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LASER BEAM ANTENNA

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LASER BEAM ANTENNA
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This invention relates to antennas and more particularly to low frequency (LF) to very low frequency (VLF) laser beam antennas.

One of the problems encountered in the construction of known LF to VLF antennas is that very large heights (as high as 400 to 500 meters) must be reached by monopole antennas in order that they possess a suitable radiation efficiency. In fact, quarterwave lengths at 500 kc., 100 kc., 50 kc. and 10 kc. are respectively: 150 m., 750 m., 1500 m. and 7500 m. In practice, the construction of such high monopole antennas is very expensive, the cost increasing rapidly as a function of the height.

Another disadvantage of known LF to VLF antennas is their need for towers, thus making them impractical for use wherever ease of transportability is an important factor. Therefore, it is the main object of this invention to provide a laser beam antenna which eliminates the need for construction of towers and which is highly transportable. According to this invention a high power laser means for producing at least one laser beam is coupled to pulsing means for repeatedly pulsing on said laser means. Also coupled to said laser means is focusing means for focusing said laser beam at different points to thereby ionize a column of air. Means are further provided for coupling a second input signal to the base of said ionized column of air to utilize said column as an antenna.

The above-mentioned and other objects of this invention will become apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a block diagram of a laser beam antenna according to this invention;

FIGURE 2 is a simplified diagram of apparatus for varying the focal length of a laser beam according to this invention;

FIGURE 3 is a schematic diagram of apparatus for applying an input signal to the ionized column of air;

FIGURE 4 is a block diagram of an alternate means for producing a laser beam antenna utilizing multiple laser beams;

FIGURE 5 is a simplified diagram of apparatus for varying the focal length of a laser beam in a curvilinear manner according to this invention; and

FIGURE 6 is a diagram of an auxiliary ionization system for use in conjunction with apparatus according to this invention.

Referring to FIGURE 1, a high-power laser (such as a ruby or neodymium-doped laser) 1 is coupled to a pulsing means 3 which pulses said laser 1 to the "on" condition for predetermined lengths of time at a predetermined repetition rate. The laser beam is passed through variable focusing system 2 and is focused at a predetermined point (point 6, for example), at which point the air is ionized. A variable focusing system 2 is also coupled to pulsing means 3 for causing the focal length thereof to change in synchronism with the pulsing "on" of said laser 1. When laser 1 is first pulsed "on" by pulsing means 3, the beam is focused, for example, at point 6 by focusing system 2, ionizing the air at said point 6. During the "off" period of said laser 1 pulsing means 3 causes the focusing system 2 to change its focal length by a predetermined amount so that during the next "on" period of laser 1, the beam is focused at point 7, for example. This process is repeated until a column of ionized air of predetermined height is produced. After the ionized column is produced once, the focusing system 2 is returned back to its initial position to repeat the ionization of the air at all of the successive focal points in order to maintain the ionization of said column. The repetition rate of the pulsing "on" of said laser 1 is determined by the lifetime of the ions produced at each focal point of the laser beam and pulsing means 3 is adjusted accordingly. Also, the focal points 6, 7 and 8, for example, are spaced such that an approximately uniform density of ionized plasma is obtained along the column after equilibrium has been reached. Said spacing is achieved by adjustment of focusing means 2 which is described below in more detail. A source of input signals 4 is coupled to the base of said ionized column via means 5 to utilize said ionized column as an antenna. The details of these elements are shown more specifically in FIGURE 3 and are described below with reference thereto.

In FIGURE 2 an embodiment of the variable focusing means 2 of FIGURE 1 is shown in detail. This is a simplified embodiment and is shown merely by way of example. Lens 10 is mounted in a stationary manner to supports 13. Lens 9 is slidable mounted to supports 13 and is further coupled to a rack gear 12 which is coupled to driving gear 11. Said driving gear 11 is mechanically coupled to motor 14 which is activated by said pulsing means 3 via variable timing means 15 and reversing means 17 in synchronism with the switching "on" of laser 1. The setting of variable timing means 15 determines how long motor 14 remains on after it is activated by means 3 and therefore determines by how much the focal length of focusing system 2 is changed each time said motor 14 is activated. When motor 14 is activated, lens 9 is caused to move a predetermined distance (determined by the timing means 15) in the vertical direction by means of gears 11 and 12 and thereby changing the focal length of lens system 9 and 10 by a fixed amount. This process is successively repeated to provide spaced focal points (points 6, 7 and 8 for example) along the length of said ionized column. Counter 16 counts the number of times motor 14 is activated and after a predetermined number of counts, causes the focal length of focusing system 2 to return to its original value the next time said motor 14 is activated by pulsing means 3. This is accomplished by means of reversing means 17 which reverses the direction of rotation of motor 14 when counter 16 has registered said predetermined number of counts. Counter 16 also causes timer 15 to allow said motor 14 to be activated for a long enough period of time to return said focusing system 2 back to its original position. In summary therefore, it is seen that the focal point of the laser beam is caused to change in such a manner as to produce a column of substantially uniform ionized plasma. When the column reaches a predetermined height, the focal point is returned to its initial value and again varied in the above manner to maintain said column in an ionized condition. It should be noted that the settings of counter 16 and variable timing timer 15 are inter-related. That is, for a given timing setting a fixed number of ionization points (or counter counts) are required to produce an ionized column of a given height. If the time delay of timer 15 is decreased, the spacing between ionization is shortened and therefore a larger number of said ionization points (or counter counts) are required to produce an ionized column of the same height. Therefore, if the setting of timer 15 is varied, the setting of counter 16 must be correspondingly varied.

It should be noted that many other methods of changing the focal point of the laser beam could also be used. For example, in an embodiment, FIGURE 2, both lenses 9 and 10 may be made to move simultaneously in order to produce equivalent results.
Further, it is possible to utilize focusing devices having no moving parts. For example, the laser beam may be deviated electrically or otherwise so that it is passed successively through different optical paths which provide focusing of said beam at the various desired points. Another possibility consists of providing a number of parallel paths for the laser beam of which only one is opened at a given instant of time. Switching in the latter case, may be implemented by use of electro-optical control, magneto-optical control of the polarization, variation of the reflectivity of a surface, etc.

FIGURE 3 illustrates a method of exciting an antenna according to this invention. This is accomplished by means of transmitter 18 coupled to a matching transformer 19. Transformer 19 is coupled to tuning coil 20 which applies the signal from transmitter 18 to the antenna by means of electrode 21 immersed in the base of the ionized plasma column. The matching transformer 19 and tuning coil 20 are similar to types used in the conventional feeding of known types of monopole antenna radiators. Assuming that the column of ionized air is vertical and has height \( H \), the radiation resistance is computed approximately with the relationship:

\[
R = 400 \left( \frac{H}{\lambda} \right)^2
\]

where \( \lambda \) is the wavelength of the injected RF current and \( H \) is assumed to be less than 0.1\( \lambda \). The value of the wavelength \( \lambda \) must be larger than the plasma cutoff wavelength; the latter is determined by the density of the plasma and corresponds to an angular frequency:

\[
\omega_c = \frac{e}{m_e N}
\]

where \( N \) is the ion density, \( e \) the ionic charge, and \( m \) the mass. The cutoff value of \( \lambda \) is expressed as follows:

\[
\lambda_{\text{cutoff}} = \frac{2 \pi e^2}{\omega_c} = \frac{2 \pi e^2}{\sqrt{m_e N}}
\]

FIGURE 4 illustrates another embodiment of this invention utilizing two lasers 22 and 23 for producing an ionized column of air. In this embodiment focusing systems 24 and 25 have a curvilinear motion, the detailed operation of which is set forth below with reference to FIGURE 5. In the circuit of FIGURE 4 both lasers are operated by a common pulsing means 26 (similar to means 3, FIGURE 1), both focusing systems 24 and 25 being operated thereby in substantially the same manner as in the system of FIGURE 1. Both lasers 22 and 23 and both focusing systems 24 and 25 are operated in synchronization and both laser beams are simultaneously successively focused at the same points in space (points 27, 28, 29 and 30, for example). Utilizing the system of FIGURE 4, lasers having approximately half the output power of the laser required in the system of FIGURE 1 may be utilized to provide results equivalent to the system of FIGURE 1. It is clear that more than two lasers may be combined in a manner similar to that shown in FIGURE 4 to produce antennas according to this invention.

FIGURE 5 illustrates focusing means 24 and 25 (both are identical) in more detail. Since they are identical the following discussion will refer only to focusing means 24. Lens 31 is moved along axis 35 via gears 33 and 34 in the same manner as lens 9 (FIGURE 2) is moved via gears 11 and 12, and further discussion of this movement is deemed unnecessary. Means 36 is further provided to impart curvilinear motion of focusing means 24 about pivot point 37, for example. The angle at which the lens system is offset from the vertical axis 35 is represented by \( \alpha \). The curvilinear motion is provided by rack gear 38 which is pivotally coupled to focusing means 24 at point 41 and which is driven by gear 39 which is mechanically coupled to motor 40. Motor 40 is activated in the identical manner as motor 14 as set forth above in the description of FIGURE 2. A successive position of focusing means 24 is shown in FIGURE 5 by the dotted lines. Corresponding elements are denoted by priming the original designating symbols.

It should also be noted that the ionization phenomenon may be aided by use of auxiliary means of ionization. One well-known method, shown in FIGURE 6, consists of the use of a high-voltage D.C. or R.F. discharge in a chamber 42 via source 43 applied to probe 44 and the simultaneous flow of a high-pressure jet of air 45 through aperture 46. Other known methods may also be used to aid the laser beam in the ionization of the air, such as the use of high power microwave beams or ultraviolet rays.

The optimization of the selection of the laser for use in this invention is made on the basis of the peak power output, of the coherence, of the wavelength, etc. For instance, it has been found that, using ruby lasers (wavelength 0.6934 microns), ionization of air at atmospheric pressure is obtained when the laser beam is focused with a peak power density of 10^8 watts/m^2 or higher, corresponding to an electric field intensity of approximately 10^7 volts/cm. These levels of peak power density and of peak electric field may be obtained by using a pulsed laser having one joule output energy per pulse and 30-nanosecond pulse duration (i.e., 30 megawatts peak power) focused on a spot of diameter 2\( \times 10^{-6} \) cm. The power required for ionization will increase when the focusing optical system has optical aberrations. On the other hand, the ionization threshold will decrease when the wavelength of the laser is decreased.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention, as set forth in the accompanying claims.

We claim:

1. A laser beam antenna comprising:
   - means for producing at least one laser beam;
   - means coupled to said laser means for repeatedly pulsing on said laser means;
   - focusing means for focusing said laser beam at different points to thereby ionize a column of air;
   - means for coupling a source of input signals to the base of said ionized column of air.

2. An antenna according to claim 1 wherein said focusing means comprises a variable focal length optical lens system.

3. An antenna according to claim 2 wherein said focusing means further comprises means for adjusting the focal length of said focusing means in synchronism with said pulsing on of said laser beam.

4. An antenna according to claim 3 wherein said means for adjusting comprises:
   - first means coupled to said pulsing means and to said lens system for adjusting the focal length of said lens system by a predetermined amount responsive to said pulsing means; and
   - second means coupled to said first means for returning the focal length back to its starting value after said focal length has been adjusted a predetermined number of times.

5. An antenna according to claim 4 wherein said focusing means comprises a stationary mounted lens and a slidable mounted lens, said lenses mounted on a common axis, and wherein said means for adjusting comprises:
   - gear means coupled to said slidable mounted lens for varying the position of said lens along said axis;
   - motor means coupled to said gear means;
   - reversing means coupled to said motor for reversing the rotation thereof;
   - timing means coupled to said reversing means for permitting said motor to be activated for a predetermined length of time;
   - means coupling said timing means to said pulsing means; and
counting means coupled to said pulsing means, to said timing means and to said reversing means for causing the focal length of said focusing means to be returned to its initial value after said laser means has been focused at a predetermined number of points.

6. An antenna according to claim 1 wherein said laser means comprises two lasers.

7. An antenna according to claim 6 wherein each said laser is coupled to a focusing means comprising a variable focal length optical lens systems for curvilinearly varying said focal points.

8. An antenna according to claim 7 wherein the focal points of each said laser are simultaneously adjusted and wherein said focal points are at the same relative position in space at the same time.

9. An antenna according to claim 8 wherein each said focusing means comprises:

   a mounting means;
   a first lens mounted in a stationary manner to said mounting means;
   a second lens slidably mounted on said mounting means on a common axis with said first lens;
   first gear means coupled to said slidably mounted lens for varying the position of said lens along said axis;
   second gear means coupled to said mounting means for rotating the axis of said lenses with respect to the vertical direction;
   a first motor coupled to said first gear means;
   a second motor coupled to said second gear means;
   reversing means coupled to both said motors;
   timing means coupled to said reversing means for permitting said motors to be activated for a predetermined length of time;
   means coupling said timing means to said pulsing means; and
   counting means coupled to said pulsing means, to said timing means and to said reversing means for causing the focal points of said laser means to be returned to their initial positions after said laser beams have been focused at a predetermined number of successive focal points.

References Cited

UNITED STATES PATENTS

1,309,031 7/1919 Hettenger 343—701
1,687,792 10/1928 Raue 343—700
2,760,055 8/1956 Laster 343—700

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