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Wireless Power Transmission
The Future to All-Electric Transportation

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ABSTRACT

This is a new transportation technology that is being developed to utilize wireless power transmission for an all-electric transportation system. The pollution-free motive power network, for both public and private vehicles, will have the same range, power and maneuverability currently enjoyed by those vehicles powered with the internal combustion (IC) engine.

The vehicles will have an electric drive motor (or motors) with on-board energy storage (battery, flywheel, fuel cell, etc.) that will be replenished utilizing wireless power beams. The on-board energy storage reservoir will be required when the vehicle is not in the range of the power beam network. The goal is to retain all the positive attributes of the IC-engine driven vehicle while eliminating pollution and dependency on hydrocarbon fuels.

The recharge network is called the Remote Charging System for a Vehicle, or simply the Vehicle Remote Charge (VRC). The recharge of the moving or parked vehicle is accomplished with a microwave or laser power beam guided to the vehicle receiver with a beacon.

Current non-polluting vehicle designs have many issues that must be overcome before the systems will be accepted by the public. Vehicle range with quick recharge and maneuverability are two qualities the American public has come to enjoy and expect. The VRC will retain these qualities, providing the nation with an all-electric, non-polluting transportation system with the same freedom as today's IC-engine powered vehicles.

Issues about the environment, safety, and government regulations must be addressed, but technological advances with a discerning government can make this system a reality. These concerns will be discussed in the paper.

INTRODUCTION

A major cause of smog today is the high volume of vehicular traffic, especially in downtown city areas. Diesel and gasoline driven buses in public transportation as well as private vehicles spew out tons of pollutants daily. In conjunction with the abatement of pollution that an all-electric transportation system would realize, the defense industry is looking for a commercial market for the technology that it has developed over the years. This new transportation system will accomplish both these goals.

To date, the most reliable electric source for public transportation has been overhead tethered lines or on-ground tracks. But these greatly reduce the convenience of route changes and are at the mercy of small traffic pattern changes which can cause traffic tie-ups. The ideal electric bus would have a completely mobile energy source, such as a battery pack. But the limited range of a battery powered vehicle has diminished its use to only specific cases. In private vehicles also, the limited range of zero-pollution battery power has reduced the desirability of all-electric transportation. The electric transportation system proposed here will eliminate these problems (Parise, 1998).

The Vehicle Remote Charge system, utilizing the wireless power transmission technology, would first be established at passenger loading/unloading locations in downtown areas to replace high polluting public transportation systems where the vehicles travel on predetermined, scheduled routes. The completely mobile vehicle will receive pulsed remote charging for intervals of a few seconds up to several minutes as it comes within range of each charging station located along its route. The receiver will be mounted on the top of each vehicle with transmitters and aiming devices strategically mounted on poles along the route where passengers enter and exit the vehicle. These would be especially useful on crowded downtown city streets where the smog and fumes of the current diesel/gasoline-fueled IC-engine vehicles would be eliminated.

The system can start out small in downtown areas with public transportation, then expand into suburban and even rural areas. The VRC network is capable of growing nationwide as did the Rural Electrification Program back in the 1940s and 1950s, as conceived to bring electric power to all Americans. Now this same philosophy can be used to power electric vehicles on our highways.

The concept of conductorless power beams has been in existence since the turn of the century to augment the existing system of electrical conductors that are used to move large quantities of electrical power over long distances. In the mid-1960s a system was proposed to convert large quantities of solar energy into an energy beam that could be transmitted from outer space to the surface of the earth through satellite transmission (Brown, 1973). Once on earth, the energy beam would be converted to a usable voltage form that would be pumped into the existing electrical energy distribution grid for a clean, renewable energy source. Now this unique power transmitting technique will be applied in a terrestrial application for usage on our nation's highways and city streets.

Thus wireless power transmission can provide the nation with a limitless supply of pollution-free energy for both the electric power grid and powering our nation's transportation system. This system will simply augment currently available non-polluting electric vehicles that utilize fuel cells, batteries, flywheels and/or ultracapacitors, but have specific drawbacks that wireless power transmission can overcome: (i) battery driven vehicles have a limited range with extended recharge time between uses; (ii) flywheels and capacitors have limited storage time - the VRC will resolve these problems; and (iii) fuel cells show promise for mobility and convenience. However, on-board fuel storage and distribution are problems. The VRC can be used to convert water into hydrogen and oxygen directly on the vehicle in a closed or open system, solving this problem as well.

The VRC will be installed on existing power line (telephone) poles or on new stand-alone poles that would be in conjunction with the existing poles similar to wireless communication towers that are being constructed around the nation. Therefore the infrastructure for the network is already in place. And the VRC will obtain its energy directly from the electric power grid, providing convenience of installation and minimizing cost.

There are many facets and attributes of this non-polluting transportation system that must be considered to demonstrate that the VRC is a viable means for powering any electric vehicle; several will be discussed here. Order of magnitude examples will show the efficacy of the system. The primary concern during system operation, safety, will be addressed specifically with three technological design aspects that will challenge these uncertainties directly. Other issues including the environment and government regulations will be discussed.

SYSTEM OPERATION

Basic components of the system are shown in Fig. 1. When a predetermined level of discharge is noted in the energy storage unit by the vehicle's central processing unit in the Power Usage Monitor, a "translocator signal" (similar to a transponder signal) is triggered on the vehicle and transmitted to alert roadside power transmitters that a vehicle is present for recharge. The translocator signal identifies the vehicle as an end-user and signals the location and movement of the vehicle. The nearest Power Transmitting Unit is activated by the translocator signal, and a coded electronic link-up between the vehicle and the power transmitter commences. The Power Transmitting Unit then tracks the vehicle while following the translocator signal, aims the power beam at the power receiving antenna, and recharges the energy storage unit on the vehicle, i.e., fills the fuel tank (Parise, 2000a)..

This electronic communication and recharge takes place as the vehicle travels adjacent to pole mounted wireless power transmitters. Line-of-sight transmission is utilized between the stationary power transmitters and the power receiver on the vehicle to ensure safe, efficient power transmission to the vehicle. When out of range of the pole, the power beam is terminated. If more recharge is required, the translocator signal would continue and the next power transmitter would be activated by the vehicle. Charging is essentially passed on from pole to pole as the vehicle travels on the roadway.

Coded translocator signals identify each vehicle and provide signal security. The identification of the signal allows the power transmission unit to track a vehicle and trade signals among receivers/transmitters to minimize interferences and crossing of energy beams when multiple vehicles are present. Figure 2 illustrates the full system in operation.

If the electronic communication and/or power beam is interrupted by any object during transmission (tree branch, wire, pigeon, etc.), the power beam is terminated immediately. However, if the translocator beacon continues to be activated, then an electronic verification and link-up would have to be re-established before the power beam recommences.

Once the energy storage reservoir on the vehicle reaches the "Full" condition, the translocator signal is terminated and power transmission stops. When more replenishing is required, the translocator signal is once again activated, and so on.

The VRC will obtain its energy directly from the electric power grid poles on which the power transmitters are mounted. In fact, it would be desirable to have the system capable of maintaining contact with the vehicle from pole to pole. This would provide a constant power transfer from electric grid to vehicle, reducing (or eliminating) the required size of the on-board energy reservoir. This would also facilitate the convenience of a continuous link between the vehicle and the internet where the possibilities become endless (Parise, 2000b).

POWER TRANSMISSION

The efficient, reliable, safe transmission of power is critical to the success of the system. Both laser-based (Smakhtin, 1999) and microwave-based (Schlesak et al., 1988; Dickinson, 1975) systems have been proposed and studied.

The usage of wireless power transmission has been demonstrated for microwave and laser based systems. Microwave energy drove a helicopter aloft for 10 hours and powered a 30 kW energy beam across one mile of open desert (Brown, 1984). Laser power beams will be utilized for such diverse applications as removing space debris from orbit and satellite battery recharging; all aspects of the laser system have been tested and proven to be economical and viable (Burke et al., 1994).

Laser systems provide small aperture and receiver sizes that would be compatible with roadside and vehicle mounting. The major concern for laser based systems has been the attenuation of the beam during severe atmospheric conditions. For space-based systems this would be a problem due to the great distances involved (hundreds of kilometers), and therefore microwave energy would seem the beaming method of choice. However, for the VRC, the distances are such that laser power beams may also be possible.

To minimize the energy loss from the beam as it travels through the atmosphere, several transmission frequencies of the energy spectrum have been considered. For the RF energy beam, atmospheric attenuation is a minimum up to 4 GHz, even during a heavy rainstorm. Other windows of transmission exist at 35 GHz and 94 GHz (Potter and Kadiramangalam, 1991), although 135 GHz may also prove efficacious over the shorter distances utilized here. Microwave power systems designed to operate at these higher frequencies have the added advantage of operating with smaller apertures. That is, the transmitting antenna and the receiving antenna can be smaller.

For the Vehicle Remote Charge system, distances of 50 to 150 meters are all that would be needed. Therefore, taking into account additional power requirements for attenuation in the earth's atmosphere, many more RF bands become available, as well as the laser beam viability. A power laser beam system operating at 1060 nm has been proposed for use in remote rescue operations (Smakhtin, 1999). The laser energy beam has the added advantage of having very small transmitting and receiving antennae. The receiving antenna for a laser beam would be photovoltaic cells that would convert the laser beam into dc voltage (Schupp and Brown, 1992).

An order of magnitude example illustrating power requirements and energy consumed better indicates the efficacy of the proposed system. The amount of energy that can be transferred via wireless power transmission has been upwards of 400 kw. The efficiency of such energy transmissions has been estimated to be about 76%. Therefore, for the example, a conservative value of 180 kw will be received and stored in the energy storage unit of a private vehicle traveling on the interstate.

For the urban setting, consider Power Transmitting Units to be located every 0.5 km (inner city units may be much closer). The urban vehicle will be about 750 kg with a 28 kw (40 hp) electric motor (Riley, 1994). Traveling at 105 km/h (65 mph) the vehicle will require about 17.5 kw of electric power, allowing about 5% for utilities: lights, wipers, radio, etc. If the Power Transmitting Unit's line of sight of the vehicle is 50 m, the energy storage unit will receive 0.0857 kw-h of recharge energy. However, the vehicle will consume 0.0833 kw-h of energy traveling at this speed between the Power Transmitting Units. This is about 3% less energy used than is available from the Power Transmitting Unit. Thus the vehicle could travel down the highway without a net loss of stored energy.

Similarly it can be shown that a 46-passenger public transportation vehicle with a 195 kw (277 hp) electric motor can operate in city traffic successfully, picking up and discharging passengers utilizing the VRC under similar conditions (Parise, 2000a). Therefore the VRC is capable of meeting the power requirements for both private vehicles in suburban travel and public transportation in cities.

COMMUNICATION

The power beam is the prime source of recharge energy for the vehicle and the motivation for the development of the system, but the communication between the moving vehicle and the power transmitter will be the backbone of its successful implementation (Parise, 2000b). Three links of communication will be needed between the power transmitter and the vehicle: the power beam and translocator will acknowledge transmission and receipt of power to the vehicle; the aiming unit will track the translocator signal to follow the path of the vehicle to aim the power beam at the proper location; and the data link between the power transmitter and the vehicle for the exchange of information will utilize the translocator signal as the communication means. Although there are three distinct modes of communication that must be performed, doubling up on one or two of the modes can be achieved.

There are many combinations of signals (microwave, radio, laser, etc.) that the communication links can assume for the system. The basic components for power transmission include tracking, aiming and communication with the vehicle. Power reception on the vehicle requires a receiver, converter and storage unit along with the communication link to the Power Transmitting Unit.

The translocator or guide beacon provides the coded (and preferably encrypted) communication link between the Power Transmitting Unit and the vehicle and indicates the movement and position of the vehicle for the Power Transmitting Unit's tracking and aiming device to follow. This identifies the vehicle as a proper end-user of power from the power grid system, and identifies individual vehicles to individual power beam transmitters when multiple vehicles are being charged.

This is also the acknowledgement link to verify to the power transmitter that the power has been received on the vehicle. If power is not received, the link is broken, and no more power is transmitted until a correct link is established.

The translocator signal ensures that the power beam travels to the intended vehicle (target) and stops transmission if the power beam path is crossed by any object.

Reliable communication between the moving beam-charged vehicle and the stationary power transmitter is critical to the efficient and secure transfer of energy. However, even more important will be concern for the safety of the people around the power beam.

SAFETY

Public sentiment for a pollution-free and renewable energy transportation system notwithstanding, uncertainty over wireless power beams must be overcome. The safety of the power transmission system is an all-important subject that must be considered if this transportation means is to be a serious contender for future use in this country. Specific design features will ensure the safety of vehicle occupants, pedestrians, animals and inanimate objects that will exist daily in and around the VRC locale. These include a coded and/or encrypted link-up, power beam transmission only during active two-way or "handshake" communication, and line-of-sight (or an optical communication link) energy transfer between the power transmitter and the vehicle; and the location of the translocator signal central to the vehicle power receiver (Parise, 2000b).

Several other designated safety and security systems are also being developed to ensure the safe transfer of power. Probably the most prevalent safety feature of the system will be that the actual energy transmission will take place in small bursts or packets of energy.

This is very important: each short burst of energy must be acknowledged by the vehicle requesting the energy from the power transmitter. Without the correct acknowledgement for reception of each energy packet from the vehicle, no more energy will be sent by the power transmitter without a proper relink of communications.

The bursts can be sized so that if a person were struck by one, two or several of these energy packets or bundles, there would be no effect on the person. In this way, an acknowledgement signal from the vehicle for each small burst of energy received must be sent to the Power Transmitting Unit before more energy is transferred. This communication link and energy transfer take place at the speed of light (3.000 x 10^8 m/sec).

Consider, for example, a 450 kw energy beam used to recharge a traveling vehicle. Note that upwards of 450 kw of energy are considered practical at this time. The distance of communication and energy transmission is 150 m, either side of the Power Transmitting Unit. Therefore guidance and energy beam travel time is a maximum of 500 ns between transmitter and receiver for this distance. For a vehicle traveling at 105 km/h, the vehicle will travel 15 microns in 500 ns.

Allow one burst of energy to last 1,000 ns, then the power transmission beam is shut down, waiting for verification from the vehicle receiver. The response time for verification of reception of the energy will be a maximum of 500 ns. Then another burst of energy is transmitted, etc. As the vehicle moves closer to the Power Transmitting Unit, the response time for verification of receipt of the energy beam will lessen, therefore more energy will be transmitted. And as the vehicle moves away, less energy will be transmitted.

One burst of energy at the 450 kw level for 1,000 ns is 0.450 w-s. This is equivalent to being exposed to 1/220 the energy of a 100 w light bulb for 1 s. Without the verification signal from the translocator signal, this is the maximum energy to which a human being or inanimate object would be exposed. Therefore the operation of the wireless power beam will be inherently safe - the warmth of a flashlight is all one would receive.

A second primary safety feature for operating the wireless power beam in the atmosphere is a means to secure the region traversed between the Power Transmitting Unit and the vehicle to ensure no power is sent while an object crosses the beam path.

Figure 3 shows the power beam enveloped by a laser beam array that monitors the air space between the vehicle and the power transmitter as the power beam is transmitted. If this array is violated during power transmission, the communication link is broken and the power beam is shut down to prevent injury or damage to any object in its path. Once the region is clear, a relink of communication is required with a safe commencement of power transmission.

A third safety guard for people moving about the outside of a parked or standing vehicle being charged is shown in Fig. 4. Here motion and/or induction detectors can secure the area directly above and around the power receiver. In this way a hand or package inadvertently placed on the vehicle will not be injured or damaged by the power beam.

Other hardware interlocks are also being developed to ensure public safety while the power beam is being transmitted. These safety measures will provide a positive, secure energy transfer between the power source and the vehicle, while instilling in the public a confidence that will be necessary.

REGULATIONS

In the United States, the Federal Communication Commission (FCC) regulates what can be transmitted through the airways. This includes assigning broadcast bandwidths and the power level of the signal. Currently there are no bandwidths available for wireless power transmission and there are limits on the power levels that are allowed in the atmosphere. Both of these issues must be addressed by either the FCC and/or the US Congress.

There is no doubt that bandwidths and power levels must be assigned and investigated to accommodate the use of wireless power transmission in vehicle operation. Cooperation at both the state and federal government levels must be attained for the implementation of the system.

The federal government must commit to an environmental clean-up to eliminate both thermal pollution and emission pollutants that are a burden on our environment. They must also commit to a renewable energy supply that will provide the motive power to maintain the national transportation infrastructure.

Part of the regulation process will require a high degree of education to assure the public that there will be no harm from the use of these energy modes in the atmosphere. Laser surgery is performed inside the human body with no adverse effects. Mankind is surrounded by RF waves constantly with no known effects. Safety measures will ensure that the power beam will be transmitted directly to the power receiver and absorbed virtually 100%. Therefore those people living and working around this means of energy transfer should be comforted to know that they will have no interaction with the energy beam.

CONCLUSIONS

There are many challenges for the technical community to ensure the safe, efficient and reliable transfer of electric power from stationary power transmitters to moving vehicles. However, much military and commercial hardware exists today for this application of an as yet unused technology.

The suitability of the power beam charging system will depend on the efficacy of the communication network established prior to and during the transfer of energy.

Wireless communication is the technology of today. Wireless power transmission will be the technology of tomorrow in transportation. This is a non-polluting, renewable energy source for a transportation system that will provide all the conveniences of today's vehicles, with none of the problems.

There are many schemes and ideas for transportation in the public domain that are trying to gain a foothold. The VRC is so versatile that it can be utilized as a means of replenishing onboard energy storage for all the pollution-free methods of powering an automobile known today: batteries, flywheel, ultracapacitor, fuel cell, hybrid-electric, etc. Most all of the necessary materials, technology, hardware and know-how are available today, with the added benefit of utilizing military hardware and expertise in a commercial application, especially in public transportation.

The benefits are well known that an all electric transportation system can make in reducing pollution, the national security issues that arise because of our dependence on foreign oil, and the reality of one day running out of this precious resource. And the VRC is a practical transportation means that utilizes technology available today that will allow people the freedom, power and mobility they currently have in operating their vehicles. This is what will be achieved with this new system.

The world needs a new way to travel that is safe and pollution-free, and has the same range and mobility currently provided by IC-engine powered vehicles; the VRC will meet these requirements.

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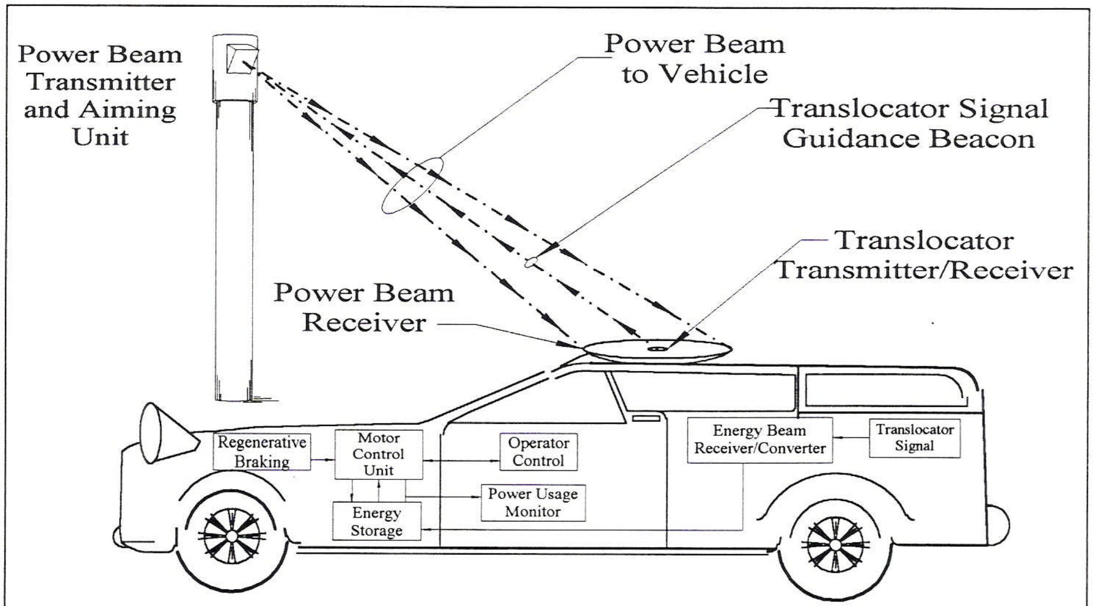

Figure 1: All-Electric Vehicle Components

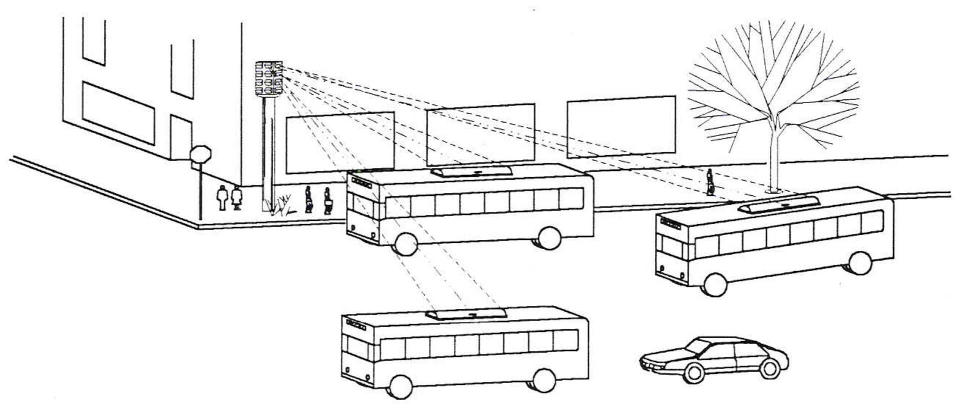

Figure 2: Wireless Power Beam Network

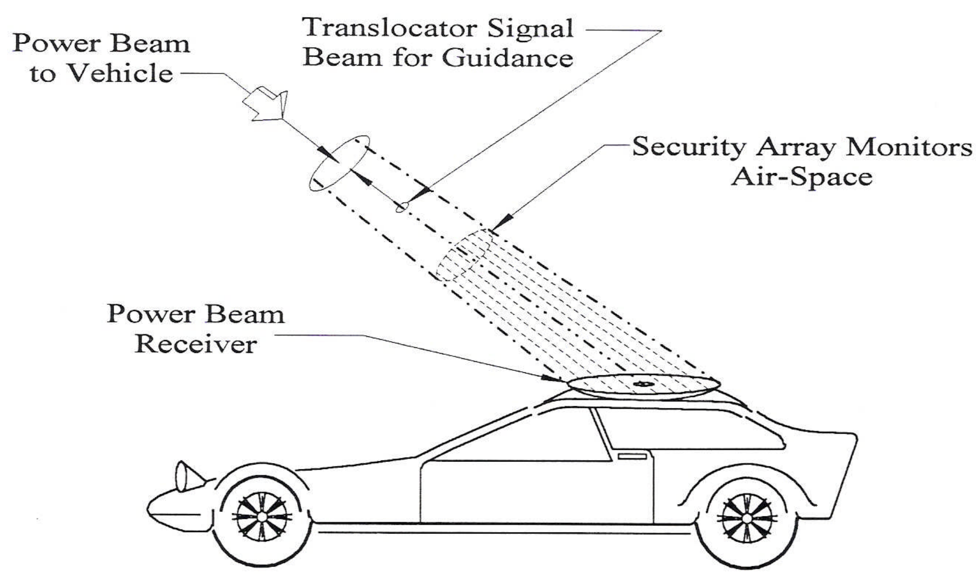

Figure 3: Secure Air-Space for Wireless Power Beam

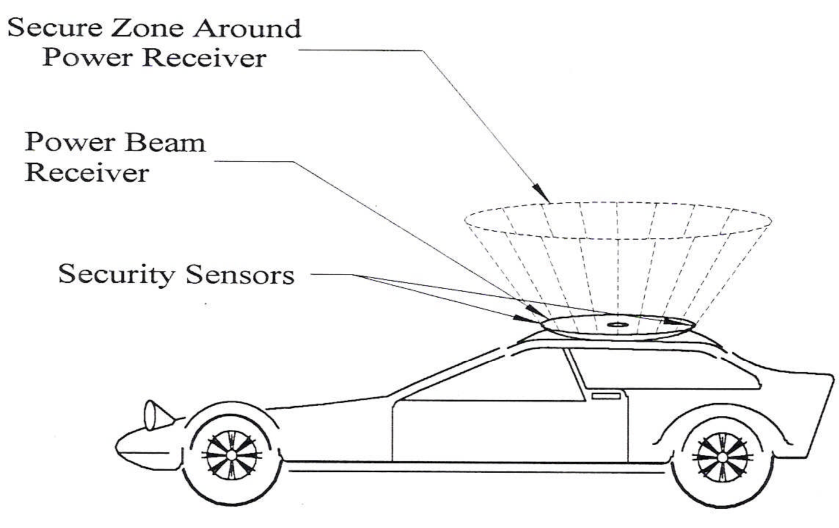

Figure 4: Secure Zone Above Vehicle