VEHICLE DISABLING WEAPON

1.0 ABSTRACT

1.1 A means of directly injecting radio-frequency electrical current into the electronic circuits of vehicles is described. The disabling current is transmitted through two channels of highly ionized air. The channels are created by the multi-photon ionization of the air within two beams of far-ultraviolet laser radiation directed to the vehicle. The current flows in a circuit from an electrode near the origin of one beam through the channel of ionized air within it, then through the target vehicle and back along the conductive channel within the second beam. The current frequency is 100 megahertz and the pulse width is 300 microseconds. The wavelength of the ultraviolet laser radiation is between 180 and 250 nanometers. At the wavelengths and fluence employed, there is little or no ocular hazard. The calculated theoretical range is two kilometers

2.0 NEED

2.1 In both civilian and military applications, there is an obvious need for a means of immobilizing dangerous vehicles without injuring the occupants or bystanders. With no practical method of safely stopping a car, police pursuits too often end with someone dead in the road. For example, the National Highway Traffic Safety Administration reported that, from 1990 through 1994, an average of 331 people were killed in the

United States each year as a result of police pursuits. Of those, an average of 68 “uninvolved" persons were killed annually (Osborne, 1998). Moreover, for every 200 police pursuits in California from 1994 through 1996, one person was killed and four were severely injured. If the California data are representative, about one-half of one percent of the pursuits in the United States result in fatalities, and two percent in serious injuries (Osborne, 1996).

2.2 In environments where hostile military or paramilitary vehicles are operating, the need is even greater. For example, the failure to stop an explosive-laden truck at an embassy checkpoint could be catastrophic. Clearly, the security of U. S. and allied personnel would be enhanced by the use of an effective non-lethal Vehicle Disabling Weapon (VDW).

3.0 ADVANTAGES

3.1 A major advantage of the VDW is that it utilizes the type of electrical energy that most effectively disables modern internal combustion engines. Of the several methodologies evaluated, the Final Report of the Institute for Non-Lethal Defense Technologies recommends the direct injection of radio-frequency (RF) current as "the best approach to stopping ground vehicles because it is the most likely to achieve irreparable damage to the target and is more likely to operate effectively each time" (Grove and Reeser, 1999).

3.2 Another major advantage of the VDW is its standoff capability. Its theoretical two kilometer range greatly exceeds that of other non-ballistic weapons. A police officer or soldier using the VDW would therefore be in far less danger from a hostile target. Moreover, such range would allow the VDW to be employed from a concealed position, thus offering the operator further protection. (The range could be extended by the development of more powerful lasers.)

3.3 The Vehicle Disabling Weapon is easily directed. The target may be acquired either by a radar-controlled servomechanism or the manual alignment of a coaxial beam of visible or infrared light.

3.4 A further advantage is that the VDW may incapacitate one target among many without affecting the others, or swept across a large number of targets to disable them all.

3.5 Because the VDW is simple to use, it should not significantly affect the operator's ability to control his own vehicle.

3.6 The VDW requires little total power to inject its single electromagnetic pulse because the energy is conducted rather than radiated.

3.7 Of additional value is that the VDW is state-of-the-art. No technological breakthroughs are necessary to bring it to fruition. It should take only months rather than years for the VDW to reach operational status.

4.0 LIMITATIONS

4.1 The VDW will not function in heavy rain. In addition, its range will be reduced to a few meters in light rain and heavy fog. This is because shortwave ultraviolet radiation is strongly absorbed by water and water vapor. For example, at a relative humidity level of 50 percent, the absorption cross section is 3×10^{-4} cm^{-2} at 193 nm, which is three times the cross section for O_2 (Scheps, 1981). However, it may be possible to reduce the amount of water vapor in the path of the ultraviolet beam. As described by Diels and Zhao (1992), a more optically transparent path can be created in rain or fog by the heating effect of a coaxial beam of infrared radiation.

4.2 Because of the ease with which RF radiation couples to electronic instruments, these devices and their associated cabling in the transporting vehicle must be shielded. If they are unshielded, they could be damaged when the VDW is used.

4.3 The VDW is not man-portable now. The combined bulk of the prototype laser and RF source is approximately that of a large suitcase. However, technological advances and user demand will almost certainly reduce its size.

5.0 PREVIOUS RELATED WORK

5.1 The ability of RF energy to damage the electronic controls of internal combustion engines has been demonstrated many times (Society of Automotive Engineers, 1999). A few of these demonstrations used RF energy radiated through the air. As disclosed by Sutton and Rains (1994), intense bursts of broadband (70 to 1500 MHz) energy from a large dish antenna may disable an automobile’s microprocessors. However, the angular width of the radiated beam is about thirty degrees. This allows its rapid dissipation and possible interference with other equipment. And, as Grove and Reeser (1999) report, “Typical tests cause the vehicle to reduce power or stall, but the vehicle resumes operation upon removal of the radiation."

5.2 The direct injection of RF energy into electronically-governed vehicles has been shown to be the most efficient means of stopping them. In an extensive series of experiments at the Applied Research Laboratory at Pennsylvania State University. RF energy from 250 kHz through 500 MHz was conducted by wire into several types of civilian and military vehicles. In those tests, 300 microsecond pulses of RF current caused the malfunction of the electronic components at levels as low as 0.5 W. A field strength of -50 V m^{-1} damaged most of the electronic systems, and a field strength of 100 V m^{-1} destroyed them. The most commonly induced failures were of the air flow sensor and the crankshaft position sensor. The destruction of those units permanently disabled the vehicle. The higher frequency currents were more effective because they more easily penetrated the seams in the vehicle bodies, and thus more easily reached the cabling of the otherwise shielded microprocessors. In addition, the higher frequencies more closely matched the cable lengths and therefore coupled more energy into them (Grove and Reeser, 1999).

5.3 The discovery that far-ultraviolet radiation can ionize electrically conductive paths through the atmosphere was first reported in the 1890s. For example, the transmission of electrical current by ionized air was one of Nikola Tesla's central interests. He claimed to have conducted such a current more than 100 feet through the open air before the turn of the century (Childress, 1993). The feasibility of atmospheric transmission was confirmed in the early 1920s. A British researcher named Harry Grindell-Matthews repeatedly demonstrated the transmission of electrical current through long channels of ionized air in 1924 (Owens, 1997). According to newspaper reports of the time, Grindell-Matthews used ionized air paths to conduct currents that destroyed electro-mechanical equipment at a distance of one-half mile. He accomplished this by using multiple electric arcs (the type in World War II era searchlights) to generate the necessary UV radiation (Barwell, 1943).

5.4 The laser is now the most efficient and compact source of ultraviolet radiation. A wide variety of ultraviolet-emitting lasers have been used to conduct electrical currents through ionized air. Among these have been frequency-quadrupled Nd:YAG (neodymium: yttrium aluminum garnet) lasers which emit radiation at 266 nm (Antipov et al., 1991), frequency-doubled dye lasers which emit at 230 nm (Clark et al., 1993), krypton fluoride excimer lasers which emit at 248 nm (Zhao et al., 1995; Miki and Wada, 1998). Most recently, Scheps (1998) used a 248 nm excimer laser to measure the distance a many-ampere arc could be extended.

6.0 OPERATIONAL MECHANISMS

6.1 The VDW stops the engine of the target vehicle by conducting a 300 microsecond pulse of radio-frequency (RF) current through its electronic circuits. The frequency of the current may vary from about 20 through 200 MHz, but is preferably about 100 MHz (Grove and Reeser, 1999). Ten watts (W) of RF energy having a field strength of 100 $V\ m^{-1}$ is transmitted to the target vehicle. (Because the energy is conducted rather than radiated, far less total power is needed to inject the 10 W than is required to generate plane waves of 10 $W\ cm^{-2}$.) The RF current easily penetrates the seams of the vehicle because of its short wavelength. After having done so, it couples efficiently into the vehicle's electrical cables because its wavelength approximates their lengths (Grove and Reeser, 1999).

6.2 The disabling current is transmitted to the target through a single channel of ionized air when the power supply and target are grounded, or through two channels when they are ungrounded. (The two channels may be separate from each other or concentric, one within the other.) They are produced by the multi-photon ionization of the oxygen (0_2) in air by beams of laser radiation having wavelengths in the far ultraviolet (Scheps, 1981). A circuit is created through the target along the electron-rich air within the beams. The current flows from an electrode near the origin of one beam through channel of ionized air within it, then through the target and back along the conductive channel within the second beam. The current reaches and destroys the vehicle's electronic circuits through its wiring and conductive metal structure (Herr, 1999).

6.3 The current conducted through the ionized air channels is limited by the density of the free electrons within them. The minimum 10 W current needed to penetrate automobile and truck bodies can be carried by a gaseous channel having a concentration of 10^{8} electrons per cubic centimeter. This concentration is efficiently achieved in air by photo-ionizing the 0_2 with ultraviolet radiation having a wavelength near 193 nm (Herr, 1999).

6.4 At that wavelength, 0_2 has a two-photon ionization cross section of 1×10^{-34} cm^{-4} W. Because of its low ionization threshold, the number of photons required for its ionization, and its large proportion in the atmosphere, 0_2 is easily able to create sufficient electron density (Herr, 1999).

6.5 The most efficient source of 193 nm radiation presently available is the argon fluoride excimer laser. A reasonable fluence (energy density), pulse duration, and pulse repetition rate for this laser is 5 MW cm^{-2}, 10 nanoseconds (ns), and 200 pulses per second (pps), respectively. Alternately, a greater fluence of 248 nm radiation from a krypton fluoride excimer laser may be used. Because the longer wavelength is less easily absorbed by 0_2, it creates a significantly longer channel of ionized air (Herr, 1999).

6.6 The electron production rate is calculated from the photo-ionization cross sections. A common pulse duration for an argon fluoride excimer laser is 10 ns. Such a laser typically emits 193 nm radiation from a 1 cm^{-2} aperture at a power level of 10 millijoules (mJ). This equates to a photon fluence of 1 MW cm^{-2}. Therefore, 6.3×10^{6} electrons cm^{-3} are liberated during each pulse, which is equivalent to 6.3×10^{14} cm^{-3} electrons per second. Because the required electron density is between 10^{6} and 10^{8} cm^{-3}, the foregoing quantity is low but sufficient. If the fluence is increased to 50 mJ (5 MW cm^{-2}), 1.6×10^{8} electrons will be generated during each laser pulse, which is certainly sufficient. When 248 nm radiation is used, the fluence must be about 100 MW cm^{-2} to create a sufficient electron density. If that beam intensity is utilized, 3.6×10^{7} electrons cm^{-3} will be liberated during each laser pulse (Herr, 1999).

6.7 The length of the ionized air channels is directly proportional to the fluence of the radiation used to create them, and inversely proportional to its wavelength. For example, ultraviolet radiation at 193 nm ionizes atmospheric oxygen much more rapidly than radiation at 248 nm. Therefore, 193 nm radiation produces a more conductive but shorter ionized air channel because it is more rapidly absorbed. Conversely, UV radiation at a significantly greater fluence but a wavelength of only 248 nm produces a much longer conductive channel.

6.8 The conductive path created by a 193 nm beam will propagate 100 meters in dry air before its intensity decreases to e^{-1} (1/2.7) of its initial value. At 248 nm the conductive pathway will propagate 2,000 meters before the intensity decreases to its e^{-1} value. For 193 nm, 5 MW cm^{-2} beam, the electron density at the laser apperture is 1.6 x.10^{8} cm^{3}. The electron density at 100 meters is 2.2 x 10^{7} cm^{-3}. The values for the 248 nm beam are proportional. In both cases the atmospheric electron densities are sufficient to conduct an electric current the respective 100 and 2,000 meter distances (Herr, 1999).

7.0 SAFETY

7.1 A major advantage of the VDW is its inherent safety. The medical literature on the ocular hazard of ultraviolet radiation indicates that, at a wavelength of 193 nm, there is little possibility of injury to the cornea and none to the retina or the other internal structures of the eye. This is because the cornea absorbs virtually all such radiation. Only those wavelengths between about 1200 nm in the infrared and 250 nm in the ultraviolet are able to reach the retina (Verhoeff and Bell, 1916). More precisely, Lembares et al. (1997) found that “corneal absorption is relatively weak from 266 to 248 nm, increases steeply from 248 to 213 nm, and remains strong from 213 to 193 nm.” At 193 nm the corneal absorption coefficient is extremely high, Petit and Ediger (1996), having calculated a value of 39,000 cm^{-1}. Although the cornea is very slightly transmissive to 248 nm radiation, the fluence of the VDW is too low to cause retinal damage without prolonged exposure.

7.2 If the VDW were directed at the eyes for several minutes at either wavelength, however, the affected person would experience actinic conjunctivitis and photokeratitis. Conjunctivitis is the inflammation of the conjunctiva, which is the membrane that covers the anterior surface of the eye and the eyelid. Photokeratitis is a painful irritation of the cornea which is accompanied by a sensation of foreign matter in the eye, minor swelling, lacrimation and photophobia. There is no permanent damage and the effects usually disappear within six to twenty-four hours (Pitts, 1973).

7.3 All ocular damage is a function or both wavelength and intensity. A beam of shortwave ultraviolet radiation can ionize the oxygen molecules in air enough to conduct an electrical current (Scheps, 1997) without harming the cornea (Pitts, 1973). Puliafito et al. (1985) determined that the lowest per-pulse ultraviolet fluences that will ablate human corneas are 46 mJ cm^{-2} at 193 nm and 58 mJ cm^{-2} at 248 nm. Moreover, Trokel et al. (1983) found no evidence of thermal damage during 193 nm corneal ablation even at an energy level of 1 J cm^{-2}.

7.4 The foregoing high level of ocular safety is in direct contrast to that presented by an equally ionizing beam of visible light from a femtosecond-pulsed laser, as has been proposed by others. For example, at 193 nm, molecular oxygen has a two-photon absorption cross section, whereas through most of the visible range it has a six photon cross section. This means that the power required for ionization by such a visible-light bean is much too high for safety, and would easily burn the eyes of anyone in its path. Most importantly, it would penetrate the cornea and irreparably damage the retina. This result is impossible with the shortwave ultraviolet radiation used by the VDW because it is almost entirely absorbed by the cornea, and is emitted at a far lower intensity.

7.5 The transmission of the RF pulse by conduction rather than by plane waves is also a safety factor. This is reflected in the much higher safety standards for plane-wave radiation than for conducted currents. Even if the requirements were identical, a 300-microsecond exposure is too brief to affect anyone adversely. For example, Stull (1998) calculated that a single L-band pulse of similar length could be as intense as 1.3 kW cm^{-2} and still be within the requirement. set by the American National Standards Institute (ANSI/IEEE C95.1).

7.6 In summary, the VDW is inherently non-injurious to human beings. It is incapable of causing shock, disorientation or loss of consciousness. It may be directed toward potentially dangerous vehicles with no significant risk to either the occupants or bystanders.

8.0 HSV TECHNOLOGIES

8.1 HSV Technologies, Inc., is a research and development corporation which specializes in non-lethal weapons. We have three patents on the use of laser radiation to create electrically conductive paths through the air, and have performed successful proof-of-principle experiments at the University of California at San Diego. We are now conducting experiments on the ability of photo-ionized air to transmit a variety of electrical currents. Our principal effort is the development of a laser-based device to safely and effectively stop vehicles at a great distance. Although the distance will vary with the type of laser used, the theoretical range of our VDW is two kilometers.

8.2 Our web site is HSVT.org ---Inquiries and requests for further information should be e-mailed to:

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