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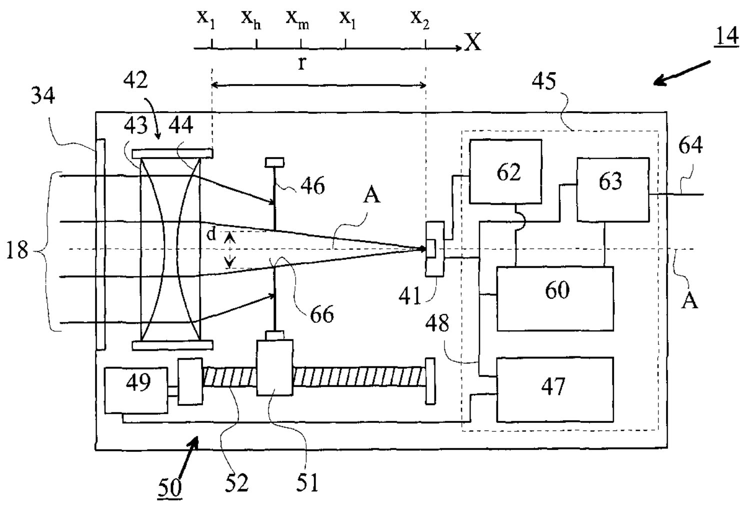
(54) **Title:** FREE SPACE COMMUNICATION RECEIVER UNIT WITH CONTROLLABLE POWER ATTENUATOR



(57) **Abstract:** A free space communication receiver unit (14) comprises a photo-detector (41) for detecting the light intensity of an incoming light beam (18), and an optical lens system (42) for focusing the incoming light beam (18) onto the photo-detector (41). Variable optical power attenuation means is provided between the lens system (42) and the photo-detector (41) for the attenuation of the optical power incident on the photo-detector (41). The attenuation means comprises an aperture (46) on the optical axis (A) between the lens system (42) and the photo-detector (41), in a region where the effective diameter of the incoming light beam (18) is varying as a function of the position along the optical axis (A). The aperture (46) may be translated along the optical axis in the region, so that the effective optical power passing through the aperture (46) varies as a function of the position along the optical axis (A).

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FREE SPACE COMMUNICATION RECEIVER UNIT WITH CONTROLLABLE POWER ATTENUATOR

Field of the invention

The invention concerns a free space communication receiver unit, which is normally used for providing a wireless data transfer facility between two sites.

Background of the invention

Most known free-space receivers have a photo-detector for detecting the light intensity of an incoming light beam. The receivers further comprise an optical lens system for focusing the incoming light beam onto the photo-detector. It is known to provide variable optical power attenuation means between the lens system and the photo-detector. These attenuation means serve for the attenuation of the optical power incident on the photo-detector. There are known solutions where the attenuation means are realised with a variable aperture, which is positioned somewhere on the optical axis before the photo-detector. US Patent No. 4,307,294 mentions the possibility to insert a motorised iris, i. e. a variable diameter aperture between the focusing lens and the photo-detector. However, this setup is prone to certain problems. Free-space communication receivers are often placed on rooftops and similar locations, and are therefore subjected to harsh weather conditions, e. g. sub-zero temperatures and sudden temperature changes. Variable apertures available on the market are mostly realised with precision mechanics that are prone to failure under such circumstances. The object of the invention is to provide an improved attenuation system, mainly for such free-space communication receivers.

Summary of the invention

According to an embodiment of the invention, there is provided a free space communication receiver unit, which comprises a photo-detector for detecting the light intensity of an incoming light beam. The receiver unit also comprises an optical lens system for focusing the incoming light beam onto the photo-detector. The variable optical power attenuation means are positioned between the lens system and the photo-detector, and during the operation of the receiver, serve for attenuating the optical power incident on the photo-detector. It is foreseen that the variable optical power attenuation means comprises an aperture, which is positioned on the optical axis between the lens system and the photo-detector. The aperture is positioned in a region where the effective diameter of the incoming light beam is varying as a function of the position along the optical axis, i. e. where the effective area of the cross section of the beam is not constant. Typically, such regions are found between focal points and the optics which generate the focal points on the beam. There are also moving means or translating means for translating the aperture along the optical axis in said region, i. e. where the effective diameter of the incoming light beam is varying as a function of the position along the optical axis. This results in the effective optical power passing through said aperture being varied as a function of the position along said optical axis, when the aperture is moved along the optical axis. The receiver unit further comprises a power control circuit connected to the photo-detector. The power control unit serves for controlling the variable optical power attenuator means, and thereby controlling the optical power level incident on the photo-detector.

The proposed receiver provides a number of advantages. Firstly, the aperture may be a fixed aperture, and the moving means for translating the aperture need not be very sophisticated, and may be easily constructed in a very rugged fashion. Secondly, the proposed attenuation system may be readily constructed from commercially available, low-cost components.

Brief description of the drawings

Fig. 1 is a schematic figure illustrating the application of the invention,

Fig. 2 is a schematic drawing of a sender unit and a receiver unit of a free-space communication link,

Fig. 3 is a schematic cross-section of a receiver unit with a power attenuation system embodying the present invention, with the aperture in a first position,

Fig. 4 is a schematic cross section of the receiver unit of Fig. 3, with the aperture in a second position,

Fig. 5 is a front view of a variable aperture applied in a further embodiment of the invention,

Fig. 6 is a schematic cross section of a receiver unit similar to that of Fig. 3, but with a different layout of the control circuitry,

Fig. 7 illustrates the relation between the output signal of the photo-detector and the position of the aperture,

Fig. 8 illustrates the relation between the output signal of the photo-detector and the output signal of the control circuit of the moving means in an embodiment of the invention, and

Fig. 9 illustrates the relation between the total optical power passing through the lens system and the position of the aperture.

Detailed description of the invention

The free space receiver unit embodying the invention is particularly used in a communication link 10, which is shown schematically in Fig. 1. As it is known in the art, the communication link 10 consist of a transmitter unit 12 and a receiver unit 14, which are placed in the shown example on the roof of two buildings 16,17. There is an unobstructed line of sight between the transmitter unit 12 and the receiver unit 14, so that a laser beam 18 emitted by the transmitter unit 12 and directed towards the receiver unit 14 will be received by the latter. The laser beam 18 is modulated with signals carrying data from a computer 21, usually forwarded to the transmitter unit via an optical cable 22. On the receiver side, the modulated laser beam 18 is detected by a photo-detector in a manner described below, and the data are extracted from the optical signal by signal decoding circuitry known per se. The extracted data are forwarded from the receiver unit 14 via the optical cable 23 to another computer 24. This arrangement is well known in the art, and need not be discussed in more detail.

Turning now to Fig. 2, the optical system of the communication link is shown in greater detail. The transmitter unit 12 comprises a laser 31 and collimating optics 32. The laser 31 is controlled by the laser driver 33, which in turn receives the modulating signal from an input source, e. g. the optical cable 22. The collimating optics 32 produces a substantially parallel laser beam 18 from the divergent radiation pattern of the laser 31, which is typically a diode laser operating in the near infrared range.

The laser beam 18 has normally expanded in diameter when it reaches the aperture 34 of the receiver unit 14, so it may be safely assumed that the complete aperture 34 is illuminated. Due to the expansion or widening of the laser beam 18, the aperture 34 is made as large as possible, to be able to trap a large portion of the optical power of the laser beam 18.

With reference to Fig. 3, the receiver unit 14 of the communication link 10 comprises a photo-detector 41 for detecting the light intensity of the incoming laser beam 18. There is an optical lens system 42 for focusing the incoming laser beam 18 onto the photo-detector 41. In the shown embodiment, the optical lens system 42 consists of two lenses 43,44, but other suitable focusing optics may be used as well. The output of the photo-detector 41 is connected to the receiver circuit 45, and the obtained data signal is forwarded to an output line 64, which may be embodied by the optical cable 23.

Due to changing atmospheric conditions, e. g. clouds 19 or fog between the two end points of the communication link 10 (see also Fig. 1), the power loss between the transmitter unit 12 and the receiver unit 14 may be substantial. To compensate for this eventual power loss, the output power of the laser 31, and therewith the power transmitted by the laser beam 18 is set to a relatively high level, even to the extent so that the power substantially surpasses the saturation threshold of the photo-detector 41. If the weather is clear, the power loss in the air may be relatively small, and the power falling on the photo-detector 41 may be too high. For this reason, variable optical power attenuation means is provided before the photo-detector 41, with the purpose of attenuating the excess optical power incident on the photo-detector 41.

Fig. 3 illustrates the structure of a variable power attenuation means embodying the invention. As seen in the figure, the variable optical power attenuation means in the receiver unit 14 comprises an aperture 46, which is positioned on the optical axis A between the lens system 42 and the photo-detector 41. The aperture 46 is placed in a region r where the effective diameter of the incoming laser beam 18 is varying as a function of the position x along the optical axis A. Such a region r may be found between focusing optics and the corresponding focal point (focus), but other regions along the optical axis A may also exhibit this property. The diameter d of the aperture 46 is smaller than the largest diameter of the laser beam 18 within the region r, so that the area of the aperture 46 is also smaller than the largest area of the cross section of the laser beam 18. Apparently, in the shown embodiment the largest cross-sectional area of the laser beam 18 within the region r will be immediately adjacent to the rear surface of the lens 44 in the lens system 42.

It will be appreciated that by changing the position of the aperture 46 along the optical axis A, the optical power passing through the aperture 46 will vary. In order to facilitate movement of the aperture 46 in the region r, there is provided moving means attached to the aperture 46, so that the effective optical power passing through the aperture 46 varies as a function of its position along the optical axis A. The receiver unit 14 also comprises a power control circuit 47 connected to the photo-detector 41. This power control circuit 47 serves the purpose of controlling the variable optical power attenuator means, and thereby controlling the optical power level incident on the photo-detector 41.

In the embodiment shown in Figs. 3 and 4, the power control circuit 47 is a simple regulating circuit, and its input 48 is connected to the output of the photo-detector 41. The functioning of this circuit will be explained with reference to Fig. 8.

In the embodiment shown in Fig. 3, the moving means in the receiver unit 14 comprises an electric motor, namely a stepper motor 49 and a screw drive 50. The aperture 46 is connected to the screw drive 50 by means of an appropriate support 51. There is threaded bore 53 through the support 51, and the shaft 52 is screwed into the threaded bore 53. As it is apparent for those skilled in the art, when the shaft 52 of the screw drive 50 is rotated by the stepper motor 49, the support 51 will move along the optical axis A. There may be a pair of supports 51 on the aperture 46, as shown in Fig. 5, and a corresponding pair of shafts 52, which are rotated together by an appropriate gear connection or similar mechanism. Other suitable guiding means may be also used to ensure the linear movement of the aperture 46 along the optical axis A.

However, other means for moving the aperture 46 are also contemplated, For example, the moving means may comprise a linear motor (not shown), where the aperture 46 or the support 51 is connected directly to the linear motor.

In most cases, the receiver unit of a communication link would also comprise a variable gain control circuit for controlling the gain of the photo-detector, typically a so-called automatic gain control circuit (hereafter referred to as AGC). Such an embodiment is shown in Fig. 3 and 4, where the AGC 60 is connected to the output 61 of the photo-detector 41. The operating voltage to the photo-detector 41 is provided by the power supply 62. The AGC 60 is an automatic control circuit which regulates the power supply 62 of the detector 41, or the signal amplifier 63, or both, in order to provide an output signal with a constant peak amplitude on the output line 64 of the receiver unit 14.

In a proposed embodiment, the aperture 46 is a fixed aperture. With other words, the diameter d of the aperture opening 66 (and therewith its area in practice) is constant. This embodiment allows a very simple attenuator mechanics, because there are no sensitive mechanical parts, like variable shutter apertures. This embodiment is shown in Figs. 3, 4 and 6.

However, in certain circumstances it may be useful if the aperture is a variable aperture, i. e. the diameter d of the aperture opening 66 may be changed. Such an aperture 146 is shown in Fig. 5. The aperture 146 is operated by the motor 147, which in turn is activated by the power control circuit 47 and/or by the AGC 60 via the input 148. This embodiment has the advantage of providing even greater operating range for the attenuator means. In practice, it is enough if the variable aperture is variable between two states only, as will be explained below.

Optionally, the input of the power control circuit 47 in the receiver unit 14 may be connected to an output 65 of the gain control circuit, e. g. an AGC 70, as shown in Fig. 6. Typically, an output signal of the AGC 70 which is either proportional or inversely proportional to the output signal of the photo-detector 41 will be used for this purpose. In effect, the power control circuit 47 need not be realised as a separate circuit, but its role may be performed directly by the AGC 70 as well. The AGC 70 and the power control circuit 47 may be an analogue or digital circuit, depending on the specific application.

The operation of the attenuator means in the receiver unit 14 is explained with reference to Figs. 7 to 9. For the purposes of the following explanation, it is assumed that the power supply 62 is not controlled, and provides a constant operating voltage to the photo-detector 41. In that case, Fig. 7 shows the operating curve of the attenuator means, with the incident power P_{inc} on the horizontal axis, and the position X of the aperture along the optical axis A being shown on the vertical axis. The variable P_{inc} denotes the optical power incident on the photo-detector 41, i. e. the total optical power passing through the optical aperture 46 or 146. In this case, the output signal S_{out} of the photo-detector 41 is practically linearly proportional to the incident power P_{inc}. The operating range of the photo-detector is between P_1 and P_2, where P2 - P1 = ΔP. This operating range may be determined by the sensitivity of the photo-detector 41 or by the input range of the AGC 60. As long as the incident power P_{inc} is in the operating range defined by P_1 and P_2, and therewith the value of the output signal S_{out} is in the input range of the AGC 60, then the AGC 60 will be able to correct the signal amplitude fluctuations caused by the power fluctuations of the laser beam 18. In effect, the relevant parameters of receiver unit 14, i. e. the incident power P_{inc} and the position X of the aperture 46 will define a horizontal section, e. g. the section m in Fig. 7.

However, if the incident power P_{inc} reaches the limits of the working range, i. e. either P_1 or P_2, the power control circuit 47 is activated. The operating curve of the power control circuit is shown in Fig. 8. The incident power P_{inc} (and the proportional output signal S_{out}) is on the horizontal axis, while the output signal Y appearing on the output line 66 of the power control circuit 47 is on the vertical axis. As it is apparent from Fig. 8, when the incident power P_{inc} reaches a limit power P_1 (too little power on the photo-detector 41) or P_2 (too much power on the photo-detector 41), the power control circuit will produce a drive signal Y_1 or $-Y_1$, which in turn will cause the stepper motor 49 to move the aperture

46 in the X direction or in the -X direction, respectively. As it is apparent from the comparison of Figs. 3 and 4, if the aperture 46 is moved in the X direction (towards right, as seen in Fig. 3 and 4), a larger portion of the laser beam 18 will pass through the aperture 46, more incident power P_{inc} will fall onto the photo-detector 41, and the photo-detector 41 will return to its normal working range between P_1 and P_2, and will work along the section l in Fig. 7 („l" denotes low intensity of incoming laser beam 18). Obviously, if too much power falls on the photo-detector 41, the inverse effect will occur, i. e. the power control circuit 47 produces a drive signal -Y, which causes the stepper motor 49 to move the aperture 46 towards the left, i. e. towards the optical lens system 42. In this case, a smaller portion of the laser beam 18 passes through the aperture 46, decreasing the incident power P_{inc} falling onto the photo-detector 41, which will again result in the re-establishment of the proper working range between P_1 and P_2. In this case the operating curve will shift from the section m to section h (see Fig. 7, where „h" denotes high intensity of incoming laser beam 18).

It must be noted that the control function of the power control circuit 47 need not exhibit the large hysteresis which is shown in Fig. 7. In theory, it is also possible to regulate the amplitude of the output signal only with the aperture 46. However, it is more advantageous if the aperture 46 provides only a coarse regulation of the incident power, and the continuous operation of the stepper motor 49 is avoided. Instead, the amplitude of the output signal on the output line 64 is held constant in the fine range by the AGC 60 or 70.

It will be clear from the above explanation that the attenuator means will greatly enhance the overall working range of the receiver unit 14, as it is illustrated with the operating curve $X(P_{tot})$ shown in Fig. 9. Here, the total incident power P_{tot} , i. e. the total optical power entering the aperture 34 of the receiver, is on the horizontal axis, while the position X of the aperture 46 along the optical axis A is shown on the vertical axis. For easier illustration, it is assumed that there is no power loss in the optical lens system 42, and the laser beam 18 will illuminate the aperture 46 with the same optical power P_{tot} which enters the aperture 34. Clearly, without the variable attenuation means, the receiver 14 would only have a working range corresponding to a small interval, e. g. as indicated by the power interval ΔP, limited by the power values $P_{tot,1}$ and $P_{tot,\Delta}$ in Fig. 9. Fig. 9 also shows the attenuator factor F(x) of the attenuating means in the receiver unit 14, as a function of the x position of the aperture 46. The attenuator factor is defined as

$P_{inc} = F(x)\ P_{tot}$, from which it follows that $F(x) = P_{inc}/P_{tot}$.

It is valid that

$$\Delta P = F(x)(P_{tot}(a) - P_{tot}(b)) = F(x)\Delta P_{tot}.$$

As it is also seen from Fig. 9, with the attenuation means the receiver unit 14 can sustain a laser beam 18 which have a power range between $P_{tot,1}$ and $P_{tot,2}$, much larger than the power range ΔP.

As mentioned above, the operation of the attenuation means may be improved, and its attenuation range extended, if the effective area of the aperture may be varied at least between two states. In a first state, the aperture 146 may have a very small opening. This state is used when a large portion of the laser beam should be blocked, and the aperture 46 is close to the optical lens system 42. With a very small opening, only a very small fraction of the optical power will pass through the aperture. However, the small opening may be a disadvantage, if it is not possible to move the aperture close enough to the photo-detector, or particularly, when the area of the photo-detector is larger than the opening of the aperture 146. Therefore, it is suggested to provide in at least a second state of the aperture another aperture size that is slightly larger than the total area of the laser beam 18 in the aperture position closest to the photo-detector 41. In this manner, the total optical power of the laser beam 18 may reach the photo-detector, if necessary.

The attenuator means in the receiver unit may be realised with numerous modifications, without departing from the scope or the spirit of the invention. Particularly, the operating curve or other characteristics of the power control circuit may have various, different forms, e. g. to take into account the variable diameter of the aperture. Such modifications are within the ordinary knowledge of the person skilled in the art. Also, it will be appreciated that the operating principle of the attenuation means is essentially the same with a controlled power supply. As above, this fact may be considered in the design of the power control circuit.

Claims

1. A free space communication receiver unit comprising

a photo-detector for detecting the light intensity of an incoming light beam,

an optical lens system for focusing the incoming light beam onto the photo-detector,

variable optical power attenuation means between the lens system and the photo-detector for the attenuation of the optical power incident on the photo-detector, wherein the variable optical power attenuation means comprises

an aperture positioned on the optical axis between the lens system and the photo-detector, in a region where the effective diameter of the incoming light beam is varying as a function of the position along the optical axis, and

moving means for translating the aperture along the optical axis in said region, so that the effective optical power passing through said aperture varies as a function of the position along said optical axis, and

a power control circuit connected to the photo-detector for controlling the variable optical power attenuator means, and thereby controlling the optical power level incident on the photo-detector.

2. The free space communication receiver unit of claim 1, wherein an input of the power control circuit is connected to the output of the photo-detector.

3. The free space communication receiver unit of claim 1, further comprising a variable gain control circuit for controlling the gain of the photo-detector, the gain control circuit being connected to the output of the photo-detector.

4. The free space communication receiver unit of claim 3, wherein an input of the power control circuit is connected to an output of the gain control circuit.

5. The free space communication receiver unit of claim 3, wherein the gain control circuit is an automatic gain control circuit.

6. The free space communication receiver unit of claim 1, wherein the moving means comprises an electric motor and a screw drive, and the aperture is connected to the screw drive.

7. The free space communication receiver unit of claim 1, wherein the moving means comprises a linear motor, and the aperture is connected directly to the linear motor.

8. The free space communication receiver unit of claim 1, wherein the aperture is a fixed aperture.

9. The free space communication receiver unit of claim 1, wherein the aperture is a variable aperture, which is activated by the power control circuit and/or by a gain control circuit.

10. Attenuation means for the attenuation of the optical power of an incoming light beam incident on a photo-detector of a free space communication receiver, wherein the optical power attenuation means comprises an aperture positioned on an optical axis between a lens system and the photo-detector, in a region where the effective diameter of the incoming light beam is varying as a function of the position along the optical axis, and moving means for translating the aperture along the optical axis in said region, so that the effective optical power passing through said aperture varies as a function of the position along said optical axis, and control means for controlling the moving means, and thereby controlling the optical power level incident on the photo-detector.

11. A method for controlling the incoming optical power on a photo-detector of a free space communication receiver, comprising the steps of

focusing an incoming light beam onto the photo-detector with a lens system, so that in at least a region an effective diameter of the incoming light beam is varying as a function of the position along an optical axis of the incoming light beam;

positioning an aperture on an optical axis between the lens system and the photo-detector in said region;

translating the aperture along the optical axis in said region, so that the effective optical power passing through said aperture varies as a function of the position along said optical axis, and thereby controlling the optical power level incident on said photo-detector.

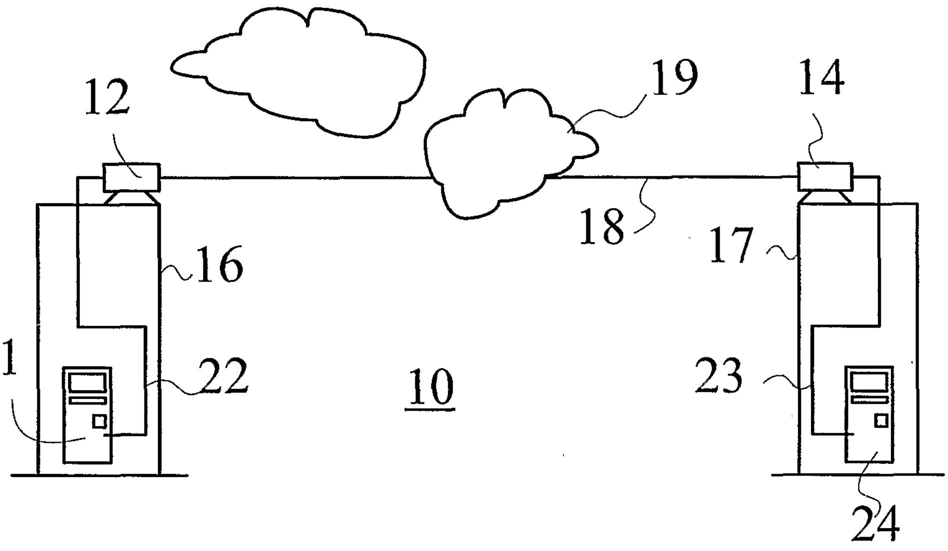

Fig. 1

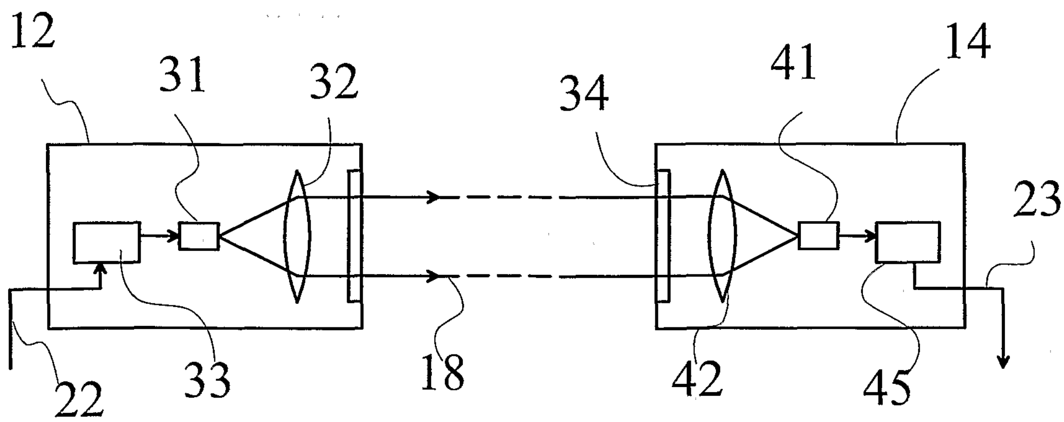

Fig. 2

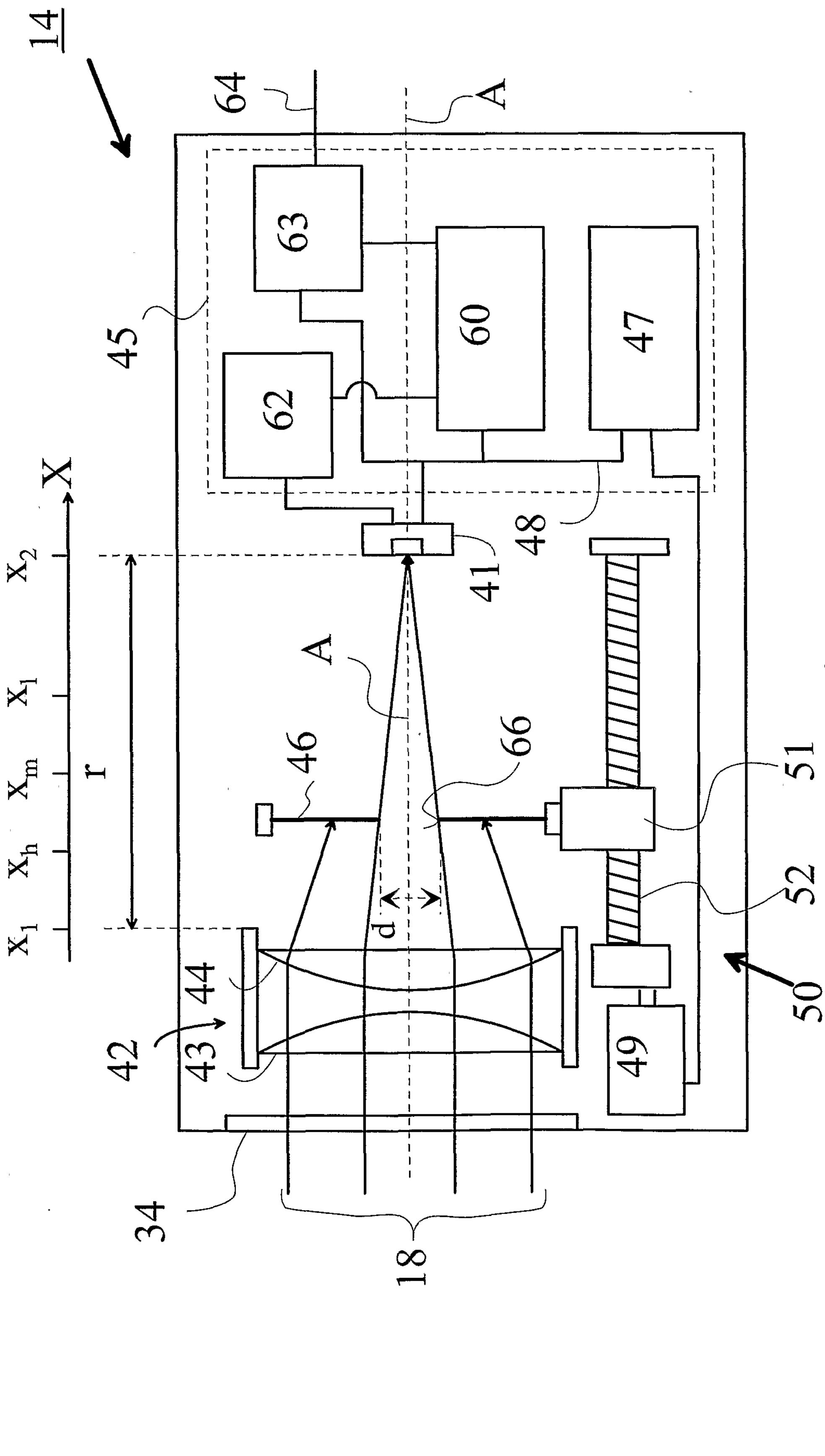
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Fig. 3

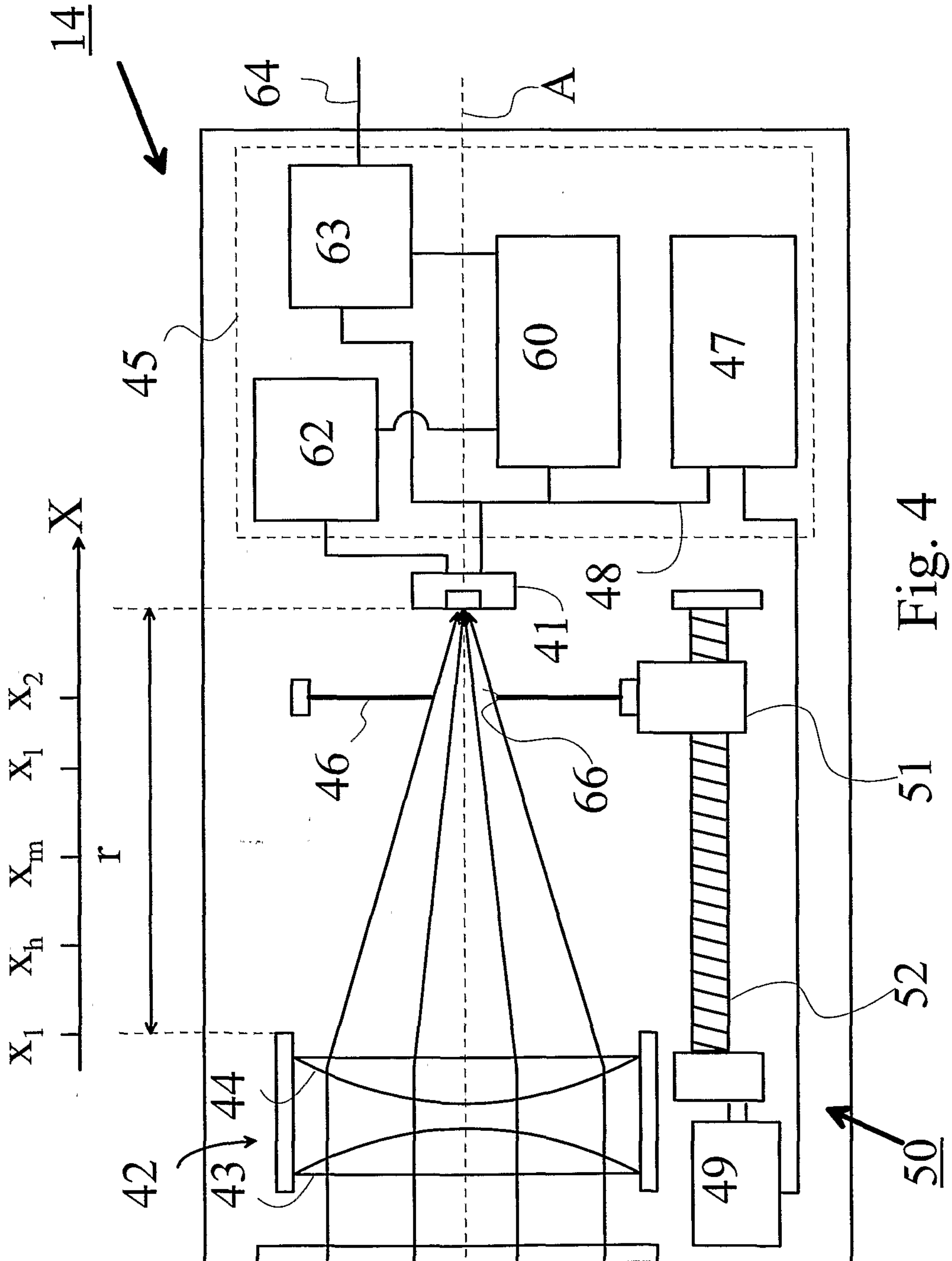
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Fig. 4

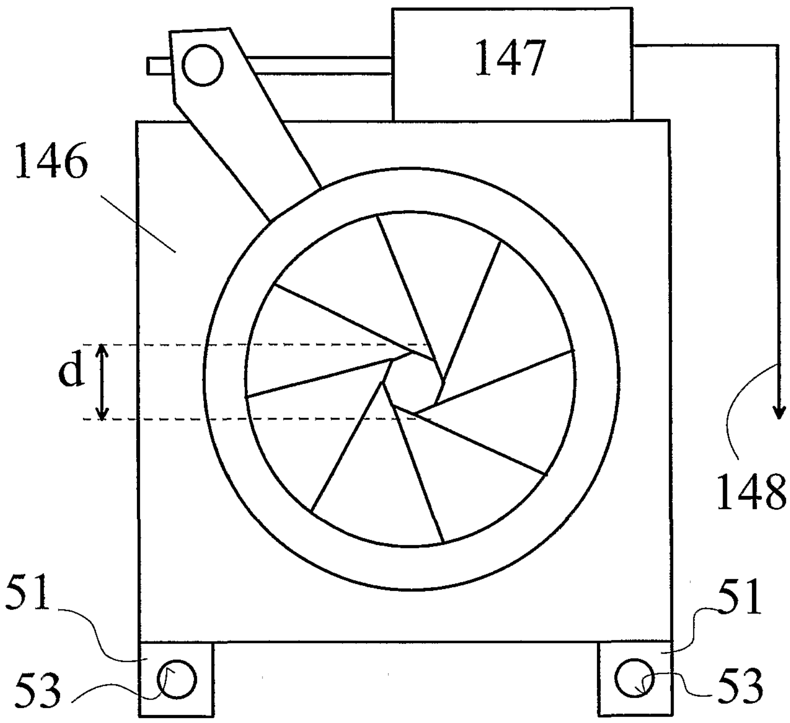

Fig. 5

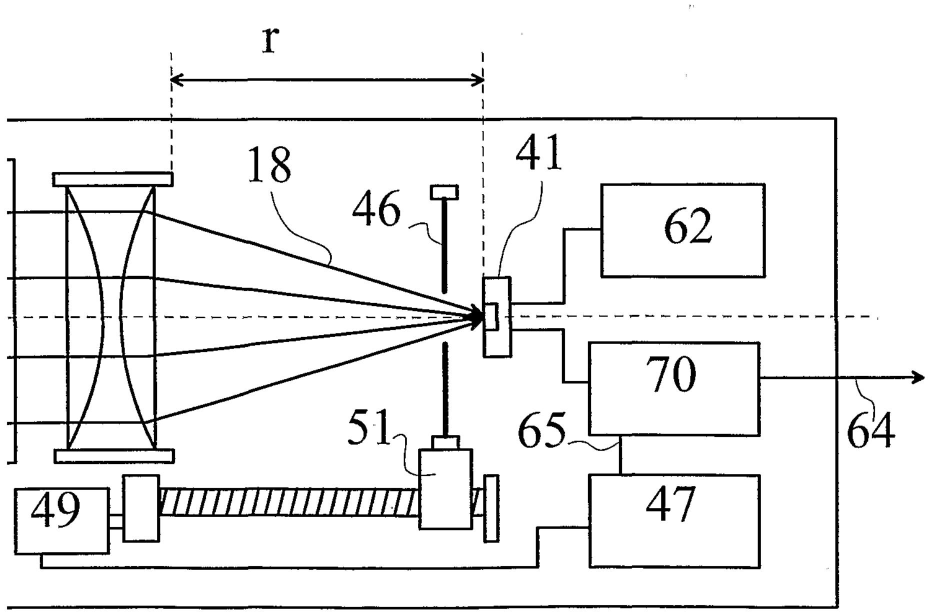

Fig. 6

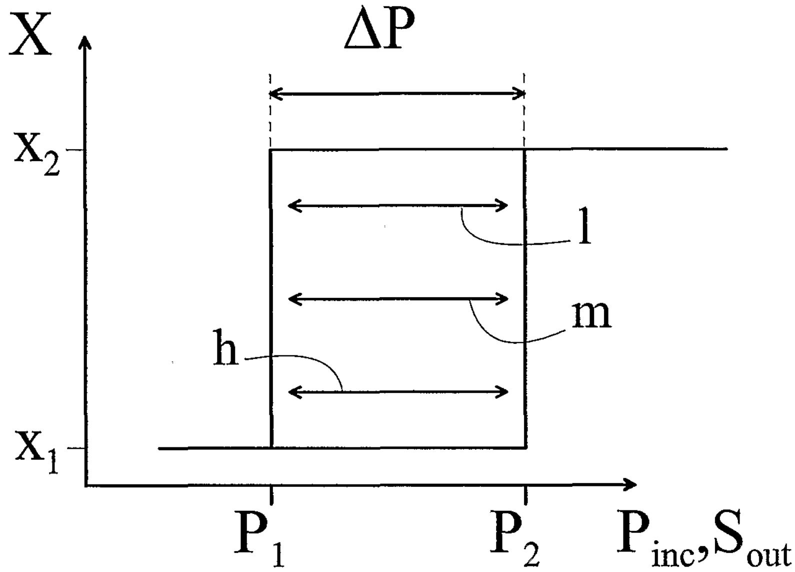

Fig. 7

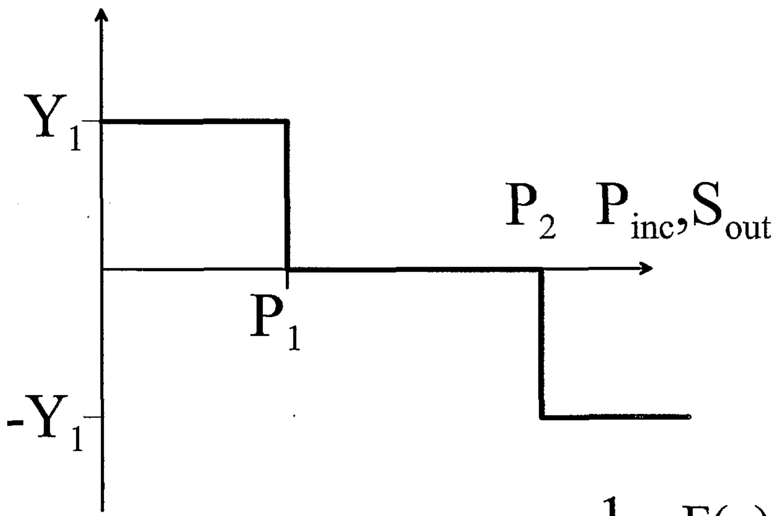

Fig. 8

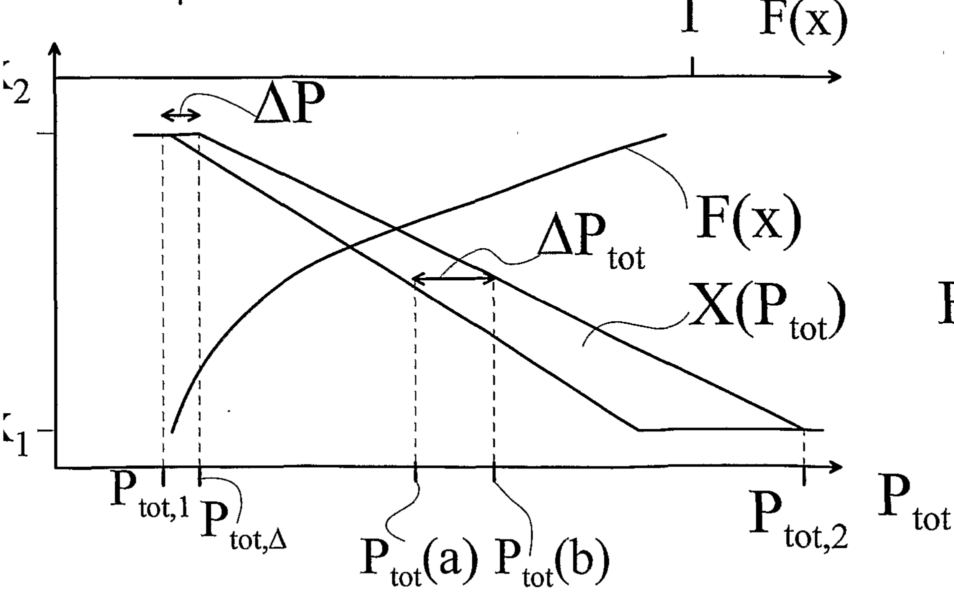

Fig. 9