Comparison of Optical Fiber to Copper Wire

Sending power over fiber optic cable to aerial platforms is preferred over copper wire for many reasons, including safety, weight, scalability, and RF emissions.

	Optical fiber	Copper wire
Safety	✔	✖
Weight	✔	✖
RF effects	✔	✖
Data bandwidth	✔	✖
Durability	✔	✔
Cost	✖	✔

Transmitting power over an optical fiber has multiple advantages over transmitting the same power over electrical conductors. Here is a brief summary; for details, see the appendix. Fiber optic is:

- Safer
    - Non-conducting
        - Not a lightning rod
        - Not a hazard around power lines (urban environments)
    - Not at high voltage
        - Not a potentially **fatal** shock hazard (electric tethers operate at high voltages, hundreds to thousands of volts)
- Lighter
    - Optical fiber solution is lighter than copper wires running at up to ~1,000 volts (weight difference gets more drastic as voltage goes down)
- No RF interference, emissions , or inadvertent antenna (because it's not a conductor)
    - Not visible to radar
- Higher data bandwidth
    - Power fiber can carry more data than twisted pair copper
    - Dedicated data fiber could carry a LOT more data than copper while being more easily integrated with a power fiber than copper

Silica glass in fiber is actually stronger than copper (per unit area), and the jacketing further improves its durability. The toughness of fiber optic cable is well understood, but very fine copper wire is not as well understood. Copper is not bad, so the two are both reasonable in terms of durability.

The one advantage wires have is that they're cheaper. The cost of laser power systems decreases faster with quantity, and they are naturally getting cheaper with time due to other market pressures.

Appendix

Safety

The fiber is nonconducting, and is therefore safe in all electromagnetic environments. On land, this means it can safely be used around electrical transmission lines, as well as in high RF and magnetic fields. Also, it will not attract or transmit lightning.

Tethered aerostat or UAV-type platforms which do use electric power tethers tend to require very high voltages (hundreds to thousands of volts) to transmit power efficiently over very thin conductors, which is both a safety hazard and a reliability and maintenance issue.

A broken or damaged, optical fiber can be detected extremely quickly by monitoring either the actual power transmission or (preferably) the transmission of a pilot signal at a shorter wavelength. With a suitable crowbar circuit, the laser transmission can be shut off within 1-2 microseconds. At a 1 kW laser power level, even a worst-case fiber break releases at most a few mJ of laser power, with no high temperature arc.

By contrast, a break in a 1 kV electrical power cable will almost certainly result in an arc discharge and unless great care is taken in the circuit design to detect arcs and minimize energy storage, the arc can persist for milliseconds and deliver joules of energy. Such an arc can ignite volatiles or flammable materials.

Both high voltages and high power lasers are potential hazards to users or (particulary) service personnel; both hazards can be readily mitigated in most cases by suitable safety interlocks. We do note, however, that high voltage, high current sources can kill if even a small fraction of the power escapes; laser sources can cause eye damage and in extreme circumstances burn skin, but <u>cannot</u> be lethal (unlike high voltage copper).

Weight and Scalability

For many combinations of power and distance, optical fiber is much lighter than any practical electrical cable. This means that, for a given payload, an airborne platform can be smaller and/or fly higher using power over fiber than it would with electric power, despite the weight differential of the on-board power receiver (photovoltaic for fiber or voltage converter for copper).

At voltages below ~1,000 V, electrical conductors are much heavier than optical fiber for similar power delivery capacity. Conductor weight tends to scale as 1/voltage^2 (because power loss varies as V^2/R), so even at 400 volts, copper weighs over twice as much as fiber. Aluminum conductors are roughly half as heavy as copper for equivalent resistance but still heavier than our best estimate for optical fibers, even with no insulation. (Nearly all high-voltage transmission lines use aluminum conductors over a steel core.) However, aluminum is much lower strength than copper and more difficult to make into fine, highly flexible cables.

Consistent with this, nearly all efforts to make electrical-power tethered vehicles have gone to hundreds of volts or higher. However, at high voltages, wire requires substantial insulation. Unlike conductor diameter, insulation thickness does not scale with current, so at high voltages and low currents, insulation can weigh as much or more than the conductors.

LaserMotive does not, of course, have access to detailed information on others' proprietary cable designs, but assuming even 8 mil (200 μm) of insulation around two parallel conductors ("lamp cord" or "twisted pair" cable), the insulation is significantly heavier than the conductors, at 1 kV or higher voltage and any power level from 200 to 2000 watts. (Of course, insulation thickness tends to increase with even higher voltages). As a consequence, even at high voltages, electrical cable is heavier than optical fiber for low power systems.

There are many other factors that can affect the relative weight of fiber vs. metallic conductors. For example, at higher power levels, the minimum wire gauge may be limited by the power dissipated in the wire itself causing the wire to heat up (which raises its resistance) and eventually melt insulation. In general, though, for <1 kW delivered power, optical fiber will be significantly lighter than electrical cable no matter what voltage is used.

(It is worth noting that the insulation thickness can **not** be calculated simply from the dielectric breakdown strength of insulator (V/cm) and operating voltage; various other factors including microscopic flaws, high electric fields near small-diameter conductors, corona discharge at high voltages and high fields, and insulation degradation due to UV exposure, all tend to drive up the insulation thickness needed on exposed cables.)

The quadcopters being consider generally have payload capacity of several hundred grams. At 100 meters, the weight difference between copper and fiber might be only 100 grams, but that is a large fraction of the payload capacity.

RFI and EMI

An optical fiber has no RFI/EMI issue, because it is not a conductor. Copper wire, on the other hand, can leak signals and can be impacted by RFI. It can act as an antenna, interfering with data being sent along the cable. In extreme cases, copper wire can pick up energy from nearby high power transmitters, not only interfering with data transmission but potentially overheating the wire.

Optical fiber is nearly invisible to radar (although radar reflectors, visual beacons, etc. can be added if desired), again because it is not conductive.

Bandwidth

Multimode optical fiber, whether or not it is also carrying laser power, can readily transmit high bandwidth data over moderate distances; a typical bandwidth-distance product for multimode fiber is 500 MHz/km, so a 500 m tether can transmit 1 GHz (several Gbits/second, with appropriate modulation). Signal losses over 500 m are negligible; the bandwidth is limited by dispersion (time-smearing) of signals. Lightweight copper cable, by contrast, has very high losses at high frequencies. Twisted pair optimized for high data rates (Cat 6) can transmit 500 MHz over only 100 meters (bandwidth-distance product of 50 MHz/km); lightweight unshielded cable optimized for power transmission will have even lower bandwidth-distance product.

Either wire or fiber tethers can of course incorporate one or more single-mode optical fibers for higher bandwidth; however, it will be easier (and probably lighter in weight) to add a fiber to a fiber cable than to an electrical cable, as thermal expansion characteristics are similar and the two fibers can share a common outer sheath.

Durability
The ultra-pure silica glass used in optical fiber has a higher tensile strength than copper. The jacketing material further strengthens and protects the fiber. The toughness of fiber optic cables is well understood. The durability of very fine copper wire without thick insulation is not as well understood. The tether for a tethered VTOL vehicle should not withstand extreme tension under nominal conditions, but handling and repeated spooling and unspooling may expose the tether to higher tensions at times. Both fiber and copper are reasonable in terms of durability, although fiber might have a slight edge.

Cost
Electrical power transmission over copper or aluminum wire is, and will likely remain, cheaper than laser power transmission over fiber. The dominant cost of the laser system is the laser itself, which is not present in the electrical system. However, the cost of the laser power system is already comparable to or less than the cost of the rest of a surveillance or communications platform, and will decline significantly with quantity purchases. The cost of lasers is also decreasing overall.