Multifunctional radio frequency directed energy system

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ABSTRACT

An RFDE system includes an RFDE transmitter and at least one RFDE antenna. The RFDE transmitter and antenna direct high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target. The RFDE system further includes a targeting system for locating the target. The targeting system includes a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target. The RFDE system also includes an antenna pointing system for aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system. Moreover, at least a portion of the radar transmitter or the at least one radar antenna is integrated within at least a portion of the RFDE transmitter or the at least one RFDE antenna.

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Inventors	Kenneth W. Brown, David J. Canich, Russell F. Berg
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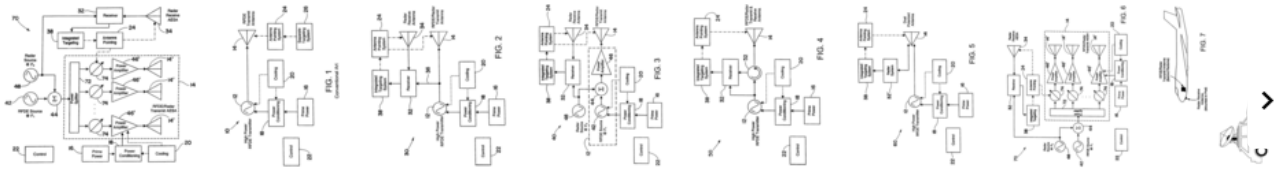

DESCRIPTION

TECHNICAL FIELD

The present invention relates generally to radio frequency directed energy (RFDE) systems, and more particularly to multifunctional type RFDE systems.

BACKGROUND OF THE INVENTION

Radio frequency directed energy (RFDE) systems are known in the art for directing high power RF, microwave and/or millimeter wave electromagnetic energy to destroy or disrupt a target. Although RFDE systems typically serve as military weapons, RFDE systems need not be limited to weapon systems. For example, RFDE systems of the present invention may be used for non-military purposes such as destroying or disrupting foreign objects, contaminants, undesirable atmospheric conditions, or other types of targets.

As for weapon systems, it is important to distinguish between an RFDE weapon system and an electronic warfare system. A primary difference between an RFDE weapon and an electronic warfare system is power and kill mode. An electronic warfare system makes use of a priori knowledge of a target it is designed to jam or disrupt. An electronic warfare system uses such a priori knowledge of a target's characteristics (e.g., frequency of operation, method of operation, etc.) to disrupt or confuse the target with “finesse”, or a relatively low amount of power.

CLAIMS (22)

1. A multi-functional radio frequency directed energy (RFDE) system, comprising:

an RFDE transmitter and at least one RFDE antenna for directing high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target;

a targeting system for locating the target, the targeting system including a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target; and

an antenna pointing system for aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system,

wherein at least a portion of the radar transmitter or the at least one radar antenna is integrated within at least a portion of the RFDE transmitter or the at least one RFDE antenna to provide simultaneous transmission of the high power electromagnetic energy and the electromagnetic energy to locate the target.

2. The multi-functional RFDE system of claim 1, wherein the at least one radar antenna is embodied at least partially within the at least one RFDE antenna.

On the other hand, an RFDE weapon system can go after a broad range of targets (electronics, biological, ordinance, structures, etc.) due to its relatively large radiated power. A priori knowledge of the intended target characteristics is typically not required because the RFDE weapon either burns-out or overwhelms its target by the shear amount of power it radiates.

An ongoing problem with RFDE systems is targeting—accurately pointing the RF directed energy beam at the intended target and establishing an accurate range from the system to the target. To date, the RFDE system targeting problem has been addressed by using what may be referred to as auxiliary add-on systems. These add-on systems could include a stand-alone radar system, a stand-alone laser range finder, stand-alone optical or infrared imaging system, etc. However, these add-on systems add significant cost to the RFDE system. In addition, these add-on systems add significant complexity by requiring calibration of the alignment between the RFDE system and the stand-alone targeting system.

FIG. 1 is a block diagram of a typical RFDE system **10**. In its simplest form, the system **10** includes a high power transmitter **12** transmitting thru a high power antenna **14**. The transmitter **12** operates at RF, microwave or millimeter wave frequencies. The system **10** operates based on a prime power source **16**, such as an AC mains, generator, high capacity battery system, etc. A power conditioning block **18** conditions power delivered from the power source **16** so as to be suitable for powering the transmitter **12**. A cooling system **20** provides appropriate cooling to the power conditioning block **18** and the high power transmitter **12** as needed. A control block **22** provides appropriate control among the various sub-systems.

The RFDE weapon system **10** further includes an antenna pointing system **24** for aiming the high power antenna **14**, and thus the high power electromagnetic energy beam transmitted therefrom, at the target. The pointing system **24** typically is driven by coordinate data identifying the direction and range of the intended target. Such coordinate data is provided by a stand-alone targeting system **26**. As is noted above, the targeting system **26** is an add-on often in the form of a stand-alone radar system, a stand-alone laser range finder, stand-alone optical or infrared imaging system, etc. As is also noted above, however, these add-on systems add significantly to the cost and complexity of the RFDE system.

In view of the aforementioned shortcomings associated with conventional RFDE systems, there is a strong need in the art for an RFDE system which is not subject to the cost and complexity associated with conventional targeting systems.

SUMMARY OF THE INVENTION

The RFDE system of the present invention eliminates the need for a separate, stand-alone targeting system by integrating a targeting system within the RFDE system itself. The RFDE system is multi-functional in that all or part of the RFDE system hardware that functions to direct high power electromagnetic energy also functions to obtain and provide targeting information to aim the high power electromagnetic energy beam. For example, the RFDE transmitter is not only used as the source of the directed electromagnetic energy, but is also used as a radar transmitter for targeting an object. A relatively simple radar receiver may then be added to the RFDE system. The cost of the overall system is substantially reduced since an expensive radar transmitter is not required.

Moreover, the complexity of the system is reduced as calibration of the alignment between the RFDE system and a stand-alone targeting system becomes unnecessary.

According to one aspect of the invention, a multi-functional RFDE system is provided. The RFDE system includes an RFDE transmitter and at least one

3. The multi-functional RFDE system of claim 1, wherein the radar transmitter is embodied at least partially within the RFDE transmitter.

4. The multi-functional RFDE system of claim 3, wherein the radar transmitter and the RFDE transmitter comprise a common RF power amplifier.

5. The multi-functional RFDE system of claim 4, wherein the electromagnetic energy for locating the target is at a first frequency, and the high power electromagnetic energy is at a second frequency different from the first.

6. The multi-functional RFDE system of claim 1, wherein the at least one radar antenna functions to transmit the electromagnetic energy for locating the target, and the at least one radar antenna is embodied at least partially in the at least one RFDE antenna.

7. The multi-functional RFDE system of claim 6, wherein the at least one radar antenna includes a first radar antenna that functions to transmit the electromagnetic energy for locating the target and to transmit the high power electromagnetic energy, and a second radar antenna that functions to receive the electromagnetic energy reflected from the target in order to locate the target.

8. The multi-functional RFDE system of claim 7, wherein the first radar antenna comprises a multi-element phased array.

9. The multi-functional RFDE system of claim 6, wherein the at least one radar antenna that functions to transmit the electromagnetic energy for locating the target also functions to receive the electromagnetic energy reflected from the target in order to locate the target.

10. The multi-functional RFDE system of claim 9, wherein the at least one radar antenna comprises a dual-polarized antenna.

11. The multi-functional RFDE system of claim 1, wherein the system comprises a beam combiner for combining the high power electromagnetic energy with the electromagnetic energy for locating the target in a path between the RFDE transmitter and the RFDE antenna.

12. The multi-functional RFDE system of claim 1, wherein the system is configured for operation in a mobile vehicle.

13. The multi-functional RFDE system of claim 12, wherein the mobile vehicle is a wheeled-vehicle.

14. The multi-functional RFDE system of claim 12, wherein the mobile vehicle is an aircraft.

15. A method of operating a multi-functional radio frequency directed energy (RFDE) system, comprising the steps of:

utilizing an RFDE transmitter and at least one RFDE antenna to direct high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target;

utilizing a targeting system to locate the target, the targeting system including a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target;

aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system; and

integrating at least a portion of the radar transmitter or the at least one

RFDE antenna. The RFDE transmitter and antenna direct high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target. The RFDE system further includes a targeting system for locating the target. The targeting system includes a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target. The RFDE system also includes an antenna pointing system for aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system. Moreover, at least a portion of the radar transmitter or the at least one radar antenna is integrated within at least a portion of the RFDE transmitter or the at least one RFDE antenna.

According to another aspect of the invention, a method is provided operating an RFDE system. The method includes the steps of utilizing an RFDE transmitter and at least one RFDE antenna to direct high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target; utilizing a targeting system to locate the target, the targeting system including a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target; aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system; and integrating at least at portion of the radar transmitter or the at least one radar antenna within, at least a portion of the RFDE transmitter or the at least one RFDE antenna.

To the accomplishment of the foregoing and related; ends, the invention, then, comprises the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed. Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a conventional RFDE system;

FIG. 2 is a block diagram of a multi-functional RFDE system in accordance with a first embodiment of the present invention;

FIG. 3 is a block diagram of a multi-functional RFDE system in accordance with a second embodiment of the present invention;

FIG. 4 is a block diagram of a multi-functional RFDE system in accordance with a third embodiment of the present invention;

FIG. 5 is a block diagram of a multi-functional RFDE system in accordance with a fourth embodiment of the present invention;

FIG. 6 is a block diagram of a multi-functional RFDE system in accordance with a fifth embodiment of the present invention;

FIG. 7 illustrates a multi-functional RFDE system mounted within an aircraft in accordance with an embodiment of the present invention;

FIG. 8 illustrates a multi-functional RFDE system mounted within a wheeled vehicle in accordance with an embodiment of the present invention; and

FIG. 9 is a schematic diagram of a multi-functional RFDE system incorporating a reflector-type antenna in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described with reference to the drawings, in which like reference numerals are provided to refer to like elements throughout.

radar antenna within at least a portion of the RFDE transmitter or the at least one RFDE antenna to provide simultaneous transmission of the high power electromagnetic energy and the electromagnetic energy to locate the target.

16. The method of claim 15, wherein the at least one radar antenna is embodied at least partially within the at least one RFDE antenna.

17. The method of claim 15, wherein the radar transmitter is embodied at least partially within the RFDE transmitter.

18. The method of claim 17, wherein the radar transmitter and the RFDE transmitter comprise a common RF power amplifier.

19. The method of claim 18, wherein the electromagnetic energy for locating the target is at a first frequency, and the high power electromagnetic energy is at a second frequency different from the first.

20. The method of claim 15, wherein the at least one radar antenna functions to transmit the electromagnetic energy for locating the target, and the at least one radar antenna is embodied at least partially in the at least one RFDE antenna.

21. A multi-functional radio frequency directed energy (RFDE) system, comprising:

an RFDE transmitter and at least one RFDE antenna for directing high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target;

a targeting system for locating the target, the targeting system including a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target; and

an antenna pointing system for aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system,

wherein at least a portion of the radar transmitter or the at least one radar antenna is integrated within at least a portion of the RFDE transmitter or the at least one RFDE antenna and the high power electromagnetic energy is used as the electromagnetic energy to locate the target.

22. A method of operating a multi-functional radio frequency directed energy (RFDE) system, comprising the steps of:

utilizing an RFDE transmitter and at least one RFDE antenna to direct high power electromagnetic energy towards a target sufficient to cause high energy damage or disruption of the target;

utilizing a targeting system to locate the target, the targeting system including a radar transmitter and at least one radar antenna for transmitting and receiving electromagnetic energy to locate the target;

aiming the at least one RFDE antenna at the target based on the location of the target as ascertained by the targeting system; and

integrating at least a portion of the radar transmitter or the at least one radar antenna within at least a portion of the RFDE transmitter or the at least one RFDE antenna,

wherein the high power electromagnetic energy is used as the electromagnetic energy to locate the target.

The RFDE system of the present invention integrates a targeting system, such as a radar targeting, system, into an otherwise conventional RFDE system. There are several ways that the targeting system can be integrated into the RFDE system as explained herein. The particular embodiments described below are meant to be merely exemplary. The present invention contemplates not only the particular embodiments described herein, but any system in which a targeting system is integrated in part or in whole within the RFDE system.

Referring to FIG. 2, an RFDE system **30** is shown in accordance with an embodiment of the present invention. Since many of the elements of the RFDE system **30** in FIG. 3 are similar to those in the conventional system **10** discussed above with respect to FIG. 1, only the relevant differences with be discussed herein for sake of brevity. In this particular embodiment, a portion of an otherwise conventional RFDE system (notably the high power transmitter **12** and/or the transmit antenna **14**) forms part of the targeting system. Specifically, during a targeting mode, the high power RFDE transmitter **12** is controlled by the control block **22** to transmit standard radar tracking signals thru the antenna **14**. The radar tracking signals may be any type of conventional radar signal such a pulse or continuous wave radar. The power level of the tracking signals may be a high powered signal, such as the RFDE signal itself, or a relatively low powered signal as more typical in radar tracking applications.

In the embodiment of FIG. 2, a separate radar receiver **32** and radar receive antenna **34** are used in conjunction with the integrated RFDE/radar transmitter **12**. In one embodiment, the RFDE high power output beam intended to destroy or disturb a target is transmitted using the RFDE/radar transmitter **12** and antenna **14**. The radar receive antenna **34** receives portions of the RFDE output beam reflected by the target back towards the system **30**. The radar receiver **32** processes the reflected return signals using conventional techniques in order to identify the location of the target. For example, the radar receiver **32** can be coherently linked to the transmitted RFDE output waveform (represented by line **36**) so that Doppler processing can be achieved and the direction and range of the target identified.

The radar receiver **32** provides the target location information to an integrated targeting system block **38** which feeds the location information to the antenna pointing system **24**. Such operation allows the antenna **14** to be directed in both search and track radar functions.

As will be appreciated, the RFDE system **30** in FIG. 2, as with the various other embodiments of the invention described herein, can operate in both an RFDE mode and a tracking mode. Both modes may be carried out simultaneously as described above, for example, where the high power electromagnetic energy output waveform of the RFDE system also serves as the radar tracking system transmit signal. Alternatively, the RFDE system **30** may switch between the RFDE mode and the tracking mode using a separate RFDE high power beam and lower power radar transmit signals, respectively. So long as the system **30** switches between the two modes rapidly enough so as not to lose track of the target, operation between RFDE mode and tracking mode may be time-division multiplexed.

Typically the radar transmitter is one of the most expensive portions of a radar tracking system. Therefore, by using the RFDE transmitter **12** and antenna **14** to function as the radar transmitter and antenna for targeting, the cost of the targeting system can be drastically reduced. Also, using the radar return of the RFDE high power beam itself to determine the target location can substantially improve the beam pointing accuracy of the RFDE system **30**. By using the RFDE high power beam to determine the location of the target, the power density on target will be maximized when standard radar tracking techniques are employed (e.g., monopulse, continuous scan, etc.).

Those of ordinary skill will appreciate that the RFDE transmitter **12** can be any transmitter suitable for transmitting an RFDE high power beam. For example, the RFDE transmitter **12** may be a single or multiple tube source, or solid state source. Moreover, it will be appreciated that the antenna **14** can be any type of suitable high power antenna which can be mechanically and/or electronically pointed and scanned via the antenna pointing system **24**. The transmitter/antenna can also be comprised of an active electronically steered array (AESA), for example, where an array of high power amplifiers/antennas is utilized. The radar receive antennas **34** can be any type of suitable antenna for receiving the radar return signals. As with the antenna **14**, the radar receive antenna **34** is mechanically and/or electronically pointed and scanned via the antenna pointing system **24**. The antenna pointing system **24** can be a mechanical gimbal or a beam steering computer controlling phase shifters in an electronically steerable array.

FIG. 3 illustrates another embodiment representing how a tracking system can be integrated with an RFDE system. The embodiment of FIG. 3, as with the other embodiments described herein, shares many of the same elements as FIG. 2, and thus again only the relevant differences between the embodiments will be discussed for sake of brevity.

Specifically, FIG. 3 illustrates an RFDE system **40** in which the power amplifier of the tracking system is integrated within the power amplifier of the RFDE system. More particularly, the RFDE transmitter **12** includes a low power RFDE signal source **42** operating at a first frequency and input to an adder **44**. The output of the adder **44** is input to a power amplifier **46** which amplifies the output before being radiated by the transmit antenna **14**. A low power radar signal source **48** at a second frequency is also input to the adder **44**. In addition, the low power radar signal source **48** is input to the radar receiver **32** to provide for coherent processing. The adder **44** thus outputs the combined RFDE signal source and radar

signal source to the power amplifier **46**. The power amplifier **46** can be any suitable type of amplifier including, for example, an injection locked magnetron, a klystron, a solid-state amplifier, etc., or an array of any of these types of amplifiers in an AESA embodiment.

In the embodiment of FIG. 3, a separate low power radar signal from the signal source **48** is used. This signal is combined with the RFDE signal from the RFDE signal source **42** prior to the combined signal being amplified by the power amplifier **46**. The frequencies of the RFDE signal and the radar signal do not have to be at the same frequency. In fact, they can be completely independent of each other within the bandwidth constraints of the power amplifier **46** and the RFDE transmit antenna **14**. It will be appreciated that significant isolation can be achieved between the RFDE and radar signals by filtering out the RFDE signal at the receive antenna **34** and/or radar receiver **32**.

Again, it will be appreciated that the RFDE system **40** of FIG. 3 may operate in an RFDE mode and a targeting mode. As in the other embodiments described herein, such modes may be carried out simultaneously or in time-multiplexed fashion. In the case where the RFDE signal source **42** and radar signal source **48** are different, one may consider such operation as frequency-multiplexed as will be appreciated.

FIG. 4 illustrates yet another embodiment of the present invention. In this embodiment, the RFDE system **50** integrates the radar receive antenna into the same antenna **14** serving as the RFDE and radar transmit antenna. This is accomplished by means of a high power circulator **52** which routes the RFDE/radar transmit signals from the shared transmitter **12** through to the antenna **14**. Reflected signals received by the antenna are routed by the circulator **52** to the receiver **32** for processing. In this example, as in the others discussed herein, the RFDE transmit signal may also be the radar transmit signal. The return signal is received by the same antenna **14** and coupled through the circulator **52** to the receiver **32**. The radar system thus can provide target information feedback to the antenna pointing system **24**.

The high power circulator **52** can be problematic in that it can be difficult to design a circulator that can handle the typical total power radiated by an RFDE system. Nevertheless, with improvements in materials and technologies such a circulator may someday be commercially feasible. Furthermore, the embodiment of FIG. 4 certainly is very suitable for an AESA system where the output power is broken-up among an array of transmit elements as discussed in more detail below.

In some integrated RFDE/targeting applications it may be desirable only to share the antenna between the RFDE and targeting systems. The RFDE system and the targeting system otherwise operate independently. An example of such an embodiment is shown in FIG. 5.

Specifically, the embodiment of FIG. 5 illustrates a radar system **32′** which functions essentially independently of the RFDE system **60** with the exception of sharing a dual polarized antenna **14**. The RFDE system transmits the RFDE high power beam from the transmitter **12** via the dual polarized antenna **14** using one polarization (e.g., vertical, right hand circular, etc.). The radar system **32′**, with its own transmitter/receiver, transmits the radar transmit signal via the antenna **14** using the orthogonal polarization (e.g., horizontal, left hand circular, etc.). The reflected radar return signal received by the antenna **14** is processed by the radar system **32′** to provide target location information, again using conventional techniques. As in the other embodiments, the location information is provided to the integrated targeting system **38** which provides the information to the antenna pointing system **24**. The embodiment of FIG. 5 can be used to provide tracking information and/or is especially suitable for providing range information for the RFDE system.

FIG. 6 illustrates an embodiment in which AESAs or phased array antennas may be incorporated within the present invention. The embodiment of FIG. 6 is fundamentally the same as the embodiment of FIG. 3, with the exception that the power amplifier **46** is represented by an array of power amplifiers **46′** included with the RFDE/radar transmit AESA antenna **14**. The radar receive antenna **34** may similarly comprise an AESA antenna.

As is shown in FIG. 6, the combined signal from the adder **44** is input to a power splitter **72** within the AESA antenna **14**. The power splitter **72** separates the signal and provides the split signal to respective phase shifters **74** and power amplifiers **46′** corresponding to respective radiator elements **14′** in the antenna **14**. The antenna pointing system **24** may steer the antenna **14** by adjusting the phase of the phase shifters **74**, as will be appreciated.

Continuing to refer to FIG. 6, it will further be appreciated that the radar source **48** and RFDE source **42** can be at different frequencies and still radiate in the same direction. As long as the phase shifters **74** are selected to provide a true time delay (which is fairly common in the art), the antenna **14** may be steered concurrently for both frequencies.

A multifunctional RFDE system of the present invention can be employed on a variety of platforms. For example, FIG. 7 illustrates an embodiment in which the system is employed on an aircraft. The combined RFDE/radar transmitter **12** and antenna **14** (not shown), for example, are mounted to radiate out the side of the aircraft. A pod is then mounted beneath the aircraft, containing the radar receiver **32** and receive antenna **34** (also not shown).

FIG. 8 shows an embodiment in which the RFDE system of the present invention can be employed on a wheeled vehicle. For example, the RFDE and radar systems are mounted in the back of the vehicle and share a common antenna. One

possible such system **80** is shown in FIG. 9. A high power RFDE source **12** radiates into a beam transport system comprised of mirrors (e.g., **82**) suitable for the frequency of operation. A cross-polarized radar transmit signal from the radar system **32′** is then injected into the RFDE beam path by means of a beam combiner/splitter **84**. The RFDE and radar transmit signal are then simultaneously transmitted from the common antenna **14**, in this embodiment a reflector-type antenna. The radar return signal is received by the antenna **14** and directed back to the cross-polarized radar system **32′** via the mirrors **82** and beam combiner/splitter **84**.

Although the invention has been shown and described with respect to certain preferred embodiments, it is obvious that equivalents and modifications will occur to others skilled in the art upon the reading and understanding of the specification. For example, although the present invention has been described primarily in the context of a conventional radar based targeting system, other types of radar-like targeting systems which rely on the transmission and return of electromagnetic energy (e.g., laser-based, infrared, etc.) can also be used without departing from the scope of the invention.

The present invention includes all such equivalents and modifications, and is limited only by the scope of the following claims.

PATENT CITATIONS

Cited Patent	Filing date	Publication date	Applicant	Title
US2703399 *	Feb 15, 1946	Mar 1, 1955	Cousy Edwin V	Apparatus for guiding and detonating missiles
US2709773 *	Oct 19, 1945	May 31, 1955	Lee L Davenport	Remote control system with position indicating means
US2745095 *	Sep 4, 1947	May 8, 1956	Stoddard James V	Radiant energy control system for missile guidance
US2840808 *	Mar 19, 1946	Jun 24, 1958	Woodward William R	Moving target indication systems
US2908870 *	Nov 5, 1957	Oct 13, 1959	Hardin Clyde D	Generation of very short microwave pulses
US3417700 *	Jul 12, 1957	Dec 24, 1968	Army Usa	Fuze arming system
US3688313 *	Dec 19, 1966	Aug 29, 1972	Motorola Inc	Combined cw and pulse tracking systems
US3714898 *	Jul 22, 1969	Feb 6, 1973	Gen Electric	Fuze actuating system
US3946233 *	Mar 18, 1970	Mar 23, 1976	Messerschmitt-Bolkow-Blohm Gmbh	Weapon system for the detection of and use against stationary or moving objects
US4004487 *	Mar 6, 1975	Jan 25, 1977	Kurt Eichweber	Missile fire-control system and method
US4035799 *	Nov 4, 1975	Jul 12, 1977	The United States Of America As Represented By The Secretary Of The Navy	Digital mean clutter doppler compensation system
US4109883 *	Mar 29, 1965	Aug 29, 1978	The United States Of America As Represented By The Secretary Of The Army	Anti-missile missile
US4119967 *	May 21, 1976	Oct 10, 1978	Teledyne, Inc.	Microwave dual mode non-interfering CW and pulsed signal system method and apparatus
US4130821 *	Apr 8, 1977	Dec 19, 1978	The United States Of America As Represented By The Secretary Of The Navy	Frequency-agile fire control radar system
US4214534 *	Jun 30, 1969	Jul 29, 1980	The United States Of America As Represented By The Secretary Of The Army	Command fuzing system
US4319242 *	Mar 4, 1980	Mar 9, 1982	The United States Of America As Represented By The Secretary Of The Navy	Integrated weapon control radar system
US4360812 *	Mar 16, 1967	Nov 23, 1982	The United States Of America As Represented By The Secretary Of The Army	FM-CW Fuze
US4456912 *	Apr 3, 1972	Jun 26, 1984	Harvest Queen Mill & Elevator Company	High energy microwave defense system
US4661819 *	May 12, 1983	Apr 28, 1987	The United States Of America As Represented By The Secretary Of The Navy	Doppler tolerant binary phase coded pulse compression system
US4740790 *	Sep 12, 1985	Apr 26, 1988	Scientific-Atlanta, Inc.	Antenna polarization measuring methods
US4890109 *	Jul 13, 1977	Dec 26, 1989	The United States Of America As Represented By The Secretary Of The Navy	Lightweight, broadband, pulsed, frequency agile, self-screening jammer for airborne deployment
US5013151 *	Dec 7, 1981	May 7, 1991	Australian Electro Optics Pty Ltd.	Variable beam width laser radar system

Cited Patent	Filing date	Publication date	Applicant	Title
US5189244 *	Aug 21, 1989	Feb 23, 1993	Board Of Regents, The University Of Texas System	Method and apparatus for spinning projectiles fired from a rail gun
US5191343 *	Feb 10, 1992	Mar 2, 1993	United Technologies Corporation	Radar target signature detector
US5387917 *	Dec 11, 1992	Feb 7, 1995	Honeywell Inc.	Radar fuze
US5389931 *	Mar 14, 1994	Feb 14, 1995	Hughes Aircraft Company	Radar signal processing system
US5432546 *	May 16, 1994	Jul 11, 1995	Enel Company	Weapon impact assessment system
US5606313 *	Nov 14, 1995	Feb 25, 1997	Motorola, Inc.	Low power addressable data communication device and method
US5613039 *	Jan 3, 1994	Mar 18, 1997	Ail Systems, Inc.	Apparatus and method for motion detection and tracking of objects in a region for collision avoidance utilizing a real-time adaptive probabilistic neural network
US5726657 *	Mar 22, 1996	Mar 10, 1998	Lockheed Martin Corporation	Phase coherent radar system using fast frequency agile waveform synthesis
US5747720 *	Jun 1, 1995	May 5, 1998	Trw Inc.	Tactical laser weapon system for handling munitions
US5777572 *	Jun 12, 1996	Jul 7, 1998	Northrop Grumman Corporation	Device for damaging electronic equipment using unfocussed high power millimeter wave beams
US5780839 *	Dec 4, 1996	Jul 14, 1998	Trw Inc.	Laser crossbody and feature curvature tracker
US5838262 *	Dec 19, 1996	Nov 17, 1998	Sikorsky Aircraft Corporation	Aircraft virtual image display system and method for providing a real-time perspective threat coverage display
US5977910 *	Aug 7, 1997	Nov 2, 1999	Space Systems/Loral, Inc.	Multibeam phased array antenna system
US6014922 *	Dec 11, 1997	Jan 18, 2000	Trw Inc.	Short range/intermediate range laser defense against chemical and biological weapons
US6265704 *	Mar 29, 1999	Jul 24, 2001	Trw Inc.	Tracking means for distant ballistic missile targets
US6347001	Nov 3, 1998	Feb 12, 2002	Trex Communications Corporation	Free-space laser communication system having six axes of movement
US6396577 *	Mar 19, 2001	May 28, 2002	Thomas P. Ramstack	Lidar-based air defense system
US6424286 *	May 30, 2001	Jul 23, 2002	The United States Of America As Represented By The Secretary Of The Army	In-seeker jamming device
US6545630 *	Jan 23, 2002	Apr 8, 2003	Itt Manufacturing Enterprises, Inc.	Efficient beam steering for closed loop polarization agile transmitter
US6731234 *	Jun 11, 2003	May 4, 2004	Honeywell International Inc.	Radar anti-fade systems and methods
US6832740 *	Jan 16, 1987	Dec 21, 2004	Short Brothers Plc	Missile system and method of missile guidance
US6859163 *	Mar 21, 2003	Feb 22, 2005	Drs Weather Systems, Inc.	Simultaneous dual polarization radar system
US6872960 *	Apr 18, 2001	Mar 29, 2005	Raytheon Company	Robust infrared countermeasure system and method
US6906659 *	Dec 19, 2003	Jun 14, 2005	Tom Ramstack	System for administering a restricted flight zone using radar and lasers
US6967614 *	May 6, 2004	Nov 22, 2005	The United States Of America As Represented By The Secretary Of The Army	Projectile launch detection system utilizing a continuous wave radio frequency signal to confirm muzzle exit
US7046187 *	Nov 17, 2004	May 16, 2006	Time Domain Corporation	System and method for active protection of a resource
US7205934 *	May 15, 2002	Apr 17, 2007	Astrium Limited	Transmit-receive module for a radar
US7212148 *	Apr 5, 2005	May 1, 2007	Itt Manufacturing Enterprises, Inc.	Apparatus for jamming infrared attack unit using a modulated radio frequency carrier
US7312744 *	May 6, 2005	Dec 25, 2007	Tom Ramstack	System for administering a restricted flight zone using radar and lasers
US20030016421 *	Aug 30, 2002	Jan 23, 2003	Small James G.	Wireless communication system with high efficiency/high power optical source
US20040075884	Oct 17, 2002	Apr 22, 2004	Byren Robert W.	Phase conjugate relay mirror apparatus for high energy laser system and method
US20050012655 *	Aug 23, 2004	Jan 20, 2005	Ball Corporation	Electronically agile multi-beam antenna system
US20050115385	Oct 17, 2003	Jun 2, 2005	Rodriguez Raul D.	Radio frequency triggered directed energy munition
US20050115387 *	Dec 31, 2003	Jun 2, 2005	Smith Patrick W.	Systems and methods for immobilization
US20060022115 *	Jul 29, 2004	Feb 2, 2006	Byren Robert W	Beam control system with extended beacon and method

Cited Patent	Filing date	Publication date	Applicant	Title
US20060082488	Oct 18, 2005	Apr 20, 2006	Nokomis, Inc.	Advanced electromagnetic location of electronic equipment
US20060238199 *	Mar 16, 2006	Oct 26, 2006	Larsen James W	Systems and methods useful for detecting presence and / or location of various materials
US20070040725 *	Aug 18, 2005	Feb 22, 2007	Raytheon Company	Weapon having lethal and non-lethal directed-energy portions
US20070051233 *	Sep 6, 2005	Mar 8, 2007	Duge Robert T	Radiant electromagnetic energy management

* Cited by examiner

NON-PATENT CITATIONS

Reference	
1	International Search Report for corresponding Application No. PCT/US2007/001831 dated Oct. 29, 2007.

REFERENCED BY

Citing Patent	Filing date	Publication date	Applicant	Title
US8188905 *	May 29, 2009	May 29, 2012	Raytheon Company	Target tracking system and method with jitter reduction suitable for directed energy systems
US8453551 *	Feb 20, 2008	Jun 4, 2013	Wavestream Corporation	Energy focusing system for active denial apparatus
US8576109 *	Jun 8, 2011	Nov 5, 2013	Diehl Bgt Defence Gmbh & Co. Kg	Method and configuration for generating high-energy microwave pulses
US8896701	Feb 23, 2010	Nov 25, 2014	Ratheon Company	Infrared concealed object detection enhanced with closed-loop control of illumination by.mmw energy
US20100282985 *		Nov 11, 2010	James Jordan Rosenberg	Energy focusing system for active denial apparatus
US20110309870 *		Dec 22, 2011	Diehl Bgt Defence Gmbh & Co. Kg	Method and configuration for generating high-energy microwave pulses
US20120212363 *	Dec 27, 2011	Aug 23, 2012	Thales	Method and device for neutralizing a target
EP2397809A2 *	Jun 7, 2011	Dec 21, 2011	Diehl BGT Defence GmbH & Co.KG	Method and assembly for the generation of high energy microwave impulses

* Cited by examiner

CLASSIFICATIONS

U.S. Classification	342/13, 89/1.11, 342/67, 342/90, 342/74, 342/97
International Classification	G01S13/66, G01S7/38
Cooperative Classification	H04K2203/32, F41H13/0043, G01S7/38, H04K3/62, H04K3/45, G01S7/024, G01S2013/0272

LEGAL EVENTS

Date	Code	Event	Description
Mar 8, 2006	AS	Assignment	**Owner name:** RAYTHEON COMPANY, MASSACHUSETTS **Free format text:** ASSIGNMENT OF ASSIGNORS INTEREST;ASSIGNORS:BROWN, KENNETH W;CANICH, DAVID J;BERG, RUSSELL F;REEL/FRAME:017276/0190 **Effective date:** 20051208
Nov 2, 2010	CC	Certificate of correction	
Mar 8, 2013	FPAY	Fee payment	**Year of fee payment:** 4