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(54) **DUAL USE RF DIRECTED ENERGY WEAPON AND IMAGER**

FOREIGN PATENT DOCUMENTS  
WO WO 2007022339 2/2007

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OTHER PUBLICATIONS

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Riu et al., "A thermal model for human thresholds of microwave-evoked warmth sensation," 1996.

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1202 days.

Blick et al., "Thresholds of microwave-evoked warmth sensation in human skin," 1997.

(21) Appl. No.: **11/750,292**

Walters et al., "Effects of blood flow on skin heating induced by millimeter wave irradiation in humans," 2004.

(22) Filed: **May 17, 2007**

Walters et al., "Heating and pain sensation produced in human skin by millimeter waves: comparison to a simple thermal model," 2000. U.S. Appl. No. 11/300,876, filed Dec. 15, 2005, Brown.

(51) **Int. Cl.**  
**G01J 5/02** (2006.01)

Delisio & York, "Quasi optical and spatial power combining," IEEE Trans. Microwave Theory and Techniques, v. 50, No. 3, Mar. 2002. Raytheon Company, Silent Guardian Protection System Datasheet, Jun. 2006.

(52) **U.S. Cl.** ..... **250/341.7**

Wikipedia, "Active Denial System", [http://en.wikipedia.org/wiki/Active\\_Denial\\_System](http://en.wikipedia.org/wiki/Active_Denial_System).

(58) **Field of Classification Search** ..... 250/341.1, 250/341.6, 341.7, 393, 370.09; 89/1.11; 342/13, 22

Malibu Research, "Technology—Introduction to FLAPS", <http://www.maliburesearch.com/technology.htm>.

See application file for complete search history.

Kelkar, FLAPS: Conformal phased reflecting surfaces, Mar. 1991, pp. 1-6.

European Patent Office, European Search Report for European Application No. 08836387.4, Mail Date Apr. 28, 2011, pp. 1-9.

\* cited by examiner

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,089,828	A	2/1992	Moss	
5,214,438	A	5/1993	Brusgard	
5,612,503	A *	3/1997	Sepp	89/1.11
6,204,762	B1	3/2001	Dering	
6,487,950	B2 *	12/2002	Samland	89/1.13
6,799,499	B2 *	10/2004	Seregelyi et al.	89/1.13
6,967,612	B1	11/2005	Gorman	
7,126,477	B2	10/2006	Gallivan	
7,490,538	B2 *	2/2009	Lowell et al.	89/1.11
7,784,390	B1 *	8/2010	Lowell et al.	89/1.11
2007/0040725	A1	2/2007	Lowell	
2007/0076774	A1	4/2007	Brown	
2008/0304549	A1 *	12/2008	Calico et al.	375/131
2009/0146907	A1	6/2009	Brown	
2010/0117885	A1 *	5/2010	Holbrook et al.	342/22

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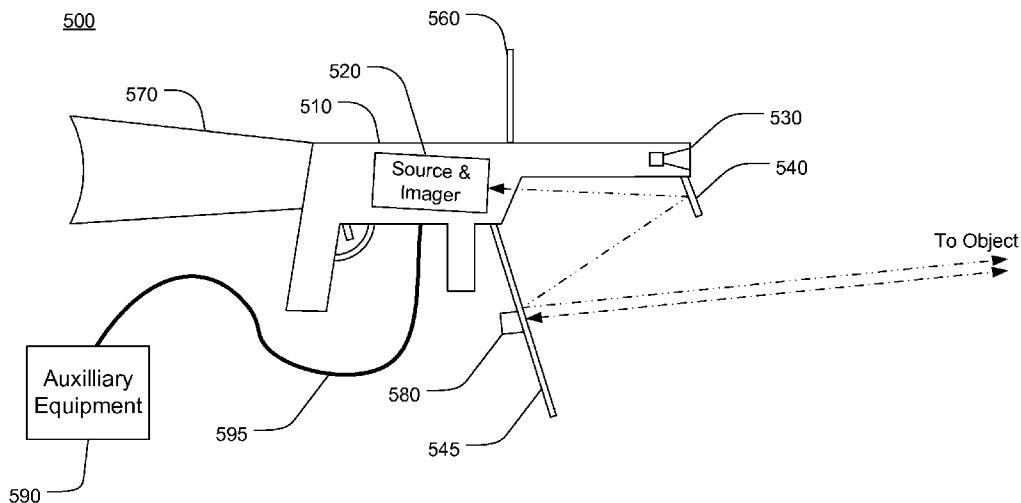
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(57) **ABSTRACT**

There is disclosed an dual use RF directed energy weapon and imager. A generator may provide a first beam of RF electromagnetic energy which may be directed to an object by a beam director. An imager may form an image of the object. The imager may share an aperture defined by the beam director.

**31 Claims, 7 Drawing Sheets**



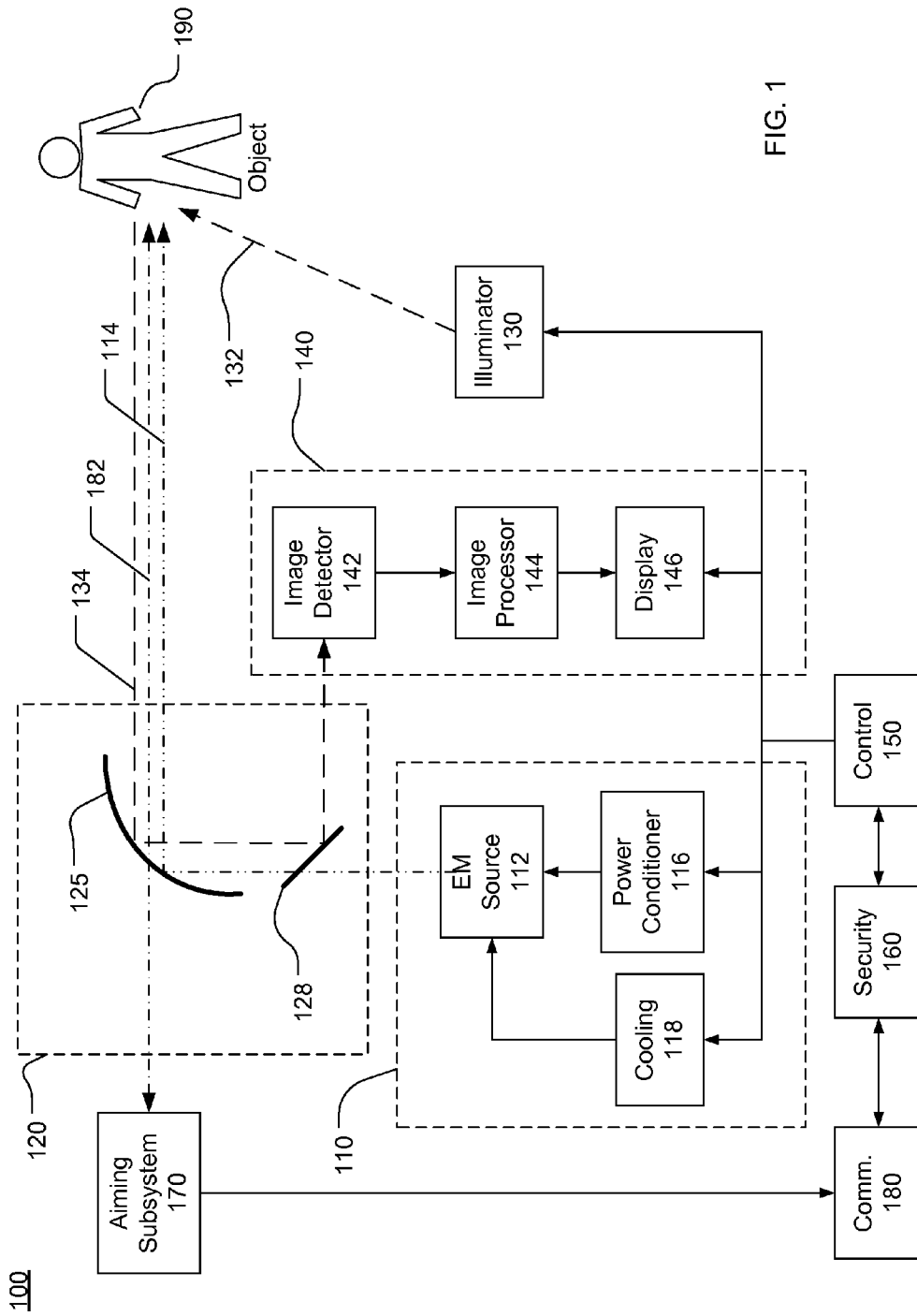


FIG. 1

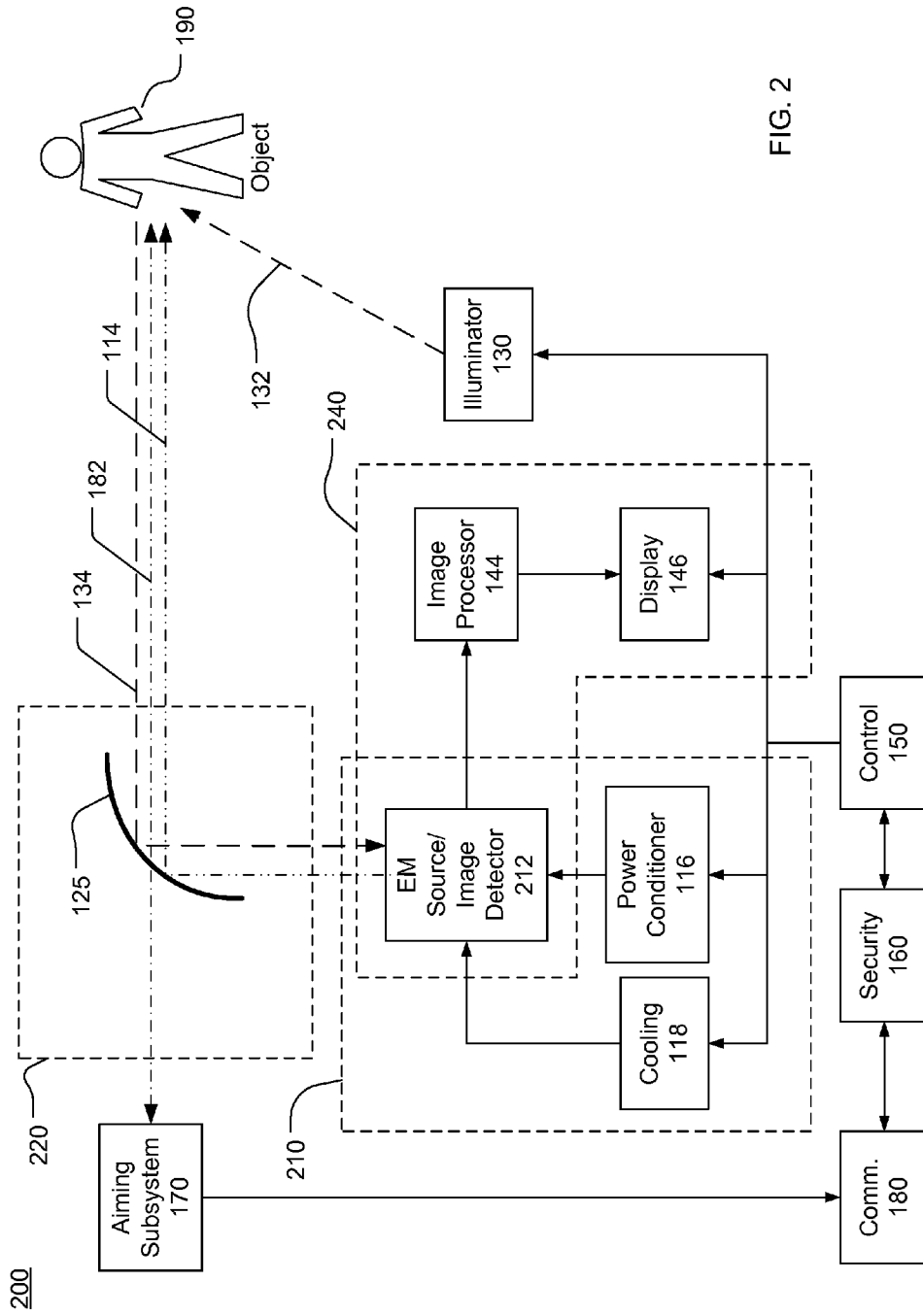


FIG. 2

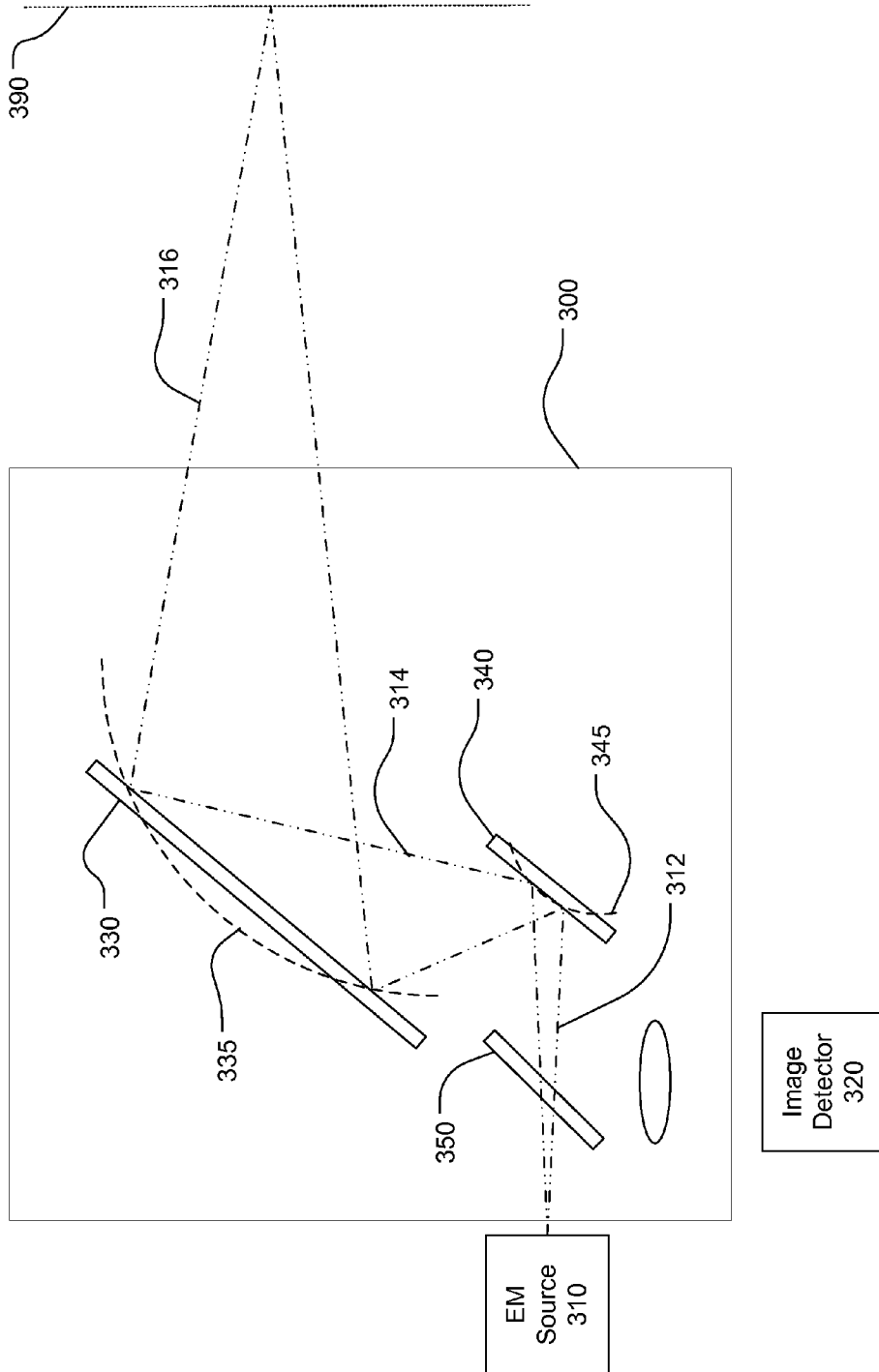


FIG. 3A

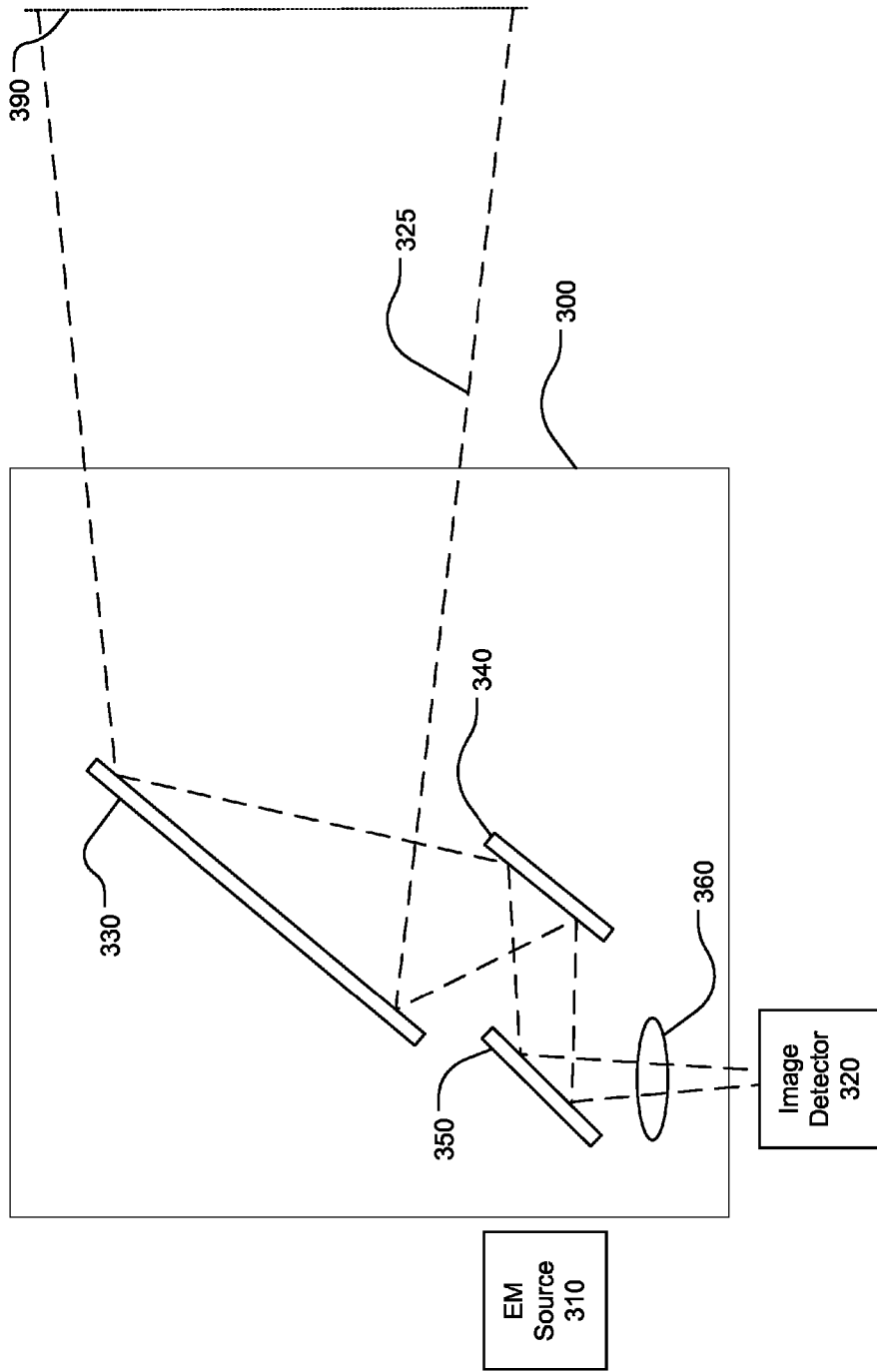


FIG. 3B

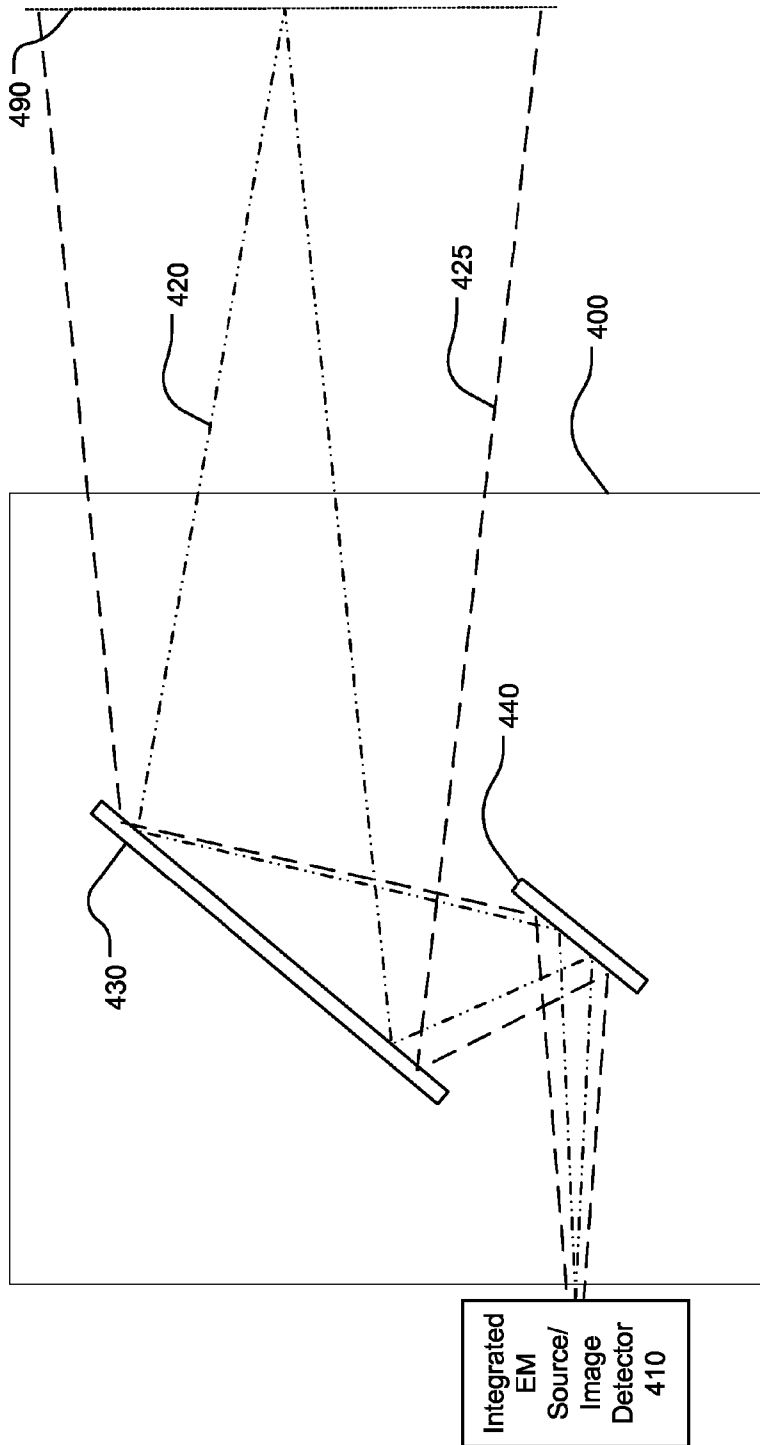


FIG. 4

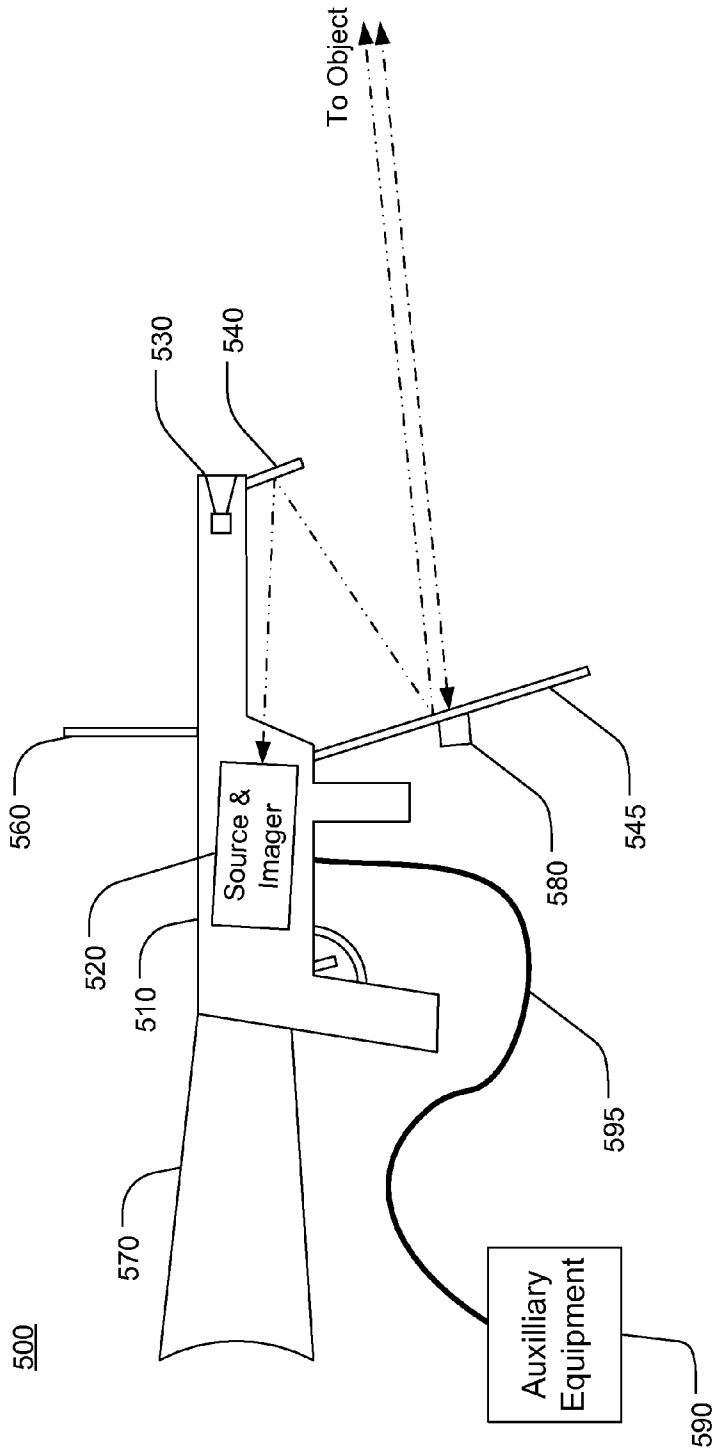


FIG. 5

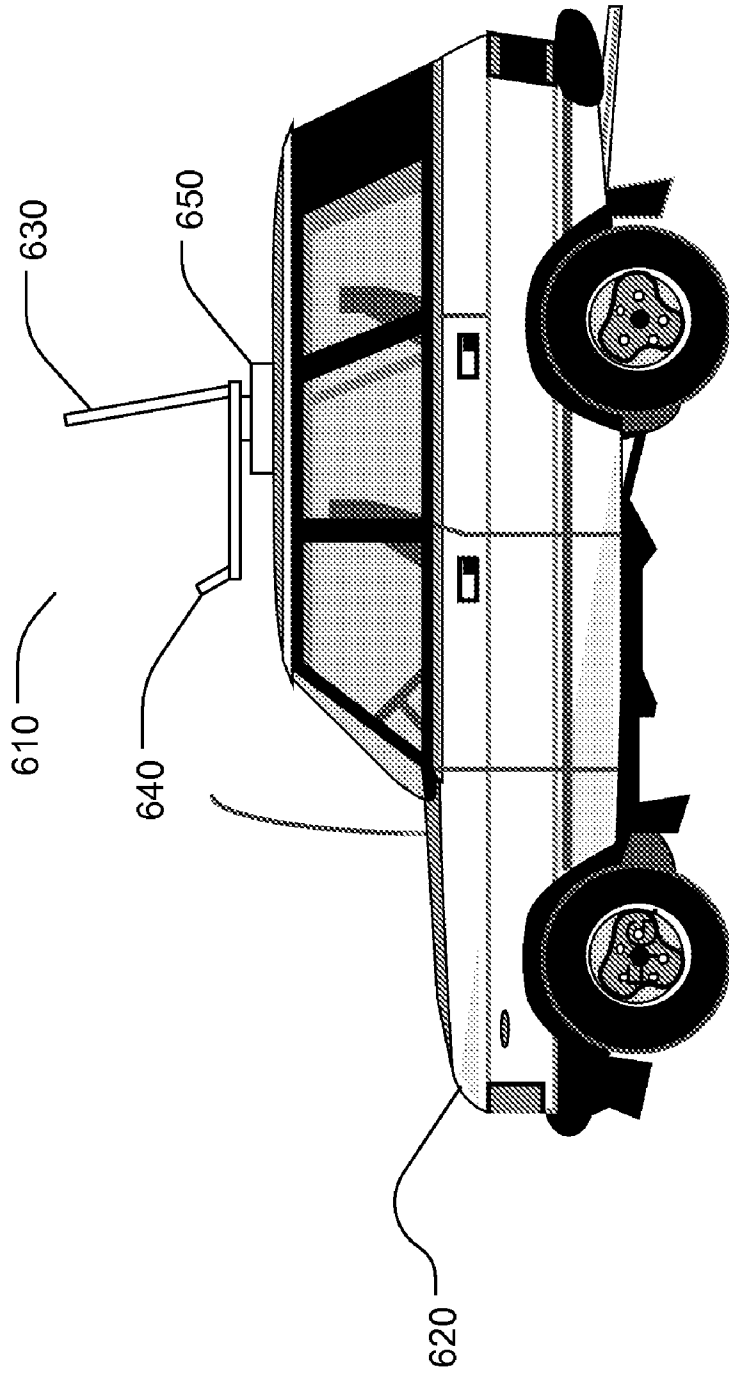


FIG. 6



## DUAL USE RF DIRECTED ENERGY WEAPON AND IMAGER

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### BACKGROUND

#### 1. Field

This disclosure relates to non-lethal weapon systems and to non-lethal weapons systems utilizing directed microwave energy in particular.

#### 2. Description of the Related Art

Non-lethal weapons employing directed microwave energy are a known method to deter or discourage an intruder or other target individual from entering a controlled area or from continuing some undesired action. Example microwave directed energy weapons, also termed "active denial" systems, are described in U.S. Pat. No. 7,126,477 B2 and US 2007/0040725 A1.

### DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a dual use directed energy weapon and imager.

FIG. 2 is a block diagram of a dual use directed energy weapon and imager.

FIG. 3A and FIG. 3B are schematic diagrams of an optical system.

FIG. 4 is a schematic diagram of an optical system.

FIG. 5 is a conceptual elevational view of a hand-held dual use directed energy weapon and imager.

FIG. 6 is a conceptual elevational view of a vehicle-mounted dual use directed energy weapon and imager.

### DETAILED DESCRIPTION

Throughout this description, the embodiments and examples shown should be considered as exemplars, rather than limitations on the apparatus and methods disclosed or claimed.

#### Description of Apparatus

Referring now to FIG. 1, a dual use directed energy weapon and imager **100** may include a generator **110** for generating a first beam of electromagnetic energy **114**, a beam director **120** for directing the first beam of electromagnetic energy **114** to an object **190**, and an imager **140** to capture an image of the object **190**. The dual use directed energy weapon and imager **100** may optionally include an illuminator **130** for illuminating the object **190** with a second beam of electromagnetic energy **132**. The imager **140** may capture the image of the object **190** using at least a portion of the second beam of electromagnetic energy **132** that is reflected from the object **190** as image beam **134**. The generator **110** may include an electromagnetic energy source **112** which may be supported by a power conditioner **116** and a cooling subsystem **118**. The electromagnetic energy source **112** may be a solid-state source, a vacuum tube source, or another source. The electromagnetic energy source **112** may include an array of solid

state sources, such as a planar reflect-array, a grid oscillator array, a grid amplifier array, or another form of amplifier array. The outputs of the array of solid state sources may be spatially combined, or combined using a conventional waveguide power combiner, stripline power combiner, or another power combining technique. The electromagnetic energy source **112** may generate W-band millimeter wave (MMW) electromagnetic energy, which may have a frequency of 75 to 110 GHz. The electromagnetic energy source **112** may generate microwave energy, terahertz energy, or other electromagnetic energy.

The power conditioner **116** may convert power from a primary power source to one or more power forms required by the electromagnetic energy source **112**. The primary power source may be a battery, a vehicle generator or other generator, or a conventional 120-volt or other AC power supply.

The cooling subsystem **118** may remove heat generated by the electromagnetic energy source **112** and power conditioner **116**. The cooling subsystem may incorporate a coolant which may be air or another gas, a liquid, or a phase change material. The cooling system may use cryogenic gas from a gas bottle as a coolant. The cooling system may include one or more heat exchangers to transfer heat from the electromagnetic energy source **112** to the coolant, and/or from the coolant to the surrounding air or to another medium.

The beam director **120** may include at least one optical element **125** which may define an aperture through which the first beam of electromagnetic energy **114** must pass. While the optical element **125** is shown schematically in FIG. 1 as a curved mirror, the beam director **120** may include multiple optical elements which may include spherical, parabolic, aspheric or other curved mirrors, flat mirrors, spherical and aspheric lenses, and passive reflect-arrays which, although physically flat, function similar to a curved mirror.

The beam director **120** may also include an aperture-sharing element **128** to separate the image beam **134** used for imaging from the first beam of electromagnetic energy **114**. Many configurations of an aperture-sharing element are known. In the example of FIG. 1, the aperture-sharing element **128** transmits the first beam of electromagnetic energy **114** but reflects the image beam **134** from the object **190**. To allow separation at the aperture-sharing element **128**, the first beam of electromagnetic energy **114** and the image beam **134** may differ in frequency, polarization state, or both frequency and polarization.

The illuminator **130** may be a continuous-wave (CW) or modulated source of millimeter wave or other electromagnetic energy. As will be discussed, the imager **140** may capture an image of the object **190** using a portion of the energy from the illuminator **130** which is reflected from the object **190**. The illuminator **130** and the imager **140** do not constitute a Radar sensor, since no attempt is made to determine the range to the object or to otherwise form a three-dimensional image. In order to allow the reflected beam **134** to be separated from the first beam of electromagnetic energy **114** at the aperture-sharing element **128**, the illuminator **130** may generate an illumination beam **132** that has a different frequency, or a different polarization, or both, from the first beam of electromagnetic energy **114**.

The imager **140** for capturing an image of object **190** may include an image detector array **142** that receives the image beam **134** from the aperture-sharing element **128**. Within this document, the phrase "capture an image" is intended to mean optically forming an image at a focal plane and detecting the image with an array of detectors to form an electronic image signal representative of the image. The captured image may be displayed and/or recorded. Within this document, an

“imager” is an opto-electronic system that captures the image of an object. The image detector array **142** may be an array of energy detectors such as an array of antennas feeding a corresponding number of bolometers, or an array of antennas coupled to detector diodes. The image detector array **142** may include low noise amplifiers for each detector element. The image detector array **142** may be any array of detectors suitable for detecting the illumination energy provided by the illuminator **130**.

The imager **140** may include an image processor **144** that converts image signals from the image detector array **142** into a form suitable for presentation on display **146**. The image processor **144** may include a wide range of signal processing and image processing functions such as amplification, thresholding, gamma correction or other nonlinear level transformation, resolution enhancement, and jitter reduction. As will be discussed subsequently, the dual use directed energy weapon and imager **100** may include an aiming subsystem **170** that may include a video camera or other instrument that forms another image of object **190**. The image processor **144** may receive one or more additional image signals (not shown in FIG. 1) from the aiming subsystem **170**, and may combine the received image signals with the image from image detector array **142** for presentation on display **146**. The image processor **144** may use known techniques, such as pseudocoloration, to combine multiple images.

The display **146** may be any display device, such as a CRT display, liquid crystal display, or light-emitting diode display having sufficient resolution to present the image or images of the object **190**. The display device may be opaque, or may be transparent and disposed in or near an operator’s line of sight to the object **190**. The display device may be a head-up display that superimposes the displayed image over the object, at the same apparent distance as the object, such that an operator may view the object and the displayed image simultaneously without any change in angle of view or eye focus. The optics required to superimpose the displayed information over the object are not shown in FIG. 1 but are well known in the display art.

The dual use directed energy weapon and imager **100** may also include a control subsystem **150**. The control subsystem **150** may include one or more ergonomically sensible controls to activate the illuminator **130** and the imager **140**, as well as a trigger or other control means to activate the generator **110** to generate the first beam of electromagnetic energy. The control subsystem **150** may include other manual or autonomous functions such as adjusting the appearance of the display **146**, limiting the duration that the first beam of electromagnetic energy can be directed towards an object, sensing hazardous conditions such as excessive temperature in the source of electromagnetic energy **112**, and informing the operator when the primary power source or coolant supply may be depleted.

The control subsystem **150** may interact with a security subsystem **160** to prevent unauthorized or inappropriate use of the dual use directed energy weapon and imager **100** and to safeguard against the use of this weapon by unauthorized persons who acquire stolen or captured weapons. The security subsystem **160** may include a simple keypad for entry of a personal identification number to authenticate a user, or a fingerprint reader or other biometric identification means such as is being used for keyless entry into automobiles. The security subsystem **160** may include less evident protection measures, such as a special protocol for replacing batteries. The security subsystem **160** may also include a “self destruct” mechanism to damage or destroy critical portions of the dual use directed energy weapon and imager **100**, such as the

electromagnetic energy source **112**, in the event of an attempt at unauthorized use or unauthorized disassembly.

The dual use directed energy weapon and imager **100** may also include an aiming subsystem **170**. The aiming subsystem **170** may include a low-magnification or unity-magnification optical telescope or a laser or other optical source to provide a visible pointing beam aligned with the direction of the first electromagnetic beam **114**. The aiming subsystem **170** may include a video camera, infrared camera, or other aiming sensor aligned with the direction of the first electromagnetic beam **114**. The image from such an aiming sensor may be displayed to allow operation of the dual use directed energy weapon and imager **100** by an operator who does not have a direct view of the object **190**. The image from an aiming sensor may also be recorded for purposes of operator training, verification of appropriate use within defined rules of engagement, and post-use analysis of tactics and command decisions. The aiming subsystem **170** may incorporate, possibly as a backup aiming means, mechanical alignment targets such as the traditional front and rear sights on a rifle.

The dual use directed energy weapon and imager **100** may also include a communication subsystem **180**. The communication subsystem **180** may use a two-way wired, wireless, or optical link to communicate image and control information to a remote or detached location. The communication subsystem **180** may be used in conjunction with the aiming, security, and control subsystems (**170**, **160**, **150**, respectively) to allow remote operation of the dual use directed energy weapon and imager **100**, or remote authorization for its use. The communication subsystem **180** may transmit image data from the imager **140** and the aiming subsystem **170** to a remote location for monitoring, recording, or analysis.

Referring now to FIG. 2, another dual use directed energy weapon and imager **200** may include a generator **210** for generating a first beam of electromagnetic energy **114**, a beam director **220** for directing the first beam of electromagnetic energy **114** to an object **190**, an illuminator **130** for illuminating the object **190** with a second beam of electromagnetic energy **132**, and an imager **240** for forming an image of the object **190** using at least a portion of the second beam of electromagnetic energy **132** that is reflected from the object **190** as image beam **134**. Elements of FIG. 2 having a reference designator between **110** and **190** have the same function as described in conjunction with FIG. 1, and the description of such elements will not be repeated. The dual use directed energy weapon and imager **200** may include an integrated electromagnetic energy source and image detector **212** which constitutes part of both the generator **210** and the imager **240**. The integrated electromagnetic energy source and image detector **212** may include an array of transmit/receive modules, each of which that function both as a source of electromagnetic energy and as a detector. The integrated electromagnetic energy source and image detector **212** may include an array of electromagnetic energy sources interleaved with a second array of detectors. The array of detectors may be adapted to detect electromagnetic energy of a different polarization or a different wavelength from the electromagnetic energy provided by the array of sources.

Since the integrated electromagnetic energy source and image detector **212** may include both the source of the first beam of electromagnetic energy **114** and the image detectors, the beam director **220** need not include an aperture-sharing element such as element **128** in FIG. 1.

FIG. 3A is a schematic diagram of an exemplary optical system **300** that may be suitable for the beam director **120** in FIG. 1. The optical system **300** may include a secondary reflective element **340** and a primary reflective element **330**.

The terms “primary” and “secondary” are consistent with common terminology for optical telescopes. The secondary reflective element 340 may be a passive reflect-array which, although physically flat, may have a negative optical power as indicated by the dashed curved surface 345. The passive reflect-array may have a pattern of discrete re-radiating elements, each of which receives and re-transmits a respective portion of the incident wavefront with an appropriate phase change such that, electrically, the passive reflect-array mimics the optical behavior of a curved reflector. An example of a passive reflect-array is the FLAPS antenna technology developed by Malibu Research, Inc.

The electromagnetic energy source 310 may generate a directed energy beam of electromagnetic energy 312 which passes through an aperture-sharing element 350 to the secondary reflective element 340. The secondary reflective element 340 may reflect a diverging directed energy beam 314 toward the primary reflective element 330. The primary reflective element 330 may also be a passive reflect-array which, although physically flat, may have positive optical power as indicated by the dashed curved line 335. The primary reflective element 330 may accept the diverging directed energy beam 314 from the secondary reflective element 340 and may form a converging directed energy beam 316 that may be focused to a spot at an object plane 390.

The physical extent of the primary reflective element 330 may define an aperture that limits the resolution of the optical system 300. The resolution of the optical system can be approximated by the simple relationship:

$$W = \frac{R\lambda}{D},$$

where W is the spatial resolution, R is the range,  $\lambda$  is the wavelength, and D is the effective diameter of the aperture. To focus the converging directed energy beam 316 to a relatively small spot at the object plane 390, the aperture diameter must be very large with respect to the waveguide of the directed energy beam 316. For example, assuming a range of 15 meters, a frequency of 95 GHz with a wavelength of 3.16 millimeters, and an effective aperture diameter of 18 inches, the optical system will have a resolution W at the object plane of 10.4 centimeters or about 4 inches.

A primary reflective element diameter of 18 inches may be suitable for a man-portable dual use directed energy weapon and imager. Tripod-mounted, vehicle-mounted, and semi-stationary dual use directed energy weapon and imager systems may include a larger primary reflective element, resulting in proportionally improved resolution (smaller spot size at the object plane).

Forming an image of an object or individual using millimeter wave or sub-millimeter (terahertz) wave radiation is known to be an effective technique for detecting and locating concealed objects such as weapons and explosives. The millimeter or sub-millimeter radiation penetrates clothing and scatters and reflects from underlying objects. The scattered and reflected radiation can be formed into an image at a focal plane by a suitable optical system and the image can be detected by an array of detectors disposed at the focal plane. The resolution of an optical system when forming an image can be approximated by the previously stated equation. Thus a millimeter wave or sub-millimeter wave imager also requires an aperture that is very large compared to the wavelength used to form the image.

The optical system 300 allows a single aperture, and at least one optical element, to be shared by the optical systems for both the directed energy beam from the electromagnetic energy source 310 and for an imaging system. An optical element is considered “shared” if the optical element forms a portion of two optical systems, and an aperture is considered “shared” if the beams for two optical system pass through it. In the example optical system 300, the primary reflective element 330, the aperture defined by the primary reflective element 330, and the secondary reflective element 340 may be shared between a directed energy optical system and an imaging optical system.

FIG. 3B shows the imaging beam path through the optical system 300, which was previously shown in FIG. 3A. The imaging beam 325 originates at the object plane 390, where light from an illumination source (not shown) reflects from an object (not shown). An image of the object plane 390 is formed at the focal plane of image detector 320 by the combined optical power of the primary reflective element 330, the secondary reflective element 340, the aperture-sharing element 350, and, optionally, additional optical elements represented schematically by lens 360.

As shown in FIG. 3A, the optical system 300 may be configured to focus the directed energy beam 316 to a relatively small spot at the object plane 390. Conversely, as shown in FIG. 3B, the optical system 300 may be configured to form an image of a larger region of object plane 390 at the image detector 320. Thus the optical system 300 may have a larger magnification factor for the imaging beam 325 than for the directed energy beam 316. A number of techniques are available to provide different magnification factors for the imaging beam 325 and the directed energy beam 316. Additional optical elements, represented schematically by lens 360, may be disposed in the imaging portion of the optical system. Additionally, the optical power or focal length of the primary reflective element 330 and/or the secondary reflective element 340 may be different for the imaging and directed energy beams. The beam sharing element 350 may have optical power for the beam reflected by the beam sharing element. Combinations of these and other techniques may be used.

The imaging beam 325 travels, for the most part, through the same space as the directed energy beam (312, 314, 316 in FIG. 3A). The imaging beam 325 is separated from the directed energy beam by the action of the aperture-sharing element 350 which, in this example, reflects the imaging beam 325 while transmitting the directed energy beam 312. In other optical systems, the aperture-sharing element 350 may reflect the directed energy beam and transmit the imaging beam. The aperture-sharing element 350 may distinguish the directed energy beam 312 and the imaging beam 325 based on polarization, frequency, or some other characteristic.

The directed energy beam 312 may have a first polarization state that is transmitted through the aperture-sharing element 350. The imaging beam 325, and the associated illumination source, may have a second polarization state different from the first polarization state. The second polarization state may be reflected from the aperture-sharing element 350. To provide different magnification for the imaging beam 325 and the directed energy beam 312, the primary reflective element 330 and, optionally, the secondary reflective element 340, may have different optical power for the first polarization state and the second polarization state.

Similarly, the directed energy beam 312 may have a first frequency that is transmitted through the aperture-sharing element 350. The imaging beam 325, and the associated illumination source, may have a second frequency different from the first frequency. The second frequency may be

reflected from the aperture-sharing element **350**. To provide different magnification for the imaging beam **325** and the directed energy beam **312**, the primary reflective element **330** and, optionally, the secondary reflective element **340**, may have different optical power for the first frequency and the second frequency. To provide improved imaging resolution, the imaging beam **325** may have a frequency that is higher than the frequency of the directed energy beam **312**. The imaging beam **325** may have a frequency that is between 1.5 and 10 times the frequency of the directed energy beam **312**.

FIG. **4** is a schematic diagram of an exemplary optical system **400** that may be suitable for the beam director **220** in FIG. **2**. The optical system **400** may include a secondary reflective element **440** and a primary reflective element **430**. One or both of the primary reflective element **430** and the secondary reflective element **440** may be a passive reflector array which, although physically flat, may have an optical power.

The integrated electromagnetic energy source/image detector **410** may generate a directed energy beam **420** of electromagnetic energy. The secondary reflective element **440** may reflect the directed energy beam as a diverging beam toward the primary reflective element **430**. The primary reflective element **430** may accept the diverging beam from the secondary reflective element **440** and may form a converging directed energy beam **420** that may be focused to a spot at an object plane **490**.

The optical system **400** may form an image of a portion of the object plane **490** at a detector array within the integrated electromagnetic energy source/image detector **410**. The optical system **400** may be adapted to provide a higher magnification factor for the imaging beam **425** than for the directed energy beam **420**.

The directed energy beam **420** may have a first polarization state. The imaging beam **425**, and the associated illumination source, may have a second polarization state different from the first polarization state. To provide different magnification for the imaging beam **425** and the directed energy beam **420**, the primary reflective element **430** and, optionally, the secondary reflective element **440**, may have different optical power for the first polarization state and the second polarization state.

Similarly, the directed energy beam **420** may have a first frequency. The imaging beam **425**, and the associated illumination source, may have a second frequency different from the first frequency. To provide different magnification for the imaging beam **425** and the directed energy beam **420**, the primary reflective element **430** and, optionally, the secondary reflective element **440**, may have different optical power for the first frequency and the second frequency. The optical system **400** is not limited to two reflective optical elements, and one or more additional elements may be added.

FIG. **5** is an example of a man-portable dual use directed energy weapon and imager **500**, which may be the dual use directed energy weapon and imager **100** or **200** of FIG. **1** and FIG. **2**, respectively. The dual use directed energy weapon and imager **500** may include a housing **510** that is generally modeled after the shape of a rifle or other weapon. The housing **510** may be shaped like a known weapon for psychological impact and because existing weapons are ergonomically designed to be accurately and comfortably pointed by their operator. The housing **510** may include a stock **570** for placement against the operator's shoulder. The housing **510** may have some shape that does not resemble a rifle or other conventional weapon.

The housing **510** may encompass a source of electromagnetic energy and an imager, shown generally at **520**. The

housing **510** may support a first reflective element **545** and a second reflective element **540**, which may be similar to the primary and secondary reflective elements **340**, **330** of FIG. **3A** and FIG. **3B**. The housing **510** may encompass an illumination source **530**, which may be disposed on or within the housing at any location that allows illumination of the object to be imaged by the imager. An aiming subsystem **580** may be mounted on the first reflective element **545**, as shown, or may be disposed at other locations on or with the housing **510**. The aiming subsystem **580** may include a laser or other optical source to generate a pointing beam, and may include a video or other camera.

The housing **510** may be connected to an auxiliary equipment container **590** by means of an umbilical cable **595**. The auxiliary equipment container **590** may take the form of a backpack, hip belt, or other form for a man portable system. The auxiliary equipment container **590** may encompass all or portions of the batteries or other primary power supply and all or portions of the cooling, power conditioning, security, and communications subsystems, if included in the dual purpose directed energy weapon and imager **500**. The umbilical cable **595** may contain electrical wiring and/or flexible tubing for conducting electrical power, signals, and gaseous or liquid coolant between the auxiliary equipment container **590** and the housing **510**.

FIG. **6** is an example of a dual use directed energy weapon and imager **610** mounted on a vehicle **620**. The dual use directed energy weapon and imager **610** may be the dual use directed energy weapon and imager **100** or **200** of FIG. **1** and FIG. **2**, respectively. The dual use directed energy weapon and imager **610** may include a beam director system, including a first reflective element **630** and a second reflective element **640**, that may be at least partially disposed external to the vehicle. The balance of the dual use directed energy weapon and imager **610** may be disposed within the passenger compartment, trunk, or other interior or exterior portion of the vehicle. The vehicle **620** is representative, and the dual use directed energy weapon and imager **610** may be mounted on an automobile, truck, van, multi-purpose vehicle, or any other suitable vehicle.

The vehicle-mounted dual use directed energy weapon and imager **610** may include a single-axis or multi-axis gimbal **650** that allows pointing a directed energy beam formed by the beam director system in different directions in azimuth and, optionally, elevation. The vehicle-mounted dual use directed energy weapon and imager **610** may include a control subsystem (not shown in FIG. **6**) that drive the gimbal **650** to track an object. The control subsystem may use image information from an imager (**140** in FIG. **1**) or an aiming subsystem (**170** in FIG. **1**) to track the object.

The man-portable dual use directed energy weapon and imager **500** of FIG. **5** and the vehicle-mounted dual use directed energy weapon and imager **610** of FIG. **6** are examples only, and other dual use directed energy weapon and imager systems may be adapted for mounting on a tripod, a stationary structure, a ship, or an air vehicle. Such other systems may be fully contained within a single housing, or may include an umbilical and an auxiliary equipment housing, and may contain additional elements and features.

#### Closing Comments

The foregoing is merely illustrative and not limiting, having been presented by way of example only. Although examples have been shown and described, it will be apparent to those having ordinary skill in the art that changes, modifications, and/or alterations may be made.

Although many of the examples presented herein involve specific combinations of method acts or system elements, it

should be understood that those acts and those elements may be combined in other ways to accomplish the same objectives. With regard to flowcharts, additional and fewer steps may be taken, and the steps as shown may be combined or further refined to achieve the methods described herein. Acts, elements and features discussed only in connection with one embodiment are not intended to be excluded from a similar role in other embodiments.

For means-plus-function limitations recited in the claims, the means are not intended to be limited to the means disclosed herein for performing the recited function, but are intended to cover in scope any means, known now or later developed, for performing the recited function.

As used herein, "plurality" means two or more.

As used herein, a "set" of items may include one or more of such items.

As used herein, whether in the written description or the claims, the terms "comprising", "including", "carrying", "having", "containing", "involving", and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Only the transitional phrases "consisting of" and "consisting essentially of" respectively, are closed or semi-closed transitional phrases with respect to claims.

Use of ordinal terms such as "first", "second", "third", etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having a same name (but for use of the ordinal term) to distinguish the claim elements.

As used herein, "and/or" means that the listed items are alternatives, but the alternatives also include any combination of the listed items.

The invention claimed is:

1. A dual use directed energy weapon and imager, comprising:

first means for providing a first beam of electromagnetic energy;

second means for directing the first beam of electromagnetic energy to an object, the second means defining an aperture; and

a third means for capturing an image of the object wherein the third means shares the aperture defined by the second means.

2. The dual use directed energy weapon and imager of claim 1, wherein the first beam of electromagnetic energy is a beam of millimeter wave electromagnetic energy.

3. The dual use directed energy weapon and imager of claim 2, wherein the first beam of electromagnetic energy has a frequency of 75 GHz to 110 GHz.

4. The dual use directed energy weapon and imager of claim 1, wherein the second means comprises a primary reflective element, the primary reflective element defining the aperture.

5. The dual use directed energy weapon of claim 1, further comprising fourth means to illuminate the object with a second beam of electromagnetic energy

wherein the third means captures an image of the object using at least a portion of the second beam reflected from the object.

6. The dual use directed energy weapon and imager of claim 5, wherein the first beam of electromagnetic energy has a first polarization state and the second beam of electromagnetic energy has a second polarization state different from the first polarization state.

7. The dual use directed energy weapon and imager of claim 6, wherein the second means further comprises an aperture-sharing element that separates the first beam of electromagnetic energy and the reflected portion of the second beam of electromagnetic energy based on polarization state.

8. The dual use directed energy weapon and imager of claim 6, wherein the primary reflective element has different optical power for the first polarization state and the second polarization state.

9. The dual use directed energy weapon and imager of claim 5, wherein the first beam of electromagnetic energy has a first frequency and the second beam of electromagnetic energy has a second frequency different from the first frequency.

10. The dual use directed energy weapon and imager of claim 9, wherein the second means further comprises an aperture-sharing element that separates the first beam of electromagnetic energy and the reflected portion of the second beam of electromagnetic energy based on frequency.

11. The dual use directed energy weapon and imager of claim 9, wherein the primary reflective element has different optical power for the first frequency and the second frequency.

12. The dual use directed energy weapon and imager of claim 9, wherein the second frequency is between 1.5 times and 10 times the first frequency.

13. The dual use directed energy weapon and imager of claim 1, further comprising a control subsystem.

14. The dual use directed energy weapon and imager of claim 1, further comprising a security subsystem.

15. The dual use directed energy weapon and imager of claim 1, further comprising an aiming subsystem.

16. The dual use directed energy weapon and imager of claim 1, further comprising a communications subsystem.

17. A dual use directed energy weapon and imager, comprising:

a generator providing a first beam of millimeter wave electromagnetic energy;

a beam director to direct the first beam of millimeter wave electromagnetic energy from the source to an object, the beam director defining an aperture; and

an imager to capture an image of the object wherein the imager shares the aperture defined by the beam director.

18. The dual use directed energy weapon and imager of claim 17, wherein the first beam of millimeter wave electromagnetic energy has a frequency of 75 GHz to 110 GHz.

19. The dual use directed energy weapon and imager of claim 17, wherein the beam director comprises a primary reflective element, the primary reflective element defining the aperture.

20. The dual use directed energy weapon of claim 17, further comprising an illuminator to illuminate the object with a second beam of electromagnetic energy

wherein the imager captures an image of the object using at least a portion of the second beam reflected from the object.

21. The dual use directed energy weapon and imager of claim 20, wherein the first beam of millimeter wave electromagnetic energy has a first polarization state and the second beam of electromagnetic energy has a second polarization state different from the first polarization state.

22. The dual use directed energy weapon and imager of claim 21, wherein the beam director comprises an aperture-sharing element that separates the first beam of millimeter wave electromagnetic energy and the reflected portion of the second beam of electromagnetic energy based on polarization state.

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23. The dual use directed energy weapon and imager of claim 21, wherein the primary reflective element has different optical power for the first polarization state and the second polarization state.

24. The dual use directed energy weapon and imager of claim 20, wherein the first beam of millimeter wave electromagnetic energy has a first frequency and the second beam of electromagnetic energy has a second frequency different from the first frequency.

25. The dual use directed energy weapon and imager of claim 24, wherein the beam director comprises an aperture-sharing element that separates the first beam of millimeter wave electromagnetic energy and the reflected portion of the second beam of electromagnetic energy based on frequency.

26. The dual use directed energy weapon and imager of claim 24, wherein the primary reflective element has different optical power for the first frequency and the second frequency.

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27. The dual use directed energy weapon and imager of claim 24, wherein the second beam of electromagnetic energy has a frequency that is 1.5 to 10 times the frequency of the first beam of electromagnetic energy.

28. The dual use directed energy weapon and imager of claim 17, further comprising a control subsystem.

29. The dual use directed energy weapon and imager of claim 17, further comprising a security subsystem.

30. The dual use directed energy weapon and imager of claim 17, further comprising an aiming subsystem.

31. The dual use directed energy weapon and imager of claim 17, further comprising a communications subsystem.

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