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(54) Title of the Invention: **Apparatus for data communications, method of performing data communications**
Abstract Title: **Apparatus and method for data communication that uses optical concentration devices**

(57) Apparatus and methods for data communications are disclosed. In a disclosed arrangement, electromagnetic radiation 5, preferably infra-red radiation, is transmitted to a first parabolic concentration stage 6. Output from concentration stage 6 is input to a second concentration stage 9 which comprises a quantum dot wavelength converting element 8 to convert the radiation to a longer wavelength. Output from concentration stage 9 is directed towards photo-detector 12 and on to a decoder 14 for obtaining information from the detected electromagnetic radiation. The use of optical concentrators in this arrangement reduces the size of the photo-detectors required. Changing the wavelength of radiation during the concentration process allows concentration levels greater than the limits imposed by the constant radiance theorem to be achieved.

Fig.2

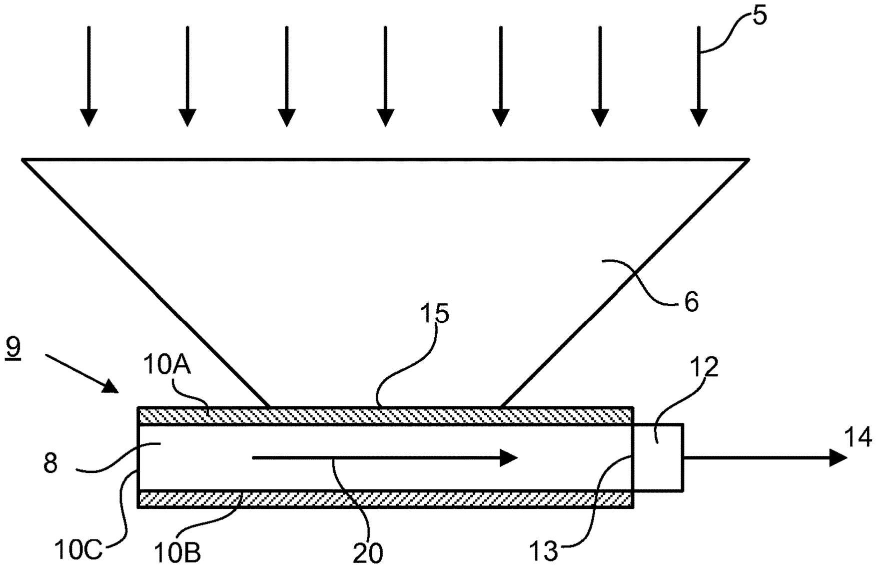


Fig.1

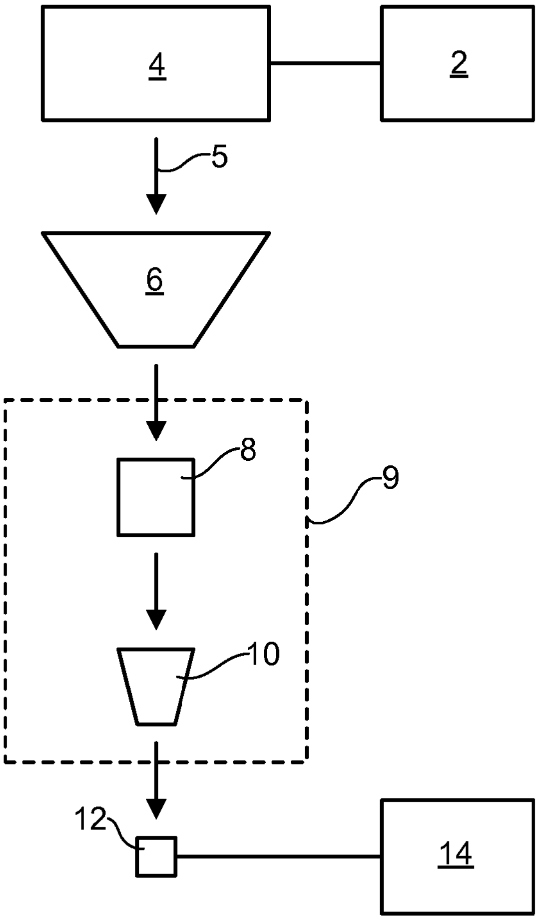


Fig.2

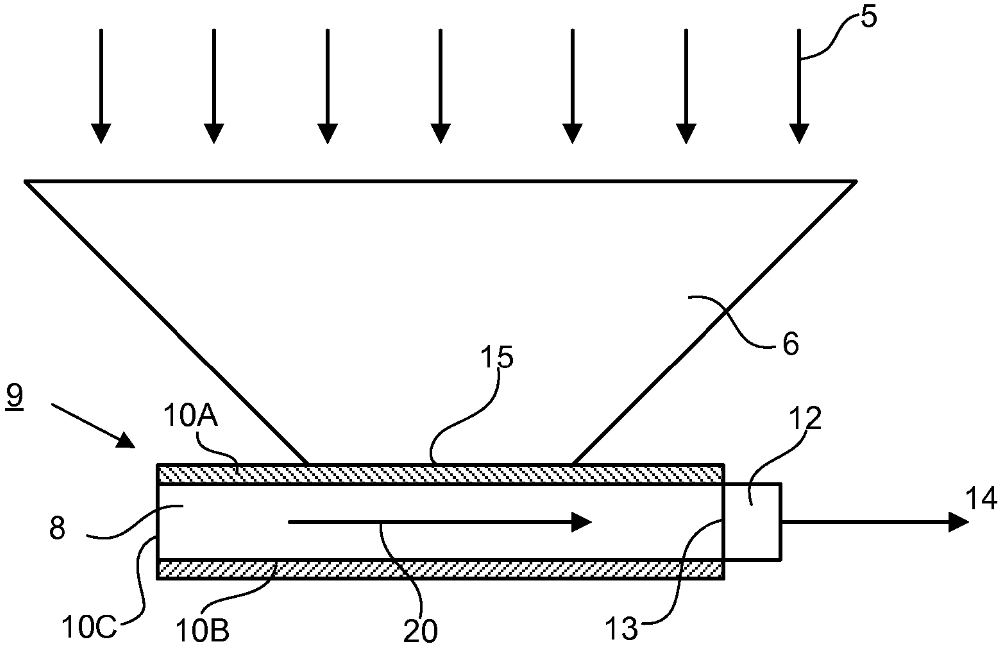


Fig.3

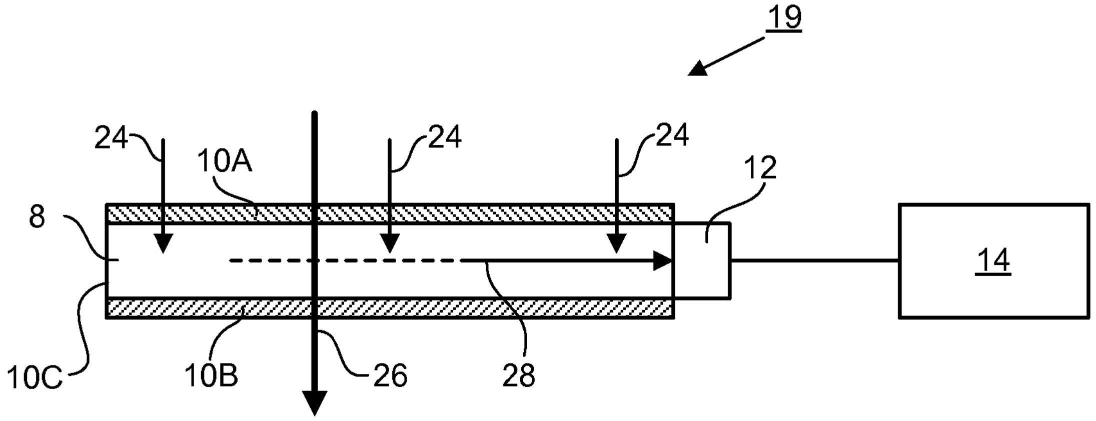


Fig.4

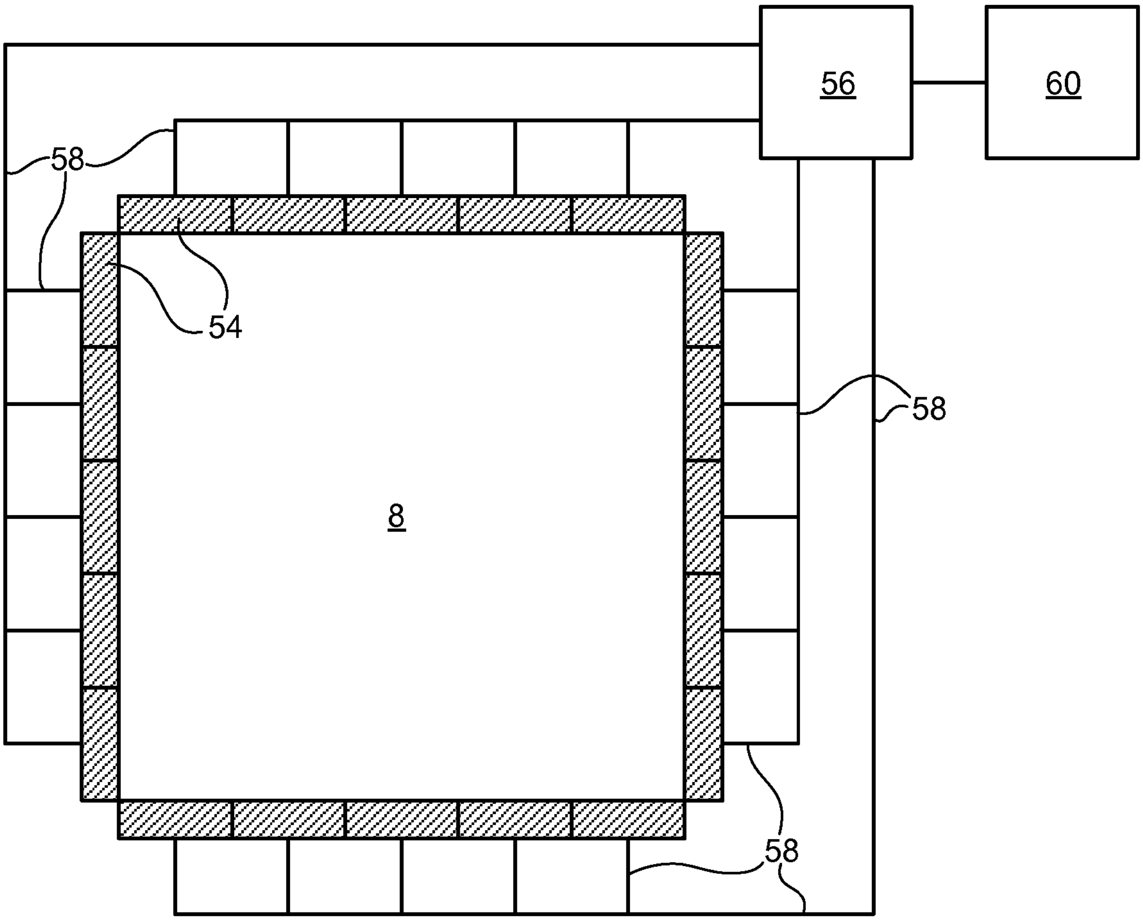


Fig.5

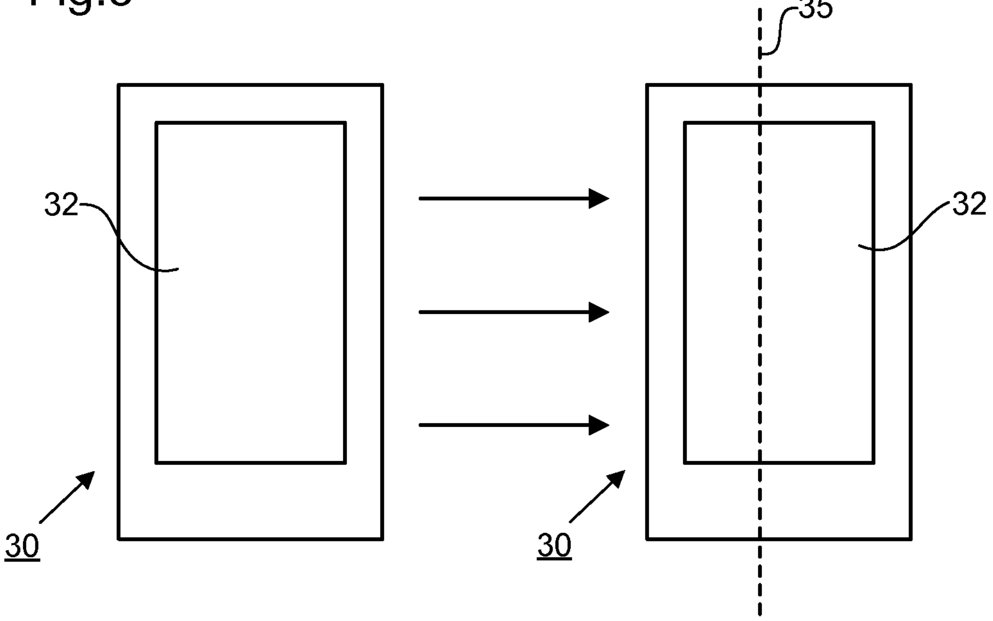


Fig.6

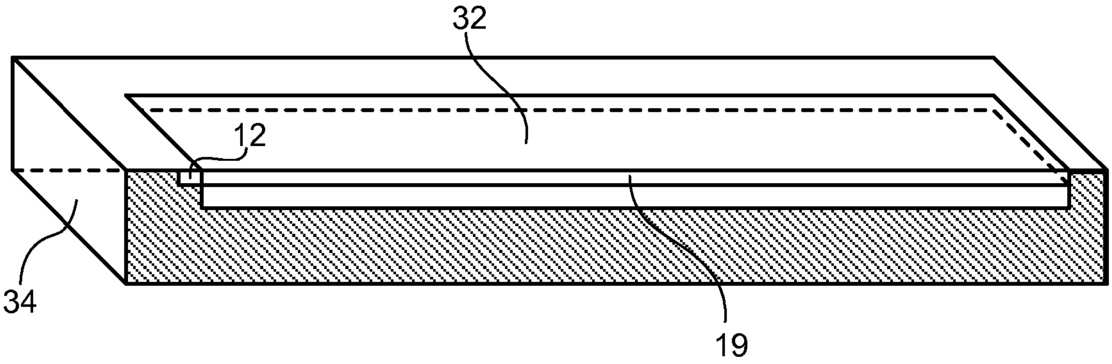


Fig.7

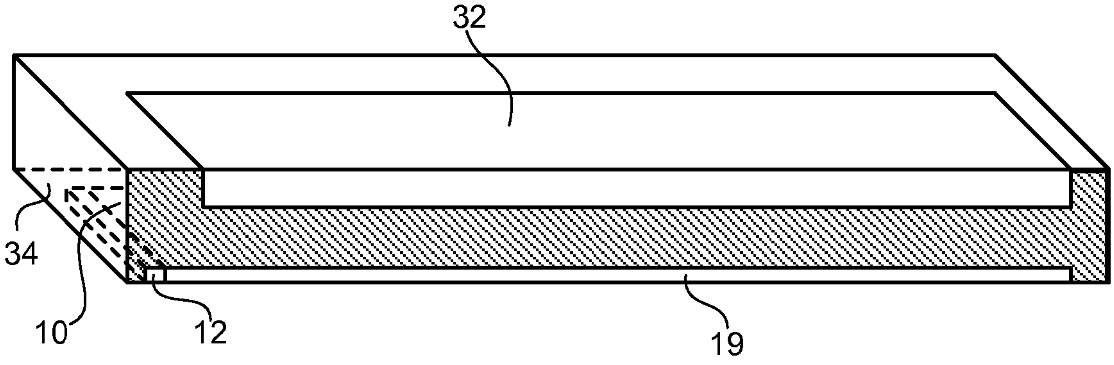
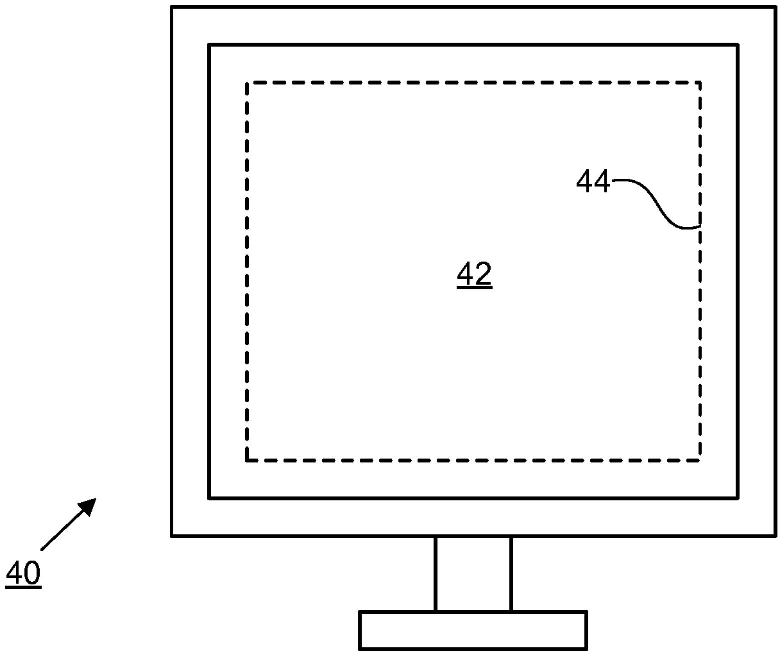


Fig.8



APPARATUS FOR DATA COMMUNICATIONS, METHOD OF PERFORMING DATA COMMUNICATIONS

The present invention relates to apparatus and methods for data communications that use optical concentration devices (“optical concentrators”).

Optical concentration refers to the process of receiving light using a relatively large collecting aperture and concentrating that light onto a much smaller area. There are many applications for concentrators, including in free space optical communications. In this case light carries an information signal, and an optical receiver uses a concentrator to collect light from the largest area possible and concentrate it on as small a photo-detector as feasible. This process is desirable because large photo-detectors tend to be more difficult to operate at high data rates than smaller photo-detectors. Conventionally lenses and mirrors are used as optical concentrators.

The amount of optical concentration that can be achieved is limited due to factors such as the constant radiance theorem and losses. This restricts the extent to which communication efficiency can be improved using optical concentrators.

A further problem is that the geometry of optical concentrators may not be convenient for data communications applications. It is difficult to provide systems having large collecting apertures and/or high concentration factors in a small volume and/or convenient shape.

It is an object of the invention to address at least one of the problems discussed above in relation to the prior art.

According to an aspect of the invention, there is provided an apparatus for data communications, comprising: a detector for detecting electromagnetic radiation; a decoder for obtaining information from the detected electromagnetic radiation; and a concentration stage for receiving and concentrating the radiation, prior to detection of the radiation by the detector, the concentration stage comprising a wavelength converting element configured to convert radiation to longer wavelength radiation.

Thus, a novel configuration for receiving data via electromagnetic radiation is provided. The configuration can be incorporated into a wide range of different devices, with a minimum of visual impact, due to the flexibility in choice of geometry for the wavelength converting element of the concentration stage. In an embodiment, the wavelength converting element has a thickness that is smaller than the length and/or width of the element. In an embodiment, the wavelength converting element is provided in a substantially sheet-like form, for example having a thickness that is at least 10 times, optionally at least 50 times, optionally at least 100 times, smaller than the length and/or width of the element. A large collection area in a relatively small volume device can thus be provided. The wavelength conversion to longer wavelengths provides a wide field of view. In an example embodiment, the wavelength converting element is provided in a substantially planar form.

Free space optical communications typically use a limited range of wavelengths for transmission of data, which enables the wavelength converting element to operate efficiently. The wavelength conversion makes it possible to achieve a higher level of concentration than would be possible using only a single wavelength from source to detector, due to the limits of the constant radiance theorem in the case where the wavelength of radiation involved is constant. Increasing the degree of concentration makes it possible for the detector to be made smaller and therefore more efficient, for example faster and/or cheaper.

In an embodiment, the concentration stage is incorporated into the screen of a display device, for example in a portable electronic device such as telephone, Personal Digital Assistant (PDA), tablet pc, etc., or in a non-portable electronic device such as television or computer monitor.

In an embodiment the wavelength converting element and/or confinement structure (where provided) of the concentration stage is/are configured to be substantially transparent to visible light and can thus be incorporated into the screen without interfering with the normal operation of the screen as a display.

In an embodiment, an additional concentration stage is provided before the concentration stage comprising the wavelength converting element. Optionally, the additional concentration stage comprises a compound parabolic concentrator.

In an embodiment, the wavelength converting element comprises a fluorescent dye. Fluorescent dyes are widely available and relatively inexpensive, facilitating cost-effective manufacture and the provision of a wide range of operational characteristics. In many cases, a change in operational characteristics can be implemented simply by changing the composition of the dye in the wavelength converting element.

In an embodiment, the wavelength converting element comprises quantum dot wavelength converters. Quantum dot wavelength converters can provide highly efficient and flexible wavelength conversion.

In an embodiment, the wavelength converting element and/or surrounding confinement structure (where provided) is provided in a flexible form. The flexibility facilitates attachment to or incorporation within a device and/or allows the wavelength converting element and/or confinement structure easily to adopt a curved form. In an embodiment, the wavelength converting element and/or confinement structure is configured so that it/they can be switched between an extended state (e.g. spread out in a flat or planar configuration suitable for collecting light efficiently) and a compact, storage state (e.g. rolled or folded up).

In an example embodiment, the apparatus for data communications is used to allow two portable electronic devices to transmit information optically, over free space, to each other. In another example embodiment, a display device is adapted to use the apparatus for data communications to receive a data signal, for example of a film or the internet, via the screen of the device. In an embodiment the data signal is transmitted via an optical signal emitted using a light source that is also used for domestic lighting, for example a modulated LED light.

According to an aspect of the invention, there is provided a method of performing data communications, comprising: using a concentration stage to receive and concentrate electromagnetic radiation; using a wavelength converting element in the concentration stage to convert radiation to longer wavelength radiation; detecting radiation output by the concentration stage; and decoding the detected radiation in order to obtain information from the detected radiation.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which corresponding reference symbols represent corresponding parts, and in which:

Figure 1 depicts a data communication system comprising an apparatus for optical concentration having a first concentration stage and second concentration stage, the second concentration stage incorporating a wavelength converting element;

Figure 2 depicts an apparatus for optical concentration comprising first and second concentration stages, in which the second concentration stage comprises a confinement structure formed of parallel planar dichroic elements containing a wavelength converting element;

Figure 3 depicts an apparatus for data communications comprising a single concentration stage that incorporates a wavelength converting element;

Figure 4 depicts a detector with a plurality of detector elements;

Figure 5 depicts communication between two portable electronic devices, each comprising a display device that has an apparatus for data communications comprising a concentration stage and wavelength converting element;

Figure 6 depicts an arrangement in which the wavelength converting element of a concentration stage is built into the screen of a display device;

Figure 7 depicts an arrangement in which a wavelength converting element of a concentration stage is built into the rear side of a display device;

Figure 8 depicts a television or monitor comprising a display device having an apparatus for data communications comprising a concentration stage and a wavelength converting element, the wavelength converting element having a geometry and size corresponding approximately to that of the screen of the television or monitor.

As mentioned in the introductory part of the description, optical concentration can be used to reduce the size of photo-detectors required in free space optical communications applications. However, the amount of concentration that can be achieved using conventional methods such as lenses or compound parabolic concentrators is limited by the constant radiance theorem (also known as étendue conservation). The constant radiance theorem holds where the wavelength of light does not change in the optical system in question. However, the inventors have recognised that concentration levels greater than the limits imposed by the constant radiance theorem for a single wavelength of light can be achieved by changing the wavelength of the light during the concentration process. In an embodiment, this is achieved using a "wavelength converting element". A wavelength converting element absorbs radiation at one wavelength or range of wavelengths and re-emits the radiation at a second wavelength or range of wavelengths that is different to the first. In an embodiment, the conversion involves shifting from a shorter wavelength to a longer wavelength. In an embodiment, the wavelength converting element is configured to have a short response time, for example of 1 microsecond or less, optionally 10 nanoseconds or less, optionally 1 nanosecond or less, in order to facilitate high bandwidth data communications. Examples of wavelength converting elements are described in further detail below.

Figure 1 illustrates schematically a data communication system based on this principle. According to this arrangement, information to be transmitted by the data communication system is encoded by encoder 2 and provided to a radiation source 4. The radiation source 4 transmits radiation 5 to a first concentration stage 6. The output from the first concentration stage 6 is input to a second concentration stage 9, which comprises a wavelength converting element 8 and means 10 for directing radiation in a concentrated manner towards a detector 12. The output from the detector 12 is provided to a decoder 14 which can retrieve the information that has been transmitted by decoding the received encoded signal.

In the arrangement shown, the wavelength converting element 8 and the means 10 for directing radiation are shown schematically as separate elements. However, as discussed below in respect of a detailed example, the wavelength converting element 8 and means 10 for directing radiation may alternatively be provided in a single unit. In further embodiments, one or more further concentration stages may be provided. In such embodiments, one or more further wavelength converting elements may also be provided, each incorporated into one or more of the further concentration stages.

In an embodiment, the wavelength converting element is configured to convert radiation to longer wavelength radiation, for example by absorbing radiation at a first wavelength or wavelengths and re-emitting the radiation at a second wavelength or wavelengths that is longer than the first. This process results in the modification of the spectrum of radiation incident on the wavelength converting element in such a way that power is shifted from the first wavelength or wavelengths to the second wavelength or wavelengths.

Figure 2 depicts an example configuration for an apparatus for optical concentration in further detail. The apparatus for optical concentration depicted comprises a first concentration stage 6 for receiving and concentrating radiation 5 input to the optical concentrator. The optical concentrator also comprises a second concentration stage 9 for receiving radiation output from the first concentration stage 6. The output from the second concentration stage 9 is directed towards a detector 12. The output from the detector 12 is provided to a decoder 14 (not shown).

In the embodiment shown, the first concentration stage 6 comprises a compound parabolic concentrator. In the embodiment shown, the second concentration stage 9 comprises a wavelength converting element 8. Radiation output from the wavelength converting element 8 is directed to a detector

12 by reflection from a confinement structure 10A, 10B and from free (e.g. exposed to the environment) peripheral sides 10C of the wavelength converting element 8. In the embodiment shown, the confinement structure 10A, 10B comprises a pair of planar dichroic elements. The confinement structure 10A, 10B is configured substantially to allow passage of radiation having a wavelength that is suitable for conversion by the wavelength converting element 8 from the outside of the confinement structure 10A, 10B to the inside of the confinement structure 10A, 10B. The confinement structure 10A, 10B is further configured to substantially block passage of radiation (e.g. by reflection) that has been converted by the wavelength converting element 8 from the inside of the confinement structure 10A, 10B to the outside of the confinement structure 10A, 10B (thus “confining” converted radiation within the confinement structure). In an alternative embodiment, the confinement structure 10A, 10B is omitted and radiation emitted by the wavelength converting element 8 is directed to the detector 12 by internal reflection within the wavelength converting element 8. Use of a confinement structure will tend to favour lower losses. Omitting the confinement structure will tend to facilitate manufacture.

In the embodiment shown, the detector 12 is arranged along one peripheral side only (the right hand peripheral side in the orientation of Figure 2) of the second concentration stage 10. However, this is not essential. In other embodiments, the detector 12 may be provided along more than one of the sides. In an embodiment, the detector 12 is provided on all peripheral sides of the second concentration stage 10, for example so as to form a closed loop. Configuring the detector to be present on more than one side may increase the proportion of radiation emitted by the wavelength converting element 8 that is detected. Additionally or alternatively, where the detector 12 comprises a plurality of detector elements, optionally spread around two or more of the peripheral sides, that can independently measure a radiation flux incident on them, the detector 12 can obtain a measure of a spatial distribution of radiation incident on the wavelength converting element (this possibility is discussed in further detail below with reference to Figure 4).

Where the detector 12 is not provided on all peripheral sides, internal reflection may be sufficient to prevent excessive loss of radiation via uncovered peripheral sides. However, in an embodiment, an additional peripheral reflector may be provided to reduce losses. The peripheral reflector may be a broadband reflector such as a metal mirror. In an embodiment, a dichroic mirror is used as the peripheral detector.

In an embodiment, the re-emission of the wavelength converted radiation within the wavelength converting element 8 happens in all directions and reflections from the surface of the wavelength converting element 8 and/or confinement structure (where provided) are effective to direct the radiation (see arrow 20) towards the detector 12. In an embodiment, the geometry and dimensions of the wavelength converting element 8 and/or confinement structure 10A, 10B determine the size of the surface area 13 on the detector 12 that receives radiation, and therefore determine, at least in part, the final concentration factor achieved. In the particular example shown, the surface area 13 will be determined by the shape of the dichroic elements

10A, 10B (e.g. rectangular), the separation between the dichroic elements 10A, 10B, and the depth (into the page) of the dichroic elements 10A, 10B. The surface area 13 will typically be much smaller than the surface area 15 defining the input to the second concentration stage 10 from the first concentration stage 6. However, the efficiency of the wavelength conversion process, which will depend on the thickness of the wavelength converting element 8, will tend to limit the amount of concentration that can be achieved. In practice, the thickness of the wavelength converting element 8 can be varied until an optimum balance is achieved between reducing the surface area 13 and increasing conversion efficiency.

In an embodiment, the wavelength converting element 8 comprises a quantum dot wavelength converter. In an embodiment, the quantum dot wavelength converter comprises solution processed quantum dots. Solution processed quantum dots are particularly suitable for this application because they have tuneable absorption and emission characteristics, large luminescence quantum yields and Stokes shifts compatible with minimal re-absorption losses. In an embodiment the quantum dot wavelength converter comprises lead chalcogenide quantum dot wavelength converters.

In an alternative embodiment, the wavelength converting element 8 comprises a fluorescent dye.

In an embodiment, the wavelength converting element 8 comprises a support body containing dispersed wavelength converting elements. The dispersed wavelength converting elements may comprise fluorescent dye. Alternatively, the dispersed wavelength converting elements may comprise quantum dot wavelength converters. The support body may comprise one or more of the following: an amorphous polymer, an inorganic glass, a SiO_2-based inorganic glass, an acrylic. In an embodiment, the wavelength converting element 8 and/or support body is/are configured to be substantially transparent to converted radiation so as to reduce or minimize re-absorption losses.

In the embodiment discussed above, the apparatus for optical concentration comprises two concentration stages. However, this is not essential. In an embodiment, an apparatus for optical concentration is provided that has a single concentration stage only. In an embodiment, the single concentration stage has a structure that is identical to the second concentration stage 9 discussed above. The variations and details discussed above with reference to the second concentration stage 9 can be applied to such an embodiment.

Figure 3 illustrates an example apparatus for data communications that comprises an apparatus for optical concentration having a single concentration stage 19 only. As can be seen, the structure of the single concentration stage 19 is the same as the second concentration stage 9 shown in the embodiment of Figure 2. In an embodiment, the wavelength converting element 8 and/or confinement structure 10A, 10B (where provided) is/are configured to allow visible light 26 to pass through it/them. In the particular example shown the confinement structure 10A, 10B and/or wavelength converting element 8 is/are arranged to be substantially transparent to visible light, while light outside of the visible spectrum (e.g. infrared light or UV light) 24 can enter the confinement structure 10A, 10B but is subject to wavelength conversion by the wavelength converting element 8. The wavelength converted radiation 28 is subsequently trapped by reflection from the (inner) surface of the wavelength converting element 8 and/or from the confinement structure 10A, 10B and/or from free peripheral surfaces 10C and is directed to a detector 12.

In an embodiment, the light 24 has a wavelength that is shorter than the visible spectrum (e.g. UV) and is converted to light having a wavelength that is longer than the visible spectrum (e.g. infrared), thus involving a large Stokes shift. Alternatively or additionally, the wavelength converting element 8 may be configured to absorb some radiation that is within the visible spectrum. In this case the absorption may be configured to be sufficiently low as to be imperceptible to a user of the device. For example, if the apparatus for optical concentration is integrated into the screen of a display device, the absorption in the visible spectrum may be arranged to be low enough that the performance of the screen is not noticeably affected. Similar considerations apply if the aim is to provide the apparatus for optical concentration as an "invisible" (or nearly invisible) layer on the surface of a device. Absorption and re-emission is preferably at wavelengths outside of the visible spectrum, or predominantly so, or the absorption is at a sufficiently low level that appearance is not affected excessively by the presence of the apparatus.

In an embodiment, the detector 12 comprises at least two detector elements 54. In an embodiment, the at least two detector elements 54 are able independently to measure a radiation flux output from different regions on the surface (e.g. different regions on the peripheral sides) of the wavelength converting element. A schematic top view of such an arrangement is shown in Figure 4. Smaller detector elements 54 tend to have lower capacitances than larger detector elements, which means they can respond more quickly and therefore deal with higher data rates. Thus, by using a plurality of smaller detector elements 54 in place of a single larger detector element it is possible to sample the same amount of output radiation while improving the bandwidth. In an embodiment, the detector elements 54 comprise single photon detector elements. Single photon detector elements can only detect one photon at a time and there is an intrinsic delay or "dead time" between when the detector detects a photon and when the detector is able to detect a subsequent photon. Using a plurality of smaller photon detectors tends to distribute output photons between different detectors more efficiently and thus reduces limitations in sensitivity and/or speed caused by the dead time of individual detector elements.

In an embodiment, an orientation optimization unit 56 is provided for automatically adjusting the orientation of one or more elements of the data communications apparatus (including for example the orientation of the wavelength converting element 8) to increase the total amount of radiation detected. In an embodiment, the orientation optimization unit 56 is configured to receive signals representing the amount of radiation detected by the detector elements 54 via tracks 58. In an embodiment, the orientation optimization unit 56 monitors changes in the output of the detector elements 54 as a function of changes in the orientation of the wavelength converting element (and/or one or more other elements of one or more concentration stages) and uses a search method based on the monitoring to find an orientation of the wavelength converting element (and/or one or more other elements of one or more concentration stages) that increases the output from the detector elements 54. In an embodiment, the orientation optimization unit 56 provides a signal to a drive unit 60 that is capable of changing the orientation of the wavelength converting element (and/or one or more other elements of one or more concentration stages) according to the signal.

In the embodiment shown, the wavelength converting element 8 is substantially square and five detector elements 54 are arranged along each of the four peripheral sides of the wavelength converting element 8. In other embodiments the wavelength converting element 8 has a different shape and/or a different number of detector elements 54 are provided.

In an embodiment, the wavelength converting element 8 is provided in a relatively flat or "sheet-like" form. Optionally, the thickness of the element 8 is arranged to be smaller, optionally at least 10 times, optionally at least 50 times, optionally at least 100 times, smaller, than any dimension (e.g. width or length) in the plane of the sheet. Such geometry can efficiently be used in conjunction with devices that naturally present relatively large exterior surfaces. In particular, where the wavelength converting element 8 and/or confinement structure 10A, 10B is substantially transparent to visible light, the apparatus can be provided as part of the screen of a display device without affecting the visual appearance and/or performance of the screen. Display devices are used to display information, so that the provision of an alternative or additional means for providing information to the device supporting the display is likely to be desirable.

In an embodiment, a concentration stage of the type shown in Figure 3 is provided as part of the screen 32 of a portable electronic device 30 such as a personal digital assistant, mobile phone, laptop, tablet pc etc., as shown schematically in Figure 5. Here, two portable electronic devices 30 are depicted. The two portable electronic devices 30 may communicate with each other by using the display (or any other source of light on the device, such as an LED flash in the case where the portable electronic device is a mobile phone or camera) to send information, as visible or infrared radiation for example, to the other portable electronic device 30. The wavelength converting element 8 and/or confinement structure 10A, 10B may be provided on the screen 32 of the portable electronic device 30. Alternatively or additionally, the wavelength converting element 8 and/or confinement structure 10A, 10B may be provided on a rear side of the device, which typically also has a relatively large planar form suitable for receiving radiation over a relatively large surface area, or on any other suitable surface of the device.

Figure 6 is a schematic sectional view along line 35 in Figure 5 showing a concentration stage 19 built into a screen 32 of the portable electronic device 30. Figure 7 is a schematic sectional view along the line 35 of the embodiment of Figure 5 showing an alternative arrangement in which the concentration stage 19 is built into a rear surface 34 of the portable electronic device 30.

In general, the concentration stage 19 may be provided in such a manner as to exploit the dimensions and/or geometry of the device into which it is incorporated. This may involve configuring the concentration stage 19 to have the same geometry as the geometry of the screen of a display device, for example.

Alternatively or additionally, the concentration stage 19 may be configured as an element having at least one dimension that is the same as a dimension of the screen of a display device, within 25% for example. In an embodiment, the concentration stage 19 comprises a wavelength converting element 8 that is planar and has at least one dimension that is the same as the dimension of the screen of the device within 25% (optionally within 15%, optionally within 5%, optionally within 1%).

In an embodiment, the apparatus for optical concentration/data communications is built into the screen of a display device that is powered completely independently of the apparatus for optical concentration/data communications. In an embodiment, the apparatus for optical concentration/data communications is used to provide some or all of the power required by the display in addition to providing data to the display. For example, excess power from the light providing the data is used to power the display or contribute to powering the display in combination with a separate power source. For example, the display device might consist of a thin sheet of material resembling a piece of paper or poster that might be attached to the wall. Data defining what is to be displayed on the poster can be transmitted to the poster via a light source and the excess power from the data provision can be used to power the display device.

In an embodiment, the wavelength converting element 8 and/or confinement structure 10A, 10B is configured to be switchable between an extended state and a storage state. The extended state provides a relatively large collection aperture and would typically correspond to the normal configuration of the device in use (e.g. when collecting radiation as part of a data communication process). The storage state is more compact and would typically correspond to a storage configuration. In an embodiment, the switching is performed by folding (unfolding) the wavelength converting element and/or confinement structure or by rolling (unrolling) the wavelength converting element and/or confinement structure.

In an embodiment, the wavelength converting element and/or confinement structure is/are configured to be flexible. This may facilitate manufacture, particularly where the wavelength converting element and/or confinement structure is required to have a curved form, and/or may facilitate switching of the wavelength converting element and/or confinement structure between an extended state and a storage stage, in embodiments where this is required.

Figure 8 is a schematic depiction of a further embodiment in which a television or monitor 40 is provided with a concentration stage 44 having a wavelength converting element incorporated into the screen 42 thereof. In this particular example, the wavelength converting element and/or confinement structure has/have both the same geometry, and two dimensions (length and width) that are within 25% of the corresponding dimensions of the screen of the display device.

In an embodiment, the wavelength converting element 8 is configured to convert UV radiation to infrared or near-infrared radiation. Alternatively or additionally, the wavelength converting element 8 is configured to convert infrared or near-infrared radiation to other infrared or near-infrared radiation. Alternatively or additionally, the wavelength converting element 8 is configured to convert visible radiation to other visible radiation or infrared or near-infrared. In an embodiment, the wavelength converting element 8 is configured to absorb radiation at approximately 475 nm and re-emit at approximately 600 nm. In such a system, a confinement structure may be provided that is configured substantially to pass radiation having a wavelength of approximately 475 nm and to trap radiation having a wavelength of approximately 600 nm. Such a system may be implemented using the dye Ru(BPY)3 for example.

CLAIMS

1. An apparatus for data communications, comprising:

a detector for detecting electromagnetic radiation;

a decoder for obtaining information from the detected electromagnetic radiation; and

a concentration stage for receiving and concentrating the radiation, prior to detection of the radiation by the detector, the concentration stage comprising a wavelength converting element configured to convert radiation to longer wavelength radiation.

2. An apparatus according to claim 1, further comprising:

an additional concentration stage positioned before said concentration stage and configured to receive electromagnetic radiation and concentrate the radiation.

3. An apparatus according to claim 2, wherein the additional concentration stage comprises a compound parabolic concentrator.

4. An apparatus according to any of the preceding claims, further comprising:

one or more further concentration stages.

5. An apparatus according to claim 4, further comprising:

one or more further wavelength converting elements incorporated into one or more of the further concentration stages.

6. An apparatus according to any of the preceding claims, wherein the concentration stage comprising the wavelength converting element further comprises a confinement structure that is configured substantially to allow passage of radiation having a wavelength suitable for conversion by the wavelength converting element from the outside of the confinement structure to the inside of the confinement structure, and substantially to block passage of radiation that has been converted by the wavelength converting element from the inside of the confinement structure to the outside of the confinement structure.

7. An apparatus according to claim 6, wherein:

the wavelength converting element is located within the confinement structure.

8. An apparatus according to claim 6 or 7, wherein the confinement structure is configured to concentrate radiation towards the detector.

9. An apparatus according to any of claims 6-8, wherein the confinement structure comprises two substantially planar elements and the wavelength converting element is located in between the two substantially planar elements.

10. An apparatus according to claim 9, wherein one or both of the substantially planar elements is/are dichroic.

11. An apparatus according to any of claims 6-10, wherein the confinement structure is substantially transparent to visible light.

12. An apparatus according to any of the preceding claims wherein the wavelength converting element is provided in a sheet-like form, with a thickness that is smaller than any dimension of the sheet perpendicular to the thickness of the sheet.

13. An apparatus according to any of the preceding claims, wherein the wavelength converting element is flexible.

14. An apparatus according to any of the preceding claims, wherein the wavelength converting element is configured to be switchable between an extended state in which the wavelength converting element presents a large collecting aperture and a storage state in which the wavelength converting element presents a smaller collecting aperture or substantially no collecting aperture.

15. An apparatus according to claim 14, wherein the wavelength converting element is configured to be switchable between the extended state and the storage state by one of the following: rolling up, folding up.

16. An apparatus according to any of the preceding claims in which the wavelength converting element is configured to do one or more of the following: convert infrared or near-infrared radiation to infrared radiation or near-infrared radiation having a longer wavelength, convert UV radiation to infrared or near-infrared radiation, convert visible radiation to infrared or near-infrared radiation.

17. An apparatus according to any of the preceding claims, wherein the detector comprises at least two detector elements.

18. An apparatus according to claim 17, wherein the at least two detector elements comprise single

photon detectors.

19. An apparatus according to claim 17 or 18, wherein the at least two detector elements are able independently to measure a radiation flux output from different regions on the surface of the wavelength converting element.

20. An apparatus according to any of the preceding claims, further comprising an orientation optimization unit configured to increase the amount of radiation detected by the detector by adjusting the orientation of the wavelength converting element.

21. An apparatus according to claim 20, wherein the orientation optimization unit is configured to monitor changes in the output from the detector as a function of changes in the orientation of the wavelength converting element and use a search method based on the monitoring to find an orientation of the wavelength converting element that increases the output from the detector.

22. An apparatus according to any of the preceding claims, wherein the wavelength converting element comprises a support body with wavelength converting elements dispersed therein.

23. An apparatus according to claim 22, wherein the support body comprises one of more of the following: an amorphous polymer, an inorganic glass, a SiO_2-based inorganic glass, an acrylic.

24. An apparatus according to any of the preceding claims, wherein the wavelength converting element is substantially transparent to converted radiation.

25. An apparatus according to any of the preceding claims, wherein the wavelength converting element comprises a quantum dot wavelength converter.

26. An apparatus according to claim 25, wherein the quantum dot wavelength converter comprises solution processed quantum dots.

27. An apparatus according to claim 25 or 26, wherein the wavelength converting element comprises a support body containing dispersed quantum dot wavelength converters.

28. An apparatus according to any of claims 25-27, wherein the quantum dot wavelength converter comprises lead chalcogenide quantum dot wavelength converters.

29. An apparatus according to any of the preceding claims, wherein the wavelength converting element comprises a fluorescent dye.

30. An apparatus according to any of the preceding claims, wherein the response time of the wavelength converting element is less than 1 microsecond.

32. A display device comprising an apparatus according to any of the preceding claims, wherein the wavelength converting element is incorporated into a screen of the display device.

33. A portable electronic device comprising a display device according to claim 32.

34. A television or monitor comprising a display device according to claim 32.

35. A portable electronic device according to claim 33 or a television or monitor according to claim 34, wherein the wavelength converting element is incorporated into an exterior side opposite to the screen of the display device.

36. A method of performing data communications, comprising:

using a concentration stage to receive and concentrate electromagnetic radiation;

using a wavelength converting element in the concentration stage to convert radiation to longer wavelength radiation;

detecting radiation output by the concentration stage; and

decoding the detected radiation in order to obtain information from the detected radiation.

37. A method according to claim 36, further comprising:

using an additional concentration stage to concentrate radiation received by the additional concentration stage, wherein said concentration stage is used to concentrate radiation output from the additional concentration stage.

38. An apparatus for optical concentration, an apparatus for data communications, a display device, a portable electronic device, a television or a monitor constructed and arranged to operate substantially as hereinbefore described with reference to and/or as illustrated in the accompanying drawings.

39. A method of performing optical concentration or data communications substantially as hereinbefore

described with reference to and/or as illustrated in the accompanying drawings.

Application No:	GB1217279.7	**Examiner:**	Helen Edwards
Claims searched:	All	**Date of search:**	23 January 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	WO2010/132955 A1 (OMEGA 3 INNOVATIONS PTY LTD)
A	-	WO2009/092041 A2 (ABU-AGEEL)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

G02F; H04B

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, TXTEN, NPL, TDB, XPI3E

International Classification:

Subclass	Subgroup	Valid From
G02F	0001/355	01/01/2006
G02F	0001/35	01/01/2006
H04B	0010/11	01/01/2013