

# Wireless Power Transmission to UAV using LASER Beaming

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## Abstract

Laser power beaming uses electricity from a common power source, such as the electrical grid or a portable generator, and converts it into light via a laser. This laser beam is then shaped with a set of optics, and directed to a remote photovoltaic receiver. The photovoltaic receiver intensity is equal to laser beam intensity to minimize the time of recharge. One of the main limitations of Unmanned Aerial Vehicles (UAVs) is poor endurance. VTOL (Vertical Take-Off and Landing) vehicles such as helicopters, quadcopter face even greater endurance challenges due to their inherently less efficient nature as compared to fixed wing aircraft. Laser power beaming enables unlimited flight endurance and in flight recharging of electric UAVs. A UAV is the target where the optical tracking is done by beam riding method here the laser beam is used as both director (guidance) and the power source for recharge UAVs.

*Keywords*-Wireless, UAVs, Optical, Photovoltaic effect, Intensity, Beam riding, Recharge.

## I. INTRODUCTION

Although wireless power is a promising technology for the 21<sup>st</sup> century, the concept is not new. In fact, rudimentary tests demonstrating the transmission of electrical energy without wires were conducted more than 120 years ago by Nikola Tesla. In 1968 American scientist Peter Glaser proposed using wireless power beaming to transmit solar power from space to Earth. Space-based solar power plants would be much more efficient than Earth-based, and they would generate power nearly 24 hours per day. Satellites with solar panels would be placed in space, and power would be beamed to the earth using microwaves, which would then be converted to electricity and transferred to power grids.

Power transmission via radio waves can be made more directional, allowing longer distance power beaming with shorter wavelengths of electromagnetic radiation, typically in the microwave range. A rectenna may be used to convert the microwave energy back into electricity. Power beaming by microwaves has the difficulty that for most space applications the required aperture sizes are very large due to diffraction limiting antenna directionality. For

example, the 1978 NASA Study of solar power satellites required a 1-km diameter transmitting antenna, and a 10 km diameter receiving rectenna, for a microwave beam at 2.45 GHz.

The Rayleigh criterion dictates that any radio wave, microwave or laser beam will spread and become weaker and diffuse over distance; the larger the transmitter antenna or laser aperture compared to the wavelength of radiation, the tighter the beam and the less it will spread as a function of distance (and vice versa). Smaller antennae also suffer from excessive losses due to side lobes. However, the concept of laser aperture considerably differs from an antenna. Typically, a laser aperture much larger than the wavelength induces multi-moded radiation and mostly collimators are used before emitted radiation couples into a fibre or into space.

While this paper concentrates on laser energy transmission, and its performances and parameters the newly emerging wireless energy transmission technology.

## II. WIRELESS POWER TRANSMISSION (WPT)

Wireless energy transfer or wireless power is the transmission of electrical energy from a power source to an electrical load without interconnecting manmade conductors. Wireless transmission is useful in cases where interconnecting wires are inconvenient, hazardous, or impossible. Laser power beaming is the wireless transfer of energy (heat or electricity) from one location to another, using laser light. The basic concept is the same as solar power, where the sun shines on a photovoltaic cell that converts the sunlight to energy. Here, a photovoltaic cell converts the laser light to energy. The key differences are that laser light is much more intense than sunlight, it can be aimed at any desired location, and it can deliver power 24 hours per day. Power can be transmitted through air or space, or through optical fibers.

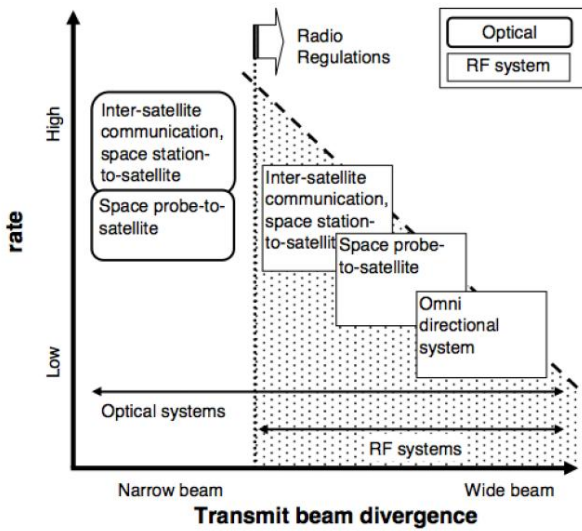


Figure .1 Beam divergence rate

The above graph (figure 1) shows the five orders of magnitude frequency divergence determine the sizing of the emitters and receiving devices as well as the energy density of the transmission beam according to standard optics principles. Similar to the higher power rate achievable with optical power links, laser energy transmission allows much higher energy densities, a narrower focus of the beam and smaller emission and receiver diameters.

### III. LASER BASED EXPERIMENT

This section presents an overview of the LASER-based power transmission experiment and its method of implementation.

#### A. Laser power beaming

A laser is a device that emits light (electromagnetic radiation) through a process of optical amplification based on the stimulated emission of photons. The emitted laser light is notable for its high degree of spatial and temporal coherence. When an electron absorbs energy either from light (photons) or heat it receives that incident quantum of energy. The light generated by stimulated emission is very similar to the input signal in terms of wavelength, phase, and polarization. This gives laser light its characteristic coherence, and allows it to maintain the uniform polarization and often monochromaticity established by the optical cavity design.

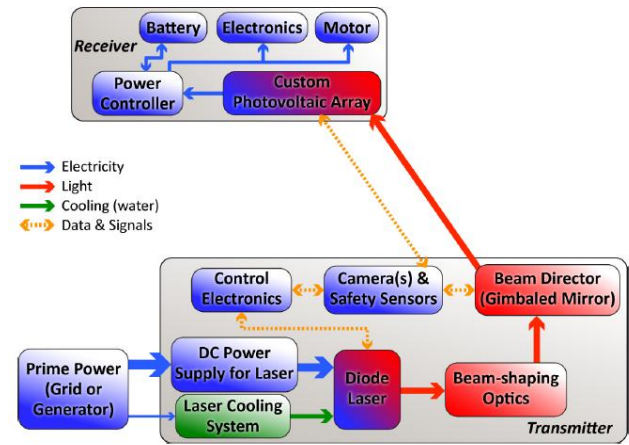


Figure 2 Functional block diagram of laser power transmission

#### B. Photovoltaic Cell

Photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell (in that its electrical characteristics e.g. current, voltage, or resistance vary when light is incident upon it) which, when exposed to light, can generate and support an electric current without being attached to any external voltage source

The Photovoltaic cell works in three steps:

- Photons in light hit the solar panel and are absorbed by semiconducting materials, such as silicon.
- Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of photovoltaic cells, the electrons are only allowed to move in a single direction.
- An array of solar cells converts light energy into a usable amount of direct current (DC) electricity.

#### C. High-power and high-efficiency laser diode

Solid-state lasers are the preferred source when single-mode output, high-peak power and a wide range of repetition rates and pulse widths are required from the laser. In particular, solid-state laser sources emitting from 1500-nm to 2100-nm have wide application in eye-safe range finding, LIDAR, infrared countermeasures, medicine, dentistry, and

others. The historically most expensive and fragile element of the pumping scheme for these long wavelength solid-state lasers, the diode laser pump sources, have matured to where resonant diode pumping of the solid-state is now a realistic alternative to the more conventional Nd-based systems.

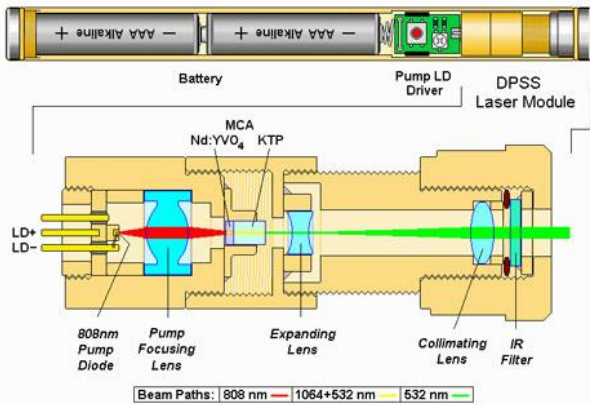


Figure 3 Yttrium orthovanadate (Nd:YVO<sub>4</sub>) solid-state LASER

To achieve the desired improvements in long-wavelength semiconductor diode lasers in peak power, special attention must be paid to designing the laser for peak electrical-to-optical (E/O) conversion efficiency. Improved E/O efficiency permits the diode laser to operate at higher output powers for a given active area temperature. High E/O efficiency lasers will also operate cooler at a given output power reducing the need for costly and heavy cooling capability. Hence, the design process emphasizes E/O efficiency as a method of achieving higher power.

Auger recombination is a many-body phenomenon where in a typical event an electron recombines with a hole, not by emitting a photon, but by transferring the energy to a third particle, usually an electron. The excited carrier will then, on average, recombine outside the active region, releasing its energy as heat. Auger then causes three problems, each detrimental to the functioning of the laser:

- An electron-hole pair is lost without radiating a photon .
- Another electron typically escapes from the active region.
- Heat is generated in or near the active region (increasing the likelihood of more Auger processes).

Therefore, minimizing Auger is one of the most important tasks in the proper design of high-power, high-efficiency lasers. While Auger recombination is present in all diode lasers it is most pronounced in the longer wavelengths of the InGa AsP- and AlIn GaAs-material systems on InP substrates. The less energetic band gap separation of the conduction and valence bands causes the bands to ‘push apart’ harder than in materials with larger band gap energies. Auger recombination requires that both energy and momentum be conserved. The more sharply bent bands of the smaller band gap material make it highly more probable that a set of particles can be found such that the Auger event can occur while conserving energy and particle momentum.

The diode laser pumping of solid-state lasers emitting in the 1500-nm to 2100-nm range places stringent demands upon the diode lasers. Ever higher peak pump powers are demanded of the > 14xx-nm diode pump lasers as a consequence of the three or quasi-four level nature of the solid-state lasers. The nature of three or quasi-four level lasers implies larger threshold power requirements than those found in true 4-level systems. Higher pump power is best achieved by increasing the power per laser bar (or, equivalently, higher bar brightness). Simply increasing the number of low power bars in the pump stacks adds considerable cost and complicates the efficient coupling of laser energy into the solid-state medium.

#### IV COMPONENTS FOR WPT

The Primary components of Wireless Power Transmission are prime power generator, beam shaping optics, beam director and power controller.

##### A .Transmitter

Lasers generate phase-coherent electromagnetic radiation at optical and infrared frequencies from external energy sources by preferentially pumping excited states of a “lasant” to create an inversion in the normal distribution of energy states. Photons of specific frequency emitted by stimulated emission enter and are amplified as standing waves in a resonant optical cavity. The most efficient DC-to-laser converters are solid-state laser diodes commercially employed in fibre optic and free-space laser communication. Alternatively, direct solar-pumping laser generation has a major advantage over conventional solid state or gas lasers, which rely on the use of electrical energy to generate laser oscillation since the generation of electricity in space implies automatically a system level efficiency loss of roughly

60%. To generate a laser beam by direct solar pumping, solar energy needs to be concentrated before being injected into the laser medium. The required concentration ratio is dependent on the size of the laser medium, the energy absorption ratio and the thermal shock parameter.

All lasers can be used for transmitting power. Using the general conditions as described in figure 3 specifically applied for the selection of lasers, these imply in addition constraints related to the efficiency of the laser generation process, and the efficiency of the absorption and laser-to-electric conversion processes. Specifically for direct solar pumped lasers, there are several types of materials suitable as laser medium: From the standpoint of resistance to thermal stress, sapphire seems the optimal material for the laser medium. Since large sapphire crystals are very difficult to produce, most concepts rely on YAG (yttrium aluminium garnet) laser crystals. Concerning the required energy densities, solar energy compression ratios of a few hundred times are required for YAG lasers.

**B .Receiver**

Designing and building a wireless power transfer system takes some determination, and doing the same such that it can be carried and powered by a UAV is at least slightly more arduous. Some challenges are managing added weight to stay within a UAV's payload, using the on board battery to drive the solar power panel circuit, designing a receiver board that can optimize power transfer from a dynamically changing system, and stabilizing the UAV to augment effective power transfer. It is possible to land and transfer power in some environments, however, recharging source located on hazardous terrain or underneath bridges can make landing unfeasible , so the overall system is designed and followed by in depth information on the power transfer coils, helicopter, and receiver node.

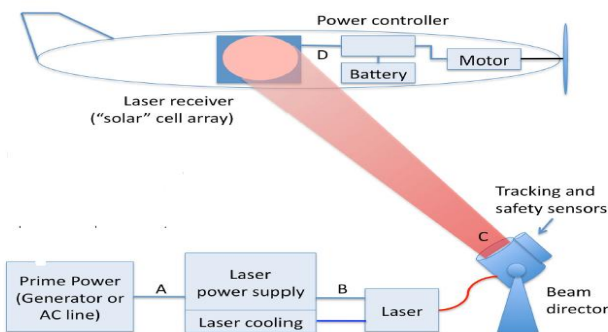


Figure 4 Laser power transmissions

For ground-dwelling and low-flying animals, a series of motion sensors around a laser transmitter can detect any motion and shut off the laser before the creature can get too close to the power beam. There is a need for protection from eye hazards for high-flying animals (including humans in aircraft) between the transmitter and receiver, and also those beyond receiver if it does not capture all the light. The multi-layered safety system will include hardware like a scanning LIDAR that will shut off the system as soon as an animal or aircraft approaches the beam, and then quickly reacquire the target when it is clear.

**V PERFORMANCE AND LIMITATIONS**

Both specific power (W/kg) and energy density (J/kg) are critical for many remote power applications, UAVs in particular. For a given power draw, greater specific power allows for more payload weight on a UAV. Similarly, higher energy density implies longer endurance, which is one of the biggest requests by users of UAVs. The figure below shows an approximate comparison of specific power and energy density for batteries, combustion engines, solar electric systems, and laser power receivers. Wireless power systems effectively leave the energy source on the ground, where power is easier and cheaper to generate. Solar electric systems do not technically have an infinite energy density because batteries have a limited lifetime, so the endurance of a solar electric based system will depend on the number of charge/discharge cycles (daily, or more frequent, for sunlight-based systems) that the battery can support. In contrast, laser power does not need to turn off at night and can power the receiver continuously, with a battery required only during beam interruptions. Batteries or other energy storage are required at the receiver to handle beam interruptions.

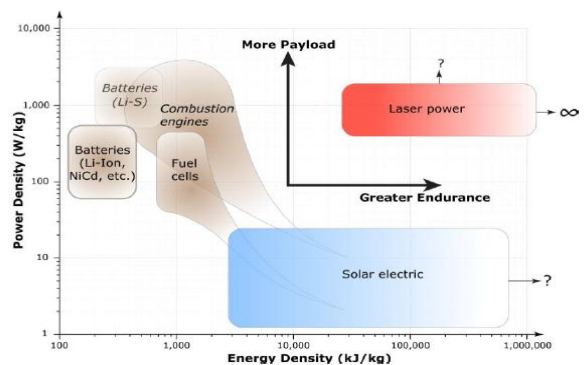


Figure 5 Power density of laser light

Range is also an important consideration and is limited primarily by source irradiance ( $W/m^2$ ) and source aperture size. Atmospheric scattering and absorption can degrade performance, but for many applications the beam has a strong vertical component or is at a reasonable altitude above ground level, either of which reduces atmospheric problems. Current diode laser technology and reasonable apertures can produce useful beam intensity at the receiver out to a range of ~10km. Longer distances can be achieved by switching to higher-quality sources (such as fibre lasers), although there is a penalty in cost and efficiency. The biggest limitation of laser power beaming is that it requires a line-of-sight (either direct or reflected off mirrors) between the transmitter and receiver. Light weather can reduce efficiency and range, but heavy weather (heavy rain or snow, or fog) can block transmission altogether. The tracking and beam steering systems were designed to track vehicles up to 1 km from the laser with an accuracy of a few cm, so for the relatively short range of this demonstration, the pointing errors were of order 1 mm over the entire +/- 15 degree pointing range of the transmitter.

A UAV can be continuously powered at long horizontal ranges, assuming it remains within line of sight of a beaming station. For a ground--based transmitter, a UAV would typically need to stay a few degrees above the horizon .The beaming station could be mobile, which would allow the UAV to operate miles ahead of the path of a fleet of vehicles, providing advance surveillance and other functions for the mobile group.

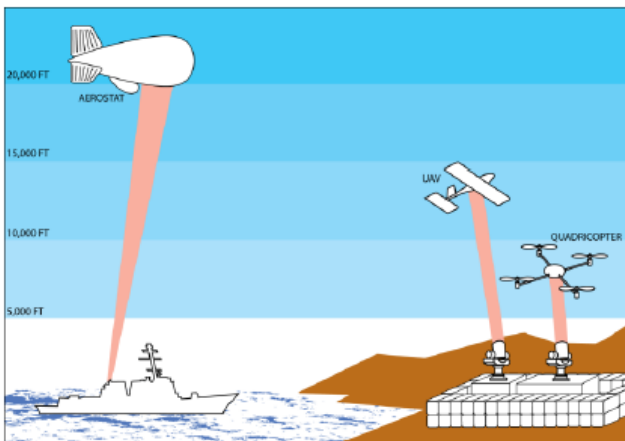


Figure 6 Altitude of laser power transmission

LASERs have high intensity to produce more power during photovoltaic process. They produce more power than microwave method which need more experimental setup to produce power. Scattering of power or loss of power can be avoided in LASER power method .We can also conclude that the design of high efficiency and high power LASER diode is low in cost. The long range laser diode also be designed and available to design a LASER power beaming setup .We can conclude that the wireless power transmission using LASER to UAVs without landing is also possible by using some methodology. The control system is designed and the implementation of some guidance system will help the wireless power transmission via LASER to UAVs.

## VI RESULTS

Overall system efficiency (DC power in through to DC power out) can be more than 25 percent, although in practice it is currently closer to 20 percent. Off the shelf diode lasers currently exhibit up to ~60 percent DC-to-light efficiency, and the DARPA SHEDS program demonstrated up to 85 percent efficiency. Current photovoltaic can achieve more than 50 percent light-to-DC efficiency, and monochromatic conversion efficiencies can theoretically go higher. We expect overall system efficiency to exceed 30 percent within several years, eventually approaching 50 percent.

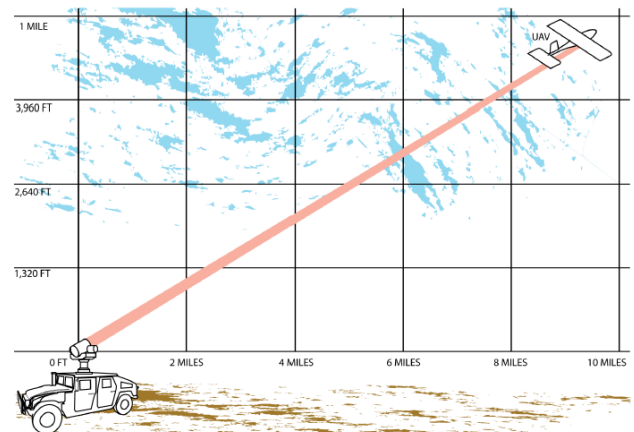


Figure 7 Maximum range of laser power transmission

- Small or Micro UAV recharging with multiple UAVs, maintaining one or more vehicles “on station” while others are in transistor recharging
- High-altitude (near-vertical) loitering: power > 10kWe, at a range of >5km
- Long range, low-angle beaming: > 10 kWe, horizontal range > 5 km, vertical range > 1.5km.

The high efficiency power transmission is made possible via laser power. Its efficiency is more than other wireless power transmission technique.

## VII CONCLUSION

Longer wavelength light outside the retinal hazard region could be a better solution because it is not focused by the eye, and the safe exposure levels are 100 or more times higher than for visible and near-visible wavelengths. These longer-wavelength laser systems may be appropriate for some applications, and that list may grow in the future as their efficiency and cost improve. Such power beaming systems that are “eye-safe” (with respect to scattered light) can be built today, but with a real efficiency of only about 10 percent and at a much higher cost. As these component technologies improve with further development, more-efficient long-wavelength systems will open additional markets for power beaming.

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