Future all-electric transportation communication and recharging via wireless power beam

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ABSTRACT

Pollution-free transportation in the new millennium will be provided by the recharging of a vehicle's non-polluting on-board energy storage unit (batteries, flywheel, ultracapacitors, etc.) as the vehicle travels unrestricted down the roadway. The backbone of this new transportation system will be wireless power transmission using laser or microwave energy technology to replenish the energy storage unit on these non-polluting vehicles while maintaining an all-important communication link for safety, security, data transmission, etc. The proposed system allows the same freedom of movement currently enjoyed by Americans with the internal combustion engine powered automobile. The all-electric vehicle transportation system has the same power, maneuverability and range capability provided by today's vehicles. The many laser-based tracking and communication challenges proposed by this new system along with vehicle configurations for energy conversion in this non-polluting transportation system will be discussed. The main concern during system operation, safety, will be addressed with specific design considerations.

1. INTRODUCTION

This is a new transportation technology that is being developed to provide pollution-free motive power for both public and private vehicles while having the same range, power and maneuverability currently enjoyed by those 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.) as a reservoir when not in the range of the recharge network. The goal is to retain all the positive attributes of the IC-engine driven vehicles while eliminating pollution and dependency on hydrocarbon fuels.

The charging of the vehicle can take place while the vehicle travels on the highway or is parked curbside. The recharging will entail sophisticated guidance systems to track, aim and guide the energy beam to the vehicle in a safe, reliable, efficient, nationwide network. Coded and/or encrypted laser (or microwave) power beams will be in continuous communication with the traveling vehicle to ensure safe, secure power transmission between the power transmitters located along the roadside and the vehicle. This communication/power network combines optical wireless communication with wireless power transmission to provide pollution-free transportation and a continuous datalink to the traveling or stationary vehicle.

The transportation/communication system incorporates technology from both the automotive and defense industries to combine the two in a commercial venture. 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 technologies that it has developed over the years. This nationwide transportation system uses defense-based military technology in a commercial application, benefiting the economy and assuring economic growth into the new millennium.

This new system is especially suited for mass transportation, eliminating the major cause of smog-producing

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traffic from congested city streets. The system can start out small in downtown areas with public transportation, then expand into suburban and even rural areas. The wireless power transmission network will be established along the roadside on existing power line (telephone) poles or new stand-alone poles similar to the many wireless communication towers now being constructed. A continuous communication link between the passenger vehicle and transportation network can keep the driver abreast of traffic and weather conditions, safety vehicles operating on the route, updated road construction, etc., while providing passengers with "hardwire" data links to offices or commerce centers. Both public transportation vehicles and private automobiles will reap the benefits of this unique technology usage. The recharge system can be used with electric or hybrid-electric vehicles.

The recharge network is called the Remote Charging System for a vehicle [1], or simply the Vehicle Remote Charge (VRC). This system replenishes on-board energy storage in a moving (or parked) vehicle via wireless power transmission using a microwave or laser energy beam.

The concept of transmitting electric power using a conductorless method has been in existence since the turn of the century. Since the mid-1960's research has concentrated on bringing solar converted electrical energy from satellites to earth-based receivers with wireless power beams, then converting into AC power for use in the electric power grid [2]. Unfortunately, the cost of such a large scale, integrated energy source thus far has not been able to compete with cheaper hydro-carbon fueled systems.

Although the efficacy of wireless power transmission has been proven in several tests [3,4], there needs to be a practical, "down-to-earth" application to demonstrate the usage of this reliable energy source. The future may one day include electric power from space using microwave or laser beams, but the best way to prove the feasibility and improve the technology is to start on a small scale in a terrestrial application. The VRC is well suited to accomplish this end.

Also, the encouragement and availability to utilize military hardware and technology in commercial applications will be instrumental in implementing the wireless power transmission network in the automotive and electric power industries. Much of the technology has been declassified and has been around for decades waiting to be used in the public sector. The VRC will meet this need as well.

A major goal for the automotive industry is to allow people the same freedom, power and mobility they currently have in operating their vehicles. Range and recharge time are key attributes in the successful transition from the existing mode of transportation to one that is pollution-free; the VRC is clean, utilizes a renewable energy source, and provides the conveniences enjoyed by today's automobiles. In this application, the VRC is a practical means to utilize and prove the effectiveness of technology that is available today.

Current non-polluting vehicle designs have many issues that must be overcome before the systems will be accepted by the public. Vehicle range and quick recharge are two qualities the American public has come to enjoy and expect. Battery driven vehicles have a limited range of 100-150 miles before a recharge is required -- a process that can take up to 16 hours; flywheels and capacitors have unacceptable storage times - three to five days; and fuel cells have storage and distribution problems for either pure hydrogen and/or other hydrocarbon fuels.

The VRC solves all these problems by replenishing on-board energy storage as needed while the vehicle is traveling or parked, utilizing any one of the all-electric storage devices currently available, with none of the limited range, replenish time or distribution problems.

The need for all-electric transportation now and in the foreseeable future is obvious. The pollution problems, concerns about global warming, national security issues that arise because of our dependence on foreign oil, and the eventual depletion of a natural resource all point in the direction of a clean, reliable, renewable energy source. Wireless power transmission can solve these problems. Both in a terrestrial application for an immediate vehicle transportation system, as well as in a long-term solution for energy beamed from satellites, wireless power transmission will be the key.

Of major concern will be safety issues: reliable transmission from the power source to the vehicle receiver and the coexistence of power beams in the atmosphere with humans, animals and inanimate objects. Communication between the power transmitter and the vehicle, plus sensing or monitoring along the power beam's full distance, will be the primary objective to ensure the safe usage of this power system. Optical wireless communication will be fundamental in assuring this safe transmission of power.

2. SYSTEM OPERATION

Basic components of the system are shown in Figure 1. When a predetermined level of discharge is noted in the energy storage unit by the vehicle's central processing unit (CPU) 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 [5].

This electronic communication and recharge takes place as the vehicle travels adjacent to the telephone pole (or stand-alone power pole), having a wireless power transmitter mounted on it. 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. The identification of the signal allows the power transmission unit to track a vehicle and trade signals among receiver/transmitters to minimize interferences and crossing of energy beams when multiple vehicles are present. Figure 2 shows the pole-mounted network with public and private vehicle operation. In addition, coded translocator guide beacons may allow user identification to electric power companies for billing purposes.

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. This is an important safety feature of the system.

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 the required size of the on-board energy reservoir, and a convenient means for connecting directly to the internet through phone or cable lines.

That is, the data link between the power transmitter and the traveling vehicle can include information off the WEB directly to the vehicle for driver travel information or passenger correspondence while traveling. Once this communication link is established between the traveling vehicle and land-based power transmitters, the possibilities become endless.

3. POWER TRANSMISSION

The efficient, reliable, safe transmission of power is critical to the success of the system. Both laser-based [6] and microwave-based [2] systems have been proposed and studied. 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 in the atmosphere. For space-based systems this would be a problem due to the great distances involved (hundreds of kilometers), therefore microwave energy has been the beaming method of choice.

Atmospheric attenuation of microwave beams is a minimum up to 4 GHz, even during a heavy rainstorm. Beam spreading becomes a problem for microwaves as the transmission distance increases, but systems designed to operate at higher frequencies have the added advantage of operating with smaller transmitting and receiving antennae. Other windows of transmission exist at 35 GHz and 94 GHz. Higher frequencies can alleviate the problem somewhat, but then beam absorption in the atmosphere becomes a problem.

However, in this automotive application, with the distances being on the order of 15 to 100 meters, many of these problems are resolved or non-existent. Thus the choice of power beam at this time would be microwave with laser as a viable option. But in this unique application of wireless power transmission, the primary concern becomes tracking the moving vehicle as it travels on the roadway and the safety of humans and objects in the surroundings.

Hence the safety of operation and the security of the power beam must be unequivocal in all instances for this application. This is the challenge for implementation of the VRC: continuous monitoring of the power beam between the vehicle receiver and the power transmitter. Absolute minimum power beam loss (stray energy) that would trigger an immediate shutdown of the power system with no harm to anyone or anything in the surroundings must be assured.

To date, upwards of 400 kw of microwave energy has been transmitted via wireless power transmission. Order of magnitude studies have shown that a vehicle traveling on the highway or a city bus en route can be supplied sufficient energy to maintain a full charge in the vehicle's energy storage unit with power transmitters 1km apart or more [5]. Therefore, with power transmitters on adjacent poles in city driving, continuous power can be supplied the vehicle with minimal or even no on-board energy storage. Again this would facilitate the addition of internet access on public transit vehicles.

The energy density of wireless power beams that have been transmitted with current technology is more than adequate to drive today's automobiles, SUVs, minivans, etc., as well as large city buses. Therefore the aiming and tracking of the moving vehicle, the security and integrity of the traveling power beam in the atmosphere, and the operation of the system around humans become safety and security issues; all depend on the competence, effectiveness and efficiency of the communication system between the vehicle and the power transmitter.

4. 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. 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. At this time only the most likely or preferred will be presented to better describe the operation of the system and discuss some of the parameters involved in these links.

Figure 3 shows a schematic diagram of the power beam transmitter and vehicle receiver. 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.

For continued power beam transmission, the communication signal from the vehicle must acknowledge receipt of the energy on-board. This is crucial for safe operation of the system. The translocator "turns on" the power beam. But if there is no acknowledgement of the energy on the vehicle, the power beam will not continue. This acknowledgement could be a function of the Communication Beam or the Guide Beacon.

The Communication Beam provides the coded (and preferably encrypted) communication link between the Power Transmitting Unit and the vehicle. This link 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 Guide Beacon indicates the movement and position of the vehicle for the Power Transmitting Unit's tracking and aiming device to follow. The Guide Beacon is shown as a thin, columnated beam that may be more suitable utilizing a laser beam. This serves two purposes: (1) the beam originates from the center of the power receiver so the power aiming device can focus on that single point to direct all the energy, hence striking the center of the receiver; and (2) the guide beacon will also act as the beam path security sensor for whenever an object crosses between the power transmitter and the vehicle receiver. If the Guide Beacon is interrupted by a tree branch, pigeon, wire or whatever, power transmission will be halted until the object has cleared from the path of the power beam.

Striking the center of the receiver is a must for the efficient transfer and absorption/conversion of microwave beam back to electrical energy for storage on the vehicle. Lost or stray energy is wasted energy that can be dangerous as well.

Both the Communication Beam and the Guide Beacon emanate from the translocator unit. Therefore in reality these can be the same signal. Combining the function of the two signals into a single signal would suit the purpose of both signals: a secure communication link between the power transmitter and the vehicle, and safe power transmission between the two. That is, if the link between the power transmitter and the vehicle is lost for any reason, power transmission is terminated. Thus a re-link of communication must be reestablished prior to recharge continuing. Therefore the translocator signal is critical to the safe operation of the system. 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.

The size (diameter) of the translocator signal will determine the size of the object that can be detected when the Guide Beacon is interrupted. Therefore the Guide Beacon would more suitably be a laser beam or possibly several laser beams to secure a larger path for the power beam. Specific design schemes are currently being developed to ensure the safe transmission of power in the atmosphere.

Using a laser beam for the combination Communication Beam/Guide Beacon as the translocator signal expands the opportunity for utilizing optical communication in a unique application. The optical link would have to be coded to avoid confusion when multiple vehicles are present, to prevent theft, and to ensure safe usage. This is another area that is currently being researched.

A fourth link may be added to ensure positive communication between the vehicle and the internet as the system becomes more prevalent. This could be a microwave signal acting in conjunction with the translocator signal, or a stand-alone signal designated for internet use only.

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.

5. SAFETY

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. Several inherent design features will ensure the safety of vehicle occupants, pedestrians, animals and inanimate objects that will exist daily in and around the VRC locale. The communication system and specific checks within the system will be the primary safeguards that ensure the integrity and safe operation of the network.

First, the coded and/or encrypted link-up and handshake between the power transmitter and the vehicle will prevent improper usage or wrongful responses of the system. This is for both safe operation and potentially mischievous tampering that may be attempted. The tampering could result in injury or theft of energy from the electrical grid.

Secondly, the location of the translocator signal, as discussed previously, guides the power beam to the safe, proper location on the vehicle receiver. The power aiming device follows and beams only at this location in the receiver.

Third, the power beam is transmitted only during active, two-way communication between the vehicle and the power transmitter. Once this two-way link is interrupted, power transmission is terminated immediately. No excess or wayward energy is transmitted.

Fourth, an optical communication link between the vehicle and the power transmitter will be used. This provides a positive, secure, line-of-sight energy transfer between the power source and the vehicle. Figure 4 illustrates the directline communication that will exist between the vehicle and the power transmitter. This will facilitate monitoring the air space between the vehicle and the power transmitter to ensure power beam shutdown should an object travel in this area when the power beam is activated.

Several other designated safety and security systems are also being studied. These would include: specific hardware to shut down the power beam if no vehicle were present or if the designated vehicle were not receiving the power beam after a short time; power beam shutdown if damage to the support pole should occur during power transmission; and a means to monitor the region traversed between the power transmitter and the vehicle to ensure no power is sent while an object crosses the normal path of the beam [7].

Therefore safe operation of the VRC will depend on several safety systems that are under development as well as the capability of the power transmitter and the vehicle to maintain a secure communication link while the transmission of power takes place. Once the safety checks are compromised or the communication link is interrupted, for whatever reason, the power beam will be terminated.

6. 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 new 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.

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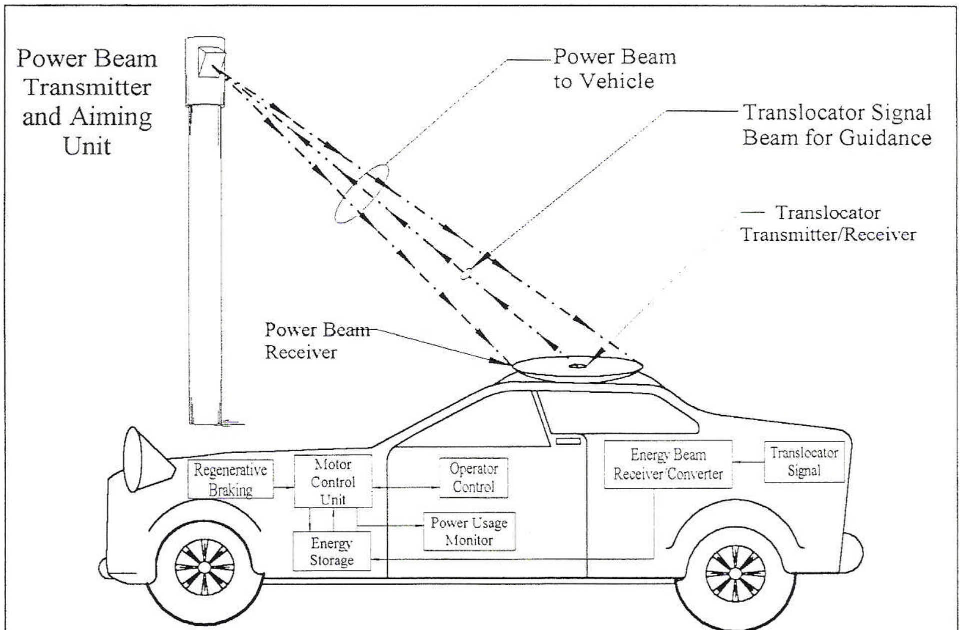

Figure 1: All-Electric Vehicle Components

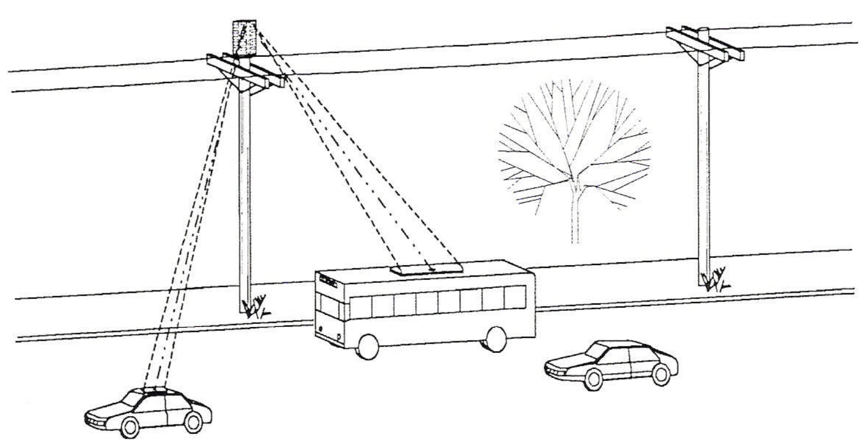

Figure 2: Wireless Power Beam Network

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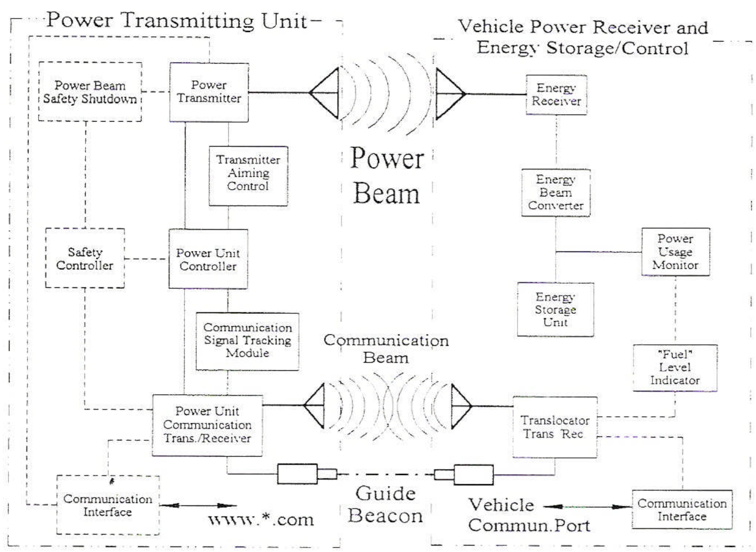

Figure 3: Power Beam Transmitter and Vehicle Receiver Control Scheme

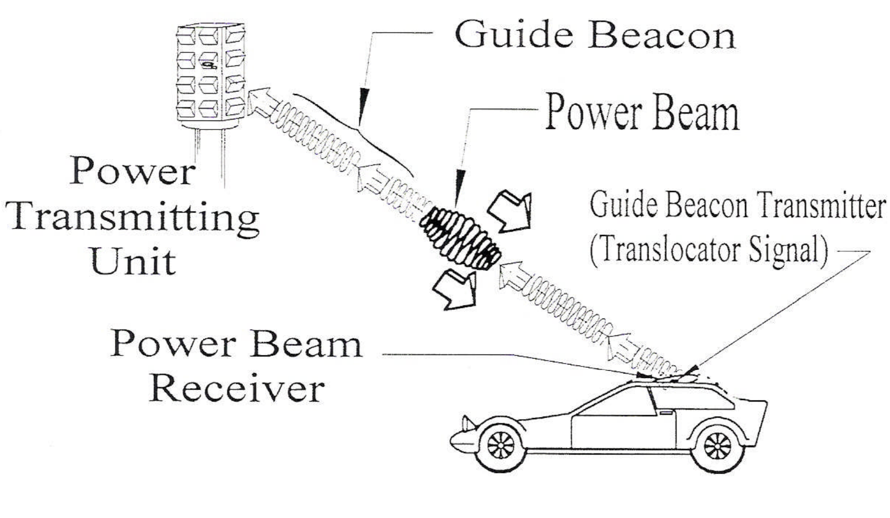

Figure 4: Line-of-Sight Communication Link

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