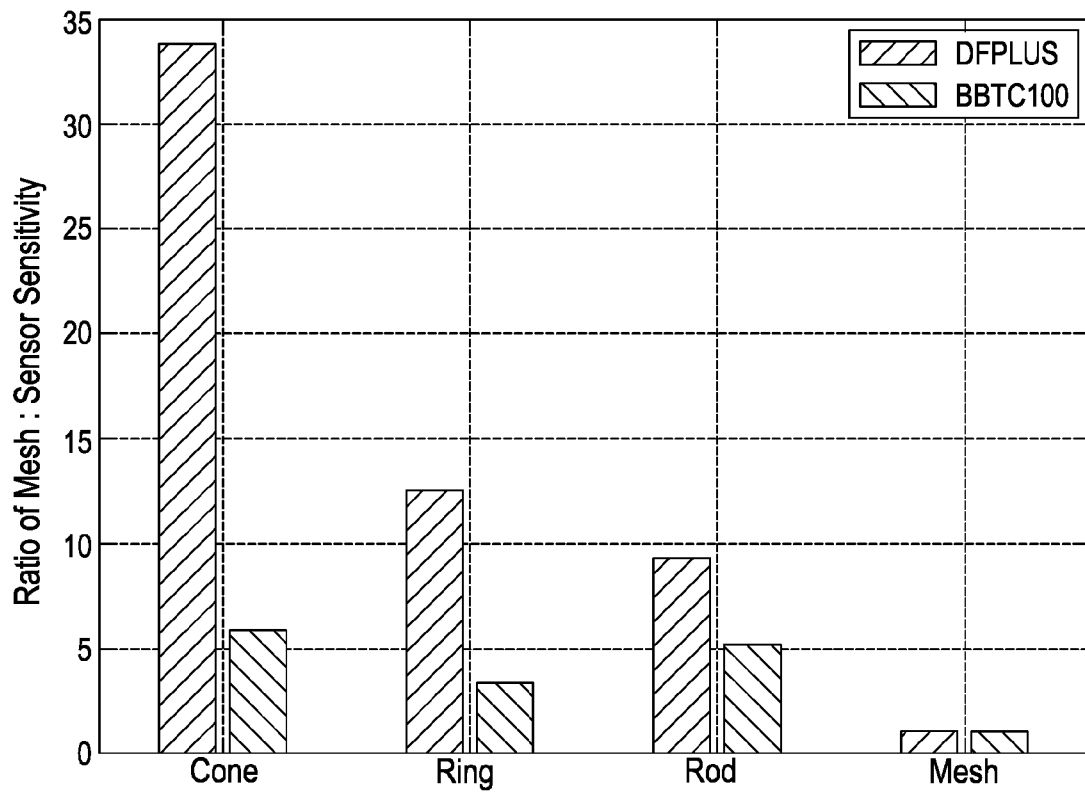


Figure 10a

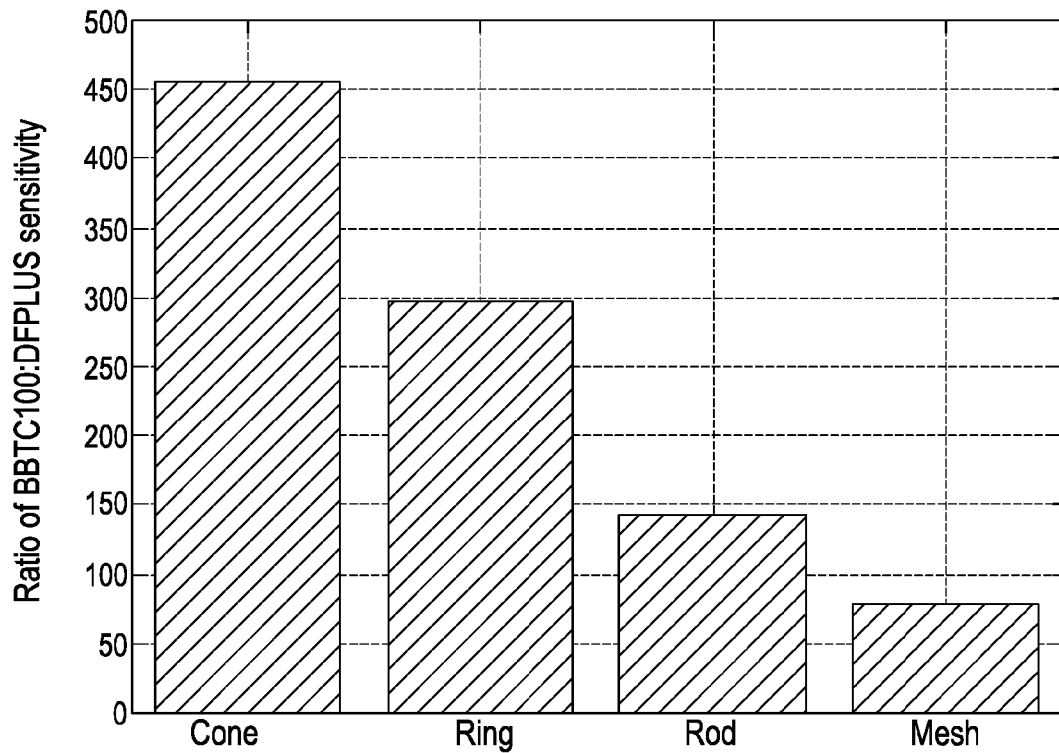


Figure 10b

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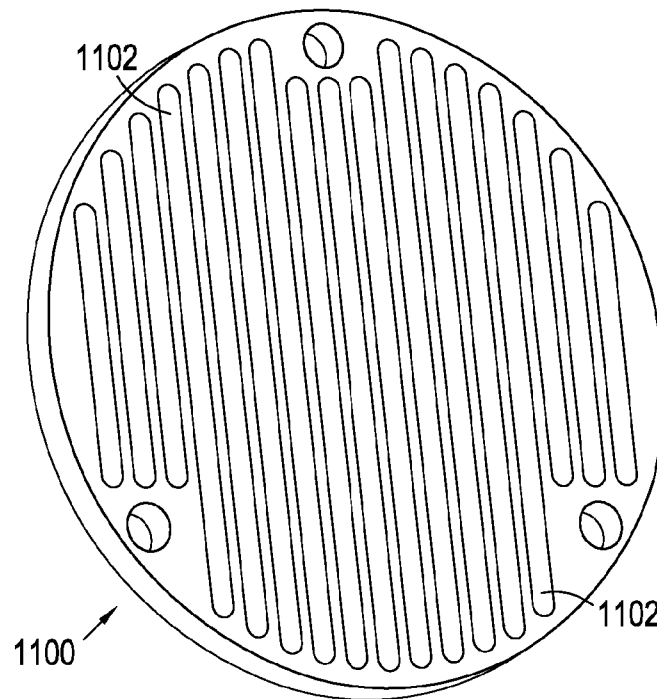


Figure 11a

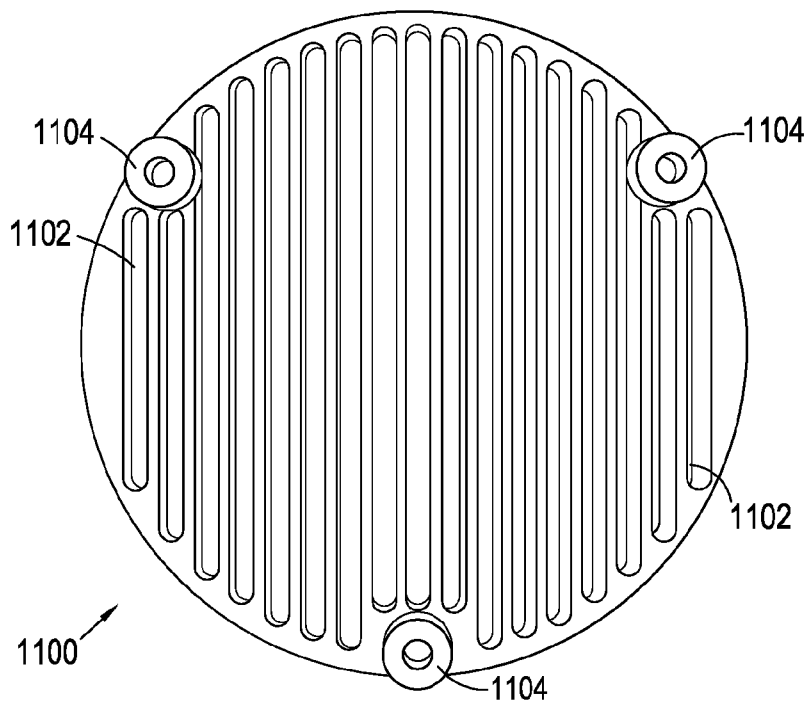


Figure 11b

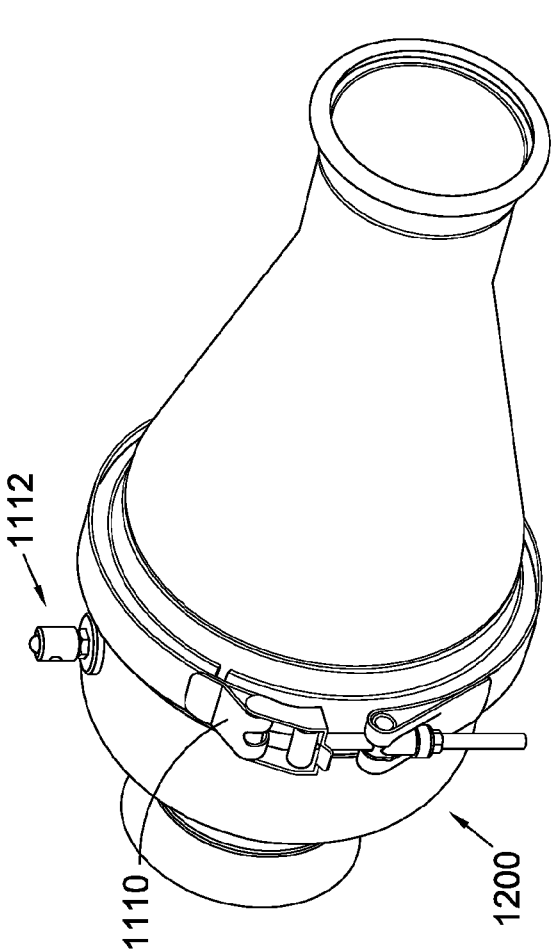


Figure 12b

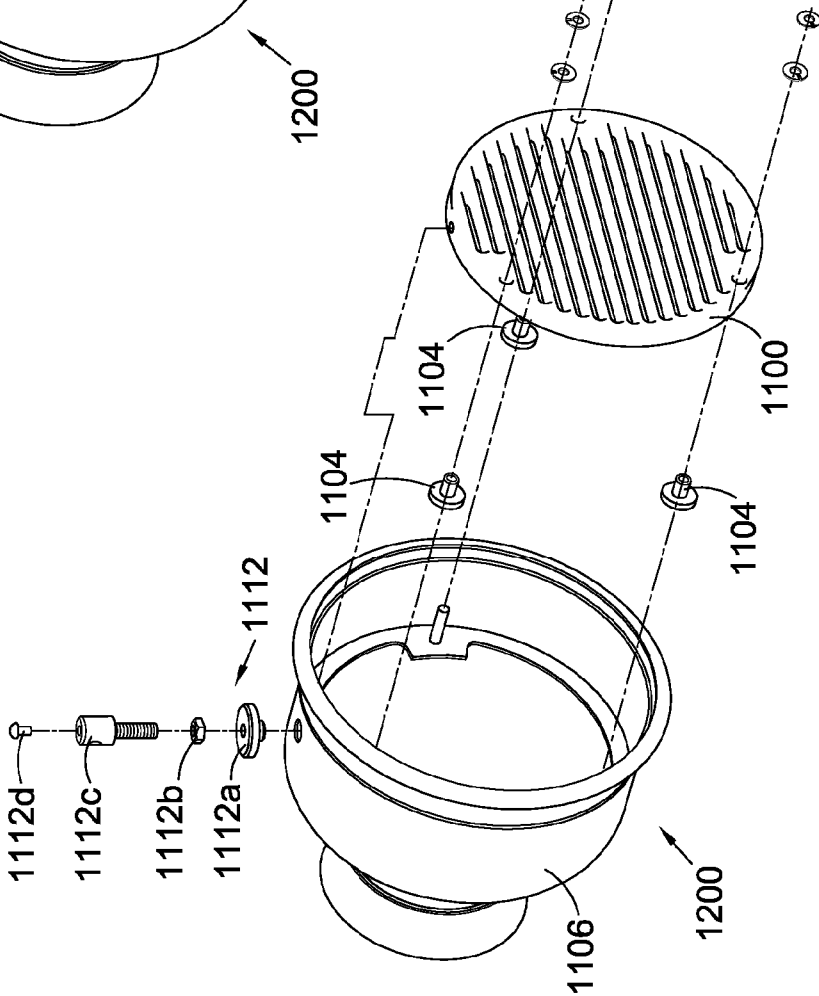
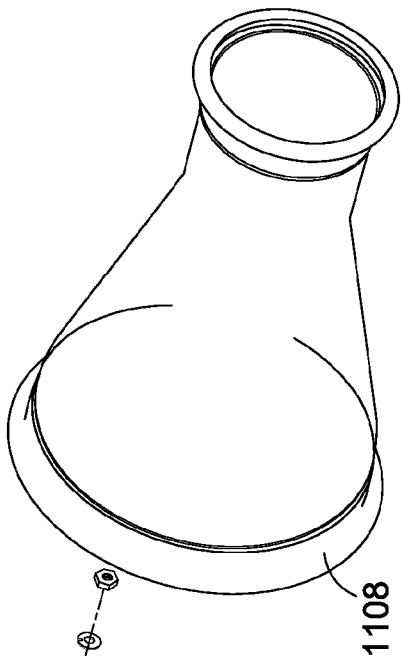


Figure 12a

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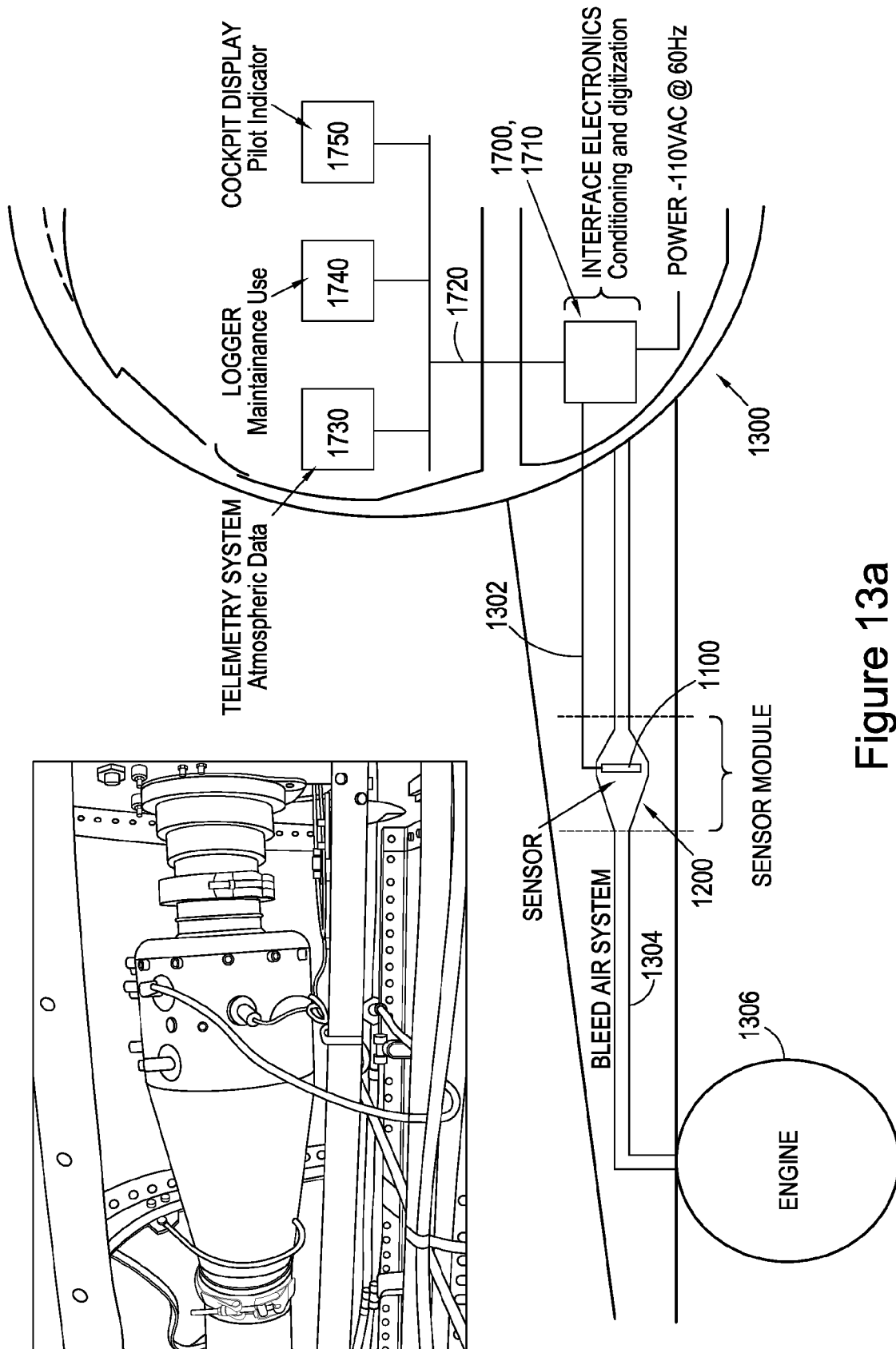


Figure 13a

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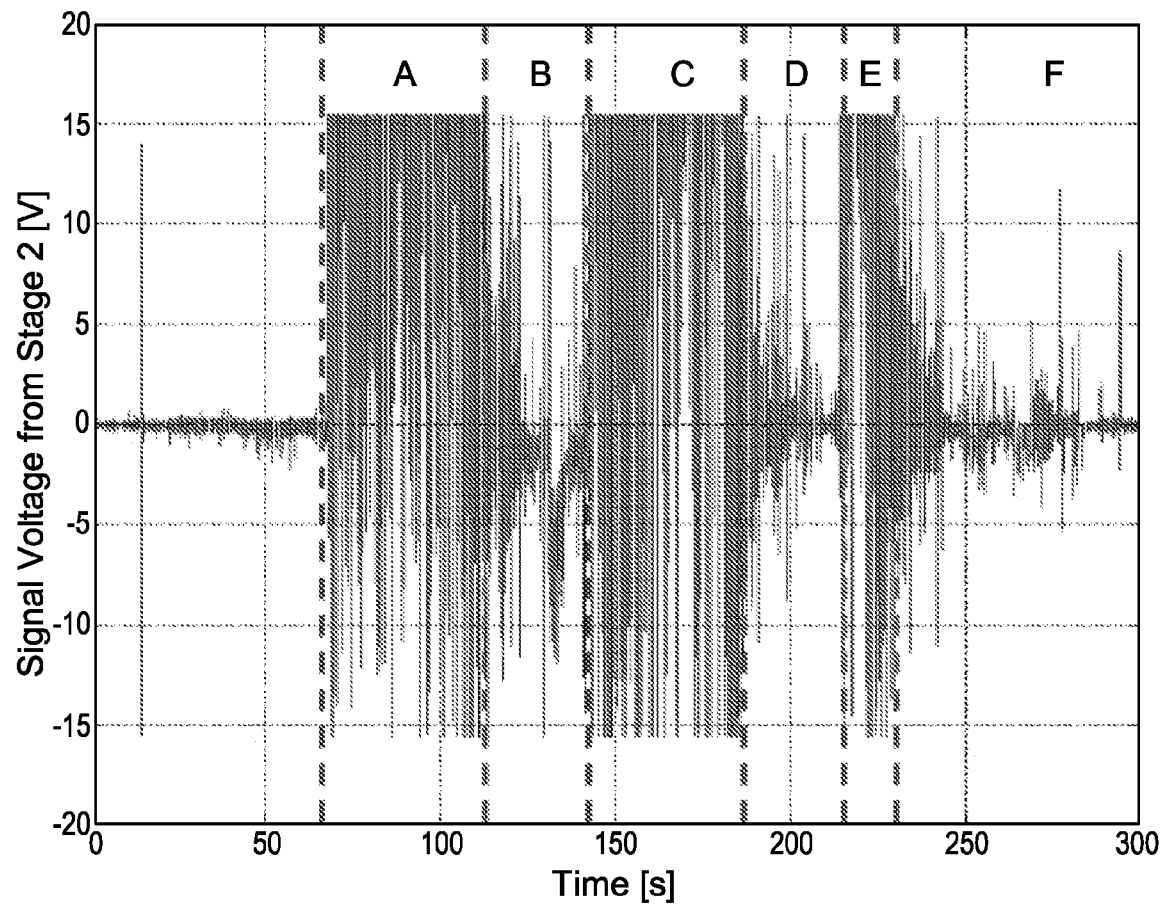


Figure 13b

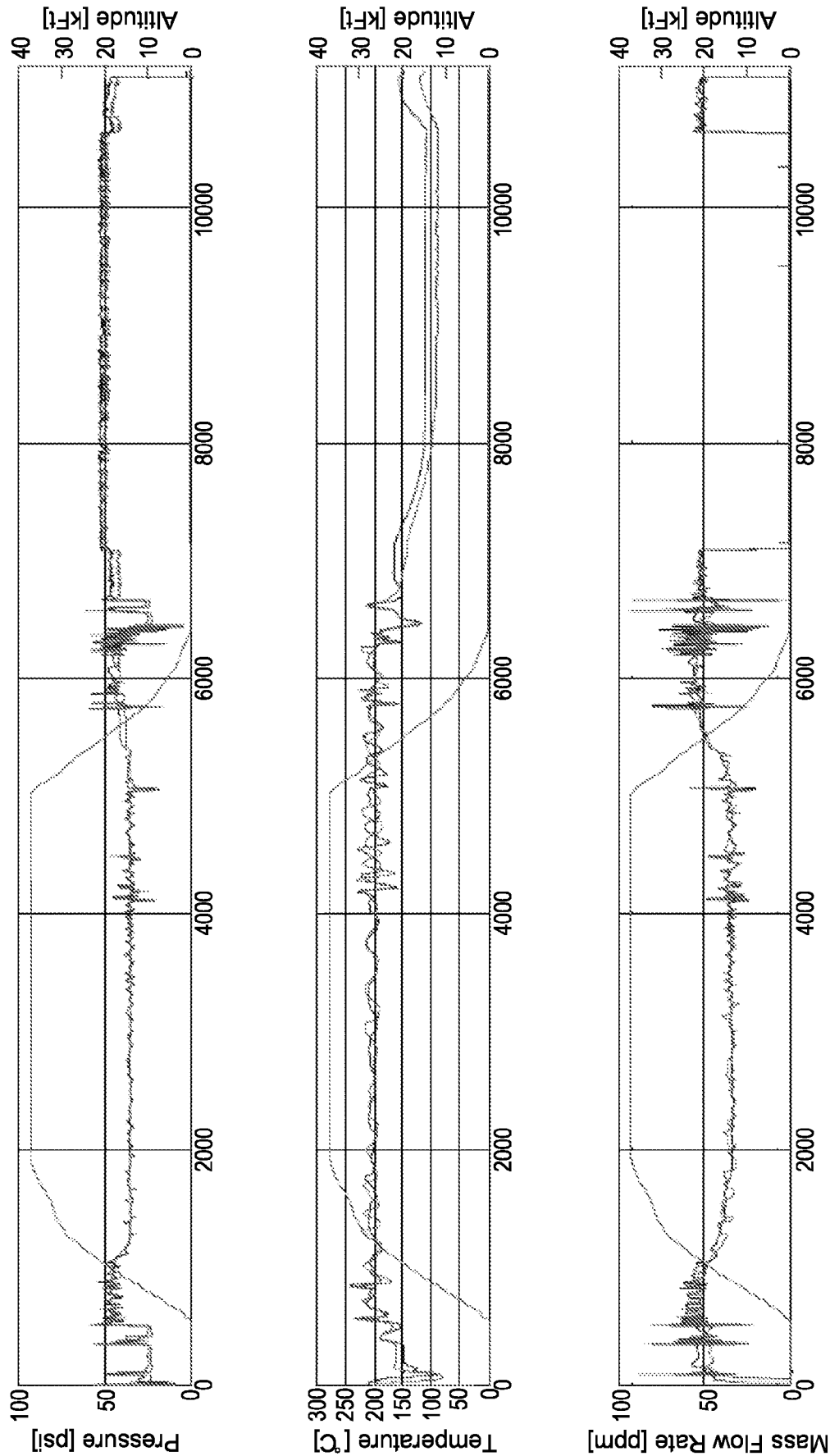
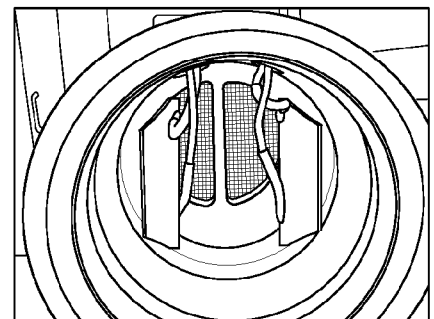
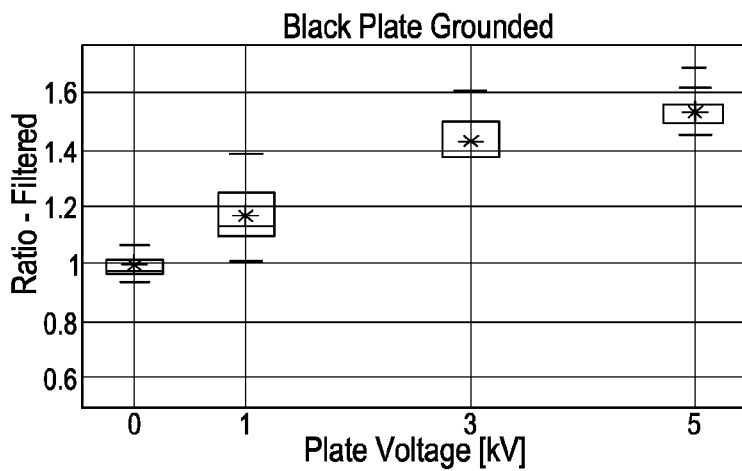
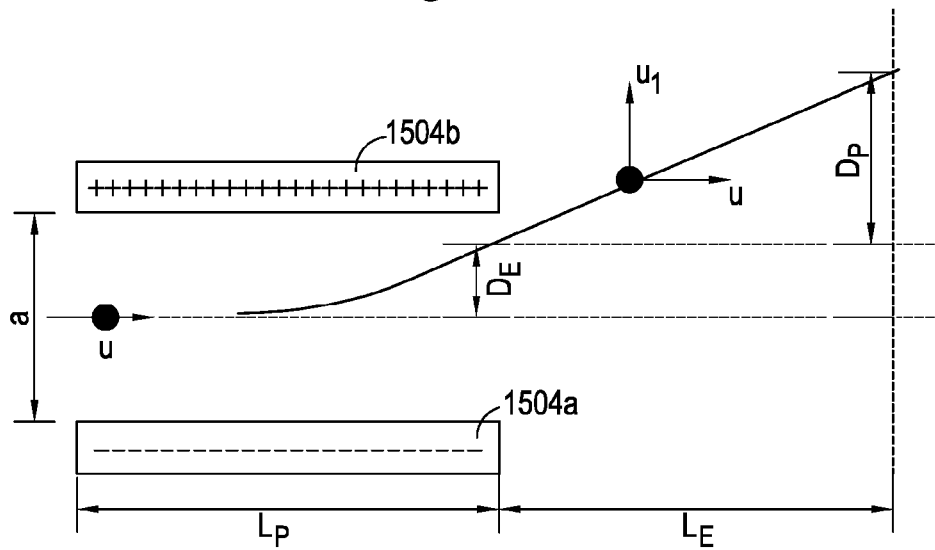
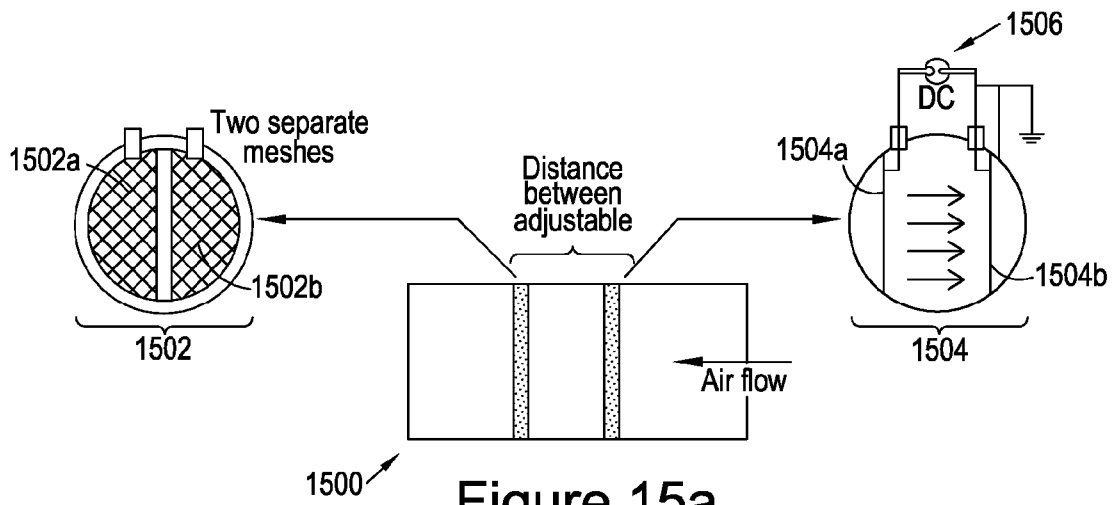


Figure 14

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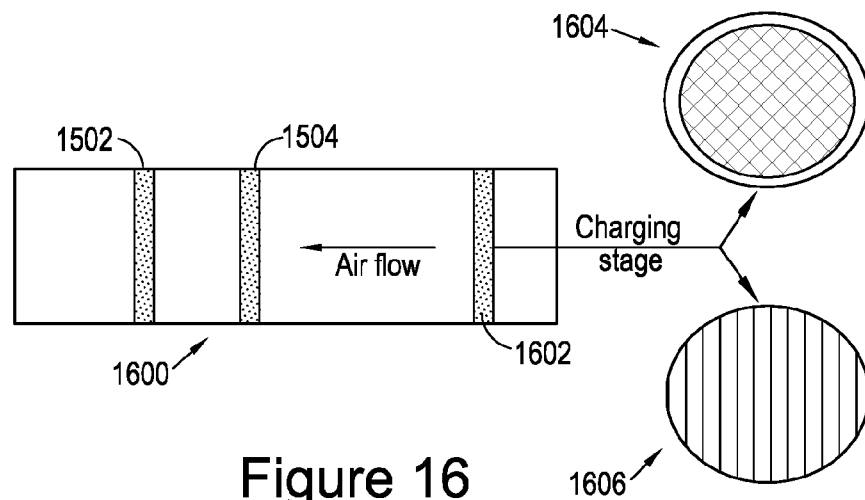


Figure 16

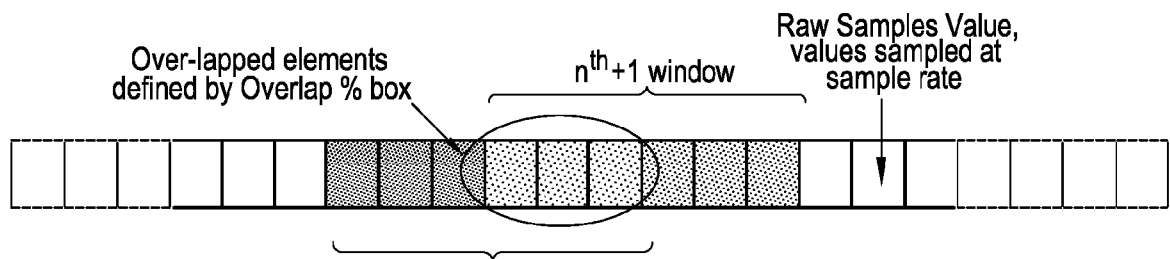


Figure 18a

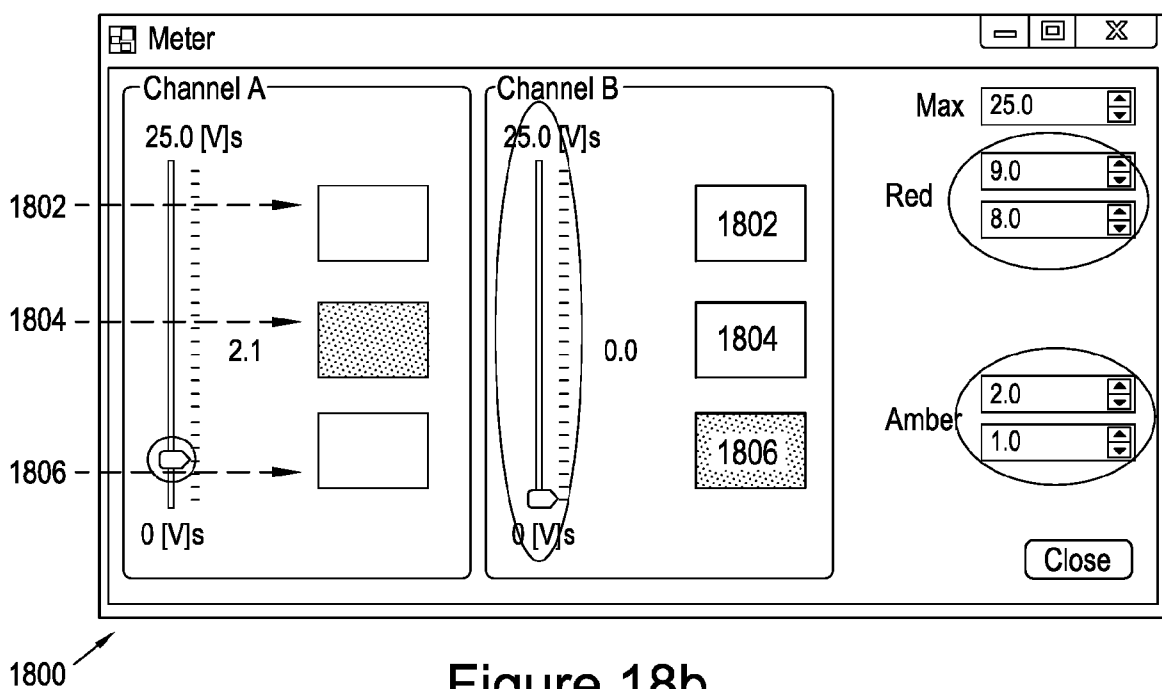


Figure 18b

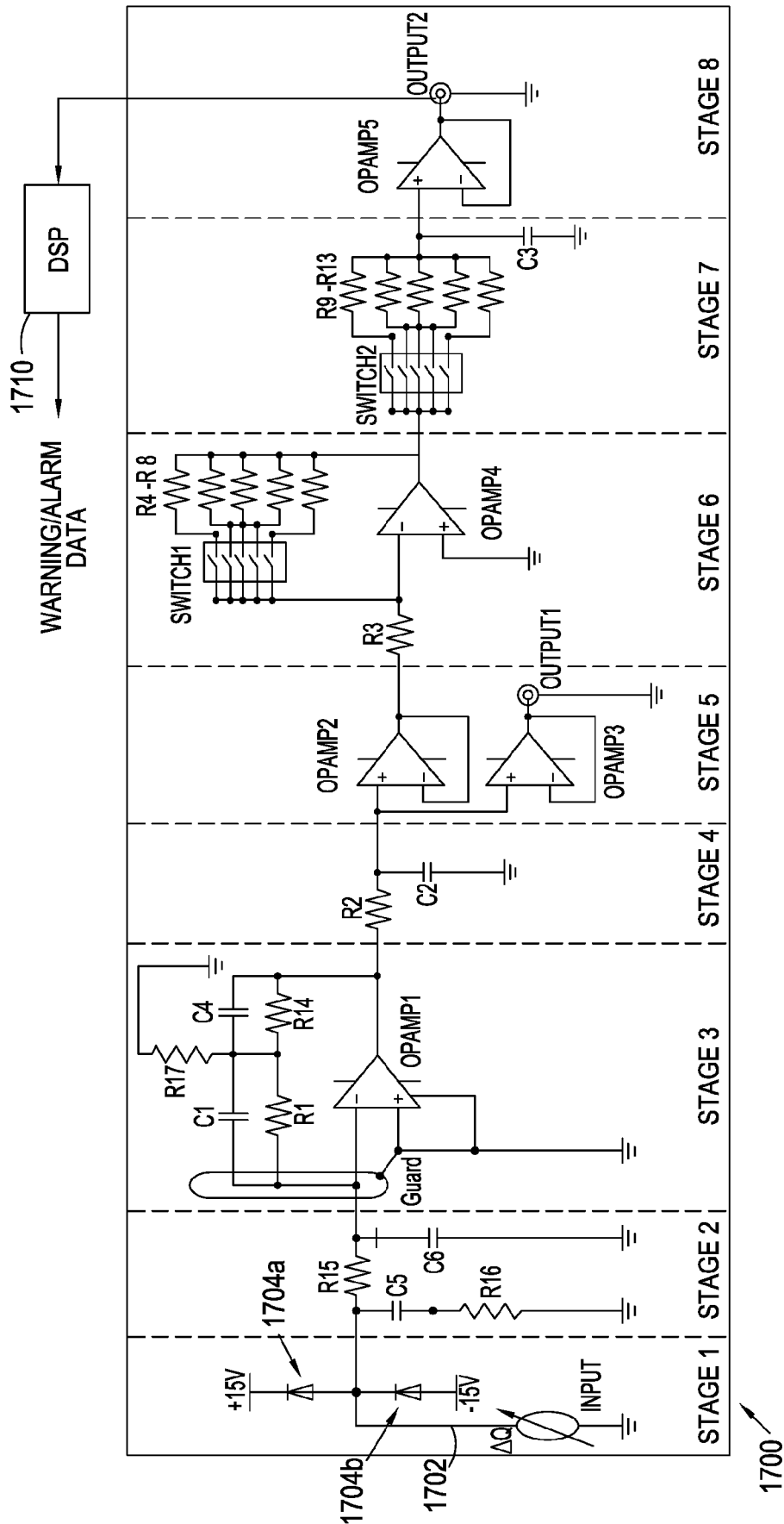


Figure 17

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2015/051681

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01N15/06

ADD.

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

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2013/017894 A1 (CAMBRIDGE ENTPR LTD [GB]; WELLAND MARK EDWARD [GB]; AZIZ ATIF [GB]; GA) 7 February 2013 (2013-02-07) page 8, lines 16-21; figure 1a page 9, lines 6-14 page 9, lines 22-32; figure 2 page 11, lines 21-32; claims 19,20 page 12, line 24 - page 14, line 24; figures 6-7 -----	1,5-13, 15,16, 18-22 2-4
X	US 4 531 486 A (REIF ROBERT B [US] ET AL) 30 July 1985 (1985-07-30) column 7, line 24 - column 8, line 59; figures 1,4 column 9, lines 49-65 column 10, lines 6-13 ----- -/-	1,5-8, 10-13, 15,16, 18-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

28 August 2015

Date of mailing of the international search report

18/11/2015

Name and mailing address of the ISA/

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Fax: (+31-70) 340-3016

Authorized officer

van Lith, Joris

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2015/051681

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 779 380 B1 (NIEUWKAMP WOLFGANG [DE]) 24 August 2004 (2004-08-24) column 3, lines 25-38 -----	1,2,4-8, 13,16, 18-20
X	US 2006/107730 A1 (SCHUMANN BERND [DE]) 25 May 2006 (2006-05-25) paragraph [0002] -----	1,5-8, 13,16, 18-20
X	US 2006/150754 A1 (BURTSCHER HEINZ [CH] ET AL) 13 July 2006 (2006-07-13) paragraphs [0018], [0051]; figure 2 -----	1,3-8, 13,16, 18-20

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Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-13, 15, 16, 18-20(completely); 21, 22(partially)

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-13, 15, 16, 18-20(completely); 21, 22(partially)

Invention 1 is directed to the sensor comprising an electrically conductive mesh or grid.

2. claims: 14, 17(completely); 21, 22(partially)

Invention 2 is directed to mounting the sensor at a location in an air bleed duct comprising a location designed for an ozone converter.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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