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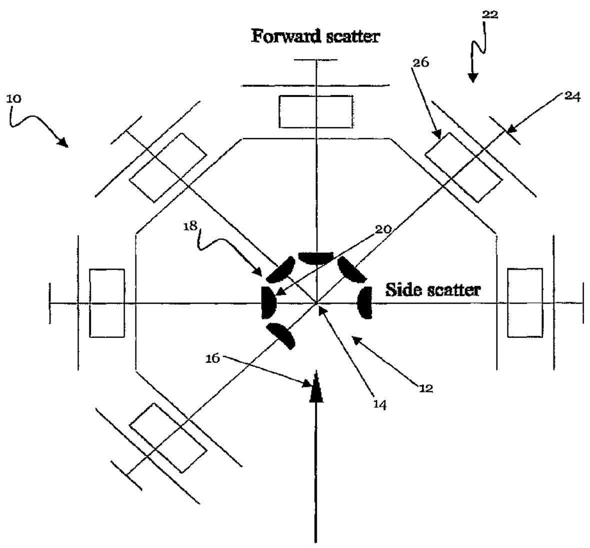
(54) Title: OPTICAL SYSTEM FOR A FLOW CYTOMETER



(57) Abstract: The preferred embodiments of the invention is an optical system for a flow cytometer including a flow channel with an interrogation zone, and an illumination source that impinges the flow channel in the interrogation zone from a particular direction. The optical system preferably includes a lens system and a detection system. The lens system preferably includes multiple lens surfaces arranged along a plane perpendicular to the flow channel and adapted to collect and collimate light from the interrogation zone. The detection system preferably includes multiple detectors adapted to detect light from the lens system. Each detector preferably includes a local filter that independently filters for specific wavelengths. Thus, the user may easily swap the filters in any order to achieve the same detection parameters.

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OPTICAL SYSTEM FOR A FLOW CYTOMETER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of US Provisional Application number 60/776,125, filed 22 February 2006 and entitled "Multiple Path System for an Interrogation Zone of a Flow Cytometer," which is incorporated in its entirety by this reference.

TECHNICAL FIELD

[0002] This invention relates generally to the flow cytometer field, and more specifically to a new and useful optical system in the flow cytometry field.

BACKGROUND

[0003] The conventional optical system for flow cytometers includes a collecting lens to collect light from the interrogation zone, beam splitters to split the light into different channels based on wavelength, and several detector subsystems with filters to pass only particular wavelengths (such as 515-545 nm, 564-606 nm, and 653-669 nm).

[0004] To use the conventional optical system, the beam splitters and filters must be arranged in a very particular order (monotonically increasing or decreasing order). For example, a first beam splitter must split between the two lower frequency bands, a first detector subsystem must filter between the lowest frequency band, a second beam splitter must split between the two higher frequency bands, a second detector subsystem must filter between the middle frequency bands, and a third detector subsystem must filter between the highest frequency bands. To change the wavelength detection of the conventional optical system (for example, to replace the frequency band that is originally the highest with a frequency band that is now the lowest) would require the re-arrangement of the entire optical system (including swapping both filters and beam splitters). In other words, with a conventional optical system, the step of filtering the light of the first channel affects the light of the second channel.

[0005] Thus, the user must skillfully arrange the filters in a particular order or the detector subsystems will not function correctly. This limitation prevents the easy swapability of the filters and the easy modification of detection parameters. Further, the particular arrangement of the optical table decreases the reliability and the ruggedness of the flow cytometer since the alignment of the beam splitters affects the detection of each of the detector subsystems.

[0006] Thus, there is a need in the flow cytometer field to create a new and useful optical system. This invention provides such new and useful optical system.

BRIEF DESCRIPTION OF THE FIGURES

[0007] FIGURE 1 is a schematic representation of the first preferred embodiment of the invention.

[0008] FIGURES 2 and 3 are detailed top and side views, respectively, of a collecting lens of a variation of the first preferred embodiment of the invention.

[0009] FIGURE 4 is a schematic representation of a second preferred embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] The following description of the preferred embodiments of the invention is not intended to limit the invention to these preferred embodiments, but rather to enable any person skilled in the art to make and use this invention.

[0011] As shown in FIGURE 1, the optical system 10 of the preferred embodiments of the invention is preferably integrated into a flow cytometer. In this preferred environment, the flow cytometer defines a flow channel 14 with an interrogation zone 12 and includes an illumination source 16 that impinges the interrogation zone 12 from a particular direction. The optical system 10 preferably includes a lens system 18 with multiple lens surfaces 20 arranged around the interrogation zone 12, and a detection system 22 with multiple detectors 24 arranged to detect the light collected and collimated by the lens system 18. The multiple detectors 24 are each coupled to a local filter 26 that independently filters the collected light for specific wavelengths. Although the optical system 10 of the preferred embodiment has been specifically designed for an interrogation zone 12 of a flow cytometer, the system may alternatively be used in any suitable system to collect light from a point along multiple paths.

[0012] The lens system 18 of the first preferred embodiment functions to collect and collimate the scattered and/or emitted light from the interrogation zone 12. Preferably, the lens system 18 includes at least three lens surfaces 20 (one forward scatter, one side scatter, and one florescence). More preferably, the lens system 18 includes five or more lens surfaces 20 (one forward, two side scatter, and two or more florescence). In the preferred embodiment, the lens system 18 is composed of separate lenses. In an alternative embodiment, the lens system 18 may be formed as a unitary piece with multiple facets. The lens system 18 is preferably arranged along a plane parallel to the light source and perpendicular to the flow channel 14, but may alternatively be arranged in any suitable manner.

[0013] In a first variation, as shown in FIGURE 1, the lens system 18 includes at least three whole lenses (preferably a 011-0330 spherical lens sourced from Optosigma of Santa Ana, California). The whole lenses preferably include a usable numerical aperture of approximately 0.31. In a second variation, as shown in FIGURE 2, the lens system 18 includes at least three truncated lenses (preferably a 46-347 aspherical lens sourced from Edmund Optics of Barrington, New Jersey). In other variations, the lenses may be whole or truncated, may be spherical or aspherical, and may be similar or dissimilar to each other.

[0014] The truncation of the lenses functions to increase the light collecting ability of the lens system 18, while maintaining a close proximity to the interrogation zone. There is a limit to the maximum size of the lens's numerical aperture due to the geometrical arrangement of the lenses around the interrogation zone 12. By truncating the lenses, they may be located the same distance from the interrogation zone 12 as a spherical lens, while having an increased height and therefore, an increased numerical aperture. With an increased light collecting ability (or increased numerical aperture of the lens surface), the system will be able to provide a brighter image and allow for the visualization of finer details. Preferably, the lenses are truncated to remove the edge of the lens. More preferably, as shown in FIGURES 2 and 3, the lenses are truncated approximately 35% in the horizontal direction to remove both the edge and a portion of the lens within the clear aperture diameter. The lenses may, however, may be truncated by any suitable amount to increase the light collecting ability of the lens system 18, while maintaining a close proximity to the interrogation zone. The width of the lens is the dimension in the plane of FIGURES 1 and 2. The numerical aperture of the lens can be increased by increasing the height of the lens. The power collection efficiency of the lens increases proportionally with the increase in height. The truncated aspherical lenses preferably include a usable numerical aperture of approximately 0.49.

[0015] The lens surfaces 20 may include coatings that function to convert the lens surfaces 20 to wavelength specific filters. The coatings may include various inorganic or organic compounds such that the compounds absorb specific wavelengths of light while transmitting other wavelengths. Each lens preferably has a different coating, such that it will filter a specific wavelength that is different from the wavelengths filtered by the other lens surfaces 20. Alternatively at least two lens surfaces 20 may have the same coating. The coated lens surfaces 20 may work cooperatively with the local filters 26 coupled to the detectors 24 that filter specific wavelengths, or may independently filter specific wavelengths.

[0016] The detector system of the first preferred embodiment functions to detect light from the lens system 18. The detector system preferably includes multiple detectors 24. The detectors are preferably a photomultiplier tube ("PMT") or a photodiode, but may alternatively include any suitable device, such as a camera, to detect light or other electromagnetic energy. In the first preferred embodiment, the detector system includes a detector 24 for every lens surface 20 of the lens system 18. The detectors 24 are preferably arranged in a direct path from the lens surfaces 20, and the light collected and directed by the lens system 18 is preferably guided to the detectors 24 by an appropriate light path. The light path is preferably an air channel for simplicity, but may alternatively be a fiber optic cable or any other appropriate waveguide. In a second preferred embodiment, as shown in FIGURE 4, the detector system includes more detectors 24 than lens surfaces 20 of the lens system 18. In this embodiment, the lens system 18 also includes conventional optic devices, such as beam splitters 28, to branch the collected and directed light to the detector system. In this embodiment, the beam splitters 28 are preferably nonselective with regard to wavelength, which preserves the freedom to independently filter for specific wavelengths (by using local filters 26) at each of the various detectors 24.

[0017] The detectors 24 are each coupled to a local filter 26 that independently filters for specific wavelengths. The local filter 26 is preferably easily accessed by the user, such that the user may swap in different filter and change the wavelength detection of the detector system. The step of filtering the light of the first channel preferably does not affect the light of the second channel of the detector system. Thus, the user may easily swap the filters in any order to achieve the same detection parameters. Further, since the each of the detectors is independently aligned with the local filter and the lens surface, the optic system experiences increased reliability and the ruggedness over conventional flow cytometers.

[0018] As a person skilled in the art will recognize from the previous detailed description and from the figures and claims, modifications and changes can be made to the preferred embodiments of the invention without departing from the scope of this invention defined in the following claims.

CLAIMS

We Claim:

1. An optical system for a flow cytometer that includes a flow channel with an interrogation zone, and an illumination source that impinges the flow channel in the interrogation zone from a particular direction, the optical system comprising:

- a lens system with multiple lens surfaces arranged along a plane perpendicular to the flow channel and adapted to collect and collimate light from the interrogation zone; and
- a detection system with multiple detectors adapted to detect light from the lens system, wherein each detector includes a local filter that independently filters for specific wavelengths.

2. The optical system of Claim 1 wherein the lens system includes a unitary piece with multiple facets defining the lens surfaces.

3. The optical system of Claim 1 wherein the lens system includes multiple lenses.

4. The optical system of Claim 3 wherein at least one of the lenses is truncated in the horizontal direction.

5. The optical system of Claim 4 wherein the truncated lens is aspherically curved in the vertical direction.

6. The optical system of Claim 5 wherein the truncated aspherical lens has a usable numerical aperture value between 0.45 and 0.55.

7. The optical system of Claim 2 wherein at least one of the multiple lenses is spherically curved.

8. The optical system of Claim 7 wherein the spherical lens has a usable numerical aperture value between 0.25 and 0.35.

9. The optical system of Claim 1 wherein the lens system includes at least three lens surfaces.

10. The optical system of Claim 9 wherein the lens system includes at least five lens surfaces.

11. The optical system of Claim 1 wherein the lens surfaces include a coating adapted converts the lens surface to a wavelength specific filter.

12. The optical system of Claim 1 wherein the detector system includes a detector for each lens surface of the lens system.

13. The optical system of Claim 12 wherein the light collected and collimated by the lens surfaces is guided in a direct path to the detectors.

14. The optical system of Claim 12 wherein the light collected and collimated by the lens surfaces is guided in an unbranched path to the detectors.

15. The optical system of Claim 1 wherein the detector system includes multiple detectors for each lens surface of the lens system.

16. The optical system of Claim 15 further including at least one beam splitter that branches the collected and collimated light from the lens surface to the multiple detectors.

17. The optical system of Claim 16 wherein the beam splitter is nonselective with respect to wavelength.

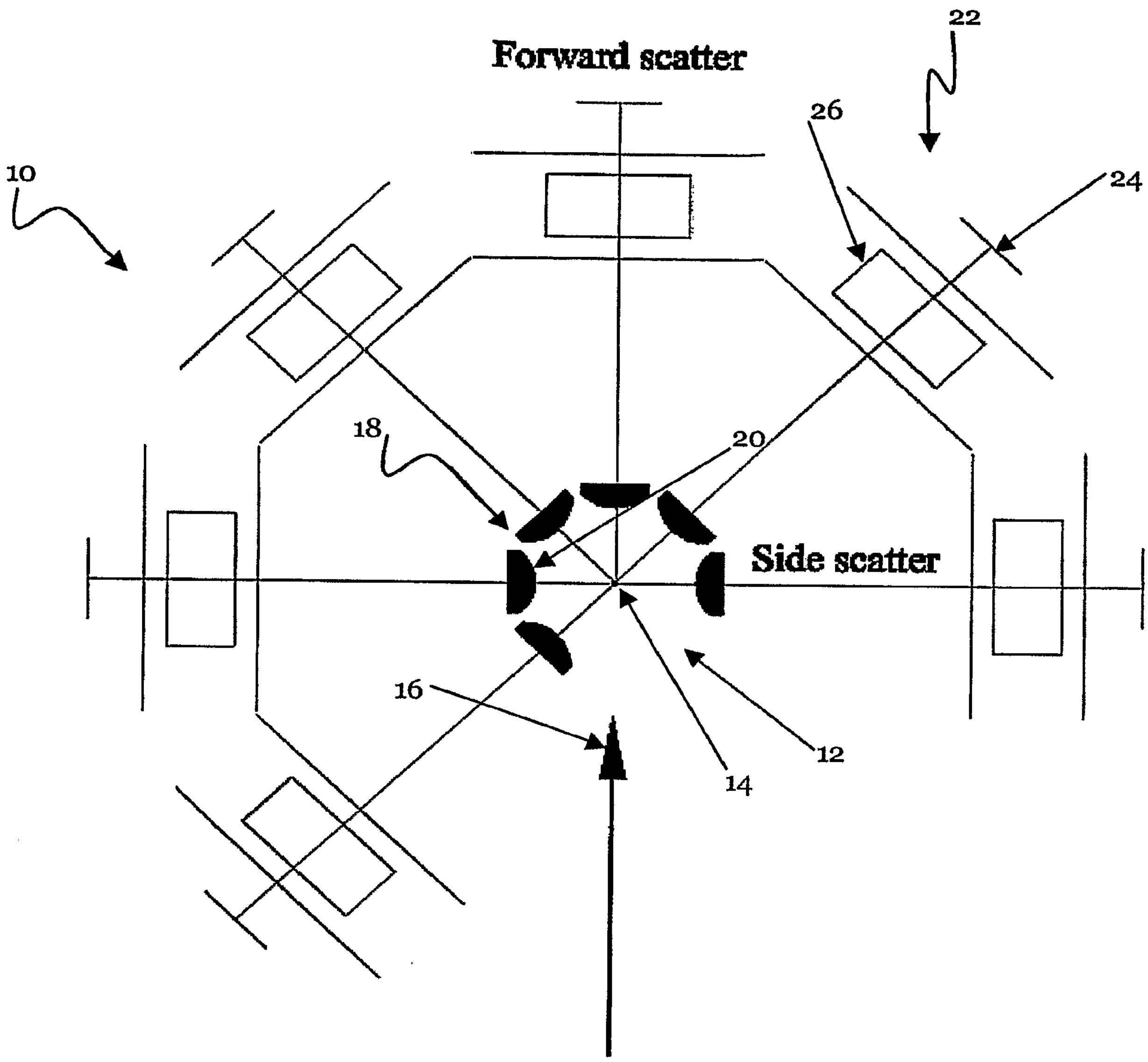

FIGURE 1

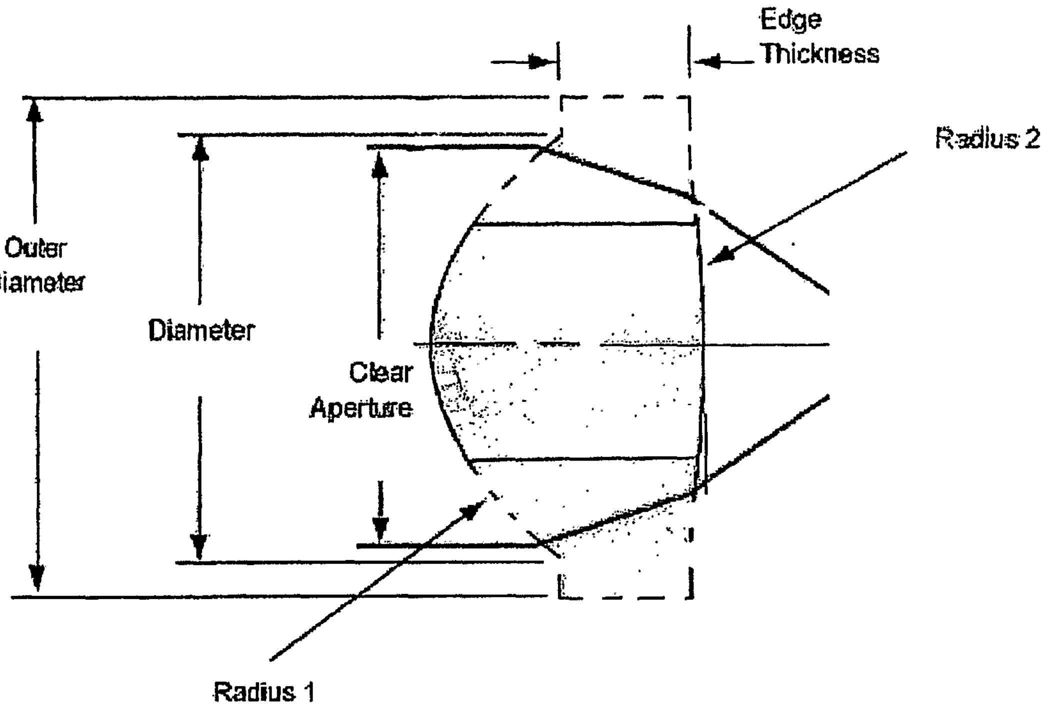
Edge
Thickness
Radius 2
Outer
Diameter
Diameter
Clear
Aperture
Radius 1

FIGURE 2

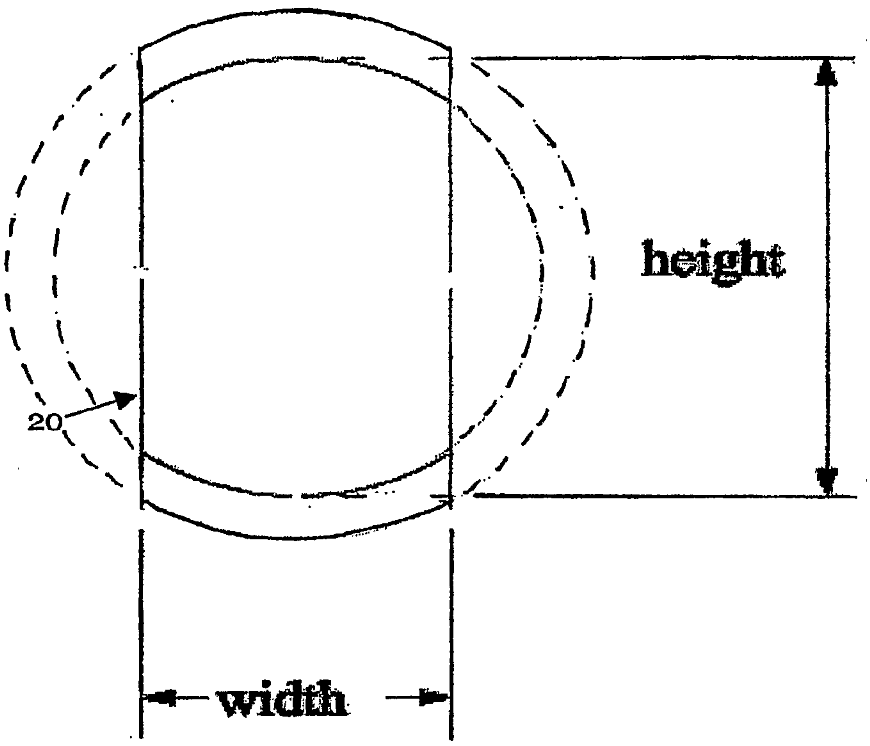

FIGURE 3

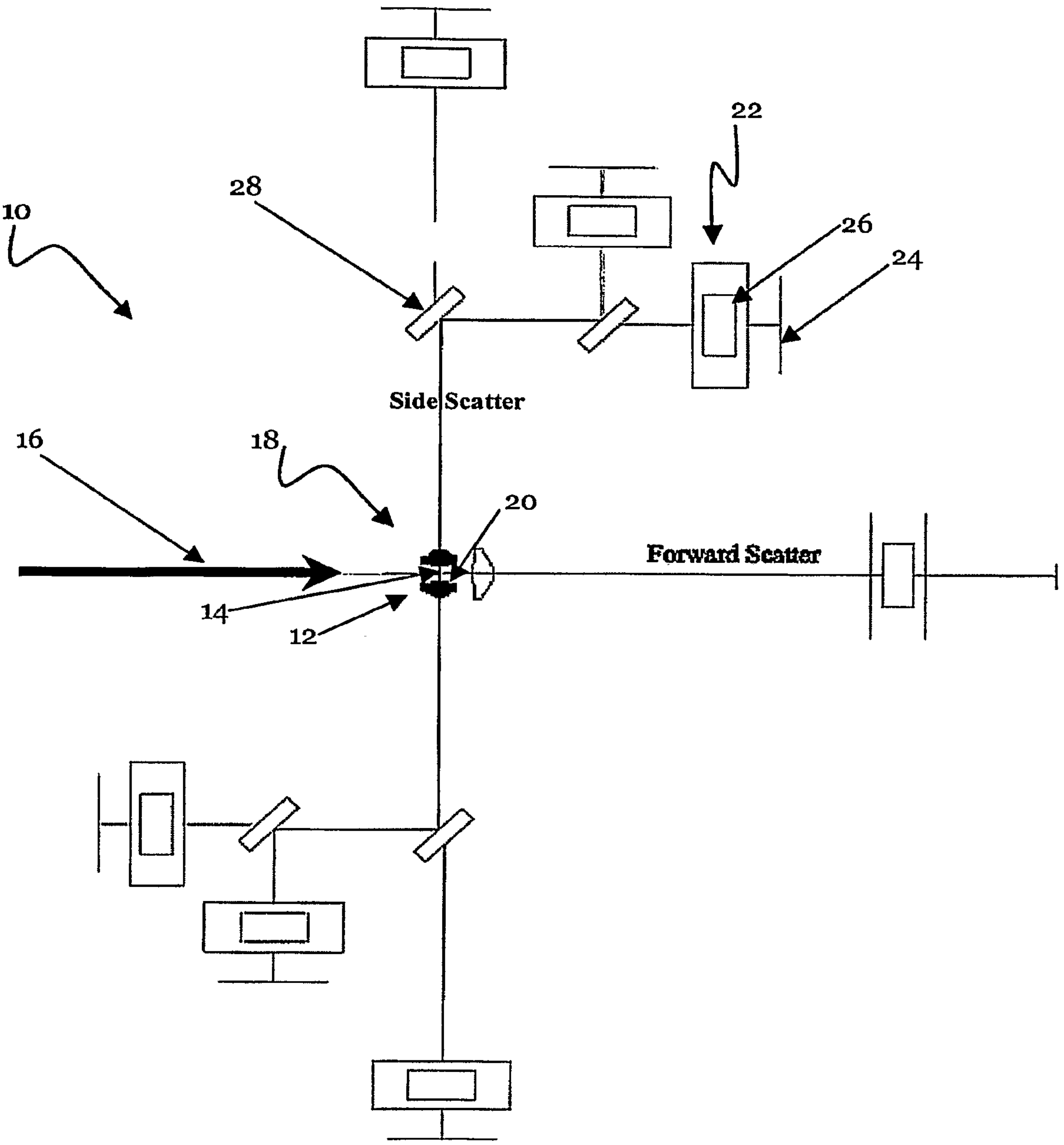

FIGURE 4