

APPLICATION FOR PATENT

TITLE

Multiple Coherent Beam Combination Systems Sharing a Common Receiver

TECHNICAL FIELD

5 The present invention relates to Coherent Beam Combination (CBC) systems.

BACKGROUND OF THE INVENTION

It is known to employ CBC systems in which a plurality of coherent laser beams are combined to form output beams in order to achieve power scaling of a laser source. In order to provide system flexibility in terms of the number and allocation of beam sources, directing the output beams from multiple CBC systems so as to combine at a target as a combined beam has been contemplated. Coherent combining of the output beams from multiple CBC systems poses technological challenges without significant benefit. In particular, because of the coherence between the output beams of the CBC systems, the resulting interference pattern of the combined beam – typically used for beam intensity optimization in combination with target imaging – consists of dense lines, which makes stabilization of the combined beam on the target exceedingly difficult. Furthermore, coherent combining of the output beams on the target requires individual measurement of each of the sub-beams of the CBC systems in order to achieve intensity optimization of the individual output beams. Similar challenges exist when the output beams from multiple CBC systems are incoherently combined.

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SUMMARY OF THE INVENTION

The present invention is a system and method for receiving radiation reflected from a target in response to illumination of the target by a plurality of beam emitters using a common receiver.

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According to the teachings of an embodiment of the present invention, there is provided a system comprising: a plurality of beam emitting subsystems, each beam emitting subsystem configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, for each composite output beam a proportion of radiation intensity of the composite output beam reflected by the target as a reflected radiation component; a telescope arrangement for collecting radiation reflected from the target and directing

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the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, and an intensity of the combined radiation indicative of radiation intensity of the composite output beams impinging on the target; a spatial filtering configuration deployed at the focal plane and configured for filtering the reflected radiation by selectively passing the combined radiation; and a radiation distinguishing module for receiving the combined radiation passed by the spatial filtering configuration and for distinguishing, for each reflected radiation component, an intensity parameter of the reflected radiation component from an intensity parameter of the combined radiation of all other of the reflected radiation components.

According to a further feature of an embodiment of the present invention, each beam emitting subsystem includes: a beam generating arrangement for generating a respective one of the composite output beams, and a beam directing arrangement for directing the composite output beam towards the target.

According to a further feature of an embodiment of the present invention, each reflected radiation component has a different wavelength from all other of the reflected radiation component, and the radiation distinguishing module includes: an optics arrangement including at least one dispersive optical component for separating the combined radiation into a plurality of constituent wavelengths corresponding to the wavelengths of the reflected radiation component, and a detector arrangement for receiving radiation separated by the at least one dispersive optical component, the detector arrangement configured to separately measure radiation at each respective wavelength of the constituent wavelengths.

According to a further feature of an embodiment of the present invention, the at least one dispersive optical component includes a prism.

According to a further feature of an embodiment of the present invention, the at least one dispersive optical component includes a diffractive grating.

According to a further feature of an embodiment of the present invention, the optics arrangement further includes a collimating element deployed in an optical path between the spatial filtering configuration and the at least one dispersive optical component, the collimating element configured for: collimating the combined

radiation so as to produce collimated radiation, and directing the collimated radiation to the at least one dispersive optical component.

According to a further feature of an embodiment of the present invention, the detector arrangement includes an array of detectors, each respective detector of the array of detectors configured to measure radiation in a different respective wavelength of the constituent wavelengths.

According to a further feature of an embodiment of the present invention, each beam emitting subsystem includes: an array of beam sources configured to generate a plurality of coherent beams for directing towards the target so as to combine at or before the target as the composite output beam, a plurality of adjustable phase modulators associated with the beams sources so as to allow adjustment of relative phase offsets of the coherent beams, and an encoding module for encoding a phase of each of the coherent beams with a code that is locally unique to the beam emitting subsystem.

According to a further feature of an embodiment of the present invention, the radiation distinguishing module includes: a detector deployed to receive the combined radiation and to monitor an intensity parameter of the combined radiation, and a decoding module configured to decode, for each composite output beam, the intensity parameter of the combined radiation according to the locally unique code of the beam emitting subsystem that generated the composite output beam to isolate an intensity parameter of the reflected radiation component corresponding to the composite output beam.

According to a further feature of an embodiment of the present invention, the encoding module includes a modulator, and the code includes a modulation frequency such that each composite output beam is assigned at least one unique modulation frequency, and the encoding module configured to encode the phase of each of the coherent beams for each beam emitting subsystem by modulating the current phase of the coherent beams at the assigned at least one modulation frequency, and the decoding module includes a plurality of demodulators, each demodulator configured to demodulate the signal at one or more selected demodulation frequency selected from the assigned unique modulation frequencies.

According to a further feature of an embodiment of the present invention, there is also provided a control subsystem associated with the radiation distinguishing

module and each of the beam emitting subsystems, and each beam emitting subsystem includes: an array of beam sources configured to generate a plurality of coherent beams for directing towards the target so as to combine at or before the target as the composite output beam, and a plurality of adjustable phase modulators associated
5 with the beams sources so as to allow adjustment of relative phase offsets of the coherent beams, and for each reflected radiation component the control subsystem is configured to: receive the intensity parameter of the reflected radiation component from the radiation distinguishing module, and adjust a beam parameter of one or more coherent beams of the composite output beam corresponding to the reflected radiation
10 component based on the received intensity parameter.

According to a further feature of an embodiment of the present invention, there is also provided an imaging system for generating images of the target, the imaging system including: a wavefront sensor, a deformable mirror for receiving radiation from the spatial filtering configuration, a beam splitter for receiving
15 radiation from the deformable mirror and providing a part of the received radiation to the wavefront sensor and providing another part of the received radiation to the radiation distinguishing module, and an adaptive optics controller associated with the wavefront sensor operative to control the deformable mirror so as to reduce optical distortions in the reflected radiation collected by the telescope arrangement.

There is also provided according to the teachings of an embodiment of the present invention, a system comprising: a plurality of beam emitting subsystems, each beam emitting subsystem including an array of beam sources configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, the composite output beams
25 generated by the beam emitting subsystems having different respective wavelengths, and for each composite output beam a proportion of radiation intensity of the composite output beam reflected by the target as a reflected radiation component; and a receiver including: a telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected
30 radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, a spatial filtering configuration deployed at the focal plane and configured for filtering the reflected radiation by selectively passing the

combined radiation, an optics arrangement for receiving the combined radiation from the spatial filtering configuration and including at least one dispersive optical component for separating the combined radiation into a plurality of constituent wavelengths corresponding to the wavelengths of the composite output beams, and a
5 detector arrangement for receiving radiation separated by the at least one dispersive optical component, the detector arrangement configured to separately measure radiation at each respective wavelength of the constituent wavelengths.

According to a further feature of an embodiment of the present invention, the at least one dispersive optical component includes a prism.

10 According to a further feature of an embodiment of the present invention, the at least one dispersive optical component includes a diffractive grating.

According to a further feature of an embodiment of the present invention, the optics arrangement further includes a collimating element deployed in an optical path between the spatial filtering configuration and the at least one optical component, the
15 collimating element configured for: collimating the combined radiation so as to produce collimated radiation, and directing the collimated radiation to the at least one optical element.

According to a further feature of an embodiment of the present invention, there is also provided a control subsystem associated with the detector arrangement
20 and each of the beam emitting subsystems, and for each beam emitting subsystem the control subsystem is configured to adjust a beam parameter of one or more coherent beams of the composite output beam generated by the beam emitting subsystem, based on the measured radiation by the detector arrangement.

According to a further feature of an embodiment of the present invention, the
25 detector arrangement includes an array of detectors, each respective detector of the array of detectors configured to measure radiation in a different respective wavelength of the constituent wavelengths.

There is also provided according to the teachings of an embodiment of the present invention, a system comprising: a plurality of beam emitting subsystems, each
30 beam emitting subsystem including: an array of beam sources configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, a proportion of radiation intensity of the composite output beam reflected by the target as a reflected radiation

component, a plurality of adjustable phase modulators associated with the beam sources so as to allow adjustment of relative phase offsets of the coherent beams, and an encoding module for encoding a phase of each of the coherent beams with a code that is locally unique to the beam emitting subsystem; and a receiver including: a
5 telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, a spatial filtering configuration deployed at the focal plane configured for filtering the reflected
10 radiation by selectively passing the combined radiation, a detector deployed to receive the combined radiation from the spatial filtering configuration and to generate a signal representative of an intensity of the combined radiation, and a decoding module for decoding the signal according to the locally unique code for each beam emitting subsystem.

15 According to a further feature of an embodiment of the present invention, the encoding module includes a modulator, and each composite output beam assigned a locally unique modulation frequency, and for each beam emitting subsystem the modulator configured to modulate a current phase of the coherent beams at the assigned modulation frequency, and the decoding module includes a plurality of
20 demodulators, each demodulator configured to demodulate the signal at one or more selected demodulation frequency selected from the assigned unique modulation frequencies.

According to a further feature of an embodiment of the present invention, for each beam emitting subsystem: the encoding module includes a sequence generator
25 for generating a code sequence, and the encoding module configured to encode the phase of each of the coherent beams by modulating the current phase of the coherent beams with a waveform associated with the code sequence, and the decoding module includes a signal generator for generating the waveforms associated with the code sequences, and the decoding module configured to demodulate the signal using each
30 of the waveforms.

There is also provided according to the teachings of an embodiment of the present invention, a system comprising: a plurality of beam emitting subsystems, each beam emitting subsystem configured to generate a plurality of coherent beams for

directing towards an area of a target so as to combine at or before the target as a composite output beam, for each composite output beam a proportion of radiation intensity of the composite output beam reflected by the target as a reflected radiation component; a plurality of receivers, each of the receivers configured to: collect
5 radiation reflected from the target and direct the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, and an intensity of the combined radiation indicative of radiation intensity of the composite output beams impinging on the target, spatially
10 filter the reflected radiation at the focal plane by selectively passing the combined radiation, and receive the combined radiation that is spatially filtered and distinguish, for each reflected radiation component, an intensity parameter of the reflected radiation component from an intensity parameter of the combined radiation of all other of the reflected radiation components; and a control subsystem associated with
15 the receivers and configured to: select a selected receiver based on an estimate of an effective resolution of the target provided by each of the receivers.

According to a further feature of an embodiment of the present invention, the control subsystem is further configured to actuate each of the beam emitting subsystems to adjust a beam parameter of one or more of the coherent beams based on
20 the intensity parameters distinguished by the selected receiver.

There is also provided according to the teachings of an embodiment of the present invention, a method comprising: transmitting a plurality of composite output beams, each output beam transmitted by generating a plurality of coherent beams and directing the coherent beams towards an area of a target so as to combine at or before
25 the target as the composite output beam, for each composite output beam a proportion of radiation intensity of the composite output beam reflected by the target as a reflected radiation component; collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation
30 combining as a combined radiation composed of the reflected radiation components, and an intensity of the combined radiation indicative of radiation intensity of the composite output beams impinging on the target; spatially filtering the reflected radiation by selectively passing the combined radiation; and receiving the combined

radiation passed by the spatial filtering configuration and distinguishing, for each reflected radiation component, an intensity parameter of the reflected radiation component from an intensity parameter of the combined radiation of all other of the reflected radiation components.

5 There is also provided according to the teachings of an embodiment of the present invention, a system comprising: a plurality of beam emitting subsystems, each beam emitting subsystem configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, each composite output beam having an associated locally
10 unique signature, and for each composite output beam a proportion of radiation intensity of the composite output beam reflected by the target as a reflected radiation component; a telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of
15 radiation combining as a combined radiation composed of the reflected radiation components, and an intensity of the combined radiation indicative of radiation intensity of the composite output beams impinging on the target; and a spatial filtering configuration deployed at the focal plane and configured for filtering the reflected radiation by selectively passing the combined radiation, and each component of the
20 combined radiation identifiable according to the locally unique signature associated with the composite output beam that corresponds to the component of the combined radiation.

 According to a further feature of an embodiment of the present invention, there is also provided at least one radiation distinguishing module for receiving the
25 combined radiation passed by the spatial filtering configuration and for distinguishing, for at least one of the reflected radiation components, an intensity parameter of the at least one of the reflected radiation components from an intensity parameter of the combined radiation of all other of the reflected radiation components, based on at least one of the locally unique signatures associated with the
30 composite output beam that corresponds to the component of the combined radiation.

 According to a further feature of an embodiment of the present invention, the at least one radiation distinguishing module includes exactly one radiation distinguishing module.

According to a further feature of an embodiment of the present invention, the at least one radiation distinguishing module includes a plurality of radiation distinguishing modules, each radiation distinguishing module associated with a respective one of the beam emitting subsystems, and for each radiation distinguishing module, the radiation distinguishing module configured to distinguish an intensity parameter of one of the reflected radiation components, corresponding to the composite output beam generated by the beam emitting subsystem associated with the radiation distinguishing module, from the intensity parameter of the combined radiation of all other of the reflected radiation components.

Unless otherwise defined herein, all technical and/or scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the invention pertains. Although methods and materials similar or equivalent to those described herein may be used in the practice or testing of embodiments of the invention, exemplary methods and/or materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and are not intended to be necessarily limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments of the present invention are herein described, by way of example only, with reference to the accompanying drawings. With specific reference to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of embodiments of the invention. In this regard, the description taken with the drawings makes apparent to those skilled in the art how embodiments of the invention may be practiced.

Attention is now directed to the drawings, where like reference numerals or characters indicate corresponding or like components. In the drawings:

FIG. 1 is a schematic representation of a system, constructed and operative according to embodiments of the present invention, having a plurality of beam emitting subsystems for transmitting beams of radiation towards a target, and a single receiver shared amongst the beam emitting subsystems having a telescope for collecting corresponding reflected radiation from the target and a radiation distinguishing module for distinguishing components of the reflected radiation from other components of the reflected radiation;

FIG. 2 is a schematic representation of a beam emitting subsystem that can be implemented in the system of FIG. 1 for transmitting the beams, according to embodiments of the present invention;

5 FIG. 3 is a schematic representation of the receiver of FIG. 1, in which the radiation distinguishing module includes dispersive optics and a detector arrangement for distinguishing components of the reflected radiation from other components of the reflected radiation, according to embodiments of the present invention;

10 FIG. 4 is a schematic representation of the receiver of FIG. 1, in which the radiation distinguishing module includes a photodetector and a decoding module that decodes information in the collected reflected radiation in order to distinguish components of the reflected radiation from other components of the reflected radiation, according to embodiments of the present invention;

15 FIG. 5 illustrates schematically a telescope arrangement, such as the telescope of the receiver of FIG. 1, that includes adaptive optics for correcting wavefront distortions and images received via the telescope arrangement;

FIG. 6 is a schematic representation of a system integrating a telescope with adaptive optics into the receiver of FIG. 1;

20 FIG. 7 is a schematic representation of a system having a plurality of beam emitting subsystems for transmitting beams and a plurality of receivers, each corresponding to the structure of the receiver of FIG. 1, according to an embodiment of the present invention;

25 FIG. 8 is a schematic representation of a system, constructed and operative according to embodiments of the present invention, generally similar to the system of FIG. 1, but in which the radiation distinguishing module is separated from the receiver; and

30 FIG. 9 is a schematic representation of a system, constructed and operative according to embodiments of the present invention, generally similar to the system of FIG. 8, but in which there are a plurality of radiation distinguishing modules, and each of the beam emitting subsystems is associated with a respective one of the radiation distinguishing modules.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a system and method for receiving radiation reflected from a target in response to illumination of the target by a plurality of beam emitters using a common receiver.

5 The beam emitters are configured to illuminate a common spot on the target with each beam emitter transmitting coherent beams that coherently combine at or before reaching the target. The receiver is deployed and aimed at the target with a view of the spot, enabling capture of reflected radiation from the spot corresponding to the radiant illumination from all of the beam emitters, and in certain embodiments
10 imaging of the spot. The receiver is typically smaller in size and of lower cost as compared to the beam emitters, and can be deployed independently from the beam emitters. Due to size, cost effectiveness, and deployment options of the receiver relative to the beam emitters, the system of the present disclosure provides significant advantages over conventional systems that employ a dedicated receiver for each CBC
15 system. One particular advantage of using a single receiver with a multitude of beam emitters (including up to several hundreds of beam emitters) according to the embodiments of the present disclosure is the capability to aim the receiver at a target spot common to the beam emitters, capture target-reflected radiation from a corresponding number of coherently combined beams, and subsequently process the
20 captured radiation to form images of the target spot and/or to use as input for other purposes, for example, as feedback to the beam emitters for beam intensity optimization. In certain embodiments, the reflected radiation is processed by a control subsystem and provided as feedback to the beam emitters for adjusting beam transmission parameters for beam intensity optimization. In order to enhance the
25 efficacy with which the beam emitters perform intensity optimization, embodiments of the present disclosure process the reflected radiation so as to isolate radiation components in the reflected radiation that corresponds to beams transmitted by specific beam emitters. The radiation processing may be performed by the receiver itself, or may be performed by one or more modules that are separate from the
30 receiver.

The principles and operation of the system and method according to present invention may be better understood with reference to the drawings accompanying the description.

The system and method according to the present invention is of particular value when applied within the context of high-energy laser or directed-energy weapons systems.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not necessarily limited in its application to the details of construction and the arrangement of the components and/or methods set forth in the following description and/or illustrated in the drawings and/or the examples. The invention is capable of other embodiments or of being practiced or carried out in various ways.

Referring now to the drawings, FIG. 1 illustrates an implementation of a multiple coherent beam combination (CBC) system (referred to hereinafter as “the system”), generally designated **10**, constructed and operative according to certain non-limiting embodiments of the present disclosure. In general terms, the system **10** includes a battery (i.e., a set or group) of beam emitting subsystems **12a**, **12b** and **12c**, configured to generate and transmit (direct) respective composite output beams **14a**, **14b** and **14c** towards an area of a target **26** (typically a remote target), and a receiver **16** (also referred to as a targeting receiver) that is common among (i.e., shared between) all of the beam emitting subsystems **12a**, **12b** and **12c** deployed to receive reflected radiation from the target **26**.

The beam emitting subsystems **12a**, **12b** and **12c** transmit the respective output beams such that the composite output beams **14a**, **14b** and **14c** are incoherently combined at or before reaching the target **26**. The composite output beams **14a**, **14b** and **14c** (referred to interchangeably as “output beams”, “composite beams”, or “output composite beams”) are transmitted along an optical path passing through an optically non-uniform and/or transiently varying medium **28**, such as the atmosphere, towards the target **26**. It is desirable that each of the composite output beams **14a**, **14b** and **14c** impinge on the same area of the target **26** so as to be able to achieve efficient power scaling of the individual beam emitting subsystems **12a**, **12b** and **12c**.

Various approaches to guiding beams from different (or the same) sources so as to combine on a common spot on a target with high precision have been presented. One approach uses a master-slave beam emitter configuration in which a master unit emits (transmits) a low-power guide beam onto the intended spot on the target, which forms a local coordinate system on the target. A slave unit tracks the spot of the guide

beam on the target, calculates a direction vector (using, for example, the formed local coordinate system) from the slave unit to the target spot, and then transmits one or more high-power beams along the vector so as to combine on the intended target spot. Further details of a system that provides combining of beams (of generally lower power than the output beams **14a**, **14b** and **14c**) on a target spot can be found in the applicant's commonly owned US Patent No. 9,003,942 B2, which is hereby incorporated by reference in its entirety herein. Although this prior approach relates to lower-power beams combining on a target, the general concept of such a system may be applicable in the context of the present invention. Here, a master unit may be deployed to transmit a low-power guide beam, and the beam emitting subsystems **12a**, **12b** and **12c** may function as synchronized slave units that transmit high-power output beams **14a**, **14b** and **14c** based on calculated direction vectors, where synchronization may be provided by a control subsystem linked to the beam emitting subsystems **12a**, **12b** and **12c** and the master unit. Direction vector calculation may be performed by such a control subsystem, or may be performed by processing hardware/software locally installed on the beam emitting subsystems **12a**, **12b** and **12c**.

The beam emitting subsystems **12a**, **12b** and **12c** can be deployed in various deployment configurations, depending on the particular case in which the system **10** is to be used. In one non-limiting example configuration, the beam emitting subsystems **12a**, **12b** and **12c** are deployed in close proximity to each other, preferably within a single modular housing. In another example configuration, the beam emitting subsystems **12a**, **12b** and **12c** are deployed in an array with even or uneven spacing between adjacent beam emitting subsystems, and in which adjacent beam emitting subsystems can be between approximately 5-50 meters apart. In other configurations, the beam emitting subsystems **12a**, **12b** and **12c** are strategically deployed in a disjointed (non-array) configuration, where adjacent beam emitting subsystems can be between up to several km apart, as long as the beam emitting subsystems **12a**, **12b** and **12c** can each be aimed at the same point on the target **26**.

Although three beam emitting subsystems are illustrated here for simplicity of presentation, the embodiments of the present disclosure may be implemented with an array containing anywhere between two and several hundreds of such subsystems.

As will be discussed, each of the composite output beams **14a**, **14b** and **14c** is formed from a plurality of respective coherent beams produced by associated beam

sources by the respective beam emitting subsystem **12a**, **12b** and **12c**. FIG. 2 schematically illustrates a non-limiting example of a beam emitting subsystem **30** which can be used to implement each of the beam emitting subsystems **12a**, **12b** and **12c**. Generally speaking, the beam emitting subsystem **30** includes an array of beam sources **32a**, **32b** and **32c** configured to generate a plurality of coherent beams **40a**, **40b** and **40c** (also referred to as “sub-beams”) for directing towards the target **26**. A plurality of adjustable phase modulators **34a**, **34b** and **34c** are associated with respective beam sources **32a**, **32b** and **32c** to allow adjustment of relative phase offsets of the beams. Although only three beam sources and phase modulators are illustrated in FIG. 2 for simplicity of presentation, the embodiments of the present disclosure are most preferably implemented with an array containing anywhere between two and a few hundred beams, and is most typically implemented with at least 10 beam sources, and in some particularly preferred cases, in the range of 15-40 beam sources. The phase modulators are typically provided one-per-source, although it will be appreciated that one of the sources may be implemented as a fixed reference phase without adjustment, and the rest of the beams and phase offsets may be measured and/or adjusted relative to that reference phase.

It will be understood that various details of the implementations of the system **10** and the beam emitting subsystem **30** will vary considerably according to the intended application of the device. The variety of applications may extend from a low-energy research tool for measuring high-speed variations in optical properties of turbulent media through various communications applications (medium energy) up to high-energy directed-energy weapon systems. Although the beam emitting subsystem **30**, and by extension the system **10**, supports a wide variety of applications, the beam emitting subsystem **30** and the system **10** are of particular value when used as part of a high-energy laser or directed-energy weapons system. In each case, the array of beam sources **32a**, **32b** and **32c** is most preferably an array of fiber lasers, seeded by a common seeder oscillator **36**. For high energy applications, each fiber laser is preferably rated for a power output of at least 100 W. The principles of the present embodiments may be used for devices operating with various different wavelengths, but is typically implemented in the near-infrared (NIR) range. Seeder oscillators and fiber lasers suitable for operating in these ranges are well known in the art, and are readily commercially available. The phase modulators **34a**, **34b** and **34c** may be any

type of phase modulator with suitable response times and low attenuation. The phase modulators are positioned after splitting the seeder **36**, but preferably before the fiber lasers in order to operate with a relatively low-power signal. Suitable phase modulators are available commercially. One suitable non-limiting example is a 10
5 GHz titanium indiffused Z-Cut LiNbO₃ phase modulator identified by model no. LN53S-FC commercially available from Thorlabs, NJ (USA). The combination of the beam sources **32a**, **32b** and **32c**, the phase modulators **34a**, **34b** and **34c**, and the seeder **36** constitute a “beam generating arrangement”.

In certain embodiments, an encoding module **44** is linked to each of the phase
10 modulators **34a**, **34b** and **34c**. As will be discussed, the encoding module **44** is operative to encode (or “tag”) the phase of the coherent beams with a code (or “signature”) that is unique to the particular beam emitting subsystem (and the output beam transmitted by that beam emitting subsystem).

A beam directing arrangement (represented schematically in FIG. 2 by a lens
15 **38**) directs the beams **40a**, **40b** and **40c** towards a particular region (area) of the target **26** such that the beams **40a**, **40b** and **40c** combine (constructively interfere), at or before reaching the target **26**, so as to form a composite output beam **42**. The composite output beam **42**, composed of sub-beams **40a**, **40b** and **40c**, is representative of any one of the composite output beams **14a**, **14b** and **14c** illustrated
20 in FIG. 1. The beam directing arrangement **38** is shown in FIG. 2 only schematically, but typically includes a separate collimator for each of the beams, and common large-aperture focusing optics for directing the beams collectively towards the target **26** so as to combine at or before reaching the target **26**. Alternatively, separate focusing optics can be provided for each beam. Within the context of this document, coherent
25 sub-beams that are combined at or before reaching the target generally refers to coherent sub-beams that are either brought into coherent combination at the target, or brought into coherent combination before the target and sustain coherent combination over the remaining distance to the target. The term “target” is used here broadly to refer to the object against which the beams **40a**, **40b** and **40c** (and the composite
30 output beams **14a**, **14a** and **14c**) are to impinge, which in certain preferred applications is a target in the military sense for weapon applications, but may also be a receiver (detector) for communications applications. In fact, the system **10** is of particular value in situations in which the target **26** is a remote non-cooperative target

(as in the military sense). However, the system **10** may also be of use in situations in which the target **26** is a cooperative target, for example in situations where the system **10** is used as a diagnostic or research tool, or as a measurement tool in support of another device/system. In such situations, a detector may be mounted to the target **26**,
5 and may provide the system **10** with feedback via a communication link.

Although the sub-beams (i.e., the coherent beams **40a**, **40b** and **40c**) for each of the respective composite output beams **14a**, **14b** and **14c** are coherent so as to constructively interfere, the composite output beams **14a**, **14b** and **14c** themselves are mutually incoherent. In other words, whereas the sub-beams of a particular composite
10 output beam have the same effective wavelength and phase, the composite output beams **14a**, **14b** and **14c** have different respective effective wavelength and/or phase.

It is noted that the number of sub-beams generated by the beam emitting subsystems need not necessarily be uniform across the beam emitting subsystems. In other words, each of the composite output beams **14a**, **14b** and **14c** may be composed
15 of a different respective number of sub-beams. For example, one of the beam emitting subsystems may generate on the order of 10 sub-beams (i.e., may include on the order of 10 beam sources), while another of the beam emitting subsystems may generate between 15-40 sub-beams (i.e., may include 15-40 beam sources), while yet another of the beam emitting subsystems may generate on the order of 100 beam sources (i.e.,
20 may include on the order of 100 beam sources).

A part of the radiation impinging on the target **26** is reflected (typically backscattered) by the target **26** towards the targeting receiver **16** that is associated with the beam emitting subsystems **12a**, **12b** and **12c**. In general, in response to illumination of the target **26** by each of the composite output beams **14a**, **14b** and **14c**,
25 a proportion of the radiation intensity of each of the composite output beams **14a**, **14b** and **14c** is reflected from the target **26** as a corresponding reflected radiation component, designated by thin dashed arrows **15a**, **15b** and **15c**. The intensity of the reflected radiation (corresponding to reflected radiation component **15a**, **15b** and **15c**) varies as a function of the radiation intensity (from the composite output beams **14a**,
30 **14b** and **14c**) impinging on the area of the target **26**. In FIG. 2, the reflected radiation from a single composite beam **42** is generally designated **43**. It is noted that the reflected radiation **43** includes radiation components corresponding to the reflections of each of the sub-beams **40a**, **40b** and **40c** from the target **26**.

The receiver **16** is deployed and configured to receive the radiation (i.e., light) reflected from the target **26**, which includes the radiation received from the reflected radiation components **15a**, **15b** and **15c**. The receiver **16** may be deployed in a location that is co-located with one or more of the beam emitting subsystems **12a**, **12b** and **12c**. Alternatively, the receiver **16** may be deployed in a separate location from some or all of the beam emitting subsystems **12a**, **12b** and **12c**. Further still, the major components of the receiver **16** may be co-located or distributed across various geographic locations. Regardless of the particular deployment configuration of the receiver **16** and its major components, the receiver **16** is preferably deployed independently from the beam emitting subsystems **12a**, **12b** and **12c**, and should be deployed such that radiation corresponding to all of the reflected radiation components **15a**, **15b** and **15c** reaches specific major components of the receiver **16**.

In general, the radiation reflected from the target (i.e., the reflected radiation) includes a plurality of components of radiation, some of which correspond to the reflected radiation components **15a**, **15b** and **15c**, and some of which correspond to other sources of radiation, including, for example atmospheric noise. The reflected radiation components **15a**, **15b** and **15c** are combined (i.e., the radiation intensity of the reflected radiation components **15a**, **15b** and **15c** is summed) at or before reaching the receiver **16** so as to form “combined radiation”. The intensity of the combined radiation (which is composed of the reflected radiation components **15a**, **15b** and **15c**) is indicative of the intensity of the radiation impinging on the area of the target **26** by the respective composite output beams **14a**, **14b** and **14c**. In certain preferred embodiments, the receiver **16** is associated with a radiation distinguishing module **22** that is configured to separate an intensity parameter of the combined radiation (an intensity signal of the combined radiation) so as to be able to distinguish the intensity parameter for each reflected radiation component, corresponding to a respective component of the combined radiation, from the intensity parameter of the combined radiation of all of the other reflected radiation components. In other words, in such embodiments, the radiation distinguishing module **22** associated with the receiver **16** is configured to distinguish the reflected intensity signal attributable to each respective one of the beam emitting subsystems **12a**, **12b** and **12b** from the received reflected intensity signal of the combined reflected radiation. As will be discussed, in certain embodiments the radiation distinguishing module **22** is functionally part of the

receiver **16** (i.e., the radiation distinguishing module **22** is a component of the receiver **16**), while in other embodiments the radiation distinguishing module **22** is a separate component from the receiver **16** and can be deployed independently from the receiver **16**.

5 It is noted that for each of the composite output beams **14a**, **14b** and **14c**, a proportion of the intensity of the sub-beams (e.g., beams **40a**, **40b** and **40c**) is reflected from the target **26**. When discussing the reflected radiation components **15a**, **15b** and **15c**, it is noted that these components are representative of the combination of the reflected radiation sub-components of the respectively associated composite
10 output beams **14a**, **14b** and **14c**. In other words, the reflected radiation component **15a** is representative of the combination of the reflected radiation sub-components of the composite output beams **14a**, the reflected radiation component **15b** is representative of the combination of the reflected radiation sub-components of the composite output beam **14b**, and so on. Accordingly, the combined radiation, which is formed from the
15 combination of the radiation corresponding to the reflected radiation components **15a**, **15b** and **15c**, in fact includes the radiation corresponding to all of the reflected radiation sub-components of all of the associated composite output beams **14a**, **14b** and **14c**. The receiver **16** is therefore configured to separate the received combined radiation in order to identify, for a particular beam emitting subsystem, the subsets of
20 the reflected radiation sub-components that correspond to a particular composite output beam generated by that beam emitting subsystem. In other terms, the receiver **16** is configured to separate the received combined radiation in order to distinguish, for a particular beam emitting subsystem, the components of the combined radiation corresponding to the composite output beam generated by that beam emitting
25 subsystem.

 In order to ensure that receiver **16** receives the correct radiation, an optical arrangement, typically in the form of a targeting telescope, is deployed to define a field of view corresponding to the region from which the reflected radiation will arrive, such that the reflected radiation is collected by the optical arrangement (at least
30 the combined radiation reaches the input aperture of the optical arrangement). The optical arrangement is represented schematically in FIG. 1 by a lens **18**, but is typically an assembly of lenses, which may be refractive or reflective, or any

combination thereof, to form an appropriate telescope, as is known in the art. The telescope **18** defines an optical path from the target **26** to the receiver **16**.

5 Parenthetically, in order to direct the output beams **14a**, **14b** and **14c** onto the same area of the target **26** (also referred to as the same “spot”), coarse alignment of the output beams **14a**, **14b** and **14c** is applied by individual tracking subsystems for each of the beam emitting subsystems **12a**, **12b** and **12c**, up to a point where the extended lobes (i.e., side lobes) of the radiation pattern of the output beams **14a**, **14b** and **14c** are overlapping. The alignment of the central lobes of the output beams **14a**, **14b** and **14c** is achieved by closing a loop via the receiver **16**, which provides
10 feedback to the beam emitting subsystems **12a**, **12b** and **12c**. In certain embodiments, the optical arrangement (i.e., telescope **18**) also preferably forms part of an imaging system or is integrated with an imaging system, which can be used for aiming each of the beam emitting subsystems **12a**, **12b** and **12c**. The imaging system creates an image of the target **26** and the desired area of the target **26** (or “spot”) upon which the
15 composite output beams **14a**, **14b** and **14c** are to impinge. By forming an image of the target **26** and the spot, the composite output beams **14a**, **14b** and **14c** can be properly aimed at the target **26** (such that the side lobes of the composite output beams **14a**, **14b** and **14c** overlap) and the intensity of the composite output beams **14a**, **14b** and **14c** can be optimized (via a control system). The imaging system is not illustrated
20 here, but a non-limiting example of a telescope integrated with an imaging system will be described in subsequent sections of the present disclosure, with reference to FIGS. 5 and 6.

 The reflected radiation collected at the input aperture of the telescope **18** is focused, by the telescope **18**, onto a focal plane. A spatial filtering configuration **20**,
25 associated with the telescope **18**, is deployed at the focal plane. The spatial filtering configuration **20** is configured to spatially filter the reflected radiation collected by the telescope **18** to produce “filtered radiation” by passing only the components of the reflected radiation originating from the “spot” on the target **26** (these components of the reflected radiation are represented as the previously mentioned “combined radiation”), such that substantially only the radiation resulting from illumination of
30 the target **26** by the composite output beams **14a**, **14b** and **14c** (i.e., reflected radiation components **15a**, **15b** and **15c**) is passed by the spatial filtering configuration **20**. A narrow passband filter (not shown) may be deployed in the optical path between the

telescope **18** and the spatial filtering configuration **20** to exclude ambient background radiation emanating from the illuminated area of the target **26**, thereby enhancing the signal-to-noise ratio at the illumination sensing components of the system **10**.

The spatial filtering configuration **20** may be implemented in various ways. In one non-limiting implementation, the spatial filtering configuration **20** is implemented as a pinhole which acts as a low pass filter for the spatial frequencies in the image plane of the telescope **18**. Similarly, the spatial filtering configuration **20** can be implemented using an optical fiber, in which the edge of the optical fiber is positioned in the image plane of the telescope **18**. Here, only the light with the desired spatial frequencies is coupled to the core of the optical fiber. Alternatively, the spatial filtering configuration **20** can be implemented using a small detector deployed at the exit aperture of the telescope **18**. After the intensity of the composite output beams **14a**, **14b** and **14c** is optimized (for example via the aforementioned imaging system and control system), the size of the spatial filtering configuration **20**, for example the size of the pinhole, can be used in order to determine the size and position of the central lobes of the composite output beams **14a**, **14b** and **14c** relative to the desired spot on the target **26**.

The deployment of the receiver **16** with the spatial filtering configuration **20** enables the receiver **16** to “see” the common spot on the target **26** that is illuminated by the beam emitting subsystems **12a**, **12b** and **12c**. Accordingly, the receiver **16** can provide feedback signals or information to the beam emitting subsystems **12a**, **12b** and **12c** based on the captured reflected radiation from the target spot.

One particular method for generating such feedback according to embodiments of the present disclosure is based on distinguishing certain components of the combined radiation (provided by the spatial filtering configuration **20**) from the remaining components of the combined radiation. The radiation distinguishing is performed by the radiation distinguishing module **22** that is associated with the telescope **18** and the spatial filtering configuration **20**, and that is deployed to receive the combined radiation from the spatial filtering configuration **20**. In the non-limiting exemplary implementation illustrated in FIG. 1, the radiation distinguishing module **22** is part of the receiver **16**, however, as will be discussed, all or some of the components of the radiation distinguishing module may be separate from the receiver **16**. In certain embodiments, a plurality of radiation distinguishing modules may be

deployed, each one being associated with (or being a part of) a respective one of the beam emitting subsystems. For clarity of illustration of the function and operation of the radiation distinguishing module **22**, the radiation distinguishing module will be described within the context of being part of the receiver **16**, unless explicitly stated
5 otherwise.

Preferably, the radiation distinguishing module **22** receives the filtered radiation from the spatial filtering configuration **20**, such that substantially only the combined radiation is received by the radiation distinguishing module **22**. The radiation distinguishing module **22** is further configured to separate the combined
10 radiation so as to be able to distinguish, for each reflected radiation component, an intensity parameter (an intensity-bearing signal) of the reflected radiation component (that corresponds to one of the components of the combined radiation, as well as one of the composite output beams), from an intensity parameter (intensity-bearing signal) of the combined radiation of all of the other reflected radiation components. In
15 particular, the radiation distinguishing module **22** is configured to receive reflected radiation having an intensity parameter that is representative of the combined radiation from the reflected radiation components, and to distinguish (for each of the reflected radiation components) the intensity parameter of particular components of the reflected radiation that correspond to that reflected radiation component.

A control subsystem **23** that has at least one controller **24**, including logic circuitry, is associated with the radiation distinguishing module **22** and the beam emitting subsystems **12a**, **12b** and **12c** via one or more communication and/or data links, and is configured to receive output signals produced by the radiation distinguishing module **22**, process those received signals, and provide the processed
20 signals to the beam emitting subsystem **12a**, **12b** and **12c** in order to allow adjustment of the composite beams **14a**, **14b** and **14c**, including adjustment of beam parameters of the coherent sub-beams generated by each of the beam emitting subsystem **12a**, **12b**, **12c**. The logic circuitry of controller **24** may be implemented as suitably configured hardware using digital and/or analog processing, including but not limited
25 to, one or more application specific integrated circuit (ASIC), one or more field programmable gate array (FPGA), one or more digital signal processor (DSP), as a general purpose computing system configured by software operating under a suitable operating system, or by any hardware/software/firmware combination configured to
30

perform the functions described herein at a suitable rate. The controller **24** typically also includes a data storage device and suitable input and output interfaces for controlling the beam emitting subsystems **12a**, **12b** and **12c** (either directly or indirectly) and receiving inputs from the radiation distinguishing module **22**, all as
5 will be clear to one having ordinary skill in the art.

The controller **24** may be linked to the receiver **16** via, for example, a data bus or a data link, which may be a wired data link or a wireless data link. In certain embodiments, the data link is embodied as a communication link of a communication network (including, for example, a wired network, a wireless network, a cellular
10 network, a satellite communication network, a private network such as an Intranet, and the like). In such embodiments, the controller **24** preferably includes communications hardware and/or software components for transmitting/receiving data to/from the receiver **16** via a communication interface of the controller **24**. The controller **24** is also linked to the beam emitting subsystems **12a**, **12b**, **12c**, preferably
15 via a data bus or data link. Preferably the receiver **16** and the beam emitting subsystems **12a**, **12b**, **12c** are deployed in a deployment configuration that supports low-latency data transmission (via the control subsystem **23**) between the receiver **16** and the beam emitting subsystems **12a**, **12b**, **12c**.

The control subsystem **23** may be further associated with a master unit that
20 transmits a low-power guide beam, and may perform direction vector calculation, so as to enable high precision combination of the output beams **14a**, **14b** and **14c** on the common target spot, as described in earlier sections of the present disclosure.

Generally speaking, the present disclosure proposes two main approaches for performing the signal separation via the radiation distinguishing module **22**, which
25 utilize two different implementation architectures. Both architectures rely on each of the beam emitting subsystems **12a**, **12b**, **12c** having an assigned locally unique signature that is associated with the respective composite beams **14a**, **14b** and **14c**. The unique signatures are assigned such that each of the components **15a**, **15b** and **15c** that make up the combined radiation can be uniquely identified (i.e., is uniquely
30 identifiable) in the combined radiation according to the signatures associated with the composite beam that is attributable to the radiation component. Within the context of this document, a component of the combined radiation is identifiable in (or separable from) the combined radiation if the intensity signal of that component can be

accurately separated from the intensity signal of the combined radiation. Preferably, the combined radiation intensity bears information pertaining to the locally unique signatures of all of the constituent components (**15a**, **15b** and **15c**) so as to enable extraction of the intensity of each constituent component from the combined radiation
5 intensity.

Within the context of this document, the term locally unique signature general refers to a signature assigned to a particular beam emitting subsystem of the system **10** that is unique to that beam emitting subsystem such that there is a one-to-one relationship between signature and beam emitting subsystem (i.e., a signature
10 assigned to one beam emitting subsystem of the system **10** is not assigned to any of the other beam emitting subsystems of the system **10**). It is noted that some or all of the signatures of the system **10** may be used as signatures for the beam emitting subsystems of other systems, generally similar to the system **10**, but deployed at a different locations from each other and from the system **10**, so long as the reflected
15 radiation components of the beam emitting subsystems of each of the systems can be accurately distinguished from the received reflected radiation.

According to a first non-limiting implementation, the radiation distinguishing module **22** performs the desired signal separation using dispersive optics to achieve spectral separation of the received radiation. In this first non-limiting implementation,
20 the signature of the beam emitting subsystems **12a**, **12b** and **12c** and the corresponding output composite beams **14a**, **14b** and **14c** is transmission wavelength or wavelength region (spectral sub-band or sub-region). According to a second non-limiting implementation, the radiation distinguishing module **22** performs the desired signal separation by decoding encoded information in the phase of the sub-beams of
25 the output composite beams **14a**, **14b** and **14c**. In this second non-limiting implementation, the signature of the beam emitting subsystems **12a**, **12b** and **12c** and the corresponding output composite beams **14a**, **14b** and **14c** is a code (which can be, for example, a modulation frequency or sequence/waveform). It is noted that in embodiments in which the spatial filtering configuration **20** is implemented using a
30 small detector deployed at the telescope exit aperture, losses in spectral information at the detector could make radiation distinguishing via spectral separation ineffective. Therefore, in such embodiments, it is preferable to implement the radiation distinguishing module **22** according to the second non-limiting implementation.

The following paragraphs describe, with reference to FIG. 3, a receiver **16** having a radiation distinguishing module **100** according to the first non-limiting implementation. By way of introduction, in order for the radiation distinguishing module **100** to achieve effective spectral separation of the filtered and collimated radiation according to the first non-limiting implementation, the output beams **14a**, **14b** and **14c** should occupy different respective spectral sub-bands or sub-regions of the electromagnetic spectrum, in accordance with the signature of the beam emitting subsystems (i.e., the spectral sub-band or sub-region at which each beam emitting subsystem is configured to transmit beams). As mentioned above, the principles of the embodiments of the present disclosure may be used for devices operating with various different wavelengths, but is typically implemented in the NIR range, which generally refers to light having wavelength in the range of 800-2500 nanometers (nm). Accordingly, in such typical implementations, the beam emitting subsystems **12a**, **12b** and **12c** are configured to generate output beams **14a**, **14b** and **14c** that occupy different respective sub-bands or sub-regions in the NIR range. For example, the beam emitting subsystem **12a** may be configured to generate the output beam **14a** at a wavelength λ_1 of approximately 1060 nm, the beam emitting subsystem **12b** may be configured to generate the output beam **14b** at a wavelength λ_2 of approximately 1065 nm, and the beam emitting subsystem **12c** may be configured to generate the output beam **14c** at a wavelength λ_3 of approximately 1070 nm. Here, the signature of the beam emitting subsystem **12a** is radiation at wavelength λ_1 , the signature of the beam emitting subsystem **12b** is radiation at wavelength λ_2 , and the signature of the beam emitting subsystem **12c** is radiation at wavelength λ_3 .

Turning now to the structural details of the radiation distinguishing module **100** of FIG. 3 in more detail, the radiation distinguishing module **100** includes a detector arrangement **108** and an optics arrangement **102** deployed in the optical path from the target **26** to the detector arrangement **108**. The optics arrangement **102** may include a collimating optical element, represented schematically in FIG. 3 by a lens **104**, but may be an assembly of lenses, and a dispersive optical component **106**. The dispersive optical component **106** is represented schematically in FIG. 3 by a prism, but may alternatively be implemented as one or more diffractive gratings.

The collimating optical element **104** receives the filtered radiation from the spatial filtering configuration **20**, and collimates the radiation so as to produce filtered

and collimated radiation. The collimated radiation impinges on the dispersive optical element **106**, which separates the filtered and collimated radiation into the constituent wavelengths corresponding to the output beams **14a**, **14b** and **14c** (i.e., according to the spectral signature of each beam emitting subsystem). For each constituent wavelength, the separated radiation for that wavelength is deflected in a specific direction in accordance with the deflecting angle for that wavelength applied to the collimated radiation by the dispersive optical element **106**. The now spectrally separated radiation impinges on the detector arrangement **108**, which is configured to separately measure radiation at each respective wavelength of the constituent wavelengths. The radiation at each constituent wavelength impinges on a different respective region of the detector arrangement **108**, in accordance with the deflection direction of the radiation. In embodiments in which the detector arrangement **108** is implemented as an array of photodetectors, the array of photodetectors preferably includes one photodetector per constituent wavelength, deployed at the requisite positions dictated by the deflection angle so as to be able measure the radiation intensity of the radiation at the constituent wavelength. This is exemplarily illustrated in FIG. 3, which shows three such photodetectors **110a**, **110b** and **110c**. The photodetectors **110a**, **110b** and **110c** are configured to measure the radiation intensity of the reflected radiation components **15a**, **15b** and **15c** in parallel, so as to isolate (distinguish) the radiation intensity of each of the reflected radiation components **15a**, **15b** and **15c** from the combined radiation intensity. Each individual photodetector is sensitive to radiation in a different particular sub-band or sub-region of the electromagnetic spectrum, corresponding to the wavelength at which the output beams **14a**, **14b** and **14c** are transmitted by the beam emitting subsystems **12a**, **12b** and **12c**. For example, continuing with the previously described example of the output beams **14a**, **14b** and **14c** having respective wavelengths of approximately 1060 nm, 1065 nm, and 1070 nm, the photodetectors **110a**, **110b** and **110c** may be configured to be sensitive to radiation in the respective ranges of 1059-1061 nm, 1064-1066 nm, and 1069-1071 nm.

The detector arrangement **108** is configured to generate, for each constituent wavelength, a signal ("intensity parameter") that is indicative of the intensity of the radiation impinging on the area of the target **26** by the respective output beams **14a**, **14b** and **14c**. In embodiments in which the detector arrangement **108** is implemented

as an array of photodetectors, each of the photodetectors **110a**, **110b** and **110c** generates such a signal. In other words, the photodetector **110a** generates a first signal that is indicative of the radiation intensity impinging on the area of the target **26** by the output beam **14a**, the photodetector **110b** generates a second signal that is
5 indicative of the radiation intensity impinging on the area of the target **26** by the output beam **14b**, and so on. Each of the generated signals varies as a function of the radiation intensity (from the corresponding composite output beam) impinging on the area of the target **26**.

The controller **24** receives the signals (i.e., the intensity parameters) from the
10 detector arrangement **108**. These received signals can be subsequently processed in order to allow the beam emitting subsystems **12a**, **12b** and **12c** to perform additional functions, including adjustment of beam parameters of the respective sub-beams. In certain non-limiting implementations, the control subsystem **23** includes a dedicated control/processing unit for each of the beam emitting subsystems **12a**, **12b** and **12c**,
15 which allows for further processing on the signals received from the detector arrangement **108**. In such implementations, for example, the controller **24** provides the first signal to a control/processing unit of the beam emitting subsystem **12a**, provides the second signal to a control/processing unit of the beam emitting subsystem **12b**, and so on.

20 In one non-limiting implementation, the signals received by the controller **24** from the detector arrangement **108** are used to adjust beam parameters of the sub-beams of one or more of the beam emitting subsystems **12a**, **12b** and **12c** by performing phase correction of the phases of the sub-beams in order to achieve effective coherent combination of the sub-beams for each of the output beams **14a**,
25 **14b** and **14c**. In general, for each of the beam emitting subsystems **12a**, **12b** and **12c**, the associated signal (i.e., intensity parameter) is monitored (either by the controller **24** or a dedicated control/processing unit of that beam emitting subsystem) while each phase modulator of the beam emitting subsystem is actuated to modulate a current phase of the correspondingly transmitted sub-beam between at least three phase states
30 (typically an initial “unmodified” phase state and two “modified” phase states). The monitoring of the signal includes analyzing of the signal (either by the controller **24** or the control/processing unit of that beam emitting subsystem) to identify variations in the measured intensity parameter resulting from the modulation of the current phase

of each transmitted sub-beam relative to a sum of all other sub-beams. The controller **24** or the control/processing unit of that beam emitting subsystem then calculates (based on the identified variations) a phase offset of the current phase for each sub-beam relative to a representative phase of the sum of all the other sub-beams emitted
5 by that particular beam emitting subsystem.

This process of modulating the phase of the sub-beams, identifying corresponding variations in the measured intensity parameter, calculating the phase offset of a sub-beam and correction of that phase offset are preferably repeated in rapid cycles, thereby correcting in real-time for dynamic variations in the operating
10 conditions, which may result from fluctuations in the beam generating hardware or from fluctuating atmospheric conditions caused by atmospheric turbulence. Further details of this process can be found in WO 2020/016824 A1, which is hereby incorporated by reference in its entirety herein.

It is noted that the current phase of each sub-beam is modulated at a particular
15 modulation frequency. In one non-limiting example, the phase of each sub-beam is varied (by the controller **24** or the control/processing unit of that beam emitting subsystem) in a sinusoidal manner about a central phase state by a phase variation modulation amplitude Φ_m at a modulation frequency ω_0 . Preferably, modulation frequencies anywhere in the MHz to GHz range are used. In particular, a range of
20 modulation frequencies between 100 kHz and 20 MHz have been found suitable. In another non-limiting example, the phase of each sub-beam is modulated stepwise between a current base value and two discrete modulated values. Regardless of the modulation approach (i.e., continuous/sinusoidal or discrete), an additional layer of modulation or coding can be applied on top of this lower level modulation. This
25 additional layer of modulation/coding is of particular use in situations in which an approach to signal separation, different from the spectral separation approach previously described, is employed. This may be the case, for example, in situations where spectral separation of the filtered and collimated radiation is not achievable, for example in scenarios in which the constituent beams transmitted by the beam emitting
30 subsystems **12a**, **12b** and **12c** have densely packed spatial frequencies and the physical limitations of the dispersive optical component **106** may not enable clean separation of the received radiation into the proper constituent radiation components. In such scenarios, a different approach to signal separation is taken in which the

radiation distinguishing module **22** is implemented according to a second non-limiting implementation so as to achieve signal separation by decoding information (i.e., the code, or signature) that is encoded in the phase of the sub-beams of the output beams **14a**, **14b** and **14c** by this additional layer of modulation/coding.

5 The following paragraphs describe, with reference to FIG. 4, a receiver **16** having a radiation distinguishing module **200** according to the second non-limiting implementation. By way of introduction, in order for the radiation distinguishing module **200** to achieve the aforementioned signal separation, the current phase of each sub-beam (for a particular beam emitting subsystem) is encoded with a code
10 (signature) that is unique to the particular beam emitting subsystem via the encoding module **44** (FIG. 2). This encoding is applied on top of the continuous/sinusoidal or discrete lower-level modulation of the phase of each sub-beam discussed above. It is noted that the term “encoding”, as used herein, encompasses both of traditional analog and digital modulation used in analog and digital communications systems, and
15 traditional information encoding techniques, including those used in spread spectrum communication. The “code” that is used to encode the phase may be, for example, a particular frequency, a particular sequence/waveform, or any other suitable type of code that can be used to uniquely encode information. It is noted that codes used to encode the phase information are locally unique to the system **10** and its relevant
20 corresponding components (i.e., beam emitting subsystems).

Bearing this in mind, various types of encoding by the encoding module **44** fall within the scope of the present disclosure. In one non-limiting example, the encoding module **44** is configured to apply an additional layer of analog frequency modulation on top of the continuous/sinusoidal or discrete lower-level modulation of
25 the phase of each sub-beam. In this example, the encoding module **44** includes one or more analog frequency modulator configured to modulate the lower-level-modulated current phase of each sub-beam at a (code) modulation frequency ω_m . The analog frequency modulator is embodied as a waveform/signal generator **46** for generating a carrier signal at the modulation frequency, and for modulating the phase with the
30 carrier signal. In certain particularly preferable implementations, the modulation frequency ω_m is higher than the modulation frequency ω_0 , and in certain more preferable implementations, the modulation frequency ω_m is significantly higher (e.g., an order of magnitude larger) than the modulation frequency ω_0 (i.e., $\omega_m \gg \omega_0$). As

mentioned above, the lower-level modulation frequency ω_o is preferably selected from a frequency in the range between 100 kHz and 20 MHz. Accordingly, in such preferable implementations the top-level modulation frequency ω_m may be selected from a frequency in the range between 1 MHz and 100 MHz. For example, if the low frequency modulation is in the range between 1 and 2 MHz, the high frequency modulation can be in the range between 10 and 20 MHz.

Each composite output beam is assigned at least one such modulation frequency ω_m . In some cases, the modulated phases of all of the sub-beams may be modulated at the same unique modulation frequency ω_m . In such cases, a single such waveform/signal generator **46** may be coupled to all of the phase modulators of the beam emitting subsystem so as to modulate the phase for all of the sub-beams generated by that beam emitting subsystem. Alternatively, a waveform/signal generator may be provided one per phase modulator, such that the phase of each sub-beam is modulated by a respective waveform/signal generator. In other cases, the modulated phase of each sub-beam is modulated at a different unique modulation frequency which can be higher or lower than the lower-level modulation frequency ω_o . For example, for a beam emitting subsystem that transmits a composite output beam composed of three sub-beams, the modulated phase of first sub-beam may be modulated with a first modulation frequency ω_{m1} , the modulated phase of first sub-beam may be modulated with a first modulation frequency ω_{m2} , and the modulated phase of first sub-beam may be modulated with a first modulation frequency ω_{m2} . In such cases each phase modulator of the particular beam emitting subsystem has an associated waveform/signal generator configured to modulate the phase of a respective sub-beam. It is noted that since the system **10** generally includes a battery of beam emitting subsystems, each having on the order of tens or hundreds of beam sources, assigning each individual beam source a unique modulation frequency may present problems in terms of bandwidth and spectral efficiency. In addition, modulating each of the lower-level-modulated phases with a unique modulation frequency would require corresponding demodulation hardware at the receiver, resulting in a bank of demodulators (one for each modulation frequency). It may therefore be preferable to modulate the lower-level-modulated phase of all of the sub-beams of a single beam emitting subsystem at a common modulation frequency unique to that beam emitting subsystem. Alternatively, the modulation of the lower-

level-modulated phases of different sub-beams of a particular beam emitting subsystem may be performed sequentially.

In another non-limiting example, the encoding module **44** is configured to encode the lower-level-modulated current phase with a distinct code sequence unique to the beam emitting subsystem and the output beam produced by that beam emitting subsystem. The code sequence may be any code sequence (for example a binary sequence) that can appropriately be used to differentiate between the reflected radiation components (and by extension the corresponding output beams which generate the reflected radiation components). In one non-limiting example, the code sequence may be selected from a set of pseudorandom sequences that are mutually orthogonal such that each sequence has high autocorrelation and low cross correlation with the other sequences, as is commonly used in certain spread spectrum communication techniques, such as code division multiple access (CDMA), as is well-known in the art. In this non-limiting example implementation, the encoding module **44** may include a sequence generator for generating code sequences (for example a pseudorandom number generator, which are well-known in the art and are readily commercially available), and a waveform generator (i.e., signal generator) for generating waveforms associated with each of the code sequences. In the context of binary sequences, a simple example of a waveform (signal) that can be generated by a waveform generator is a rectangular pulse-amplitude modulated waveform that outputs a “high” voltage for a binary “1” and a “low” voltage for a binary “0”. The sequence generator and the waveform generator may be combined as a single functional element which generates waveforms based on pseudorandom binary sequences (commonly referred to as PN sequences). In this context, the signal generator **46** is operative to perform functions for sequence generation and signal/waveform generation. In addition, the signal generator **46** is operative to modulate the lower-level-modulated current phase of each sub-beam with a generated waveform (although this modulation may be executed by a separate modulator/multiplier component of the encoding module **44**). In certain preferred implementations, the phases of all of the sub-beams generated by a particular beam emitting subsystem are modulated by the same generated waveform. In other words, for each beam emitting subsystem, a single unique code sequence is used to encode the phase information for all of the sub-beams generated by that beam emitting

subsystem. A single signal generator may be coupled to all of the phase modulators of the beam emitting subsystem so as to modulate the phase of each of the sub-beams with a common signal generator. Alternatively, each beam source of the beam emitting subsystem may have an associated signal generator that modulates the phase of the sub-beam generated by the beam source. In addition, and similar to as described in the frequency modulator example discussed above, the lower-level-modulated phase of each sub-beam of a particular beam emitting subsystem may be provided with a unique encoding, such that all of the sub-beams of the entire system **10** each have a unique code. However, here too this may raise performance issues, as the receiver **16** is required to cycle through a large number of demodulating waveforms (code sequences) in order to receive the modulated phase of all of the sub-beams generated by all of the beam emitting subsystems.

Although the phase encoding process has been described within the context of specific examples of top-level frequency modulation and (binary) sequence (waveform) encoding, the scope of the embodiments of the present disclosure should not be limited to the particular examples of frequency modulation and encoding sequences described above. As should be apparent to those skilled in the art, a wide variety of techniques for encoding the lower-level-modulated phases of the sub-beams is available, including techniques typically utilized in spread spectrum communications systems and free space optical communications, including, multiplexing and/or multiple access techniques such as, for example, orthogonal/optical frequency division multiplexing (OFDM) and frequency division multiple access (FDMA).

Turning now to the structural details of the radiation distinguishing module **200** of FIG. 4 in more detail, the radiation distinguishing module **200** includes a photodetector **202** and a decoding module **204**. The photodetector **202** is configured to receive the filtered radiation from the spatial filtering configuration **20**, such that substantially only the combined radiation is sensed by photodetector **202**. The photodetector **202** converts the sensed radiation into a received signal (i.e., the photodetector **202** generates a signal (“intensity parameter”), from the received combined radiation). Preferably, the photodetector **202** is AC coupled (for example via a DC blocking capacitor) so as to remove DC offsets from the signal and prevent detector saturation. The signal, generated by the photodetector **202**, is representative

of the combined (i.e., summed) radiation intensity of the reflected radiation components **15a**, **15b** and **15c**, and is indicative of the combined radiation intensity impinging on the area of the target **26**. In particular, the generated signal varies as a function of the combined (i.e., summed) radiation intensity (corresponding to the composite output beams **14a**, **14b** and **14c**) impinging on the area of the target **26**. The signal includes multiple signal components, each component corresponding to the radiation intensity associated with a respective one of the composite output beams **14a**, **14b** and **14c**. Since the phases of the sub-beams of each of the composite output beams **14a**, **14b** and **14c** is encoded with a code that is unique to the beam emitting subsystem that transmitted the composite output beam, the signal component corresponding to each individual composite output beam (and each individual beam emitting subsystem) can be isolated, i.e., separated from the other signal components of the overall received signal.

The decoding module **204** is configured to perform the above-mentioned signal separation by applying decoding techniques in order to isolate individual signal components from the received signal. The decoding module **204** may include a bank of decoders **206**, and preferably includes one decoder for each unique code used to encode information by the encoding modules of the beam emitting subsystems. For example, in the non-limiting example in which the encoding module **44** for each beam emitting subsystem is implemented as one or more analog frequency modulator, the decoding module **204** includes a corresponding number of demodulators (decoders), embodied as signal generators **208**. If the encoding module **44** for each beam emitting subsystem is configured to modulate the lower-level-modulated phases of all of the sub-beams generated by that beam emitting subsystem with the same modulation frequency ω_m , the decoding module **204** will include one decoder (implemented, for example, as a signal generator that generates the demodulation signal and performs the frequency demodulation to generate the demodulated signal) per beam emitting subsystem. The decoders are preferably configured to operate in parallel, such that the received signal is simultaneously decoded by each of the decoders. When the decoders **206** are implemented as a bank of demodulators, the decoding module **204** may include a low-pass filter associated with each demodulator for removing residual signal effects and noise from the demodulated signals.

In the non-limiting example in which the encoding module **44** for each beam emitting subsystem is configured to encode the lower-level-modulated current phase of the sub-beams with a distinct code sequence unique to the beam emitting subsystem, the bank of decoders **206** are configured with components for decoding the signal based on the sequences so as to isolate the relevant signal components from the received signal. Here too the decoders **206** may be deployed one-per sequence, and each decoder may be assigned a specific one of the sequences. In this context, each of the signal generators **208** is operative to perform functions of sequence generation and waveform generation for generating the code sequence assigned to that decoder and generating the waveform associated with the assigned code sequence (the sequence generator and waveform generator may be combined as a single functional element). The signal generators are also preferably configured to perform demodulation by demodulating the received signal with the generated waveform (i.e., applies the generated waveform to the received signal). Additional logic circuitry, embodied as part of the decoders **206**, is configured to identify correlation peaks in the demodulated signal to isolate the signal component corresponding to the relevant composite output beam (and relevant beam emitting subsystem) from the overall received signal.

Each decoder **206** provides the isolated component of the received signal as an output signal, such that the decoding module **204** outputs a plurality of output signals (one output signal per decoder). In the non-limiting exemplary implementation illustrated in FIG. 4, the controller **24** receives the output signals (which are indicative of the radiation intensity impinging on the area of the target **26** by the respective composite output beams **14a**, **14b** and **14c**) from the bank of decoders **206**. The output signals received by the controller **24** can be subsequently processed in order to allow the beam emitting subsystems **12a**, **12b** and **12c** to perform additional functions, for example to adjust beam parameters of the generated sub-beams by performing phase correction of the phases of the sub-beams generated by the beam emitting subsystems **12a**, **12b** and **12c** (as described above with reference to FIG. 3). In other non-limiting implementations, the decoding module **204** can be implemented as a part of the control subsystem **23**.

Note that although the encoding module **44** as illustrated and described herein includes a signal generator **46** for performing multiple functions, including functions

for sequence generation, signal/waveform generation and modulation, each of those functions may be performed by a dedicated separate component (e.g., a sequence generator, signal generator, and modulator). Likewise, although the decoding module **204** as illustrated and described herein includes a signal generator **208** for performing multiple functions, including functions for sequence generation, signal/waveform generation and demodulation, each of those functions may be performed by a dedicated separate component (e.g., a sequence generator, signal generator, and a demodulator).

As mentioned above, in certain embodiments the optical arrangement (i.e., telescope **18**) is integrated with an imaging system, which can be used for aiming each of the beam emitting subsystems **12a**, **12b** and **12c** at the target spot. FIG. 5 schematically illustrates an adaptive optics arrangement for correcting distortions of an image received via a telescope. Light (i.e., radiation) collected by a telescope (not shown, but which can be the telescope **18**) is reflected from an adaptive optical element, such as a deformable mirror **50**, which typically has a reflective surface which can be selectively deformed by a plurality of actuators. The deformable mirror **50** can be implemented using any suitable deformable mirror technology including, but not limited to, MEMS actuated mirrors, electrostatically actuated mirror membranes, piezoelectric actuated mirrors, and magnetic actuated mirrors. The light reflected by the deformable mirror is divided by a beam splitter **52**, from which part of the light emerging from the beam splitter **52** passes to a wavefront sensor **54**, such as a Shack-Hartman wavefront sensor, which measures distortion of the wavefront. A control system **56** analyzes the wavefront distortions that reach the wavefront sensor **54** and dynamically adjusts the deformable mirror **50** so as to reduce the wavefront distortions. The rest of the light emerging from the beam splitter **52** is directed towards an imaging system **60** (and/or other sensors). The components described with reference to FIG. 5, as well as the processing required to provide wavefront correction, are well known and can readily be implemented by a person of ordinary skill in the art.

FIG. 6 illustrates a particular implementation of an adaptive optics arrangement, such as the arrangement illustrated in FIG. 5, in the context of the multiple coherent beam combination (CBC) systems. Here, the adaptive optics arrangement is integrated as part of the targeting receiver described with reference to

FIGS. 1, 3 and 4. The telescope arrangement **18** receives reflected light (i.e., radiation) from the target **26** that has passed through the medium **28** which introduces optical distortions. The light collected by the telescope **18** is spatially filtered by the spatial filtering configuration **20**, and is directed from the deformable mirror **40** through the beam splitter **52** to the wavefront sensor **54**, the output of which is processed by adaptive optics control system **56** to provide closed-loop feedback to adjust the deformable mirror **50**, as described above with reference to FIG. 5. The rest of the light emerging from the beam splitter **52** passes to a second beam splitter **58**, which directs part of the light to an imaging sensor (camera **60**) and part of the light to the radiation distinguishing module **22**, which distinguishes radiation intensity of each reflected radiation component. An overall control system **62** receives images produced by the camera **60** to control operation of the system, such as target selection, aiming correction, etc.

It is noted that the subdivision of the control systems into separate elements **24**, **56** and **62** is shown here according to a functional subdivision. It should be noted however that these functions may be performed by processing systems or other logic circuitry hardware which can be subdivided in any desired manner, with one or more function being performed by a single processing system, or by a single function being performed by separate distributed processing systems. In some cases, certain processing and control functions may be performed remotely.

It should be noted that the two non-limiting implementations of the radiation distinguishing module **22** according to the embodiments presented herein have independent utility, such that the beam emitting subsystems and the control subsystem are not limited to use with a specific one of the radiation distinguishing modules **100**, **200**. It is further noted that each of the radiation distinguishing modules **100**, **200** is most preferably implemented in combination with a battery containing between 10-30 beam emitting subsystems. In situations where it is desirable to use a battery containing more than 30 beam emitting subsystems, and up to several hundreds of beam emitting subsystems, the receiver **16** may be implemented so as to utilize the radiation distinguishing module **100** and the radiation distinguishing module **200** in parallel. In such embodiments, the light collected by the telescope **18** may be routed separately to the radiation distinguishing module **100** and the radiation distinguishing module **200**, for parallel radiation distinguishing by the modules **100** and **200**. The

routing may be effectuated, for example, by a beam splitter (no shown) deployed in the optical path of the telescope **18** after the spatial filtering configuration **20**.

As discussed above, the receiver **16** may be deployed in various deployment configurations, so long as the receiver has line of sight with the target (i.e., can receive the radiation reflected from the target **26**) and can support a low-latency data link to the beam emitting subsystems **12a**, **12b** and **12c**. The receiver **16** is also generally smaller in size and of lower cost as compared to the beam emitting subsystems, and therefore there may be advantage in deploying multiple such receivers **16** at various respective positions (i.e., geographic locations). One advantage in deploying multiple receivers is the capability to utilize the output from the receiver that provides the best effective resolution of the target for performing additional functions (e.g., beam parameter adjustment for the beam emitting subsystems **12a**, **12b** and **12c**).

There are several contributing factors that can be used alone or in combination in determining the effective resolution for a receiver-target pair. Such factors include, but are not limited to, the (linear) distance between the target and the receiver, the level of turbulence along the optical path from the target to the receiver, the aperture size of the receiver optics (telescope), and the line of sight stability between the receiver and the target. Estimation of the effective resolution can be performed based on images of the target produced by the receiver (for example produced by the camera **60**) and/or from known mission parameters and turbulence models, all as is known in the art. Determining which receiver provides the “best” effective resolution can be performed by comparing the estimates and identifying the receiver that produces the highest estimated effective resolution.

FIG. 7 illustrates a non-limiting example deployment configuration for receivers in a system having three receivers **160a**, **160b** and **160c**, each corresponding to the structure and operation of the receiver **16**. In this non-limiting example configuration, the receivers **160a**, **160b** and **160c** are deployed in different positions with respect to a battery **120** of beam emitting subsystems **12a**, **12b** and **12c** and two targets **26a** and **26b**. Here, the composite output beams directed toward the targets by each of the beam emitting subsystems **12a**, **12b** and **12c** are generally designated by the thick arrows, and the radiation reflected by the targets is generally designated by thin dashed arrows. Although only three receivers are illustrated, the present

embodiments may be implemented with anywhere between 2 and several dozen receivers, most preferably between 2 and 10 receivers.

For each target that is illuminated by beam emitting subsystems **12a**, **12b** and **12c**, the control subsystem **23**, which is associated with each of the receivers **160a**, **160b** and **160c**, is preferably configured to estimate the effective resolution for each receiver, and select the receiver that provides the best effective resolution (based on the effective resolution estimates). The control subsystem **23** is further configured to select the output signal(s), resultant from the radiation separation performed by the radiation distinguishing module **22** of the selected receiver, for subsequent processing in order to allow the beam emitting subsystems of the battery **120** to perform additional functions (e.g., adjusting beam parameters of the generated sub-beams by performing phase correction of the phases of the sub-beams generated by the beam emitting subsystems).

If/when the beam emitting subsystems of the battery **120** are aimed at a different target (e.g., switching from target **26a** to target **26b**), the control subsystem **23** re-estimates the effective resolution for each receiver, and then again selects the signal output from the receiver that provides the best effective resolution for the new target. In this way, the control subsystem **23** is able to dynamically switch between the receivers to select the output from the receiver that provides the best effective resolution for a particular target. It may be advantageous to switch between receivers during the engagement time on a single target if the selected receiver suffers a drop in effective resolution. Such drops may occur sporadically as the mission situation evolves since the engagement time on a particular target can last up to several seconds. In order to effectively switch receivers during the engagement time, the effective resolution for all of the receivers is preferably re-calculated at rapid cycles (e.g., 10 or more times per second) throughout the duration of the engagement time on the target. If the effective resolution of the selected target drops below a usability threshold, the control subsystem **23** may switch to a different receiver that has a higher effective resolution than the previously selected receiver.

It is noted that the radiation distinguishing module of the receivers **160a**, **160b** and **160c** need not necessarily be implemented according to the same implementation. For example, the radiation distinguishing module of some of the receivers may be implemented as the radiation distinguishing module **100**, while the radiation

distinguishing module of the remaining receivers may be implemented as the radiation distinguishing module **200**.

In addition, the control subsystem **23** may be configured to receive output signal(s) from receivers other than the selected receiver, and combine the output signal(s) provided by the selected receiver with output signal(s) provided by the additional receivers to form an aggregated (combined) output signal. This aggregated output signal can be subsequently processed in order to allow the beam emitting subsystems of the battery **120** to perform additional functions. The signals can be combined using various signal combining techniques, including, for example, weighted averaging techniques in which the signal from the receiver that provides the best effective resolution for the target is given the highest weight, and the signal from the receiver that provides the second best effective resolution is given the second highest weight, and so on. Preferably, the receivers that contribute to the aggregated signal are pointed at the same spot on the target with high precision, which could require a dedicated target tracking and aiming subsystem linked to the receivers and the control subsystem **23**.

Although the radiation distinguishing module **22** has been predominantly described within the context of embodiments in which the radiation distinguishing module **22** is a part of the receiver **16**, as mentioned above other embodiments are possible in which the radiation distinguishing module **22** is associated with, but separated from, the receiver **16**. FIG. 8 illustrates one such embodiment, in which the radiation distinguishing module **22** is deployed between the receiver **16** and the control subsystem **23**. In certain implementations, the radiation distinguishing module **22** may be implemented as a module of the control subsystem **23** that is deployed between the controller **24** and the receiver **16**. Different coupling configurations between the radiation distinguishing module **22** and the receiver **16** are possible. For example, an optical fiber can be used to provide a coupling (connection) between the receiver telescope **20** and the radiation distinguishing module **22**. The optical fiber additionally can be used to perform spatial filtering (thereby functioning as the spatial filtering configuration **20**) of the radiation received by the telescope **18**, such that the radiation distinguishing module **22** receives spatially filtered radiation directly from the telescope **20** via the (spatial filtering) optical fiber. In implementations in which the radiation distinguishing module **22** is implemented using decoding (as in the case

of the radiation distinguishing module **200**), a low-latency broadband data link can provide a coupling between the receiver **16** (which includes the photodetector **202** for generating encoded signals from the received radiation) and the radiation distinguishing module **22**. In such implementations, the generated signal is transmitted from the receiver **16** to the radiation distinguishing module **22** over the low-latency link.

The control subsystem **23** and radiation distinguishing module **22** configuration illustrated in FIG. 8 can be extrapolated to include configurations in which each beam emitting subsystem is associated with a respective control and radiation distinguishing subsystem. A non-limiting example of such a configuration is illustrated schematically in FIG. 9. Here, three radiation distinguishing modules **22a**, **22b** and **22c** are deployed as part of three respective control subsystems **23a**, **23b** and **23c** (having controllers **24a**, **24b** and **24c**), which are associated with the respective beam emitting subsystems **12a**, **12b** and **12c**. Although not shown in FIG. 9, the control subsystems **23a**, **23b** and **23c** are preferably linked via a low-latency link, either directly or indirectly, and form an overall control subsystem of the system.

The descriptions of the various embodiments of the present disclosure have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

As used herein, the singular form, “a”, “an” and “the” include plural references unless the context clearly dictates otherwise.

The word “exemplary” is used herein to mean “serving as an example, instance or illustration”. Any embodiment described as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention,

which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination or as suitable in any other described embodiment of the invention. Certain features described in the context of various embodiments are not to be considered essential features of those
5 embodiments, unless the embodiment is inoperative without those elements.

To the extent that the appended claims have been drafted without multiple dependencies, this has been done only to accommodate formal requirements in jurisdictions which do not allow such multiple dependencies. It should be noted that all possible combinations of features which would be implied by rendering the claims
10 multiply dependent are explicitly envisaged and should be considered part of the invention.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all
15 such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

WHAT IS CLAIMED IS:

1. A system, comprising:
 - a plurality of beam emitting subsystems, each beam emitting subsystem configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, wherein for each composite output beam a proportion of radiation intensity of the composite output beam is reflected by the target as a reflected radiation component;
 - a telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, and wherein an intensity of the combined radiation is indicative of radiation intensity of the composite output beams impinging on the target;
 - a spatial filtering configuration deployed at the focal plane and configured for filtering the reflected radiation by selectively passing the combined radiation; and
 - a radiation distinguishing module for receiving the combined radiation passed by the spatial filtering configuration and for distinguishing, for each reflected radiation component, an intensity parameter of the reflected radiation component from an intensity parameter of the combined radiation of all other of the reflected radiation components.
2. The system of claim 1, wherein each beam emitting subsystem includes:
 - a beam generating arrangement for generating a respective one of the composite output beams, and
 - a beam directing arrangement for directing the composite output beam towards the target.

3. The system of claim 1, wherein each reflected radiation component has a different wavelength from all other of the reflected radiation component, and wherein the radiation distinguishing module includes:

an optics arrangement including at least one dispersive optical component for separating the combined radiation into a plurality of constituent wavelengths corresponding to the wavelengths of the reflected radiation component, and

a detector arrangement for receiving radiation separated by the at least one dispersive optical component, the detector arrangement configured to separately measure radiation at each respective wavelength of the constituent wavelengths.

4. The system of claim 3, wherein the at least one dispersive optical component includes a prism.

5. The system of claim 3, wherein the at least one dispersive optical component includes a diffractive grating.

6. The system of claim 3, wherein the optics arrangement further includes a collimating element deployed in an optical path between the spatial filtering configuration and the at least one dispersive optical component, the collimating element configured for: collimating the combined radiation so as to produce collimated radiation, and directing the collimated radiation to the at least one dispersive optical component.

7. The system of claim 3, wherein the detector arrangement includes an array of detectors, each respective detector of the array of detectors configured to measure radiation in a different respective wavelength of the constituent wavelengths.

8. The system of claim 1, wherein each beam emitting subsystem includes:

an array of beam sources configured to generate a plurality of coherent beams for directing towards the target so as to combine at or before the target as the composite output beam,
a plurality of adjustable phase modulators associated with the beams sources so as to allow adjustment of relative phase offsets of the coherent beams, and
an encoding module for encoding a phase of each of the coherent beams with a code that is locally unique to the beam emitting subsystem.

9. The system of claim 8, wherein the radiation distinguishing module includes:

a detector deployed to receive the combined radiation and to monitor an intensity parameter of the combined radiation, and
a decoding module configured to decode, for each composite output beam, the intensity parameter of the combined radiation according to the locally unique code of the beam emitting subsystem that generated the composite output beam to isolate an intensity parameter of the reflected radiation component corresponding to the composite output beam.

10. The system of claim 9, wherein the encoding module includes a modulator, and wherein the code includes a modulation frequency such that each composite output beam is assigned at least one unique modulation frequency, and wherein the encoding module is configured to encode the phase of each of the coherent beams for each beam emitting subsystem by modulating the current phase of the coherent beams at the assigned at least one modulation frequency, and wherein the decoding module includes a plurality of demodulators, each demodulator configured to demodulate the signal at one or more selected demodulation frequency selected from the assigned unique modulation frequencies.

11. The system of claim 1, further comprising: a control subsystem associated with the radiation distinguishing module and each of the beam emitting subsystems, and wherein each beam emitting subsystem includes:

an array of beam sources configured to generate a plurality of coherent beams for directing towards the target so as to combine at or before the target as the composite output beam, and

a plurality of adjustable phase modulators associated with the beams sources so as to allow adjustment of relative phase offsets of the coherent beams, and

wherein for each reflected radiation component the control subsystem is configured to:

receive the intensity parameter of the reflected radiation component from the radiation distinguishing module, and

adjust a beam parameter of one or more coherent beams of the composite output beam corresponding to the reflected radiation component based on the received intensity parameter.

12. The system of claim 1, further comprising:

an imaging system for generating images of the target, the imaging system including:

a wavefront sensor,

a deformable mirror for receiving radiation from the spatial filtering configuration,

a beam splitter for receiving radiation from the deformable mirror and providing a part of the received radiation to the wavefront sensor and providing another part of the received radiation to the radiation distinguishing module, and

an adaptive optics controller associated with the wavefront sensor operative to control the deformable mirror so as to reduce optical distortions in the reflected radiation collected by the telescope arrangement.

13. A system, comprising:

a plurality of beam emitting subsystems, each beam emitting subsystem including an array of beam sources configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, wherein the composite output beams generated by the beam emitting subsystems have different respective wavelengths, and wherein for each composite output beam a proportion of radiation intensity of the composite output beam is reflected by the target as a reflected radiation component; and

a receiver including:

a telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components,

a spatial filtering configuration deployed at the focal plane and configured for filtering the reflected radiation by selectively passing the combined radiation,

an optics arrangement for receiving the combined radiation from the spatial filtering configuration and including at least one dispersive optical component for separating the combined radiation into a plurality of constituent wavelengths corresponding to the wavelengths of the composite output beams, and

a detector arrangement for receiving radiation separated by the at least one dispersive optical component, the detector arrangement configured to separately measure radiation at each respective wavelength of the constituent wavelengths.

14. The system of claim 13, wherein the at least one dispersive optical component includes a prism.

15. The system of claim 13, wherein the at least one dispersive optical component includes a diffractive grating.

16. The system of claim 13, wherein the optics arrangement further includes a collimating element deployed in an optical path between the spatial filtering configuration and the at least one optical component, the collimating element configured for: collimating the combined radiation so as to produce collimated radiation, and directing the collimated radiation to the at least one optical element.

17. The system of claim 13, further comprising: a control subsystem associated with the detector arrangement and each of the beam emitting subsystems, and wherein for each beam emitting subsystem the control subsystem is configured to adjust a beam parameter of one or more coherent beams of the composite output beam generated by the beam emitting subsystem, based on the measured radiation by the detector arrangement.

18. The system of claim 13, wherein the detector arrangement includes an array of detectors, each respective detector of the array of detectors configured to measure radiation in a different respective wavelength of the constituent wavelengths.

19. A system, comprising:

a plurality of beam emitting subsystems, each beam emitting subsystem including:

an array of beam sources configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, wherein a proportion of radiation intensity of the composite output beam is reflected by the target as a reflected radiation component,

a plurality of adjustable phase modulators associated with the beam sources so as to allow adjustment of relative phase offsets of the coherent beams, and

an encoding module for encoding a phase of each of the coherent beams with a code that is locally unique to the beam emitting subsystem; and

a receiver including:

- a telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components,
- a spatial filtering configuration deployed at the focal plane configured for filtering the reflected radiation by selectively passing the combined radiation,
- a detector deployed to receive the combined radiation from the spatial filtering configuration and to generate a signal representative of an intensity of the combined radiation, and
- a decoding module for decoding the signal according to the locally unique code for each beam emitting subsystem.

20. The system of claim 19, wherein the encoding module includes a modulator, and wherein each composite output beam is assigned a locally unique modulation frequency, and wherein for each beam emitting subsystem the modulator is configured to modulate a current phase of the coherent beams at the assigned modulation frequency, and wherein the decoding module includes a plurality of demodulators, each demodulator configured to demodulate the signal at one or more selected demodulation frequency selected from the assigned unique modulation frequencies.

21. The system of claim 19, wherein for each beam emitting subsystem: the encoding module includes a sequence generator for generating a code sequence, and wherein the encoding module is configured to encode the phase of each of the coherent beams by modulating the current phase of the coherent beams with a

waveform associated with the code sequence, and wherein the decoding module includes a signal generator for generating the waveforms associated with the code sequences, and wherein the decoding module is configured to demodulate the signal using each of the waveforms.

22. A system, comprising:

a plurality of beam emitting subsystems, each beam emitting subsystem configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a composite output beam, wherein for each composite output beam a proportion of radiation intensity of the composite output beam is reflected by the target as a reflected radiation component;

a plurality of receivers, each of the receivers configured to:

collect radiation reflected from the target and direct the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, and wherein an intensity of the combined radiation is indicative of radiation intensity of the composite output beams impinging on the target,

spatially filter the reflected radiation at the focal plane by selectively passing the combined radiation, and

receive the combined radiation that is spatially filtered and distinguish, for each reflected radiation component, an intensity parameter of the reflected radiation component from an intensity parameter of the combined radiation of all other of the reflected radiation components; and

a control subsystem associated with the receivers and configured to:

select a selected receiver based on an estimate of an effective resolution of the target provided by each of the receivers.

23. The system of claim 22, wherein the control subsystem is further configured to actuate each of the beam emitting subsystems to adjust a beam parameter of one or more of the coherent beams based on the intensity parameters distinguished by the selected receiver.

24. A method, comprising:

transmitting a plurality of composite output beams, wherein each output beam is transmitted by generating a plurality of coherent beams and directing the coherent beams towards an area of a target so as to combine at or before the target as the composite output beam, wherein for each composite output beam a proportion of radiation intensity of the composite output beam is reflected by the target as a reflected radiation component;

collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, and wherein an intensity of the combined radiation is indicative of radiation intensity of the composite output beams impinging on the target;

spatially filtering the reflected radiation by selectively passing the combined radiation; and

receiving the combined radiation passed by the spatial filtering configuration and distinguishing, for each reflected radiation component, an intensity parameter of the reflected radiation component from an intensity parameter of the combined radiation of all other of the reflected radiation components.

25. A system, comprising:

a plurality of beam emitting subsystems, each beam emitting subsystem configured to generate a plurality of coherent beams for directing towards an area of a target so as to combine at or before the target as a

- composite output beam, wherein each composite output beam has an associated locally unique signature, and wherein for each composite output beam a proportion of radiation intensity of the composite output beam is reflected by the target as a reflected radiation component;
- a telescope arrangement for collecting radiation reflected from the target and directing the reflected radiation onto a focal plane, the reflected radiation including a plurality of components of radiation, at least some of the components of radiation combining as a combined radiation composed of the reflected radiation components, and wherein an intensity of the combined radiation is indicative of radiation intensity of the composite output beams impinging on the target; and
- a spatial filtering configuration deployed at the focal plane and configured for filtering the reflected radiation by selectively passing the combined radiation, and wherein each component of the combined radiation is identifiable according to the locally unique signature associated with the composite output beam that corresponds to the component of the combined radiation.

26. The system of claim 25, further comprising: at least one radiation distinguishing module for receiving the combined radiation passed by the spatial filtering configuration and for distinguishing, for at least one of the reflected radiation components, an intensity parameter of the at least one of the reflected radiation components from an intensity parameter of the combined radiation of all other of the reflected radiation components, based on at least one of the locally unique signatures associated with the composite output beam that corresponds to the component of the combined radiation.

27. The system of claim 26, wherein the at least one radiation distinguishing module includes exactly one radiation distinguishing module.

28. The system of claim 26, wherein the at least one radiation distinguishing module includes a plurality of radiation distinguishing modules, each radiation

distinguishing module associated with a respective one of the beam emitting subsystems, and wherein for each radiation distinguishing module, the radiation distinguishing module is configured to distinguish an intensity parameter of one of the reflected radiation components, corresponding to the composite output beam generated by the beam emitting subsystem associated with the radiation distinguishing module, from the intensity parameter of the combined radiation of all other of the reflected radiation components.