US006377436B1

(12) **United States Patent**
Margolin

(10) **Patent No.: US 6,377,436 B1**
(45) **Date of Patent: Apr. 23, 2002**

(54) **MICROWAVE TRANSMISSION USING A LASER-GENERATED PLASMA BEAM WAVEGUIDE**

(76) Inventor: **Jed Margolin**, 3570 Pleasant Echo Dr., San Jose, CA (US) 95148-1916

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/543,252**

(22) Filed: **Apr. 5, 2000**

Related U.S. Application Data

(60) Provisional application No. 60/173,148, filed on Dec. 27, 1999.

(51) **Int. Cl.**^{7} **H01T 23/00**

(52) **U.S. Cl.** **361/230**; 307/149

(58) **Field of Search** .... 361/230, 231; 307/149; 372/1, 4, 9, 14, 15, 29.01, 109, 76; 250/396 R, 423 R, 424; 385/147; 342/54; 359/27, 34, 179, 188, 298, 299, 342, 349

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,719,829	A	*	3/1973	Vaill	307/149
5,726,855	A		3/1998	Mourou et al.	361/213
5,930,313	A	*	7/1999	Slinker et al.	376/127
6,111,237	A	*	8/2000	Paustian	361/117

OTHER PUBLICATIONS

News Release: Los Alamos National Labortary, Aug. 19, 1996, "There's new light at the end of the tunnel for some laser–based technologies." http://www/.lanl.gov.

Product Announcement: Lawrence Livermore National Laboratory, "High–Average–Power Titanium:Sapphire Laser", http://www.Illnl.gov/IPandC/op96/05/5f–hig.html, No Date.

Company Information: Hardric Laboratories, Inc., http://www.hardic.com, No Month 1999.

Product/Services Announcement: Hardric Laboratories, Inc. "Beryllium Optics", http://www.hardric.com/page 4.html, No Date.

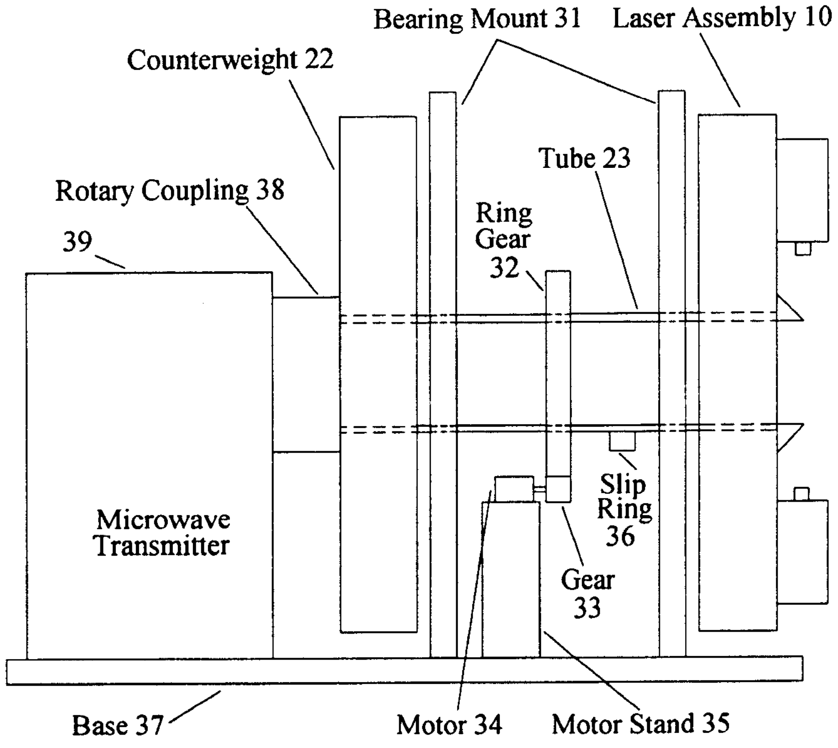
* cited by examiner

Primary Examiner—Ronald W. Leja

(57) **ABSTRACT**

A directed energy beam system uses an ultra-fast laser system, such as one using a titanium-sapphire infrared laser to produce a thin ionizing beam through the atmosphere. The beam is moved in either a circular or rectangular fashion to produce a conductive shell to act as a waveguide for microwave energy. Because the waveguide is produced by a plasma it is called a plasma beam waveguide. The directed energy beam system can be used as a weapon, to provide power to an unmanned aerial vehicle (UAV) such as for providing communications in a cellular telephone system, or as an ultra-precise radar system.

11 Claims, 23 Drawing Sheets



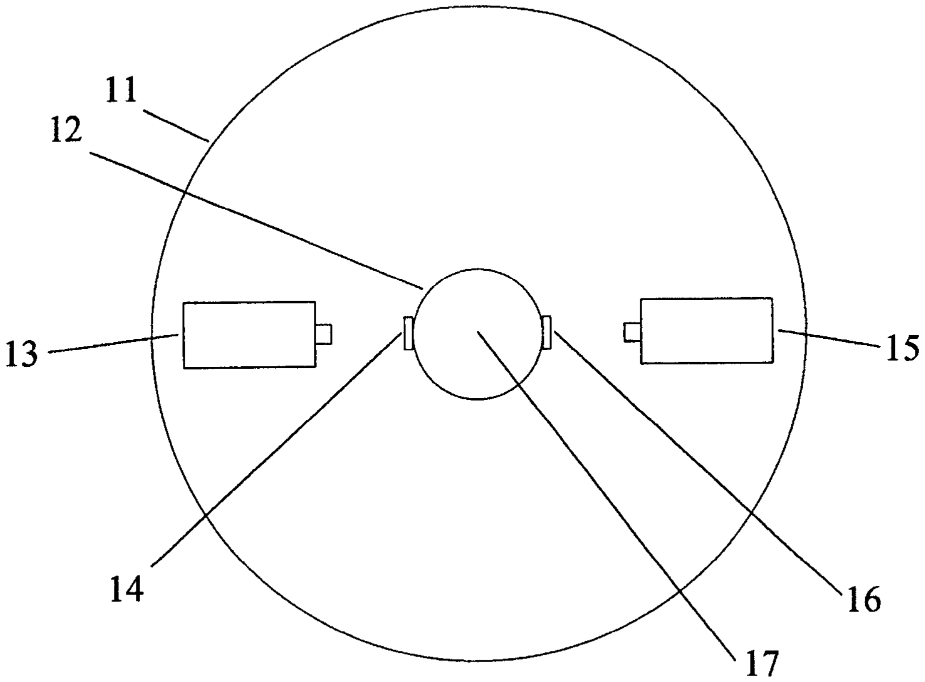
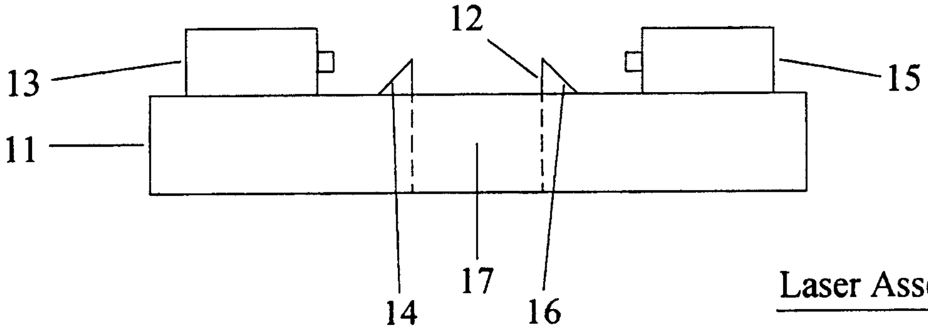


Fig. 1A

Laser Assembly 10

(Front View)



Laser Assembly 10

(Bottom View)

Fig. 1B

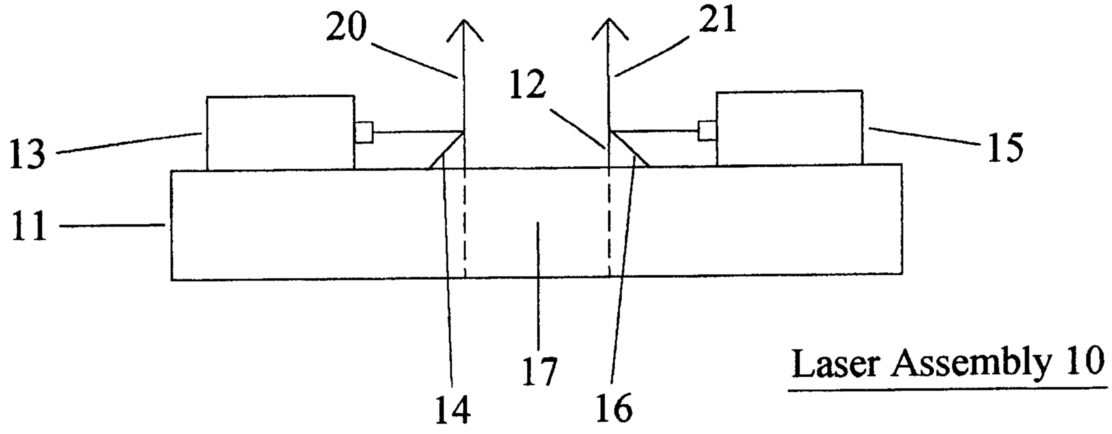

20
21
12
13
15
11
17
14
16
Laser Assembly 10

Fig. 2A

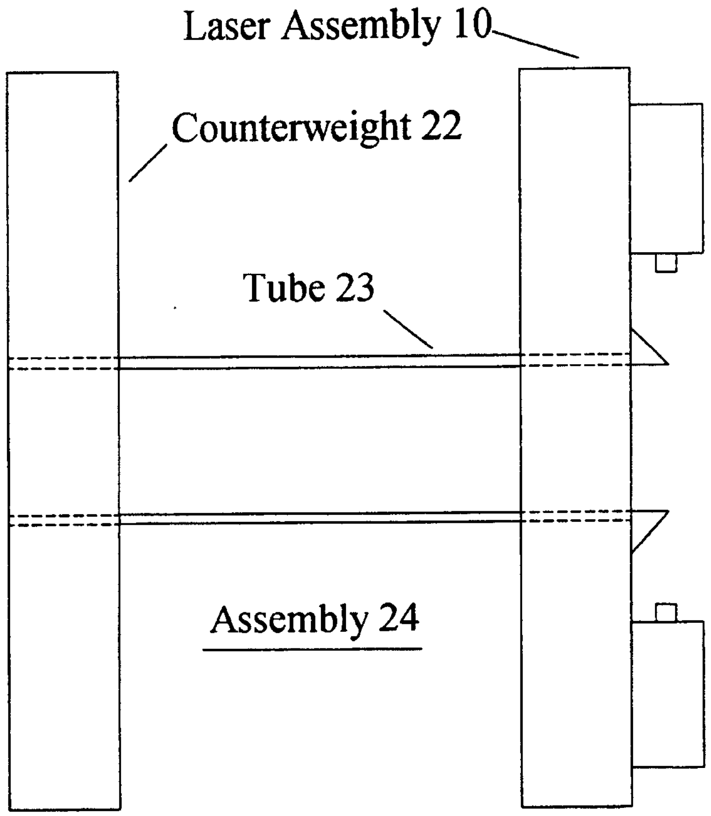

Laser Assembly 10
Counterweight 22
Tube 23
Assembly 24

Fig. 2B

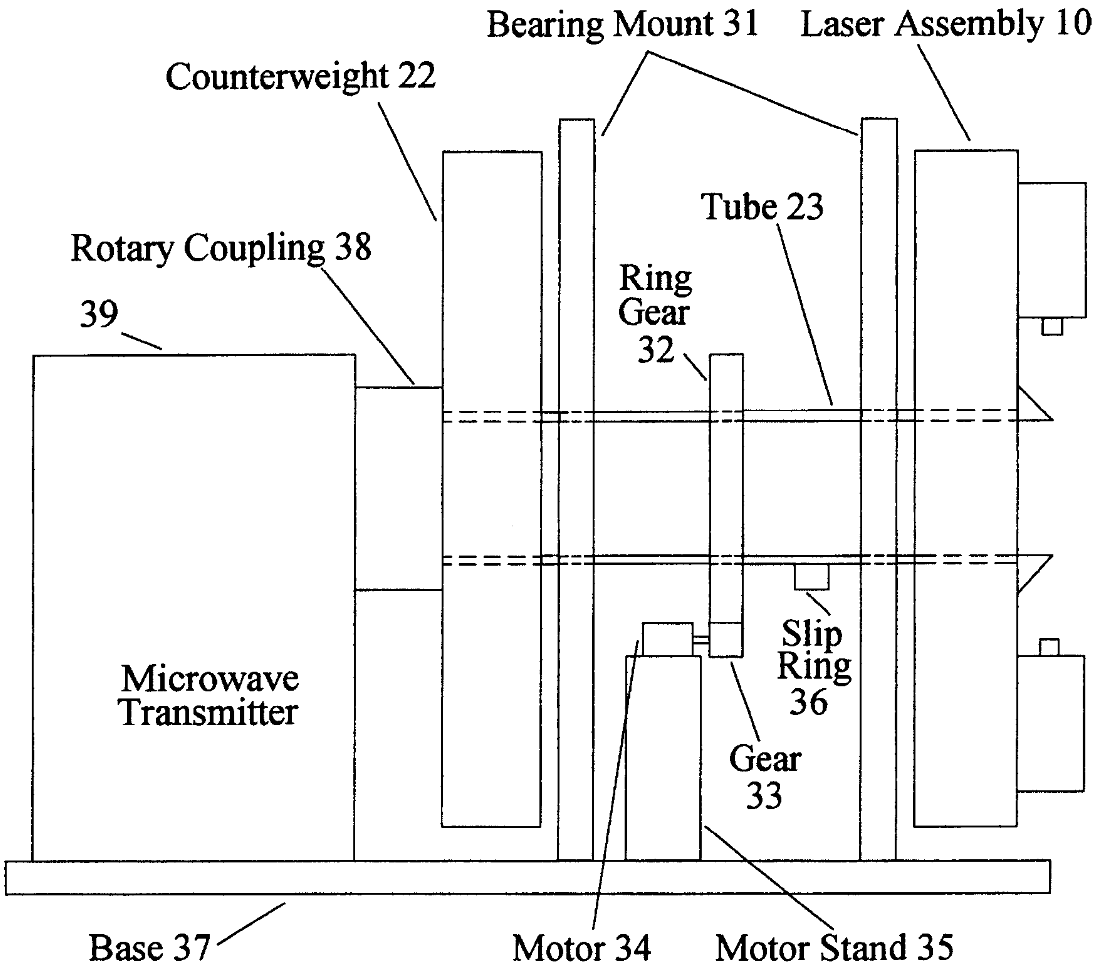
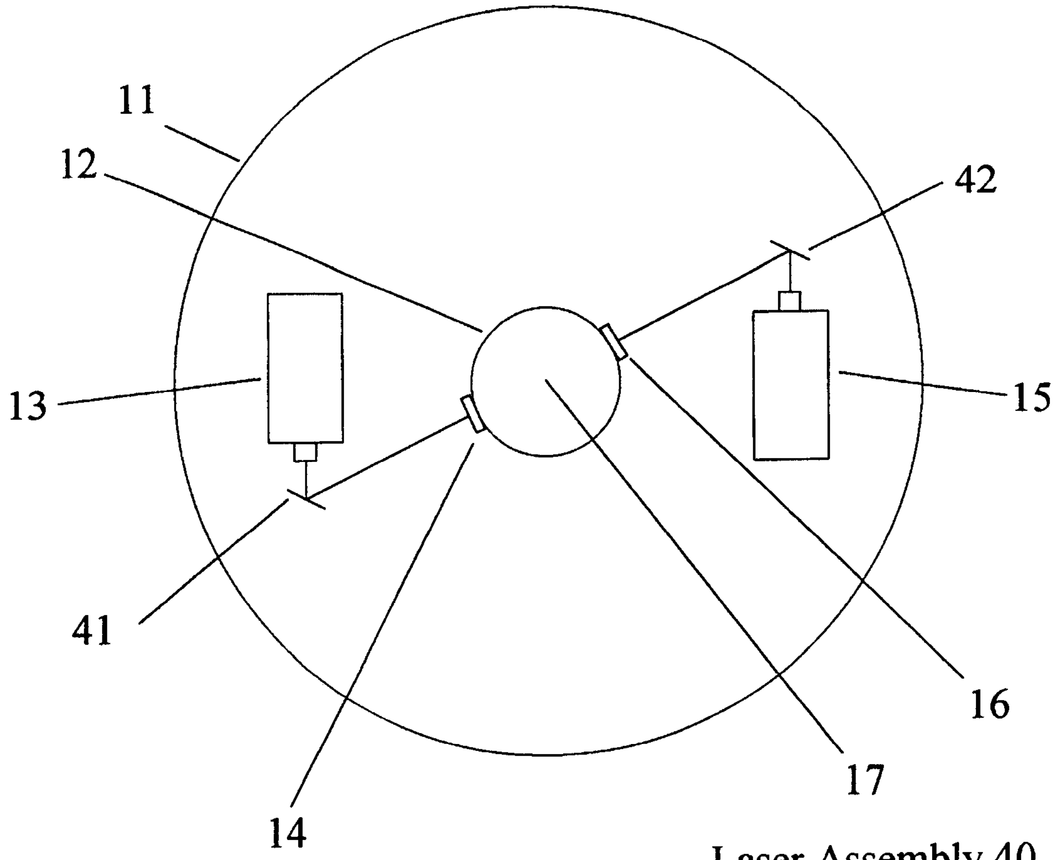

Bearing Mount 31
Laser Assembly 10
Counterweight 22
Tube 23
Rotary Coupling 38
Ring Gear 32
39
Microwave Transmitter
Slip Ring 36
Gear 33
Base 37
Motor 34
Motor Stand 35

Fig. 3



Laser Assembly 40

(Front View)

Fig. 4

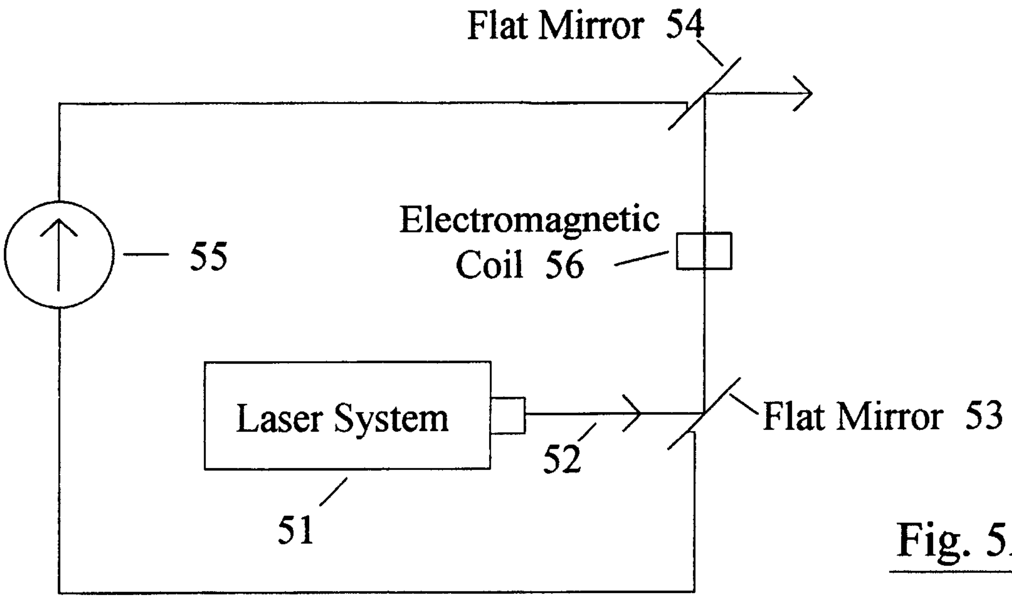

Flat Mirror 54
55
Electromagnetic Coil 56
Laser System
52
Flat Mirror 53
51

Fig. 5A

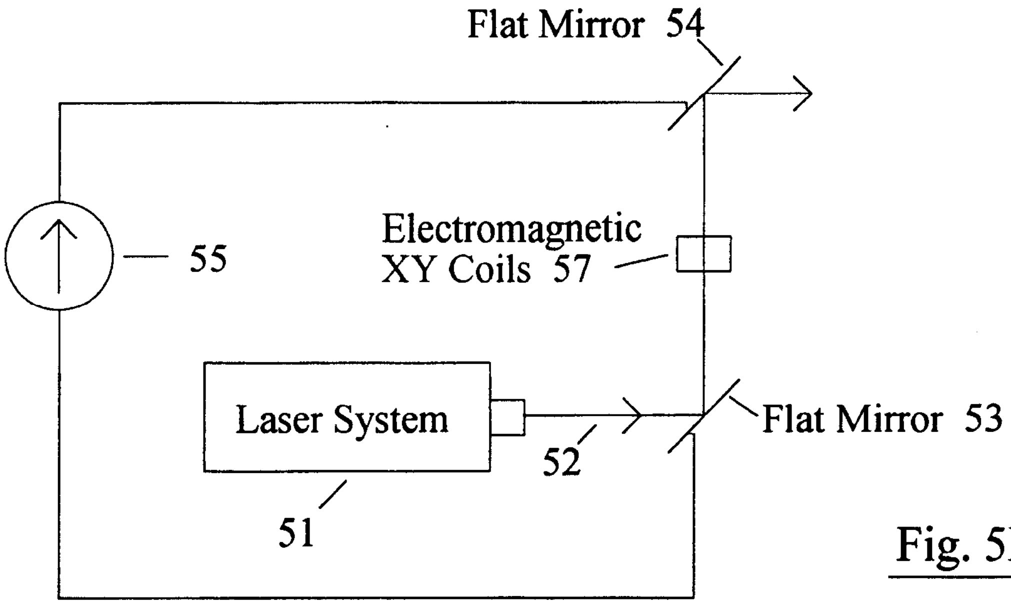
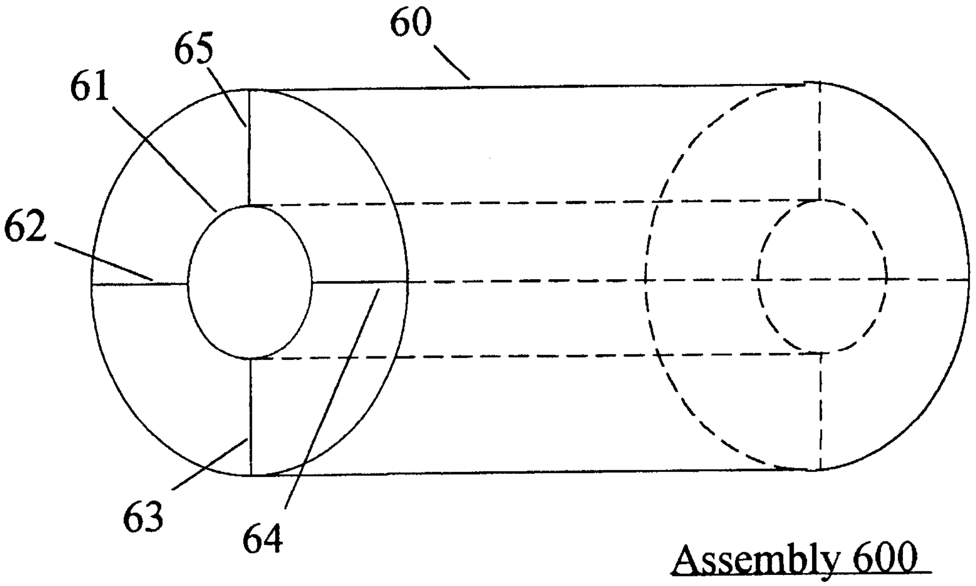
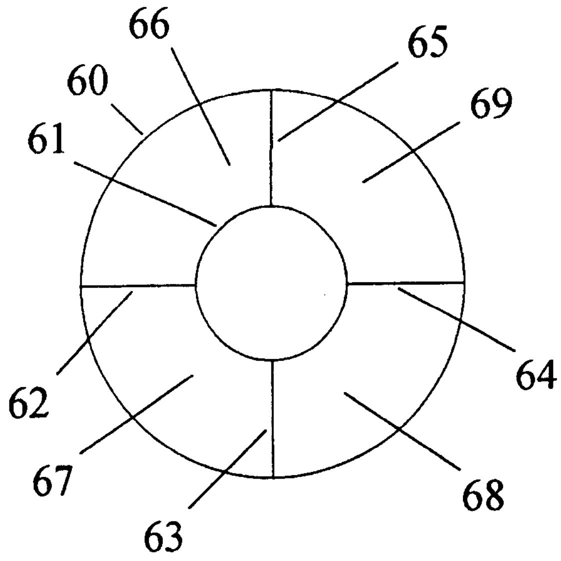

Flat Mirror 54
55
Electromagnetic XY Coils 57
Laser System
52
Flat Mirror 53
51

Fig. 5B



Assembly 600

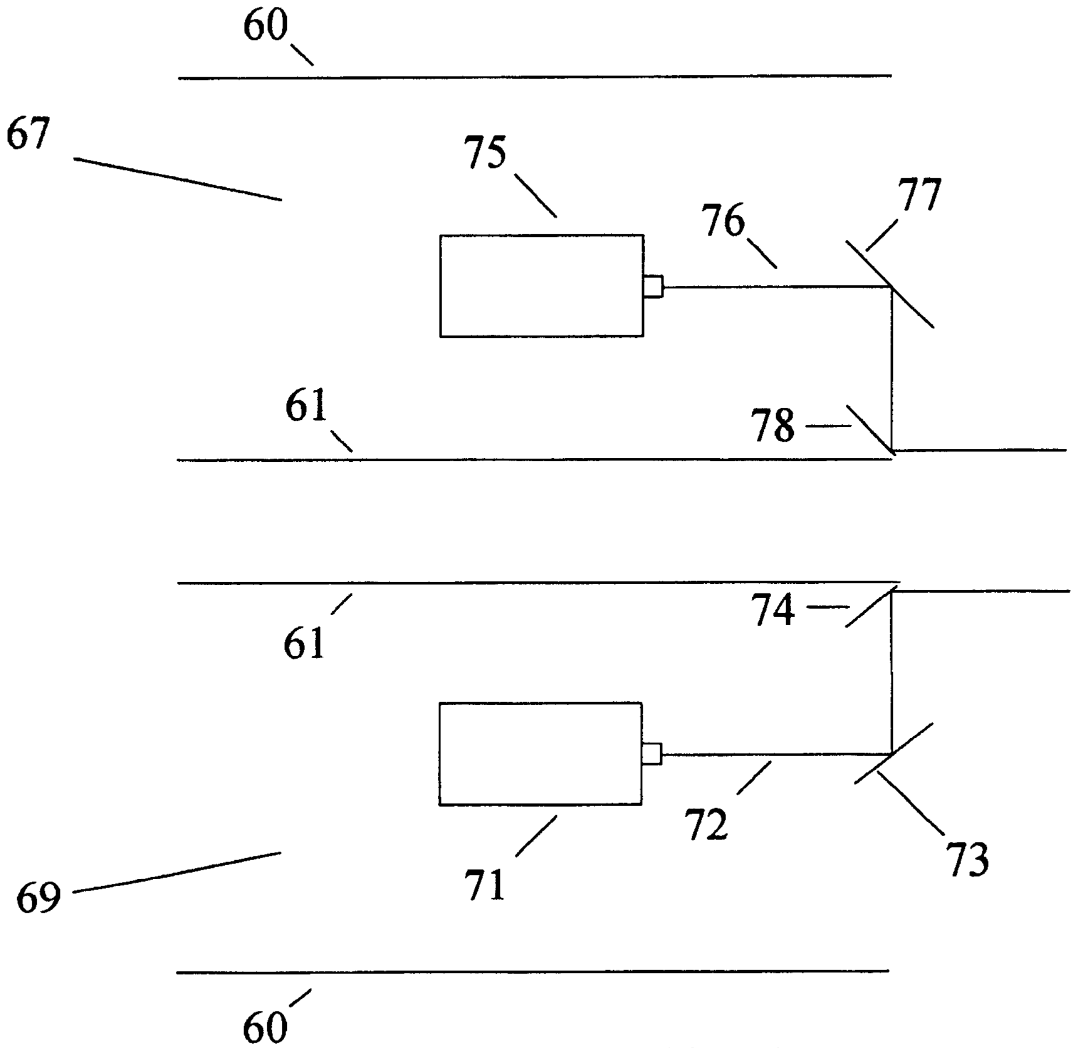
Fig. 6A



Assembly 600

Fig. 6B

(End View)



Laser Assembly 70

Fig. 7

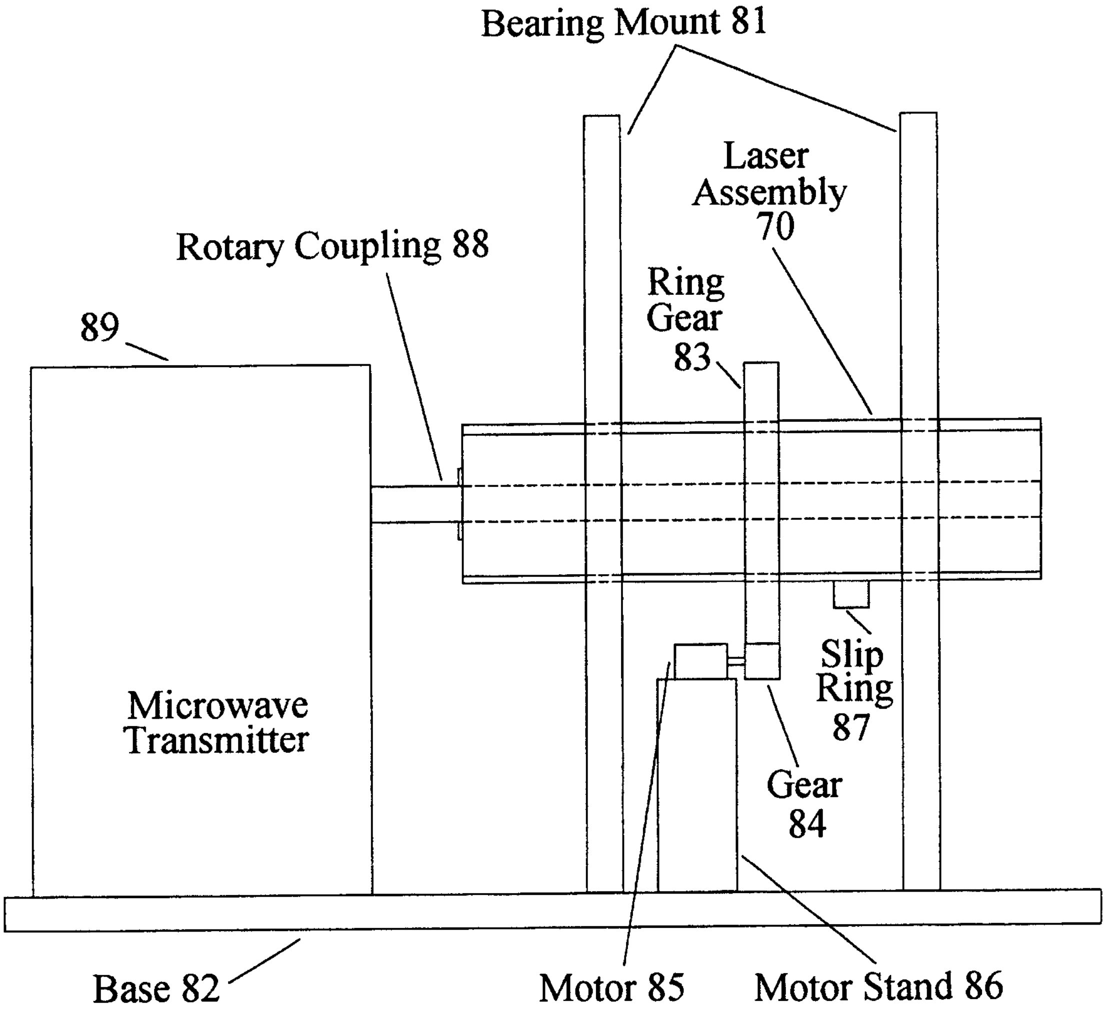

Bearing Mount 81
Laser Assembly 70
Rotary Coupling 88
Ring Gear 83
89
Slip Ring 87
Microwave Transmitter
Gear 84
Base 82
Motor 85
Motor Stand 86

Fig. 8

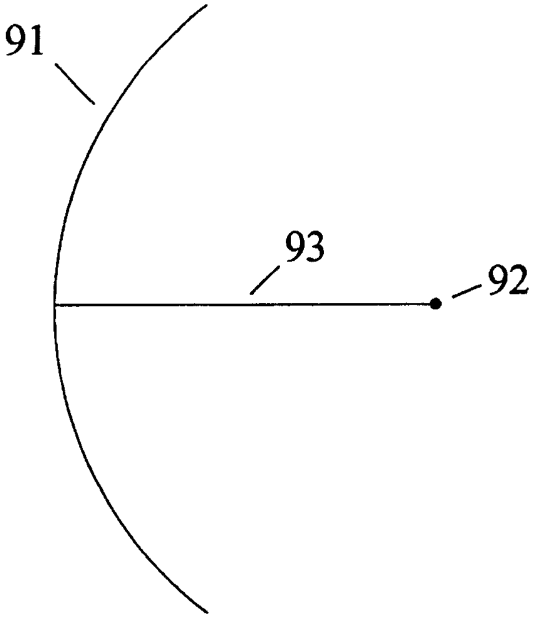


Fig. 9A

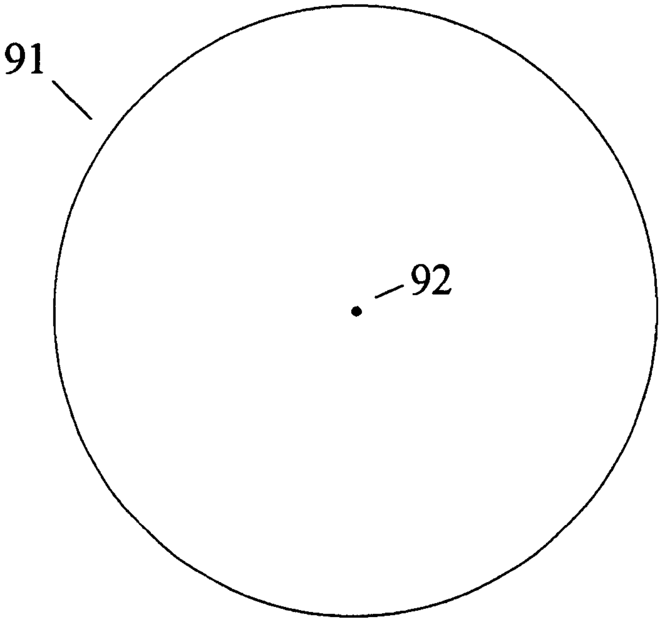


Fig. 9B

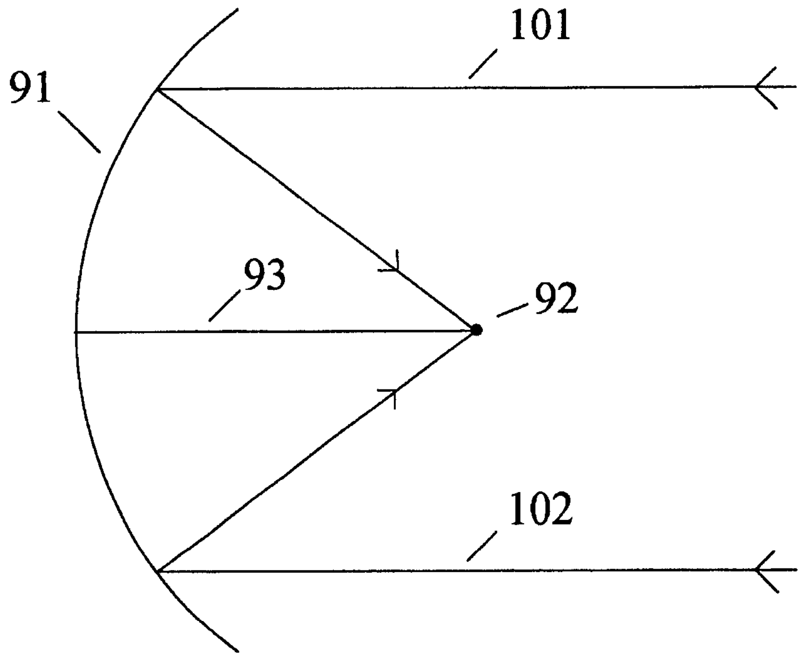


Fig. 10A

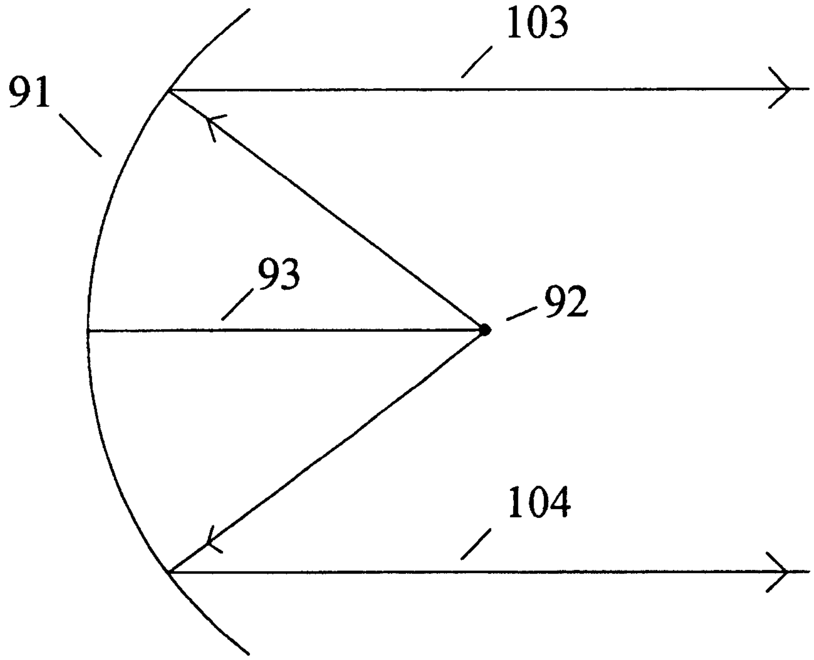


Fig. 10B

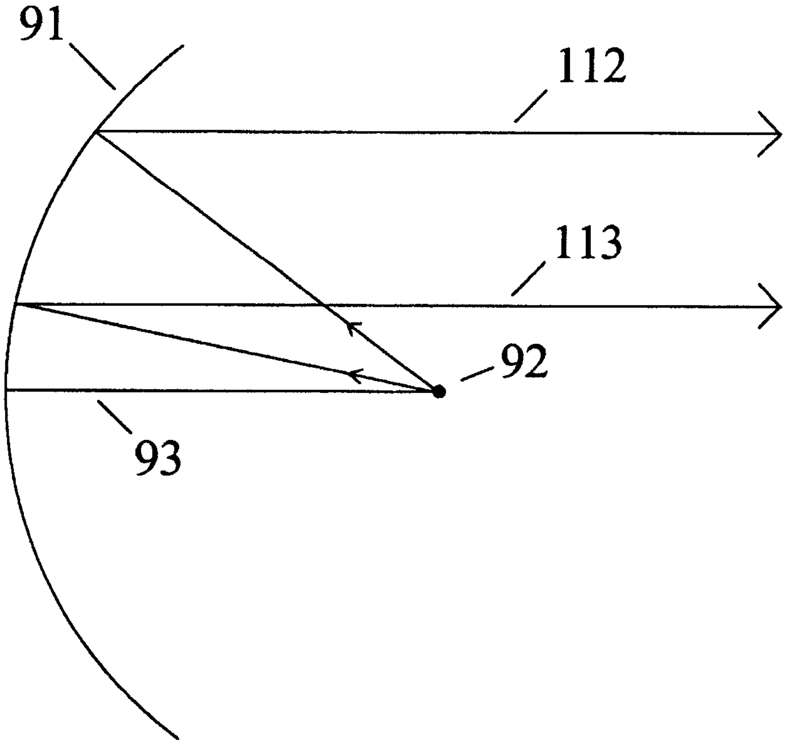


Fig. 11A

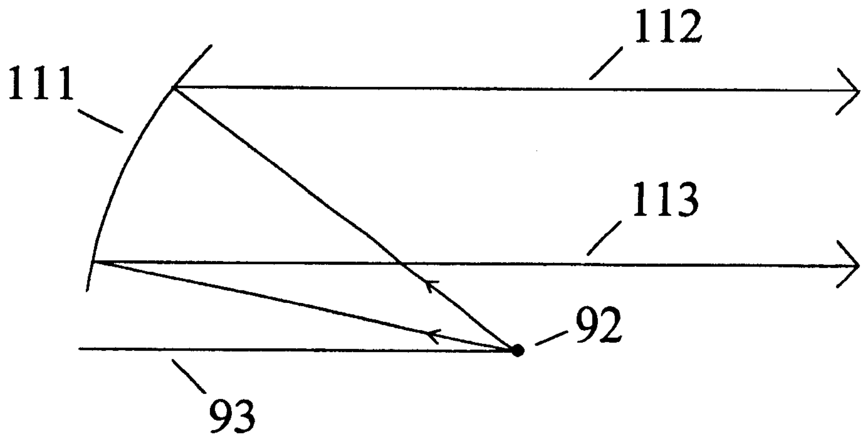


Fig. 11B

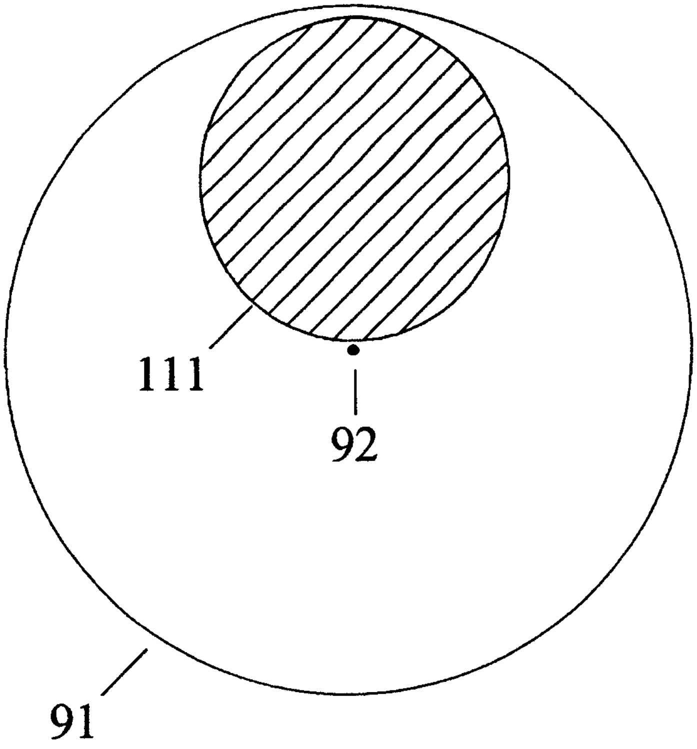


Fig. 12A

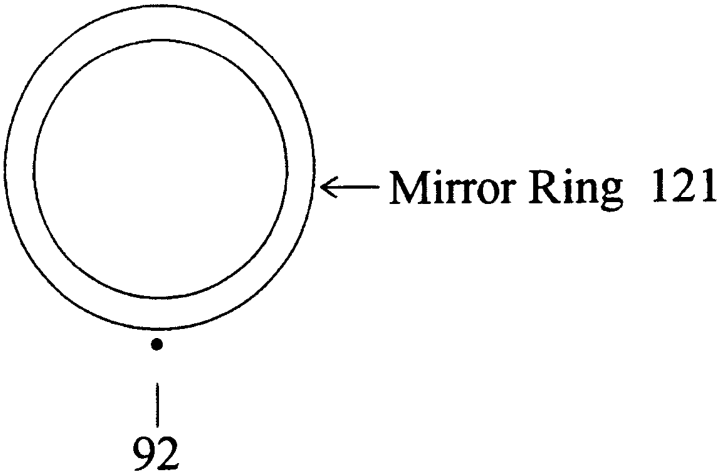


Fig. 12B

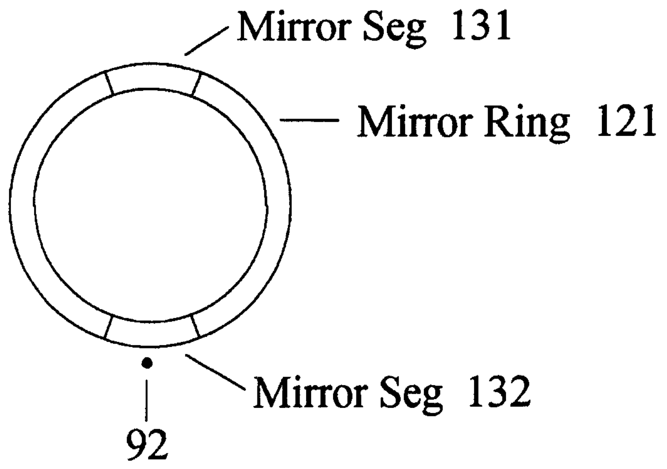


Fig. 13A

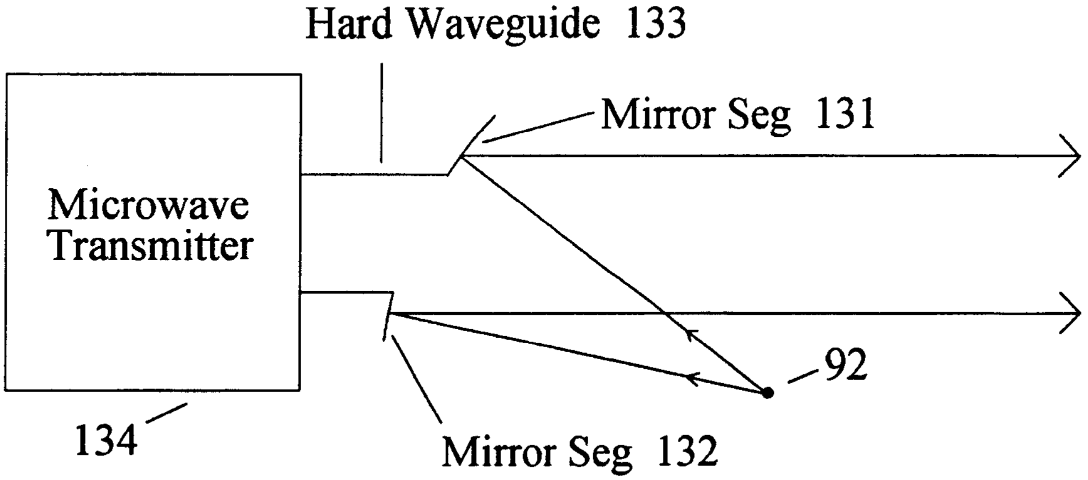


Fig. 13B

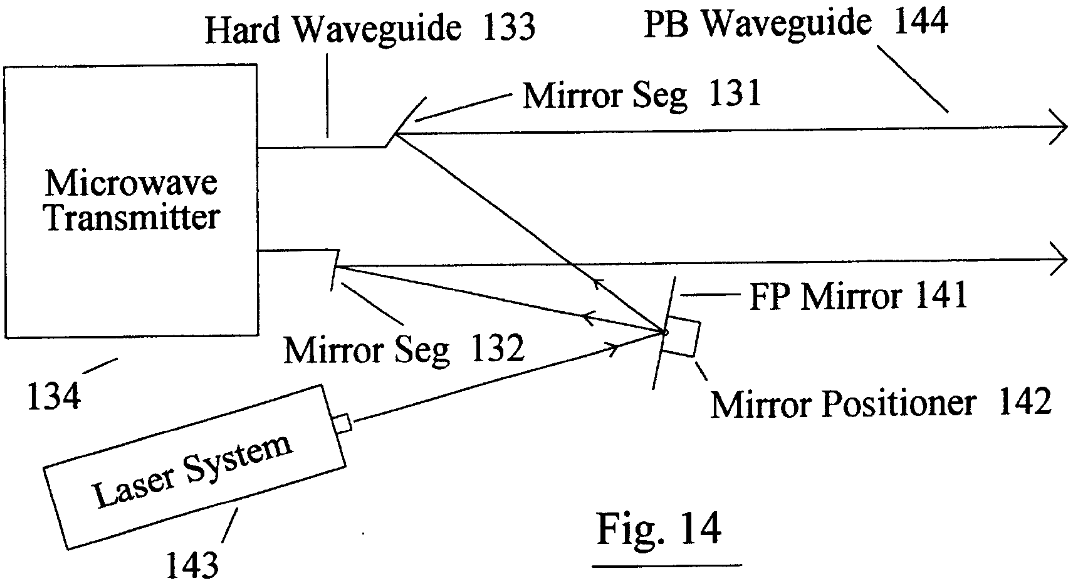

Hard Waveguide 133
PB Waveguide 144
Mirror Seg 131
Microwave Transmitter
FP Mirror 141
Mirror Seg 132
134
Mirror Positioner 142
Laser System
143

Fig. 14

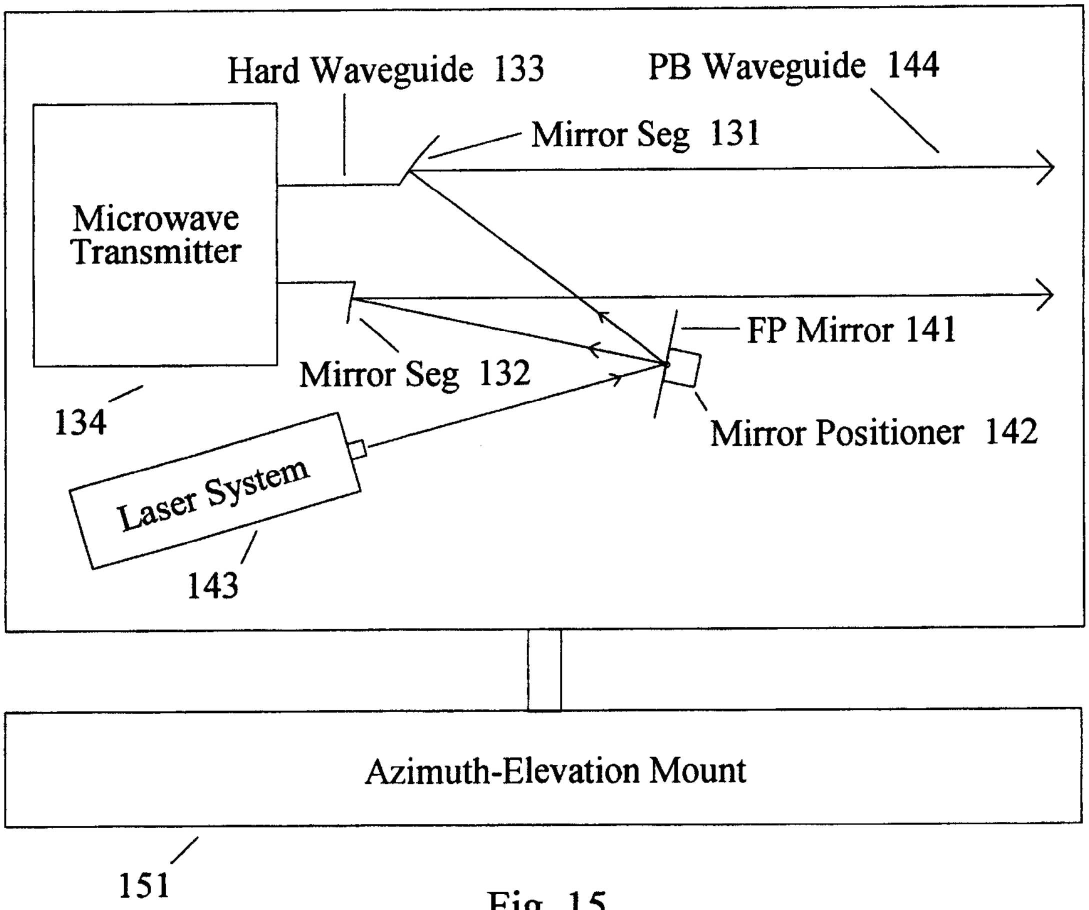

Hard Waveguide 133
PB Waveguide 144
Mirror Seg 131
Microwave Transmitter
FP Mirror 141
Mirror Seg 132
134
Mirror Positioner 142
Laser System
143
Azimuth-Elevation Mount
151

Fig. 15

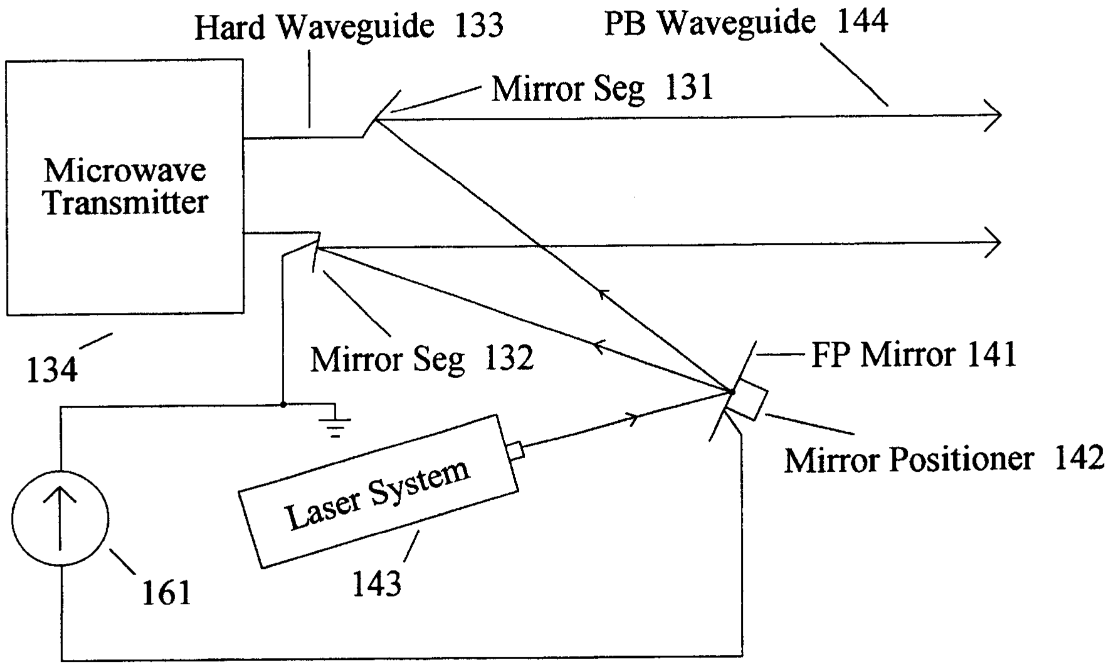

Hard Waveguide 133
PB Waveguide 144
Mirror Seg 131
Microwave Transmitter
134
Mirror Seg 132
FP Mirror 141
Mirror Positioner 142
Laser System
143
161

Fig. 16

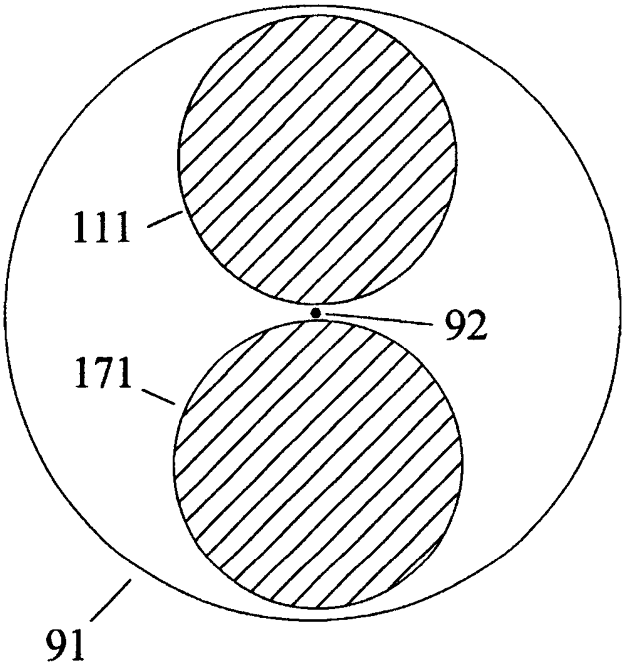


Fig. 17A

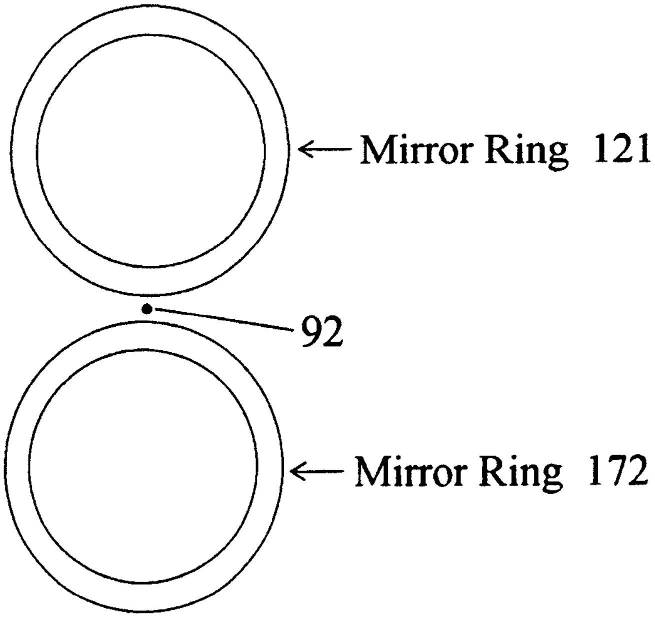


Fig. 17B

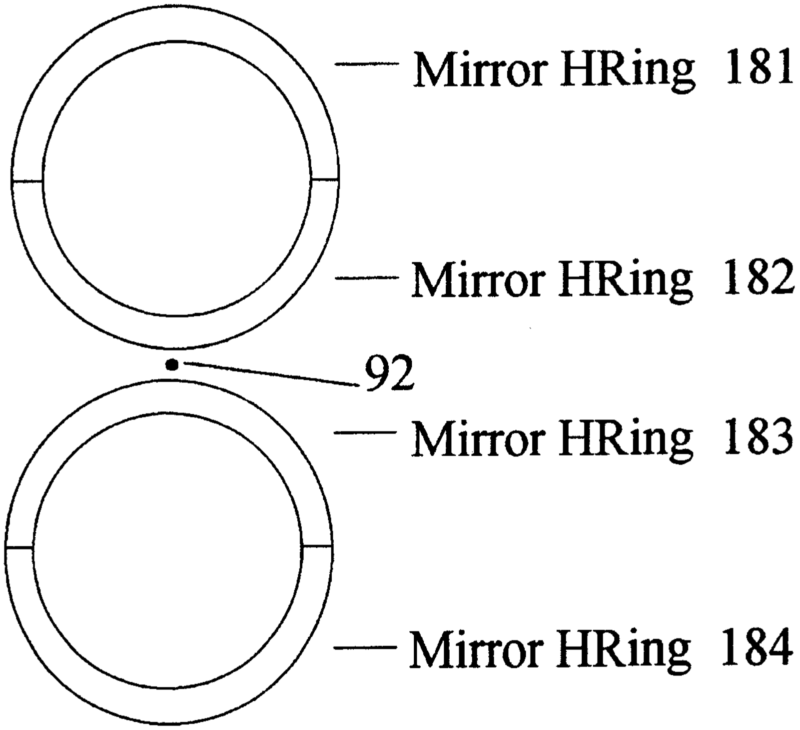


Fig. 18A

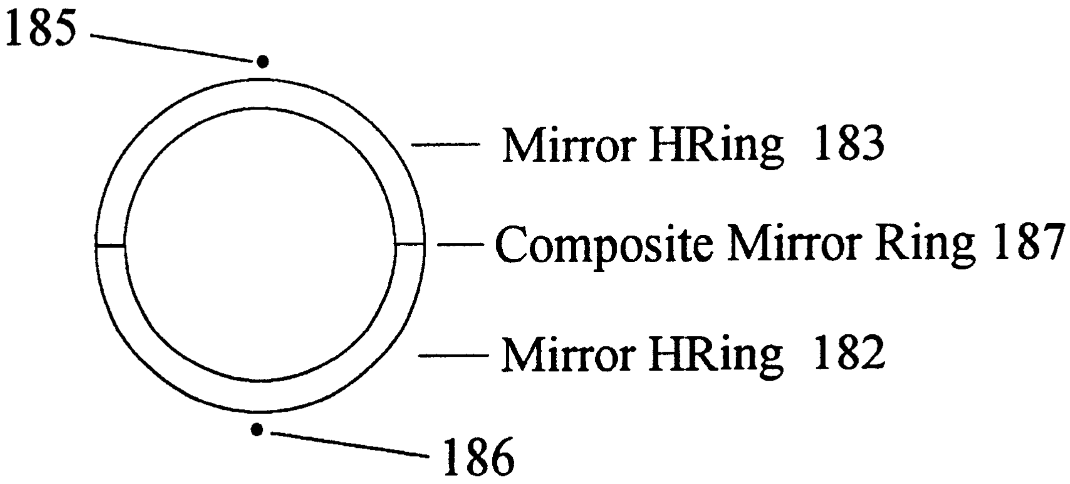


Fig. 18B

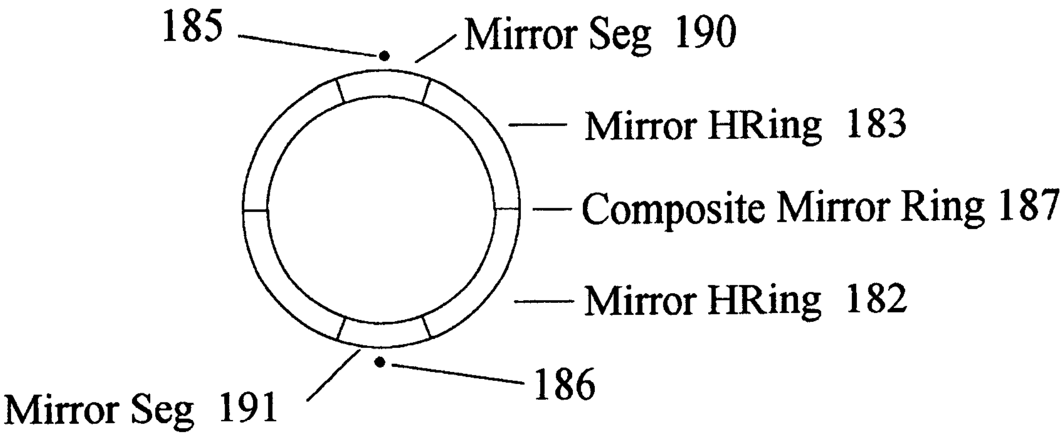


Fig. 19A

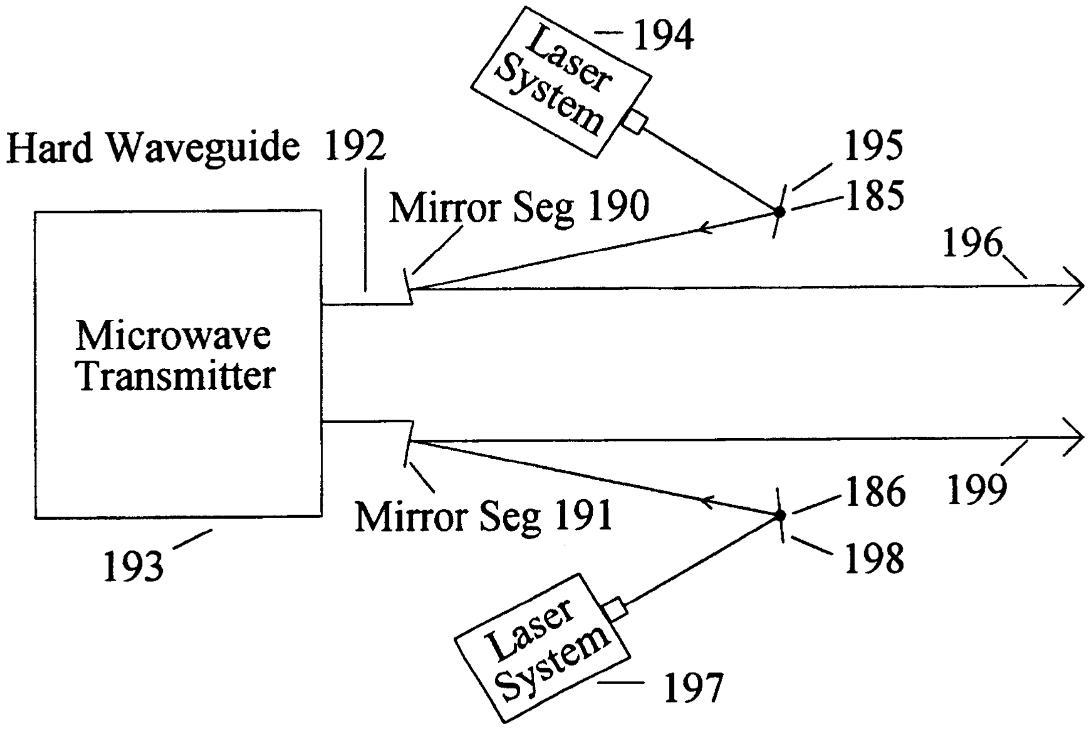


Fig. 19B

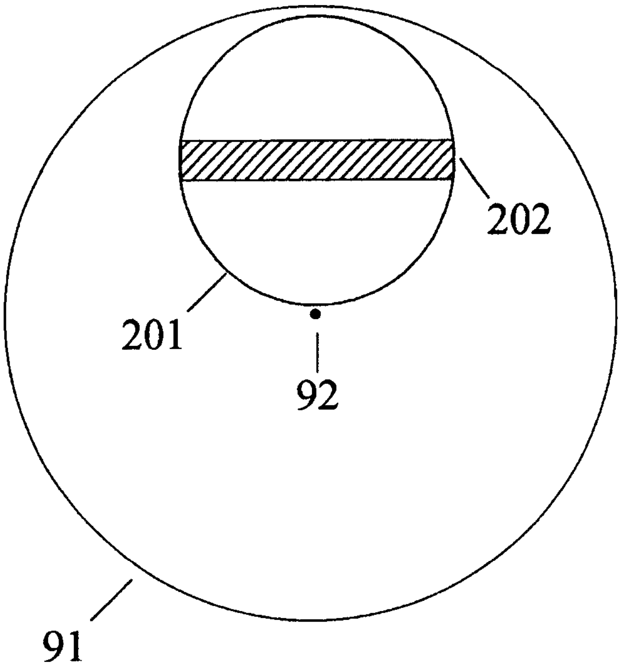
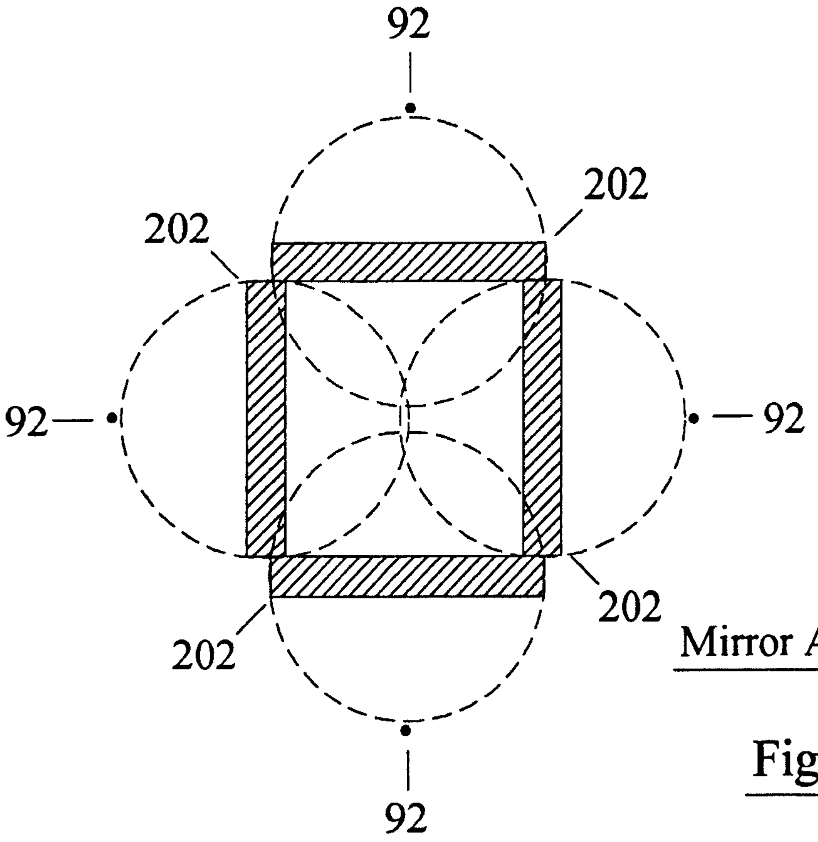


Fig. 20A



Mirror Assembly 203

Fig. 20B

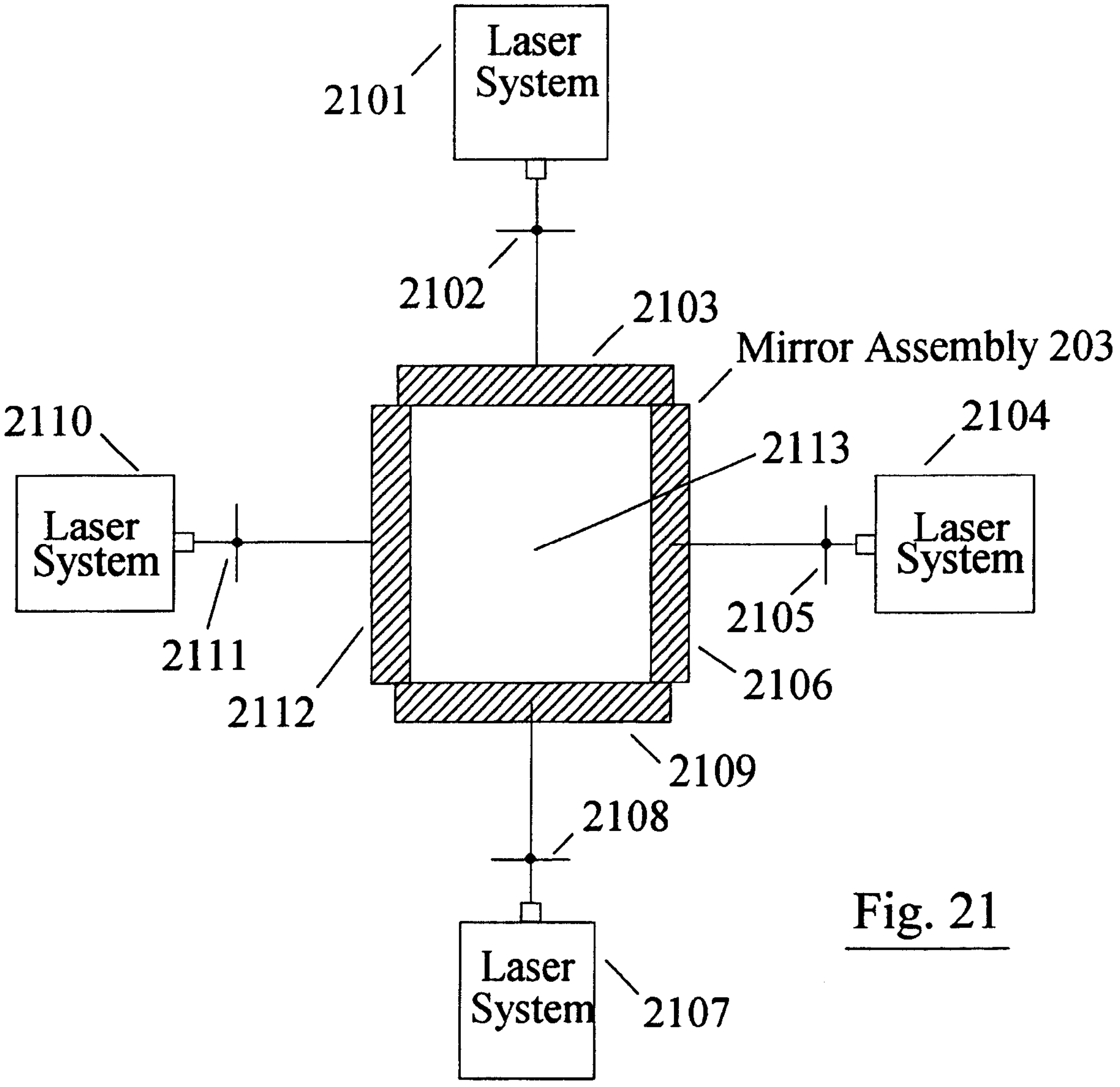

Laser System
2101
2102
2103
Mirror Assembly 203
2110
Laser System
2104
2113
Laser System
2111
2105
2112
2106
2109
2108
Laser System
2107

Fig. 21

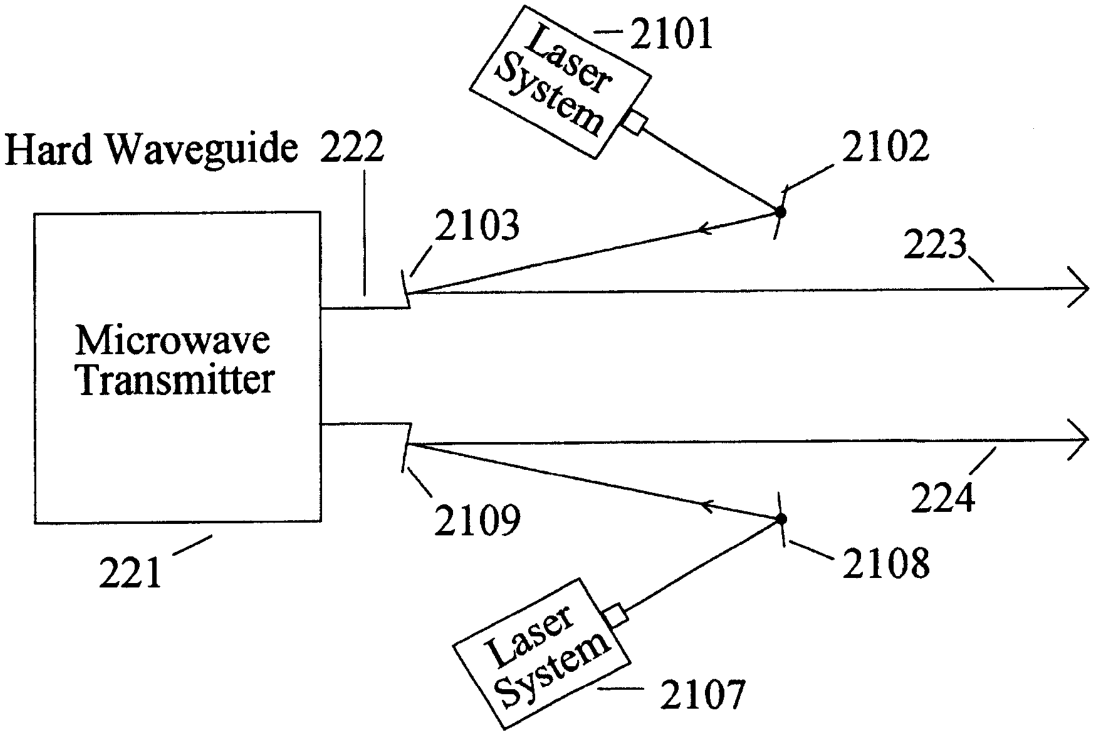

Laser System
2101
Hard Waveguide 222
2102
2103
223
Microwave Transmitter
224
2109
221
2108
Laser System
2107

Fig. 22

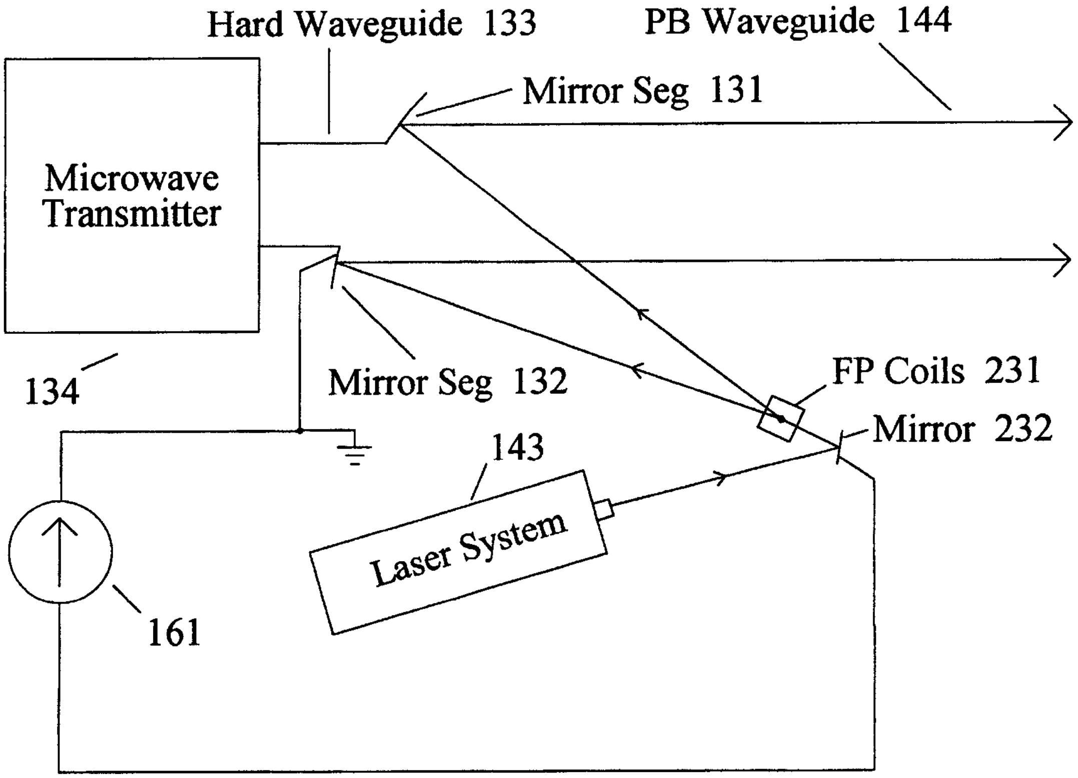

Hard Waveguide 133
PB Waveguide 144
Mirror Seg 131
Microwave Transmitter
134
Mirror Seg 132
FP Coils 231
Mirror 232
143
Laser System
161

Fig. 23

MICROWAVE TRANSMISSION USING A LASER-GENERATED PLASMA BEAM WAVEGUIDE

CROSS REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/173,148 filed on Dec. 27, 1999.

BACKGROUND OF THE INVENTION

Field of Invention

This invention relates to a directed energy beam system.

BACKGROUND OF THE INVENTION

Prior Art

From a 1996 press release from Los Alamos National Laboratory titled, "There's new light at the end of the tunnel for some laser-based technologies":

> "Researchers Xin Miao Zhao, David Funk, Charlie Strauss, Toni Taylor and Jason Jones experimenting with a powerful infrared titanium-sapphire laser found that when a light pulse intensity reaches a critical value, the beam focuses itself into a thin filament without the aid of focusing lenses or mirrors and perpetuates itself for long distances.
>
> The beam—two to three times the thickness of a human hair—propagates virtually indefinitely through air without spreading, something conventional lasers cannot do."

U.S. Pat. No. 5,726,855 APPARATUS AND METHOD FOR ENABLING THE CREATION OF MULTIPLE EXTENDED CONDUCTION PATHS IN THE ATMOSPHERE, issued Mar. 10, 1998 to Mourou et al. teaches a method for enabling the creation of multiple extended conduction paths in the atmosphere through the use of a chirped-pulse amplification laser system having a high peak-power laser capable of transmitting through the atmosphere a high-peak power ultrashort laser pulse.

The creation of the conduction path is described in Column 4, line 50 through Column 5, line 22:

> "For a high peak-power ultrashort pulse, the peak-power can be strong enough to drive the electrons of the material it is propagating through their linear regime and into a nonlinear regime. In this case, the index of refraction for the material can be written n(r)=n.sub.0+ n.sub.2 I(r), where n(r) is the radially varying index of refraction, n.sub.o is the linear (standard) index of refraction, n.sub.2 is the nonlinear refractive index, and I(r) is the radially varying intensity. Since the center of the beam has a higher intensity than the outer edges, the index of refraction varies radially (just as in a regular glass lens), and the pulse experiences a positive lensing effect, even if it is collimated at low powers. This is called self-focusing. The critical peak-power needed to start self-focusing is given by Pcr=.lambda.. sup.2/(2.pi.n.sub.2) which for air is 1.8.times.10.sup.9 W but has been measured to be more like 1.times.10.sup.10 W. With an initially smooth spacial beam, only one filament appears at the center of the beam. Once the beam (or part of it) self-focuses, it will not focus to an arbitrarily small size. It will self-focus until the intensity of the pulse is large enough to ionize the material. This generated plasma reduces the on-axis index of refraction by an amount given by 4.pi.e.sup.2 n.sub.e (I)/(2m.sub.e omega.. sup.2) where n.sub.e (I) is the intensity dependent generated plasma density, e is the electron charge, m.sub.e is the electron mass, and omega. is the laser frequency. Again, the beam experiences a radially varying index of refraction change (because n.sub.e (I) is radially varying) and the change due to the plasma acts as a negative (defocusing) lens. So, through the balance of the continual self-focusing (positive lens) and the plasma defocusing and natural diffraction (negative lens), the pulse stays confined to a high-intensity, small diameter over many meters of propagation while automatically producing free electrons. This is a 'natural' way of generating an extended plasma channel. The only preparation needed from the user is to generate the high peak-power laser pulse.
>
> Each self-focused "hotspot" creates one electrically conductive ionized channel or plasma column in the atmosphere. The plasma columns can be used for many different applications, one such application being to safely and repetitively control the discharge of lightning strikes before natural breakdown occurs to protect power plants, airports, launch sites, etc."

Hardric Laboratories, Inc. of North Chelmsford, Mass., produces mirrors made of bare-polished beryllium metal that produce a high level of reflectivity.

BACKGROUND OF THE INVENTION

The world is a hostile place. In recent years there has been a proliferation of countries with strategic and tactical ballistic missiles and cruise missiles capable of delivering nuclear, biological, and chemical weapons. The methods used to combat these threats fall into two categories: Lasers and Anti-Missile Missiles (AMM).

An example of the first category is the Airborne Laser (ABL) which uses a high-power chemical laser and is carried in a 747 aircraft. Because it uses a chemical laser it can fire only a limited number of times before the chemicals are used up. In addition, its use in a 747 makes it vulnerable to being shot down.

In the category of Anti-Missile Missiles, all systems share the disadvantage that an AMM, however fast, takes time to reach the target. This reduces the time available for finding and identifying it as a threat. It also makes second shots less possible.

Accordingly, one of the objects and advantages of my invention is to provide a new method of providing a defense against ballistic missiles and cruise missiles.

Further objects and advantages of my invention will become apparent from a consideration of the drawings and ensuing description.

SUMMARY OF THE INVENTION

A laser system, such as the one taught by Mourou et al. is used to produce a thin ionizing beam through the atmosphere. The thin ionizing beam, or plasma beam, is electrically conducting and is moved in either a circular or rectangular fashion to produce a conductive shell to act as a waveguide for microwave energy. Since the waveguide is composed of a plasma it is called a plasma beam waveguide.

In a first embodiment the plasma beam waveguide is formed by physically moving the laser system used to produce the beam. Microwave energy is coupled into the plasma beam waveguide through a hole in the laser assembly.

In a second embodiment the laser system is stationary and the beam is moved by using a parabolic mirror with an offset feed. A flat mirror, using a mirror positioner having either one or two degrees of freedom, is mounted at the feedpoint and is used to reflect the laser beam around the periphery of the parabolic mirror, producing a shell. Microwave energy is coupled into the plasma beam waveguide through a hole in the center of the parabolic mirror. This is the reason for using a parabolic mirror with an offset feed.

In a third embodiment the laser system is also stationary and the beam is moved by using a parabolic mirror with an offset feed. However, the beam is electrically accelerated and then magnetically deflected by an orthogonal pair of electromagnetic coils at the feedpoint. The plasma beam is electrically accelerated by inducing a current in the plasma beam between two conducting mirrors. To accomplish this, both mirrors are made of a conducting material such as beryllium metal, and a current source is connected between them.

In all three embodiments the entire assembly can be mounted on a standard azimuth-elevation mount to allow the system to be aimed.

Since microwave energy can be produced more efficiently than laser energy, this system can be used to deliver a directed beam of energy more efficiently than a laser acting alone.

At high power levels the directed energy beam system can be used as a weapon. Because the system operates soley from electricity it is easily scaled by adding more units. Therefore its use as a defense weapon has an advantage over its use as an offensive weapon.

Another use at high power levels is to power the first stage of a rocket booster. A number of directed energy beam systems are arranged to direct their energy beams at a rocket booster whose fuel consists of water. The microwave energy is used to superheat the water which is then directed through a conventional rocket engine nozzle. The use of water as a fuel eliminates the toxicity problems of conventional rocket fuels. Water is also less expensive and more easily stored than conventional rocket fuels.

At moderate power levels the directed energy beam system can be used to provide power to an unmanned aerial vehicle (UAV), enabling the UAV to remain on-station for extended periods of time.

Because an object interrupting a waveguide produces a discontinuity in waveguide impedance which is reflected back to the source this system can also be used to track the UAV to maintain beam position.

Where it is not necessary to transmit appreciable amounts of power, the directed energy beam system can be used as an ultra-precise radar system.

DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows the front view of an assembly with two laser systems mounted on a cylindrical disk with a hole in the center of the cylindrical disk.

FIG. **1**B shows the bottom view of the assembly of FIG. **1**A.

FIG. **2**A shows the assembly of FIG. **1**B with a plasma beam being generated by each laser system.

FIG. **2**B shows the assembly of FIG. **1**A mounted on a cylindrical tube with a counterweight on the opposite end of the cylindrical tube.

FIG. **3** shows the assembly of FIG. **2**B supported by a bearing mount attached to a base, rotated by a motor, and coupled to a microwave transmitter.

FIG. **4** shows an alternate arrangement of two laser systems mounted on a cylindrical disk with a hole in the center of the cylindrical disk.

FIG. **5**A shows a general method of accelerating a Plasma Beam and affecting its properties with an electromagnetic coil.

FIG. **5**B shows a general method of accelerating a Plasma Beam and affecting its properties with a set of orthogonal electromagnetic coils.

FIG. **6**A shows an assembly with an inner cylinder attached to an outer cylinder with four rectangular members to create four cavities.

FIG. **6**B shows an end view of the assembly of FIG. **6**A.

FIG. **7** shows an assembly with a laser system mounted in each of two opposing cavities shown in FIG. **6**A.

FIG. **8** shows the assembly of FIG. **7** supported by a bearing mount attached to a base, rotated by a motor, and coupled to a microwave transmitter.

FIG. **9**A shows the side view of a parabolic reflector with a center feedpoint.

FIG. **9**B shows the front view of a parabolic reflector shown in FIG. **9**A.

FIG. **10**A shows the side view of a parabolic reflector with a center feedpoint where two incoming parallel rays are reflected to the feedpoint.

FIG. **10**B shows the side view of a parabolic reflector with a center feedpoint where two rays coming from the feedpoint are reflected from the parabolic reflector as parallel rays.

FIG. **11**A shows the side view of a parabolic reflector with a center feedpoint where a different pair of rays coming from the feedpoint are reflected from the parabolic reflector as parallel rays.

FIG. **11**B shows the side view of the section of the parabolic reflector of FIG. **11**A where the pair of rays coming from the feedpoint are reflected from the parabolic reflector as parallel rays.

FIG. **12**A shows the front view of the parabolic reflector of FIG. **11**A where the area of the parabolic reflector used in FIG. **11**B is highlighted.

FIG. **12**B shows the front view of the inside parabolic reflector of FIG. **12**A where the center area of the inside parabolic reflector has been removed to form a mirror ring.

FIG. **13**A shows the mirror ring of FIG. **12**B with upper and lower segments marked.

FIG. **13**B shows the side view of the mirror ring of FIG. **13**A with a hard waveguide attached to the center hole area and with rays coming from the offset feedpoint and reflecting off the upper and lower segments of the parabolic mirror ring.

FIG. **14** shows the side view of the system of FIG. **13**B where a two-axis mirror at the feedpoint directs the beam from a laser in a circular fashion around the periphery of the parabolic mirror ring.

FIG. **15** shows the system of FIG. **14** mounted in an azimuth-elevation mount.

FIG. **16** shows how the Plasma Beam can be electrically accelerated between the feedpoint mirror and the parabolic mirror.

FIG. **17**A shows the front view of a parabolic reflector where two areas of the parabolic reflector being used are highlighted.

FIG. **17**B shows the front view of the two inside areas of FIG. **17**A where the center areas of the two inside areas have been removed to form two mirror rings.

FIG. **18**A shows the two mirror rings of FIG. **18**B where each mirror ring is divided into upper and lower halves.

FIG. **18**B shows a mirror ring formed from the upper half of the lower mirror ring of FIG. **18**A and the lower half of the upper mirror ring of FIG. **18**A.

FIG. **19**A shows the mirror ring of FIG. **18**B with upper and lower segments marked.

FIG. **19**B shows the side view of a system using the mirror ring of FIG. **19**A where a two-axis mirror at each feedpoint directs the beam from its associated laser system around its associated periphery of the parabolic mirror ring.

FIG. **20**A shows the front view of a parabolic reflector where a rectangular segment of a parabolic reflector is highlighted.

FIG. **20**B shows a mirror assembly made from four indentical rectangular segments of FIG. **20**A.

FIG. **21** shows each rectangular segment of FIG. **20**B with its own associated feedpoint and laser system.

FIG. **22** shows the side view of a system using the rectangular mirror segments of FIG. **21** where a single-axis mirror at each feedpoint directs the beam from its associated laser system to its associated rectangular mirror segment. Only the upper and lower rectangular mirror segments are shown.

FIG. **23** shows the side view of a system where the plasma beam is electrically accelerated and then magnetically deflected in a circular fashion around the periphery of the parabolic mirror ring by a pair of electromagnetic coils located at the feedpoint.

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the invention. However, it is understood that the invention may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to obscure the invention.

A laser system is used to produce a thin ionizing beam through the atmosphere. An example of such a laser system using a titanium-sapphire infrared laser is taught in U.S. Pat. No. 5,726,855 APPARATUS AND METHOD FOR ENABLING THE CREATION OF MULTIPLE EXTENDED CONDUCTION PATHS IN THE ATMOSPHERE, issued Mar. 10, 1998 to Mourou et al.

The beam is moved in either a circular or rectangular fashion to produce a conductive shell to act as a waveguide for microwave energy.

For the purposes of this application the terms Focal Point, Feedpoint, and FP will mean the same thing. The terms Plasma Beam Waveguide, Plasma Beam Conduit, and Plasma Beam Shell will also all mean the same thing. In addition, the term Laser System means a chirped-pulse amplification laser system having a high peak-power laser capable of transmitting a high-peak power ultrashort laser pulse through the atmosphere.

A general method of accelerating a plasma beam is shown in FIG. **5**A. Laser System **51** produces Plasma Beam **52** which is reflected off Flat Mirror **53** and Flat Mirror **54** which are made of an electrically conducting material such as beryllium metal. Current Source **55** is connected between Flat Mirror **53** and Flat Mirror **54**. Current Source **55** may be a direct current, an alternating current, and may also be modulated. Electromagnetic Coil **56** may also be used to modulate Plasma Beam **52**.

In FIG. **5**B the plasma beam between Flat Mirror **53** and Flat Mirror **54** is deflected by a pair of orthogonally mounted electromagnetic coils, designated as Electromagnetic XY Coils **57**, much as the electron beam in a cathode ray tube is magnetically deflected by a standard set of deflection coils.

First Embodiment

The following describes a system using two laser systems where the plasma beam conduit is formed using a mechanical system that physically moves the laser systems used to produce the beam. Microwave energy is coupled into the plasma beam conduit through a hole in the laser assembly. The plasma beam conduit has a circular cross-section.

In FIG. **1**A, Laser Assembly **10** is formed by mounting Laser System **13** and Laser System **15** on Cylindrical Disk **11** which is electrically conductive. Hole **17** is in the center of Cylindrical Disk **11**. Mirror **14** deflects the beam from Laser System **13**. Similarly, Mirror **16** deflects the beam from Laser System **15**. Sleeve **12** is electrically conducting and provides a smooth conducting surface extending from Hole **17**. This is shown in FIG. **1**B. FIG. **2**A shows Beam **21** from Laser System **15** being deflected from Mirror **16** to continue the conducting path from Hole **17** and Sleeve **12**. Similarly, Beam **20** from Laser System **13** is deflected from Mirror **14** to continue the conducting path from Hole **17** and Sleeve **12**.

In FIG. **2**B, Assembly **24** is made by mounting Laser Assembly **10** at one end of Conducting Tube **23**. Counterweight **22** is mounted at the opposite end of Conducting Tube **23** to provide dynamic balancing.

In FIG. **3**, Assembly **24** (made from Laser Assembly **10**, Conducting Tube **23**, and Counterweight **22**) is mounted on Bearing Mount **31** to allow Assembly **24** to rotate. Ring Gear **32** is mounted around the circumference of Conducting Tube **23** and engages Gear **33** which is turned by Motor **34**. Motor **34** is supported by Motor Stand **35**. Base **37** supports both Motor Stand **35** and Bearing Mount **31**. Microwave Transmitter **39** is also mounted on Base **37** and is coupled to Conducting Tube **23** through Rotary Coupling **38**, whose design is well known to those in the field of Radar. Power to Laser Assembly **10** is supplied through Slip Ring Assembly **36**. In operation, Laser Assembly **10** rotates, causing the beams from Laser System **13** and Laser System **15** to produce a cylindrical conductive shell to act as a waveguide for the Energy from Microwave Transmitter **39**. Mirror **14** and Mirror **16** are precisely aligned so that only a single conductive shell is produced.

Referring to FIG. **1**A, the reason for using two laser systems is to dynamically balance Cylindrical Disk **11** and to reduce the speed at which the system must rotate. Alternately, one laser system can be replaced by the appropriate balancing weights. As a further alternative, more than two laser systems may be used as long as they are spaced appropriately in order to preserve the dynamic balance of Laser Assembly **10**. Where more than one laser system is used, they are precisely aligned so that only a single conductive shell is produced.

An alternative to the arrangement shown for mounting Laser System **13** and Laser System **15** is shown in FIG. **4**. In this arrangement, Laser System **13** and Laser System **15** are mounted tangentially on Conducting Disk **11**. Mirror **41** directs the beam from Laser System **13** to Mirror **14**, while Mirror **42** directs the beam from Laser System **15** to Mirror **16**. The assembly thus produced (Laser Assembly **40**) is used in place of Laser Assembly **10** in FIG. **3**. Again, the reason for using two laser systems is to dynamically balance Cylindrical Disk **11** and to reduce the speed at which the system must rotate. Alternately, one laser system can be replaced by the appropriate balancing weights. As a further alternative, more than two laser systems may be used as long as they are spaced appropriately in order to preserve the dynamic balance of Laser Assembly **40**. Where more than one laser system is used, they are precisely aligned so that only a single conductive shell is produced.

One advantage of Laser Assembly **40** is to produce a more compact arrangement of its components. Another advantage is that it makes it easy to use an electric current to accelerate the plasma beams produced by Laser System **13** and Laser System **15** by the method previously described in reference to FIG. **5**A and FIG. **5**B.

The following describes a different arrangement using two laser systems where the plasma beam conduit is formed using a mechanical system that physically moves the laser systems used to produce the beam. Microwave energy is coupled into the plasma beam conduit through a tube in the laser assembly. The plasma beam conduit has a circular cross-section.

In FIG. **6**A, Assembly **600** consists of an electrically conducting Inner Cylinder **61** attached to Outer Cylinder **60** through the use of Rectangular Members **62**, **63**, **64**, and **65**. Referring to FIG. **6**B, this results in the creation of Cavities **66**, **67**, **68**, and **69**.

Referring to FIG. **7**, two opposing cavities (Cavity **67** and Cavity **69**) each contain a laser system with associated mirrors to produce Laser Assembly **70**. Cavity **67** contains Laser System **75**, Mirror **77**, and Mirror **78**. Laser System **75** produces Beam **76** which is reflected off Mirror **77** and Mirror **78**. Cavity **69** contains Laser System **71**, Mirror **73**, and Mirror **74**. Laser System **71** produces Beam **72** which is reflected off Mirror **73** and Mirror **74**.

In FIG. **8**, Laser Assembly **70** is mounted on Bearing Mount **81** to allow Laser Assembly **70** to rotate. Ring Gear **83** is mounted around the circumference of Laser Assembly **70** and engages Gear **84** which is turned by Motor **85**. Motor **85** is supported by Motor Stand **86**. Base **82** supports both Motor Stand **86** and Bearing Mount **81**. Microwave Transmitter **89** is also mounted on Base **82** and is coupled to Laser Assembly **70** through Rotary Coupling **88**, whose design is well known to those in the field of Radar. Power to Laser Assembly **70** is supplied through Slip Ring Assembly **87**. In operation, Laser Assembly **70** rotates, causing the beams from Laser System **75** and Laser System **71** to produce a cylindrical conducting shell to act as a waveguide for the energy from Microwave Transmitter **89**. Mirrors **73**, **74**, **77**, and **78** are precisely aligned so that only a single conductive shell is produced.

Referring to FIG. **7**, the reason for using two laser systems is to dynamically balance Laser Assembly **70** and to reduce the speed at which the system must rotate. Alternately, one laser system can be replaced by the appropriate balancing weights. As a further alternative, more than two laser systems may be used as long as they are spaced appropriately in order to preserve the dynamic balance of Laser Assembly **70**. Where more than one laser system is used, they are precisely aligned so that only a single conductive shell is produced.

Second Embodiment

The following describes a system using a single laser system where the laser system is stationary and the plasma beam conduit is formed by an opto-mechanical system using a parabolic section mirror with an offset feed. Microwave energy is coupled into the plasma beam conduit through a hole in the parabolic mirror section. The plasma beam conduit has a circular cross-section.

FIG. **9**A shows a side view of parabolic Reflector **91** with Axis **93** and Focal Point **92**. FIG. **9**B shows the front view of parabolic Reflector **91** and Focal Point **92**.

A parabolic reflector has the property that all rays arriving parallel to the axis will be reflected to the focal point.

Referring to FIG. **10**A, since Rays **101** and **102** are parallel to Axis **93** they are both reflected off Reflector **91** to Focal Point **92**.

Similarly, all rays emanating from the focal point and reflecting off the parabolic reflector will depart parallel to the axis.

Referring to FIG. **10**B, since Rays **103** and **104** emanate from Focal Point **92** and reflect off Reflector **91**, they will depart parallel to Axis **93**.

Similarly, in FIG. **11**A, Rays **112** and **113** emanate from Focal Point **92**, reflect off Reflector **91**, and depart parallel to Axis **93**.

If we are only interested in Rays **112** and **113**, we do not need all of Reflector **91**.

FIG. **11**B shows the only part of Reflector **91** that we do need, designated as Reflector **111**. Note that Axis **93** still exists even though there is no physical reflector for it to intercept.

FIG. **12**A shows the front view of Reflector **111**, which is the part of Reflector **91** needed to produce a cylinder where Rays **112** and **113** represent the boundaries of the cylinder. The part of Reflector **91** not used in Reflector **111** is simply not built. Note that Focal Point **92** is no longer in front of Reflector **111**. This is known as an offset feedpoint.

Moving a light source from Focal Point **92** around the outside circumference of Reflector **111** produces a cylinder of light. Since we will only be using the outside of Reflector **111** we can make a hole in the center to produce Mirror Ring **121** as shown in FIG. **12**B. The front view of Mirror Ring **111** is shown in FIG. **12**B. In order to make the following drawings clearer we will designate Mirror Segment **131** and Mirror Segment **132** on Mirror Ring **121** in FIG. **13**A. On drawings where Mirror Segment **131** and Mirror Segment **132** are shown it is to be understood that they are present as part of Mirror Ring **121**. Referring to FIG. **13**B, the side view of Mirror Ring **121** showing Mirror Segment **131** and Mirror Segment **132** shows two rays coming from Focal Point **92**. A hole in the center of Mirror Ring **121** allows us to couple microwave energy from Microwave Transmitter **134** through microwave Hard Waveguide **133** to the center of Mirror Ring **121**.

In FIG. **14**, for clarity only Mirror Segment **131** and Mirror Segment **132** of Mirror Ring **121** are shown. A flat mirror at the Focal Point, shown as FP Mirror **141**, is mounted with two degrees of freedom and Mirror Positioner **142** directs the output from Laser System **143** around Mirror Ring **121** to produce a Plasma Beam Waveguide (PB Waveguide **144**). Mirror Positioner **142** is of conventional electromechanical design.

As shown in FIG. **15**, the system can be aimed by mounting it in Azimuth-Elevation Mount **151**, which is of conventional design.

FIG. **16** shows how the Plasma Beam can be electrically accelerated between FP Mirror **141** and Mirror Ring **121** of which only Mirror Segment **131** and Mirror Segment **132** are shown. By using an electrically conducting material such as beryllium metal for FP Mirror **141** and Mirror Ring **121**, and by using Current Source **161** to induce an electrical current between the two mirrors, the plasma beam produced by Laser System **143** is electrically accelerated. Normally, for operator safety, Current Source **161** will be grounded at Mirror Ring **121**. Current Source **161** may be a direct current or an alternating current, and may also be modulated.

As one example, the transmission of 3 GHz. microwave energy requires a plasma beam waveguide with a diameter of approximately 2.5 inches. Naturally, other dimensions may be used in other applications with other requirements.

The following describes an opto-mechanical system using two laser systems where the laser systems are stationary and the plasma beam waveguide is formed by an opto-mechanical system using two parabolic section mirrors, each with an offset feed. The plasma beam conduit has a circular cross-section. This is the preferred embodiment.

FIG. **17**A shows the front view of Parabolic Reflector **91** with Focal Point **92**, where two inside areas of Parabolic Reflector **91** are highlighted. Area **111** has already been described in conection with FIG. **11**B. Area **171** is a reflection of Area **111** and has the same properties.

FIG. **17**B shows the front view of Area **111** and Area **171** of FIG. **17**A where the center areas of Area **111** and Area **171** have been removed to form Mirror Ring **121** and Mirror Ring **172**.

In FIG. **18**A Mirror Ring **121** has been divided in half to form Mirror HRing **181** and Mirror HRing **182**. Similarly, Mirror Ring **172** has been divided in half to form Mirror HRing **183** and Mirror HRing **184**.

In FIG. **18**B Composite Mirror Ring **187** has been formed from the upper half of the lower mirror ring of FIG. **18**A (Mirror HRing **183**) and the lower half of the upper mirror ring of FIG. **18**A (Mirror HRing **182**). In order to distinguish the two focal points derived from Focal Point **92**, the focal point associated with Mirror HRing **182** will be designated as Focal Point **186**, while the focal point associated with Mirror HRing **183** will be designated as Focal Point **185**.

In order to make the following drawings clearer we will designate Mirror Segment **190** and Mirror Segment **191** on Composite Mirror Ring **187** as shown in FIG. **19**A. In drawings where Mirror Segment **190** and Mirror Segment **191** are shown it is to be understood that they are present as part of Composite Mirror Ring **187** made of Mirror HRing **183** and Mirror HRing **182**. Referring to FIG. **19**B, the side view of Composite Mirror Ring **187** shows Ray **196** from Laser System **194** reflecting off Two-Axis Mirror Positioner **195** located at Focal Point **185** and Ray **199** from Laser System **197** reflecting off Two-Axis Mirror Positioner **198** located at Focal Point **186**. With a full composite mirror Laser System **194**, Mirror Positioner **195**, and Mirror HRing **183** will produce the top half of the plasma beam waveguide, while Laser System **197**, Mirror Positioner **198**, and Mirror HRing **182** will produce the bottom half of the plasma beam waveguide. Hard Waveguide **192** couples the energy from Microwave Transmitter **193** to the center of Composite Mirror Ring **187**.

Plasma beam waveguides of other cross-sectional shapes, such as rectangular, may be formed by appropriate mirror design.

The following describes a system using four laser systems where the laser systems are stationary and the plasma beam conduit is formed by an opto-mechanical system using four parabolic section mirrors, each with an offset feed. The plasma beam conduit has a rectangular cross-section.

FIG. **20**A shows the front view of Parabolic Reflector **91** where Rectangular Segment **202** of Area **201** is highlighted. A ray emanating from Focal Point **92** that is directed along the center of the long axis of Rectangular Segment **202** will produce a planar beam.

FIG. **20**B shows Mirror Assembly **203** made from four indentical pieces, each one consisting of Rectangular Segment **202** in the appropriate position and orientation to form Mirror Assembly **203**. Each rectangular segment has its own focal point.

In FIG. **21** the top of the plasma beam waveguide is produced by Laser System **2101**, Single-Axis Mirror Positioner **2102**, and Rectangular Segment **2103**. The right side of the plasma beam waveguide is produced by Laser System **2104**, Single-Axis Mirror Positioner **2105**, and Rectangular Segment **2106**. The bottom of the plasma beam waveguide is produced by Laser System **2107**, Single-Axis Mirror Positioner **2108**, and Rectangular Segment **2109**. The left side of the plasma beam waveguide is produced by Laser System **2110**, Single-Axis Mirror Positioner **2111**, and Rectangular Segment **2112**. Square Section **2113** allows microwave energy to be coupled into the plasma beam waveguide.

In FIG. **22**, for clarity only the top and bottom parts are shown. The top of the plasma beam waveguide (**223**) is produced by Laser System **2101**, Single-Axis Mirror Positioner **2102**, and Rectangular Segment **2103**. The bottom of the plasma beam waveguide (**224**) is produced by Laser System **2107**, Single-Axis Mirror Positioner **2108**, and Rectangular Segment **2109**. The two sides not shown (Laser System **2104**, Single-Axis Mirror Positioner **2105**, Rectangular Segment **2106**, Laser System **2110**, Single-Axis Mirror Positioner **2111**, and Rectangular Segment **2112** complete the plasma beam waveguide. Hard Waveguide **222** couples the energy from Microwave Transmitter **221** to the center of Mirror Assembly **203** and into the plasma beam waveguide.

Third Embodiment

The following describes a system using a single laser system where the laser system is stationary and the plasma beam conduit is formed by an opto-electromagnetic system using a parabolic section mirror with an offset feed. Microwave energy is coupled into the plasma beam conduit through a hole in the parabolic mirror section. The plasma beam conduit has a circular cross-section.

FIG. **23** shows Mirror Segment **131**, Mirror Segment **132**, Hard Waveguide **133**, Microwave Transmitter **134**, and Laser System **143** as previously described in connection with FIG. **16**. However, in this embodiment a pair or orthogonal electromagnetic coils (FP Coils **231**) located at the feedpoint are used to deflect the plasma beam around the periphery of Mirror Ring **121**, of which only Mirror Segment **131** and Mirror Segment **132** are shown. FP Coils **231** are electrically driven to produce a changing magnetic field to deflect the plasma beam in a circular fashion around the periphery of Mirror Ring **121**. Mirror **232** is used for providing a conducting surface in order to provide an electrically path through the plasma beam. As with the Second Embodiment, more than one laser system may be used by choosing the appropriate configuration of parabolic section mirrors. The method taught in the Second Embodiment may also be used to produce a rectangular waveguide.

While preferred embodiments of the present invention have been shown, it is to be expressly understood that modifications and changes may be made thereto and that the present invention is set forth in the following claims.

I claim:

1. An apparatus for transmitting microwave energy through the atmosphere comprising:

(a) one or more laser systems, whereby each said one or more laser systems produces a thin ionizing beam through the atmosphere;

(b) a mechanical means for rotating said one or more laser systems such that said thin ionizing beam from said one or more laser systems produces a single conductive shell;

(c) a microwave transmitter;

(d) a means for coupling the output of said microwave transmitter to said conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

2. The apparatus of claim **1** further including an electrical current means for accelerating said thin ionizing beam from said one or more laser systems.

3. An apparatus for transmitting microwave energy through the atmosphere comprising:

(a) one or more laser systems, whereby each said one or more laser systems produces a thin ionizing beam through the atmosphere;

(b) an opto-mechanical means for moving said thin ionizing beam from said one or more laser systems to produce a single conductive shell, whereby said opto-mechanical means comprises one or more parabolic section mirrors and a controllable flat mirror at the focal point of each said one or more parabolic section mirrors;

(c) a microwave transmitter;

(d) a means for coupling the output of said microwave transmitter to said conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

4. The apparatus of claim **3** further including an electrical current means for accelerating said thin ionizing beam from said one or more laser systems.

5. An apparatus for transmitting microwave energy through the atmosphere comprising:

(a) one or more laser systems, whereby each said one or more laser systems produces a thin ionizing beam through the atmosphere;

(b) an opto-electromagnetic means for moving said thin ionizing beam from said one or more laser systems to produce a single conductive shell, whereby said opto-electromagnetic means comprises:

  (i) an electrical current means for accelerating said thin ionizing beam from said one or more laser systems;

  (ii) a pair of electrically driven orthogonal magnetic coils for deflecting said thin ionizing beam from said one or more laser systems;

  (iii) one or more parabolic section mirrors;

(c) a microwave transmitter;

(d) a means for coupling the output of said microwave transmitter to said conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

6. A method for transmitting microwave energy through the atmosphere comprising the steps of:

(a) using one or more laser systems to produce a thin ionizing beam through the atmosphere;

(b) mechanically rotating said one or more laser systems such that said thin ionizing beam from said one or more laser systems produces a single conductive shell;

(c) coupling the output of a microwave transmitter to said single conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

7. The method of claim **6** further including the step of electrically accelerating said thin ionizing beam from said one or more laser systems.

8. A method for transmitting microwave energy through the atmosphere comprising the steps of:

(a) using one or more laser systems to produce a thin ionizing beam through the atmosphere;

(b) using opto-mechanical means to move said thin ionizing beam from said one or more laser systems to produce a single conductive shell, whereby said opto-mechanical means moves said thin ionizing beam from said one or more laser systems to produce a single conductive shell by using one or more parabolic section mirrors and a controllable flat mirror at the focal point of each said one or more parabolic section mirrors;

(c) coupling the output of a microwave transmitter to said single conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

9. The method of claim **8** further including the step of electrically accelerating said thin ionizing beam from said one or more laser systems.

10. A method for transmitting microwave energy through the atmosphere comprising the steps of:

(a) using one or more laser systems to produce a thin ionizing beam through the atmosphere;

(b) using opto-electromagnetic means for moving said thin ionizing beam from said one or more laser systems to produce a single conductive shell, whereby said opto-electromagnetic means comprises the steps of:

  (i) using an electrical current means for accelerating said thin ionizing beam from said one or more laser systems;

  (ii) using a pair of electrically driven orthogonal magnetic coils for deflecting said thin ionizing beam from said one or more laser systems;

  (iii) using one or more parabolic section mirrors; (c) coupling the output of a microwave transmitter to said single conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

11. A method for transmitting microwave energy through the atmosphere comprising the steps of:

(a) using one or more laser systems to produce a thin ionizing beam through the atmosphere;

(b) using said thin ionizing beam from said one or more laser systems to produce a single conductive shell;

(c) coupling the output of a microwave transmitter to said single conductive shell;

whereby said single conductive shell acts as a waveguide for said output of said microwave transmitter.

* * * * *