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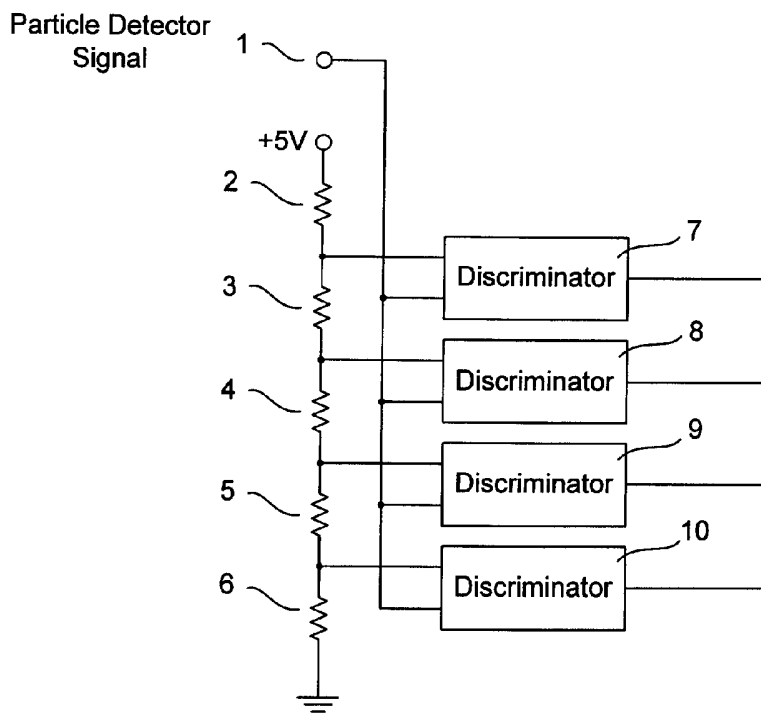
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(54) Title: METHOD AND APPARATUS FOR PARTICLE SIZING



(57) Abstract: A method and apparatus (100) for particle sizing. A particle detector signal (1) is utilized to provide particle size information (60). The particle detection signal (1) is obtained by utilizing particle detection information (102).

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METHOD AND APPARATUS FOR PARTICLE SIZING

RELATED APPLICATION

This application claims priority to U.S. Provisional Application number 60/415,911, titled "Particle Sizing Method", filed on October 2, 2002, which is
5 hereby fully incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the field of hygiene. More specifically it relates to the monitoring of airborne contaminants inside structures,
10 including but are not limited commercial, industrial, and residential buildings, as well as public transportation, airplane, train, ship, and the like.

2. Background Information

The measurement of indoor aerosols is a key activity in diagnosing indoor air quality problems in buildings, residences, public offices, manufacturing
15 sites, public transportation and other places where people spend extended time indoors. These aerosols can vary in composition and concentration by location, geography, time-of-day and other factors. Identifying the size distribution of the indoor aerosol is very important in diagnosing and fixing indoor air quality problems. Size is considered a strong function of the origin of the contaminant.
20 For example, cigarette smoke particles are generally less than 1 micron in size where most pollens range from 5-50 microns in size.

Light scattering instruments have been used for the past 20 years to quantify the amount of aerosol by providing a single number that can be used to estimate the total concentration in units of mass/volume, e.g. micrograms per
25 cubic meter. These instruments are typically expensive, heavy, and provide only a simple snapshot of the distribution of particles in an aerosol.

3. Terminology

Throughout the remaining specification, including the claims, usage of the term "particle" is intended to include aerosols found in buildings, residences, mass transportation vehicles etc., such as: general particulate matter, fine dust
5 from building materials, plants and animal allergens, mold and mildew spores, the inflammatory, toxic or mutagenic residue from the growth of mold or gram negative bacteria, man-made pollution such as exhaust from fuel combustion, and any other matter suspended in the ambient air in the form of an aerosol that will scatter light. Further, the use of the term "nephelometer" applies to a general class of
10 instruments that use scattered light measurement to quantity the amount and provide information on the size of particles in an indoor aerosol.

BRIEF DESCRIPTION OF DRAWINGS

Embodiments of the present invention will be described referencing the accompanying drawings in which like references denote similar elements, and in
15 which:

Figure 1 illustrates the digitization of amplified pulses from the detector of a nephelometer into four channels that are determined by voltage levels on four comparators, in accordance with one embodiment.

Figure 2 illustrates comparing a particle detector signal to different trigger
20 levels of different discriminators, in accordance with one embodiment.

Figure 3 illustrates programming a threshold level by a microprocessor, in accordance with one embodiment.

Figure 4 illustrates the signal representing the amplified pulses from the detector of a nephelometer and conversion to digital pulses via comparators, in
25 accordance with one embodiment.

Figure 5 illustrates the arrangement reading the information of e.g. two channels and transferring it to a microcontroller, in accordance with one embodiment.

5 Figure 6 illustrates a similar arrangement as in Figure 5, but implemented in programmable logic or ASIC, in accordance with one embodiment.

Figure 7 illustrates the implementation of four channels using a dedicated microcontroller, in accordance with one embodiment.

Figure 8 illustrates the direct reading of the analog data from Figure 1 with an Analog to Digital converter, in accordance with one embodiment.

10 Figure 9 illustrates an exemplary method of analyzing the particle data, in accordance with one embodiment.

Figure 10 illustrates analyzing particle data with an Analog to Digital converter and Peak Detector, in accordance with one embodiment.

15 Figure 11 illustrates the timing sequence of the implementation of Figure 8, in accordance with one embodiment.

Figure 12 illustrates an example of the digitization of amplified pulses from the detector of a nephelometer into a channel that is determined by a voltage level on a comparator to provide output data expressed as mass per volume of air, in accordance with one embodiment

20 Figure 13 illustrates an example of analog output data expressed as mass per volume of air for three particle ranges, in accordance with one embodiment.

Figure 14 illustrates an example of providing data expressed as mass per volume of air measured multiple particle size ranges, in accordance with one embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of particle sizing methodology and apparatus are described herein. In the following description, numerous specific details are set forth to provide a thorough understanding of embodiments of the invention. One skilled
5 in the relevant art will recognize, however, that the invention can be practiced without one or more of the specific details, or with other methods, components, materials, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of the invention.

Reference throughout this specification to "one embodiment" or "an
10 embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment.
15 Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

Overview

The scattered light signal from the light detector of a nephelometer, resulting from a particle moving through the focal point by simple movement of
20 air, can be measured. When the signal is strong enough to be distinguished from background noise, amplified and connected to several signal level discriminators or comparators, the resulting signal can then be processed by various methods. A typical nephelometer has an optical section, a differentiator to select particle related signals from background light and pre-amplifier to
25 enhance the signal level. The resulting signal is fed to a discriminator and a charging circuit that produces an averaged signal and is proportional to mass per volume of air. The invention makes use of the signal prior to the built-in

discriminator. During this discussion, the signal prior to the built-in discriminator is referred to as the particle detector signal.

A larger particle results in a larger signal at the particle detector signal, likely triggering a voltage discriminator with a higher voltage reference level.

5 Taking advantage of this, several channels can be designed to represent pulses from particles able to trigger the discriminator for each channel. The data from these channels can then be analyzed to determine the ratio of particles in each channel. This process is independent of the airflow within certain levels as all particles are drawn through the detector at virtually the same speed. Depending
10 on the number of channels, a histogram can be calculated from the data of each channel. This channel information can be obtained by counting the number of pulses of each channel in a preset time interval. Assuming that the lowest particle size range is represented by channel A, the middle particle size range by channel B and the largest particle size range by channel C; the percentages of
15 each channel can be calculated in the following way from the total particle distribution.

$$\text{Percentage of particles in range A} = (A - B) / A$$

$$\text{Percentage of particles in range B} = (B - C) / A$$

$$\text{Percentage of particles in range C} = C / A$$

20 The typical analog output of the nephelometer provides the total particulate level and is fairly independent of airflow. The analog value is proportional to the total mass per volume of particles in the air. The invention provides the additional particle sizing information for a nephelometer. The particle sizing results are fairly independent of airflow since the particle sizing
25 information is ratio metric as expressed by the equation above. When the airflow changes, all of the particle size ranges are affected by the same relative change. For applications where the airflow is well defined, a more accurate particle count per volume of air can be measured.

The invention also provides a means to add particle size dependent analog output channels that provide data is expressed as mass per volume of air for particles larger than set by the added discriminator.

The output formats of the invention include (A) relative pulse data per
5 particle size, (B) calculated mass per volume of air for each particle size range
and/or (C) direct analog output in mass per volume of air similar to the traditional
output of the nephelometer.

While a typical nephelometer expresses particles in the air in mass per
volume of air, a particle counter will yield particles per volume of air. The
10 invention adds (A) absolute and ratio metric particle size information and (B)
particle size count to a typical nephelometer by extracting the analog signal from
the preamplifier output.

Detailed Description

The scattered light signal from the light detector of a nephelometer
15 resulting from a particle moving through the focal point by simple movement of
air can be measured by converting the light signal to an electrical signal that can
be connected to particle detector signal to obtain specific size data of that
particle. An example of a nephelometer **100** is illustrated in Figure 1. The device
has the ability to separate particle signals from background light. A particle **101**
20 passes the particle detector optics **102** that detect its scattered light. The
electrical signal from detector **102** is separated from background light and
amplified by differentiator amplifier **103**. The resulting analog pulse is connected
to a voltage discriminator to separate particle signals from noise signals. A
discriminator is a device to provide an output when an input is over a given
25 voltage or trigger level. This device is also known as voltage comparator.
Processing circuit **105** and output amplifier **106** typically provide an analog
voltage proportional with mass per volume of air. However, the added particle

detector signal **1**, at the output of particle detector **102**, can be used to obtain particle-sizing information.

As illustrated in Figure 2, the added particle detector signal **1** can be compared to four trigger levels of discriminators **7**, **8**, **9** and **10**, in accordance with one embodiment. The trigger levels are set by resistors **2**, **3**, **4**, **5** and **6**. Discriminator **10** has a lowest trigger level and discriminator **7** has a highest trigger level. The resulting digital pulses from such an analog signal are depicted in Figure 4; higher pulses represent larger particles. Channels CH1 - 4 show pulses of particles that are equal to or larger than the certain particle sizes. All pulses of a minimal particle detection size trigger, L1, are represented in channel CH1. Each subsequent channel represents particles higher than its correspondingly assigned trigger level L1 – L4. Figure 4 also shows when particle detector signal pulses, from different particle sizes resulting in different amplitudes, trigger various levels of four discriminators with levels L1, L2, L3 and L4. A small particle will yield only a small signal and result in a single pulse in channel CH1, while a larger particle may exceed the trigger levels of discriminators with higher trigger levels and yield a pulse.

The particle size distribution can be obtained in several ways. The embodiment of Figure 5 shows two channels. The analog particle detector signal **1** is connected to discriminators **9** and **10**. Discriminator **9** is connected to a counter device **11**. The parallel output bus of counter **11** is connected to a parallel to serial shift register **13**. Discriminator **10** is connected to counter **12**. The parallel output bus of counter **12** is connected to a parallel to shift register **14**. The serial output of shift register **13** is fed to shift register **14**. The output of shift register **14** is also connected to microprocessor **15**. The microprocessor **15** also controls the timing of the counters and shift registers. In one embodiment, the execution could be as follows. Microprocessor **15** enables counters **11** and **12** for a fixed time period, then clocks the data into shift registers **13** and **14** and finally resets counters **11** and **12** for the next time period and clocks the data into

the microprocessor **15** for further processing. The channel pulse distribution can be calculated from the ratio metric data from the channels. In alternative embodiments, other processing devices such as microcontrollers and digital signal processor may be utilized to perform the functions of, at least, the
5 microprocessor.

Figure 6 is a similar embodiment of Figure 5, but instead of individual counters and shift registers, programmable logic **16** such as a PLD or an ASIC is used. This may be a more economical implementation in case more than two channels are needed. The output of programmable logic **16** is connected to
10 microprocessor **15**. Further reduction is possible, as shown in Figure 7, by using a dedicated microprocessor **17** to analyze the data in the channels directly and transfer the results to the main system microprocessor **15**. If microprocessor **15** has enough I/O pins, then microprocessor **17** can be eliminated also.

The particle detector output of the nephelometer can be measured directly
15 with an analog to digital converter. The signal can be digitized and the result categorized to provide a histogram of the particle size distribution. One can measure each particle size by detecting the peak of each analog signal representing the scattered light of a particle. Figure 8 shows that the particle detector signal **1** can be connected to Analog to Digital (ADC) converter **19**. The
20 output of the ADC can be directly connected to the system microprocessor **15**. Particle detector signal **1** is also connected to discriminator **18**. ADC **19** can continuously take readings according to Figure 9. ADC **19** provides digitized values to the system microprocessor **15** of the analog particle detector signal illustrated in the top of Figure 9. The example illustrated in Figure 9 shows two
25 pulses of different peak values **21** and **22**. Trigger level **20** starts search period **28** at time **23** when the input signal exceeds trigger level **20** of discriminator **18**. The process is finished after the signal drops below and later exceeds the trigger level **20** again. The period between timestamps **25** and **26** is marked in Figure 7 as "search period 1" **27**. It is also possible to complete the sequence when the

signal drops below the trigger level at **24**. This results in "search period 2" **28**. The peak value is the highest reading during the search period. In another embodiment, it is possible to use a more extensive algorithm without the use of discriminator **18** that continuously searches for peak data.

5 A far less calculation intensive solution is in Figure 10, where peak detector **29** monitors particle detector signal **1** from the nephelometer. Microprocessor **15** monitors discriminator **31** and peak detector **29**. Peak detector **29** is enabled when trigger level **20** of Figure 11 is exceeded. Peak detector **29** is activated when the particle detector signal **1** exceeds trigger level
10 **20** as indicated by pulses **32** generated by discriminator **31**. When peak **21** is detected, resulting pulses **33** and **34** capture the peak voltage on sample and hold **61** and start Analog to Digital converter **30** to take a peak reading. The results are read by microprocessor **15**. Microprocessor **15** also controls Analog to Digital converter **30**. In another embodiment, Analog to Digital converter **30** can
15 be connected to the output of peak detector **29** and sample and hold **61** that also captures and stores the peak value of the pulse. After processing the Analog to Digital converter **30** data, microprocessor **15** resets peak detector **29** for the next event.

20 An implementation that does not require a microprocessor is shown in Figure **12**. The particle detector signal **1** is connected to discriminator **10** with trigger level **35**. Discriminator **10** output is at zero level when it is not triggered. When a pulse exceeds trigger level **35** then the output is high, e.g. +5V. The output is connected to capacitor **37** via resistor **36**. When the output is high, capacitor **37** will be charged by discriminator **10** via resistor **36**, otherwise it will
25 be discharged via resistor **36**. Low pass filter network resistor **36** and capacitor **37** integrate the pulses produced by discriminator **10** over time. Depending on component selection, the current charging via resistor **36** resembles a current source when operating at relative low voltages. Scaling amplifier **38** is used to

produce an analog output voltage on output **39** proportional with mass per volume of air.

Figure 13 shows the additional analog circuitry to create output channels that produce an analog voltage proportional with mass per volume of air for three channels. Input signals **40**, **41** and **32** are connected to the output of three
5 circuits as in Figure 12, each having a different trigger level. The circuit connected to input **40** has a trigger level slightly above the noise level, while **41** and **42** respond to higher trigger levels to accommodate larger particles. Amplifier **51**, resistors **43**, **44**, **45** and **46** serve as a differential amplifier to
10 produce analog output values for particles in the range between **40** and **41**. Amplifier **53**, resistors **47**, **48**, **49** and **50** serve as a differential amplifier to produce analog output values for particles in the range between **41** and **42**. As a result, output **53** provides an analog output for the smallest particles, while output **54** provides an analog output for medium sized particles and output **55** only
15 responds to larger particles.

The embodiments described in Figure 1 through Figure 9 can be used to enhance a particle sensor such as a nephelometer with additional particle details. A 'virtual' particle-sizing sensor can be computed by multiplying the channel count ratios described in the overview above with the traditional analog output of
20 the nephelometer that represents an analog voltage proportional with mass per volume of air. As a result, each calculated value will then represent a value proportional with mass per volume of air for the specific particle sizing range, e.g. 1 – 2 μm and 2 – 5 μm . These embodiments require a microprocessor. With the added circuitry of Figure 12 and Figure 13, the desired result is obtained without
25 microprocessor computations, and implemented in hardware directly.

Figure 14 shows nephelometer **56** and a particle sizing embodiment **58** such as described but not limited to Figures 1 – 9. Analog to Digital converter **57** reads the nephelometer data expressed as mass per volume of air and transfers it to microprocessor **59**. Microprocessor **59** also multiplies this data with the

ratios of particle sizing embodiment **58** and calculates the output data **60** representing mass per volume of air data for each particle range.

The threshold level for a discriminator can be determined by a fixed resistor ratio as in Figure 1, or may be programmed by a microprocessor such as
5 Figure 3. Microprocessor **61** generates a Pulse Width Modulated signal **62** that is connected to discriminator **64** via low pass filter **63**. The particle detector signal **1** is connected to the other input of discriminator **64**. By changing the duty cycle of Pulse Width Modulated **62** signal, the averaged DC level of low pass filter **63**
10 output effectively changes the desired particle size. While Figure 3 shows one method to provide a means for programmable particle sizing, there are many other embodiments that can accomplish the same, e.g. a microprocessor with built-in Digital to Analog converter. Figure 3 is only used to describe the basic idea.

Epilogue

15 Various embodiments for methods and apparatus of detecting particle size distribution are described. In one embodiment, a histogram describes the distribution of particles. This may be an additional piece of data of the analog output of an existing nephelometer representing the total particle level of an air sample. These methods will provide more specific information of the air sample.

20 As can be seen from the above description, a novel method and apparatus for determining particle sizing is disclosed. The above description of illustrated embodiments of the invention is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes,
25 various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. These modifications can be made to the invention in light of the above description.

CLAIMS

What is claimed is:

1. A particle sizing method comprising:
 - receiving a measurement value from a device;
 - 5 comparing said received measurement value against a plurality of reference values, said plurality of reference values each indicating a size of a particle; and
 - providing a particle size of a particle associated with said received measurement value based at least upon said comparing.
- 10 2. The particle sizing method of claim 1 wherein said measurement value comprises an analog measurement value.
3. The particle sizing method of claim 1 further comprising incrementing a
15 count associated with said particle size upon said providing a particle size.
4. The particle sizing method of claim 1 wherein said device comprises a nephelometer.
- 20 5. A particle sizing apparatus comprising:
 - an input to receive an indicia of particle size;
 - a plurality of discriminators coupled to said input; and
 - a reference circuit coupled to said plurality of discriminators, said
reference circuit to provide particle size reference information.
- 25 6. The particle sizing apparatus of claim 5 wherein said reference circuit comprises a plurality of resistors serially connected between a first reference voltage and a second reference voltage.

7. The particle sizing apparatus of claim 5 wherein said input to receive an indicia of particle size is coupled to an output of a nephelometer.
8. The particle sizing apparatus of claim 7 wherein said output of said nephelometer is coupled to particle detector of said nephelometer.
9. The particle sizing apparatus of claim 5 further comprising one or more logic devices coupled to said plurality of discriminators, said one or more logic devices to receive data from said plurality of discriminators.
10. The particle sizing apparatus of claim 9 wherein said one or more logic devices comprises a plurality of counters correspondingly coupled to said plurality of discriminators.
11. The particle sizing apparatus of claim 10 wherein said one or more logic devices further comprises a plurality of shift registers correspondingly coupled to said plurality of counters.
12. The particle sizing apparatus of claim 11 wherein said one or more logic devices further comprises at least one of a microprocessor, a digital signal processor and a microcontroller and wherein said plurality of shift registers are coupled together and wherein said plurality of shift registers are coupled to said at least one of a microprocessor, a digital signal processor and a microcontroller.
13. The particle sizing apparatus of claim 12 wherein said at least one of a microprocessor, a digital signal processor and a microcontroller to analyze pulse data from said discriminators, said pulse data indicating particle size information.

14. The particle sizing apparatus of claim 9 wherein said one or more logic devices comprises at least one of a Programmable Logic Device (PLD), an Application Specific Integrated Circuit (ASIC), and an Application Specific Standard Product (ASSP).
- 5
15. The particle sizing apparatus of claim 14 wherein said one or more logic devices further comprises at least one of a microprocessor, a digital signal processor and a microcontroller coupled to said at least one of a Programmable Logic Device (PLD), an Application Specific Integrated
- 10 Circuit (ASIC), and an Application Specific Standard Product (ASSP), said at least one of a microprocessor, a digital signal processor and a microcontroller to analyze pulse data from said discriminators, said pulse data indicating particle size information.
- 15 16. The particle sizing apparatus of claim 9 wherein said one or more logic devices comprises at least one of a microprocessor, a digital signal processor and a microcontroller to analyze pulse data from said discriminators, said pulse data indicating particle size information.
- 20 17. The particle sizing apparatus of claim 5 further comprising:
a plurality of resistors correspondingly coupled to outputs of said plurality of discriminators; and
a plurality of capacitors coupled to said plurality of resistors.
- 25 18. The particle sizing apparatus of claim 17 further comprising one or more scaling amplifiers correspondingly coupled to one or more of said plurality of capacitors.
- 30 19. The particle sizing apparatus of claim 18 wherein outputs from said one or more scaling amplifiers provide a voltage proportional with a mass per volume of air.

20. The particle sizing apparatus of claim 5 further comprising:
a plurality of resistors coupled to outputs of said plurality of
discriminators; and
5 one or more differential amplifiers coupled to said plurality of resistors.
21. The particle sizing apparatus of claim 20 wherein outputs of said
differential amplifiers provide analog voltage indications of mass per
volume of air for a particle size range.
10
22. A particle sizing apparatus comprising:
a plurality of low pass filter circuits;
a plurality of discriminators correspondingly coupled to said plurality of low
pass filter circuits;
15 a microprocessor coupled to said plurality of low pass filter circuits, said
microprocessor to facilitate provision of reference particle size
information to said plurality of discriminators; and
an input coupled to said plurality of discriminators to receive an indicia of
particle size.
20
23. The particle sizing apparatus of claim 22 wherein said provision of
reference particle size information is provided via a pulse width modulated
signal.
- 25 24. A particle sizing apparatus comprising:
an input to receive an indicia of particle size wherein said input receives
an analog indicia of particle size;
an analog to digital converter coupled to said input, said analog to digital
converter to provide digital particle size data corresponding to said
30 analog indicia of particle size; and

at least one of a microprocessor, a digital signal processor and a microcontroller coupled to said analog to digital converter.

- 5 25. The particle sizing apparatus of claim 24 wherein said input to receive an indicia of particle size is coupled to an output of a nephelometer.
26. The particle sizing apparatus of claim 25 wherein said output of said nephelometer is coupled to particle detector of said nephelometer.
- 10 27. The particle sizing apparatus of claim 24 further comprising a discriminator coupled to said input and said at least one of a microprocessor, a digital signal processor and a microcontroller.
- 15 28. The particle sizing apparatus of claim 27 wherein said at least one of a microprocessor, a digital signal processor and a microcontroller receives a trigger indicia from said discriminator and analyzes pulse data from said analog to digital converter based at least in part upon said received trigger indicia.
- 20 29. A particle sizing apparatus comprising:
an input to receive an indicia of particle size wherein said input receives
an analog indicia of particle size;
a peak detector coupled to said input;
sample and hold circuitry coupled to said peak detector;
25 an analog to digital converter coupled to said sample and hold circuitry;
and
at least one of a microprocessor, a digital signal processor and a
microcontroller coupled to said peak detector and said analog to digital
converter.

30

30. The particle sizing apparatus of claim 29 wherein said input to receive an indicia of particle size is coupled to an output of a nephelometer.
- 5 31. The particle sizing apparatus of claim 29 wherein said output of said nephelometer is coupled to particle detector of said nephelometer.
- 10 32. The particle sizing apparatus of claim 29 wherein said at least one of a microprocessor, a digital signal processor and a microcontroller receives a trigger indicia from said peak detector and analyzes pulse data from said analog to digital converter based at least in part upon said received trigger indicia.
- 15 33. The particle sizing apparatus of claim 29 further comprising a discriminator coupled to said input and said at least one of a microprocessor, a digital signal processor and a microcontroller.
- 20 34. The particle sizing apparatus of claim 33 said at least one of a microprocessor, a digital signal processor and a microcontroller receives a trigger indicia from at least one of said discriminator and said peak detector and wherein said at least one of a microprocessor, a digital signal processor and a microcontroller analyzes pulse data from said analog to digital converter based at least in part upon said received trigger indicia.
- 25 35. An apparatus comprising:
particle detector to detect particle related information;
first output circuitry coupled to said particle detector to provide a first output of detected particle related information;
integration circuitry coupled to said particle detector to integrate said particle related information over a period; and
30 second output circuitry coupled to said integration circuitry to provide a second output related to integrated particle related information.

36. The apparatus of claim 35 wherein said first output is an analog output.
37. The apparatus of claim 35 wherein said particle related information
5 comprises particle size information.

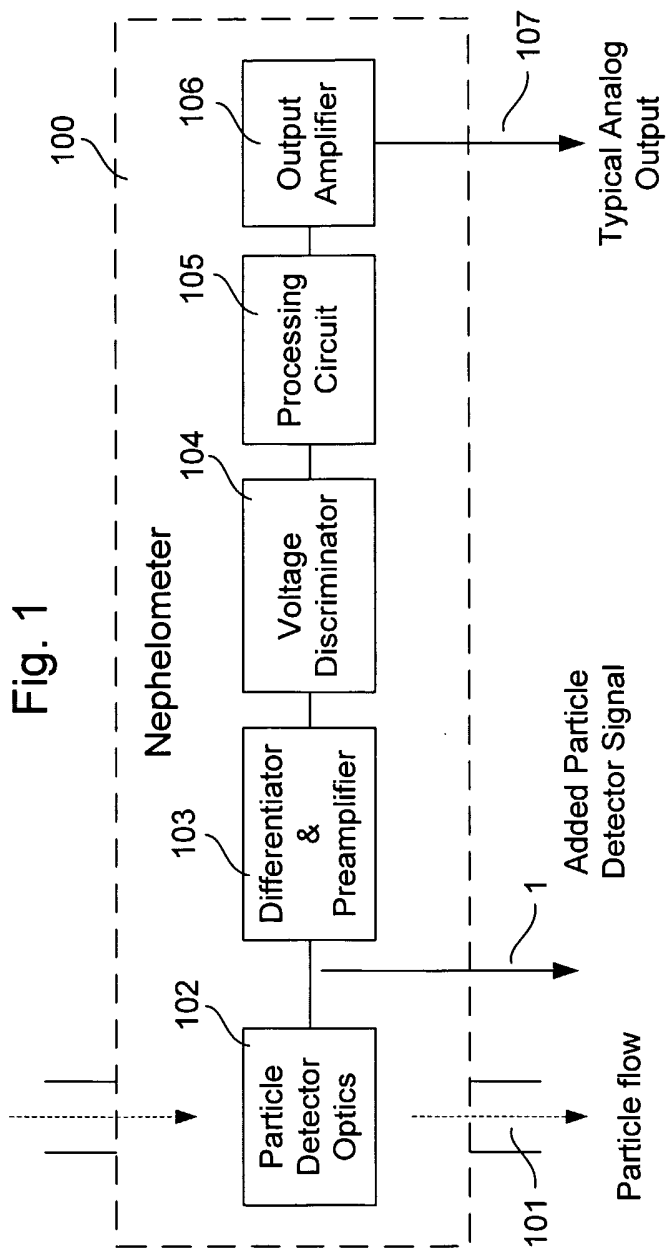


Fig. 1

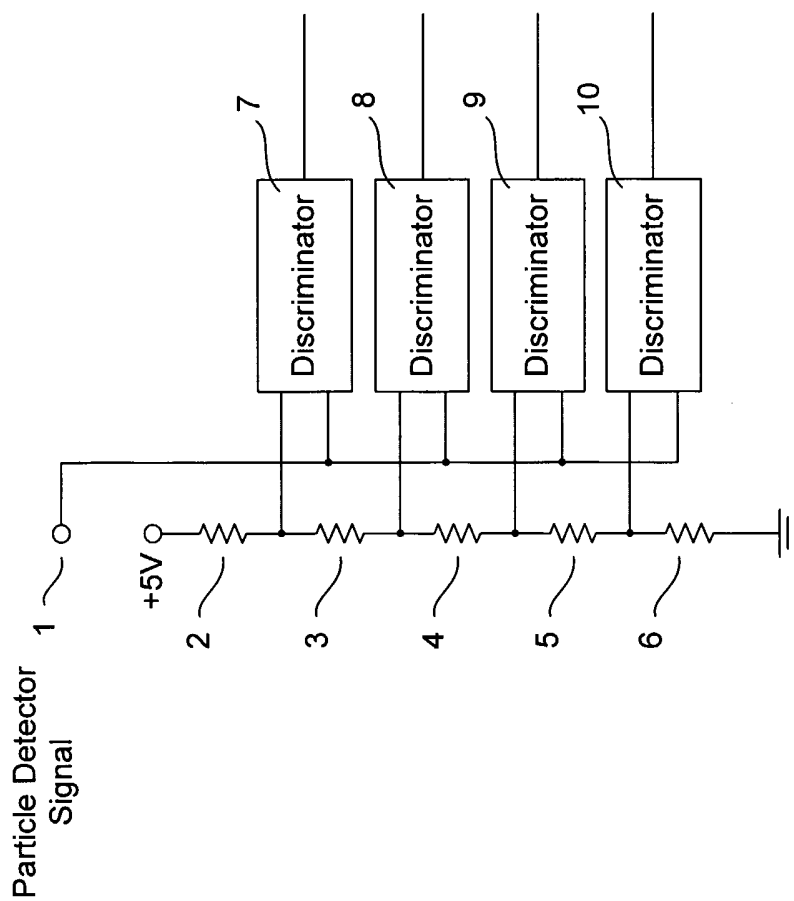


Fig. 2

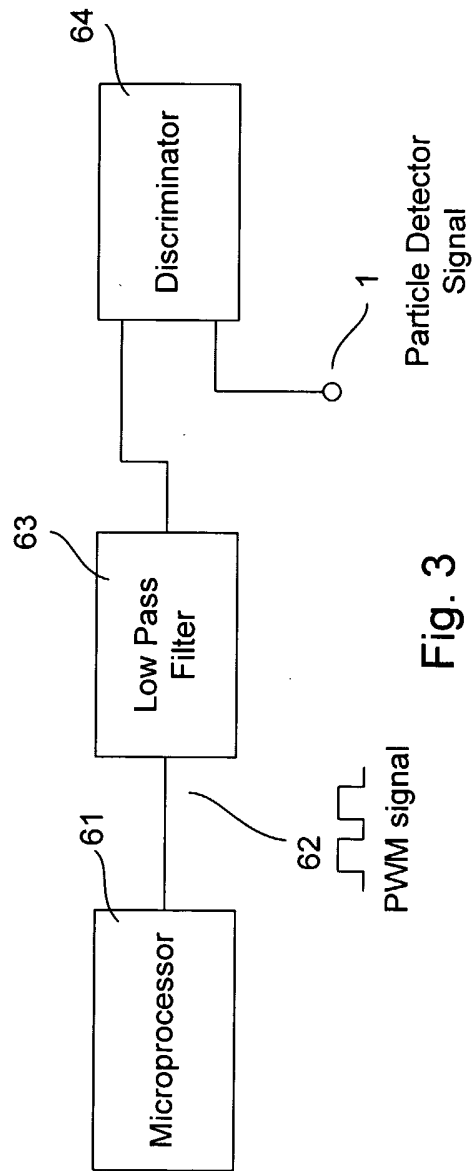


Fig. 3

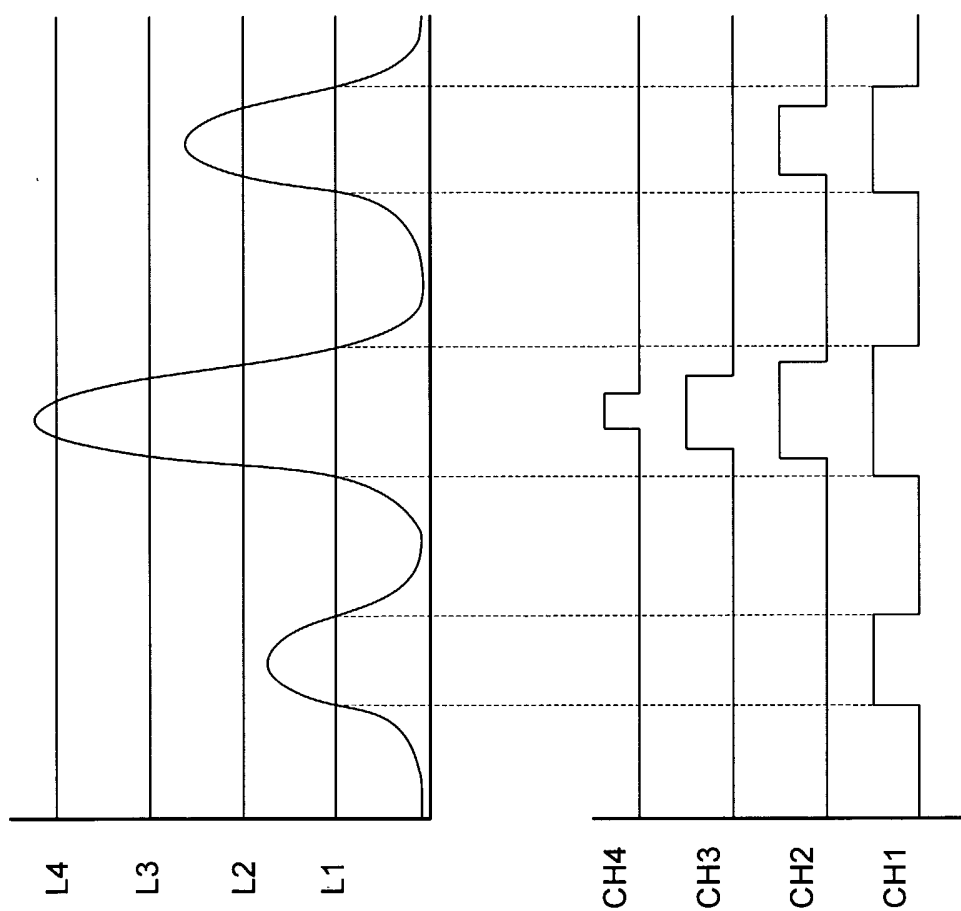


Fig. 4

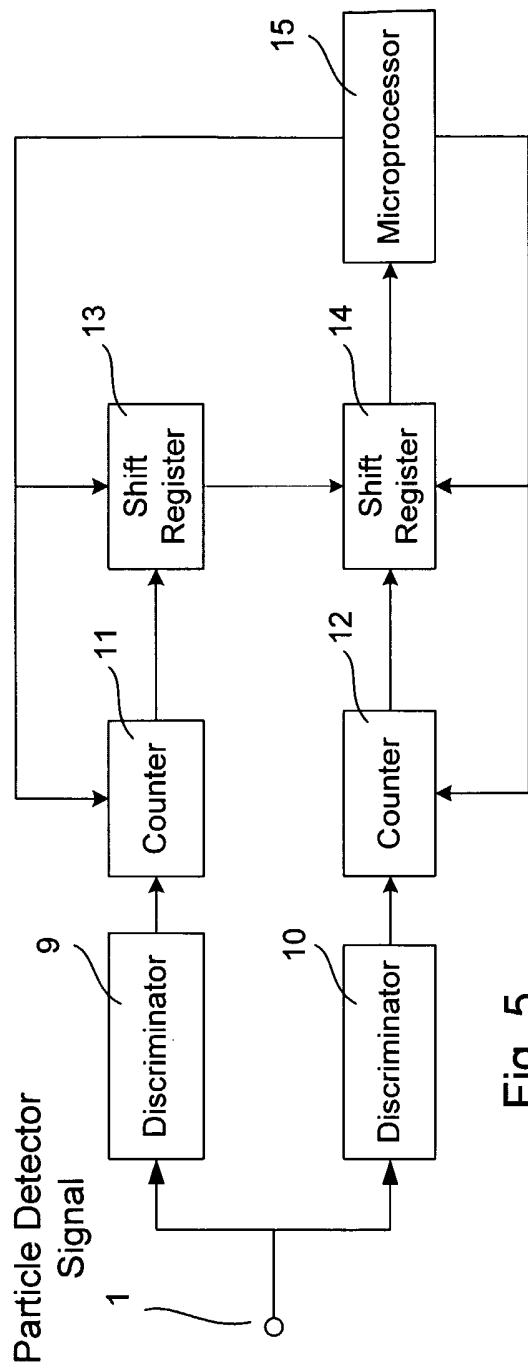


Fig. 5

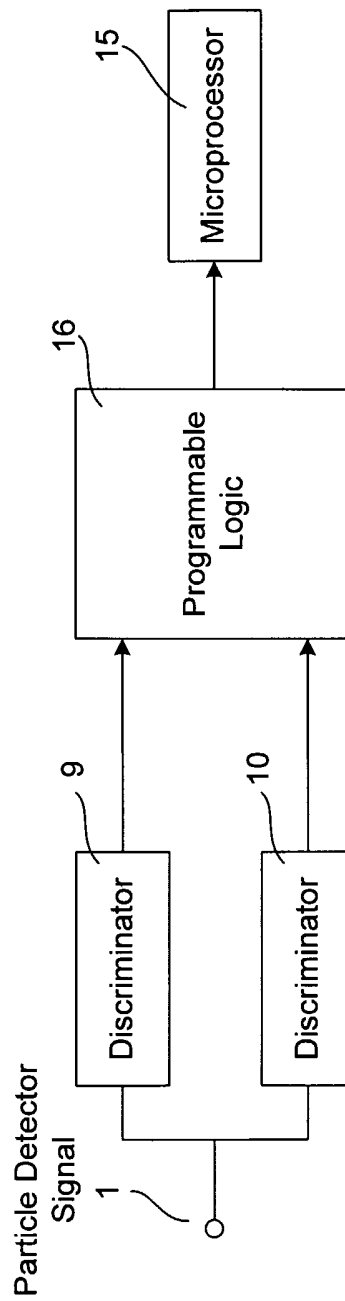
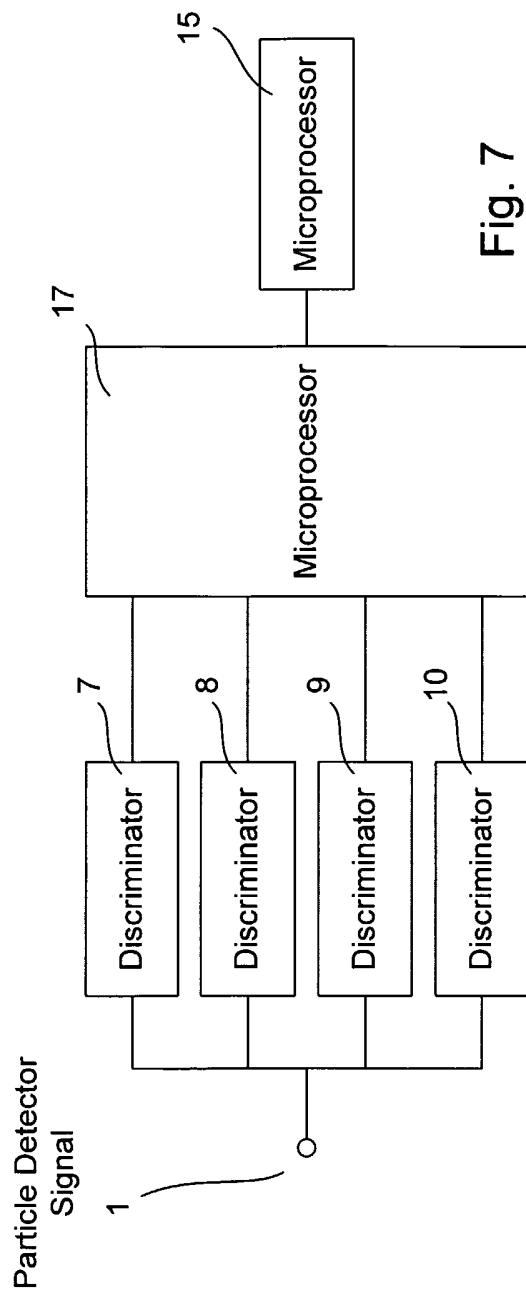


Fig. 6



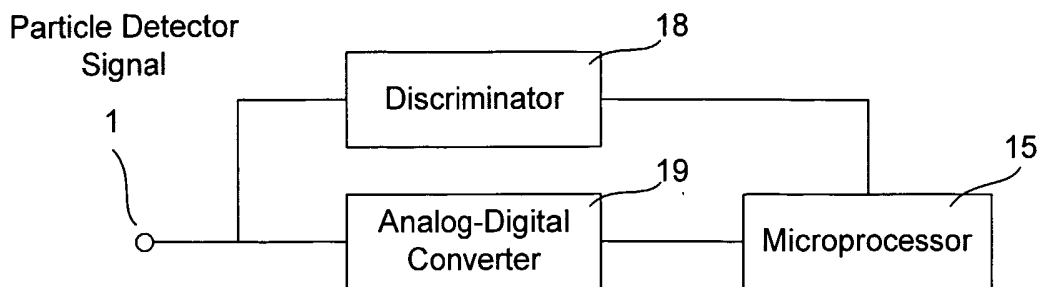


Fig. 8

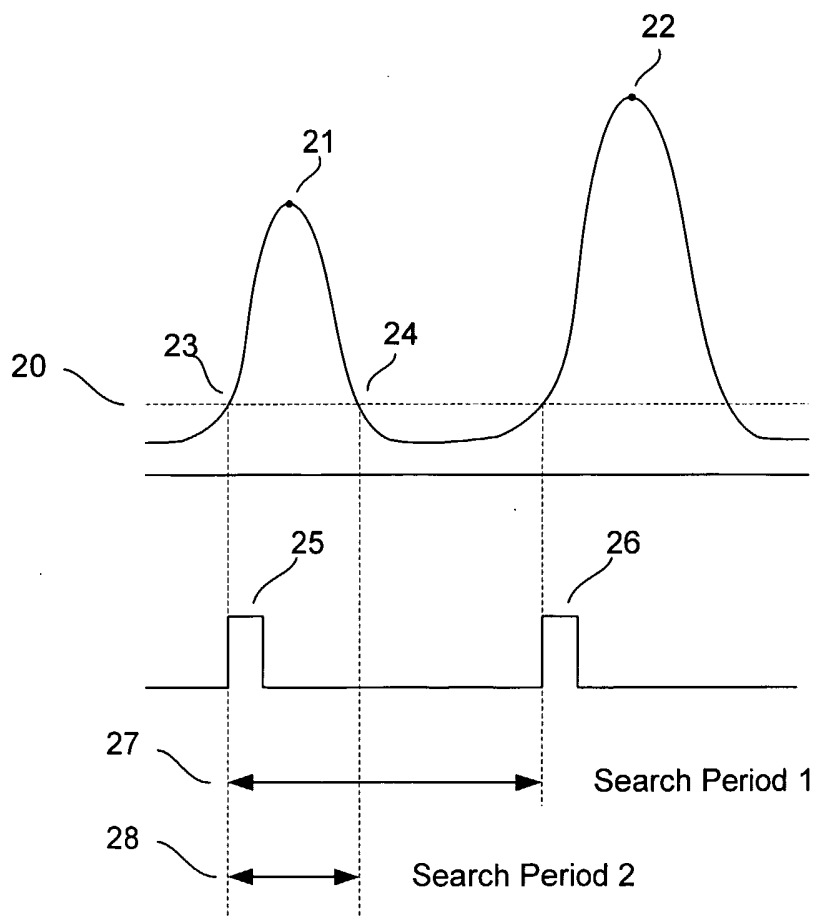


Fig. 9

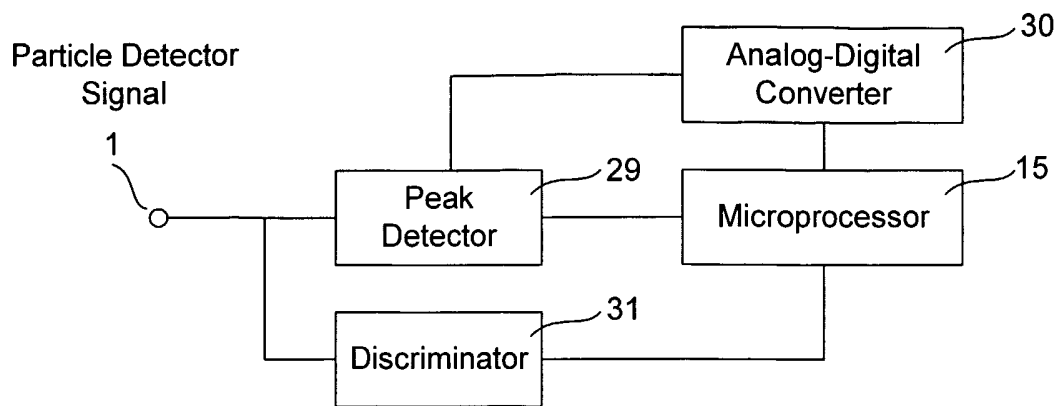


Fig. 10

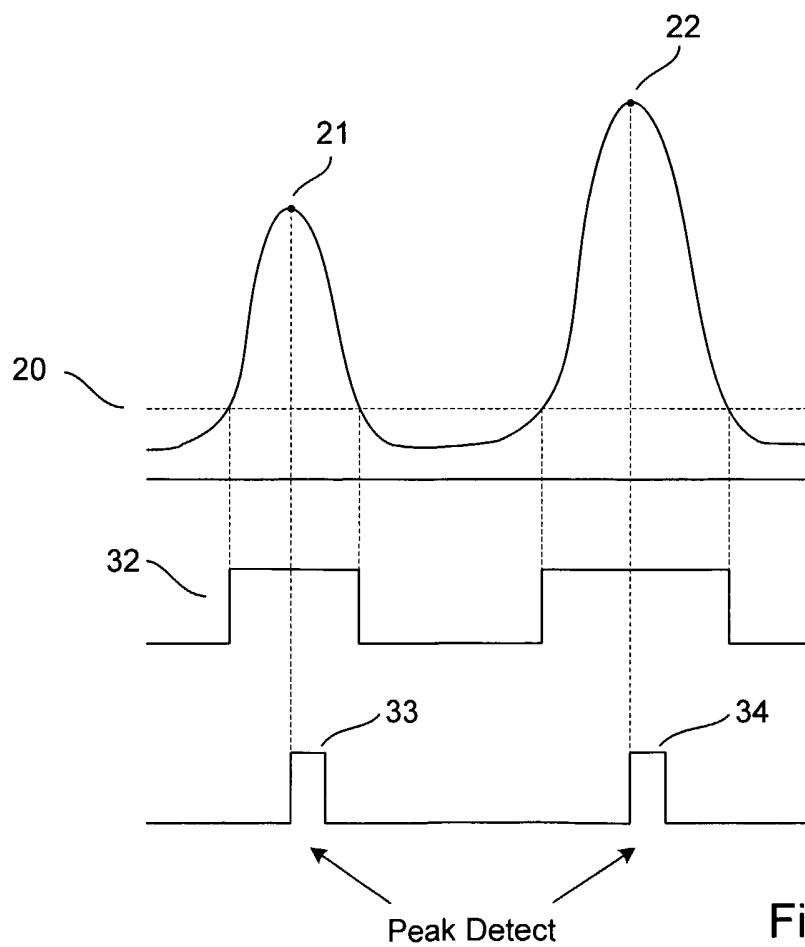


Fig. 11

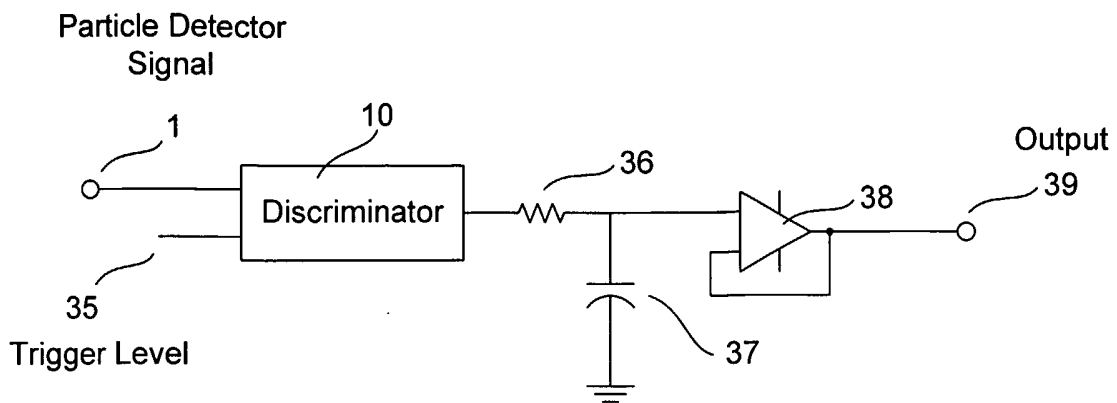


Fig. 12

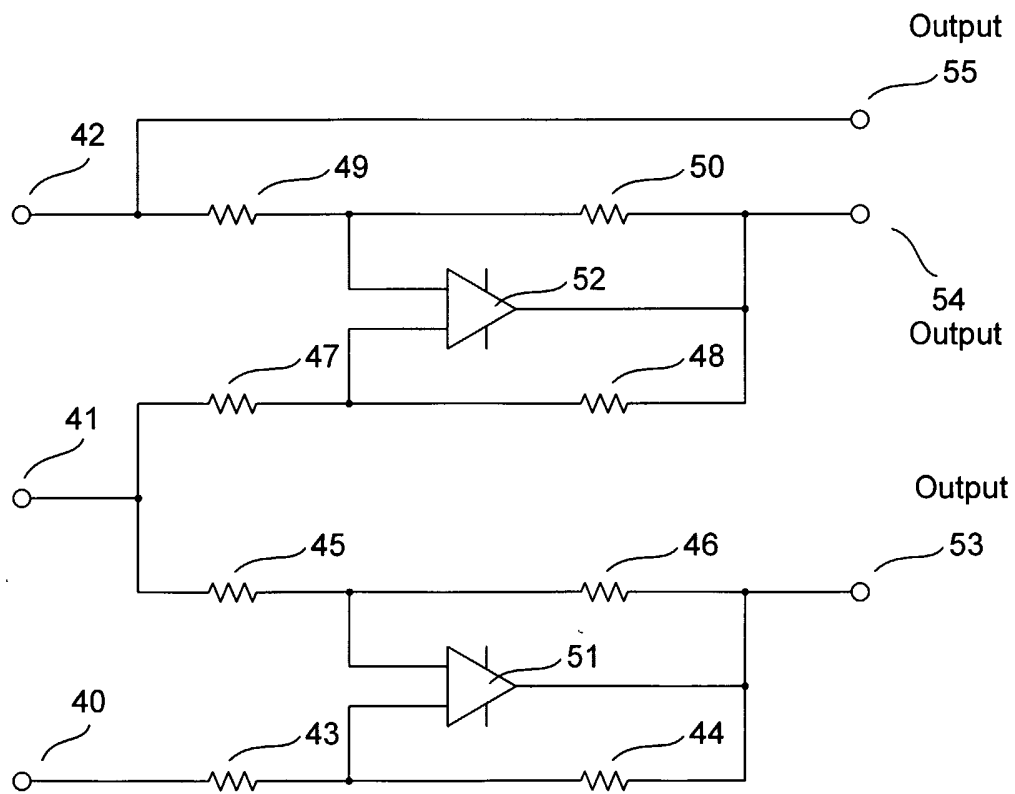


Fig. 13

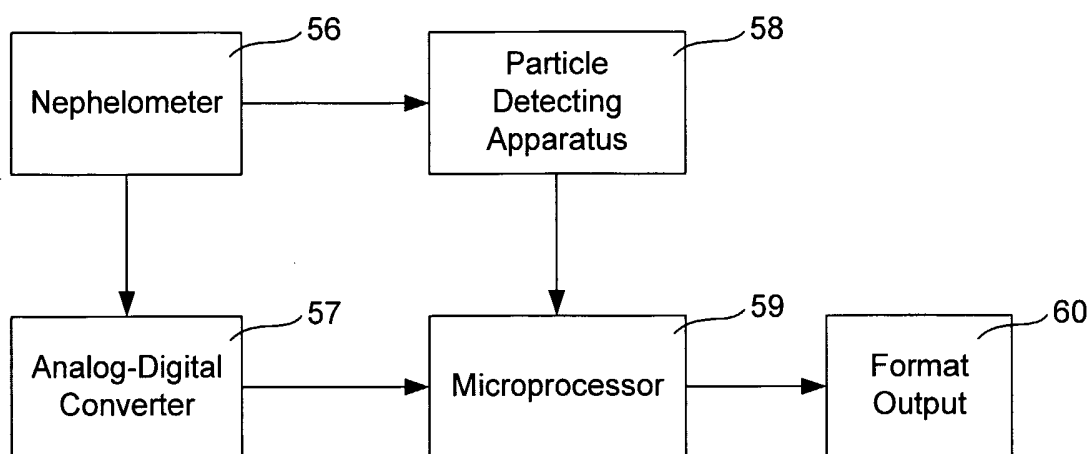


Fig. 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/31447

A. CLASSIFICATION OF SUBJECT MATTER
 IPC(7) : G01N 27/00, 21/00; G01R 23/165, 27/02, 27/08; G06M 1/00
 US CL : 324/71.4
 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)
 U.S. : 324/71.4, 71.1, 76.46, 76.48, 76.62, 76.63, 607, 712; 356/339, 341, 343

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 NONE

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,882,385 A (COULTER et al) 06 May 1975 (06.05.1975), see entire document.	1-3
X	US 4,305,665 A (ACHTER et al) 15 December 1981 (15.12.1981), see entire document.	1-9,17-21
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Y		10-16
X	US 6,337,564 B2 (MANZINI et al) 08 January 2002 (08.01.2002), see entire document.	22-24,27-29,35-37
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Y		10-16,25,26,30-34
A	US 3,902,053 A (FIGUEROA) 26 August 1975 (26.08.1975), see entire document.	1-3,5,6
Y	US 4,547,070 A (MOLL et al) 15 October 1985 (15.10.1985), see entire document.	25,26,30-34

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

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search: 23 January 2004 (23.01.2004)
 Date of mailing of the international search report: **18 MAR 2004**

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