9x.23 Sending Power on a Beam of Light

Radiation of light conveys energy, sometimes illustrated in physics courses with a charming antique *Crookes radiometer* (Fig. 9x.92), with a set of vanes that are blackened on one side, shiny on the other, and in which the vanes spin around happily when illuminated.[63] In a more practical vein (pun, get it?), you can exploit light's energy flux to power a circuit with no wire connections – thus achieving complete galvanic isolation.

In one common application diode emitter(s) illuminate a series-connected stack of photovoltaics to generate an isolated dc source for high-side gate drive. We saw this back in §3.5.6B, where a PVI5033 (dual-channel LED to PV-stack) was used to generate MOSFET gate drive (Fig. 3.107A). Parts like that can create enough bias to switch a MOSFET, but they are feeble, and slow: the PVI5033's photovoltaic stack generates 5–10 V, with a short-circuit current of just a few microamps, and with a time constant of a few milliseconds. That's not enough to power much of anything, nor can it switch a MOSFET's input capacitance quickly (e.g., the PVI5033's 5 μA output would take some 5 ms to switch a classic power MOSFET like the IRF520N, with its total gate charge of Q_g=25 nC); recall that's why hefty gate driver ICs like the TC4420-series are rated to source or sink many *amperes* of peak current).

But it's possible to generate and transmit plenty of optical power, most easily with power LEDs or, better, diode lasers. The latter couple nicely to low-loss optical fiber, a convenient medium for safe transport to the receiving photovoltaic. The common 62.5/125 μm graded-index glass fiber, for example, has an attenuation of less than 0.7 dB/km at minimum-dispersion infrared (λ=1300 nm), and 3 dB/km at commonly used "redder-than-red" (800–850 nm) wavelengths for power transmission. Power-over-fiber has many attractive features: it's non-conducting, therefore immune to transients (e.g., lightning) and magnetic fields, and does not create sparks; it has perfect galvanic isolation, and thus total common-mode rejection; it's lightweight, and can be used to send high-bandwidth data as well as power. Some disadvantages are cost, efficiency, and the need for careful design to ensure eye safety.

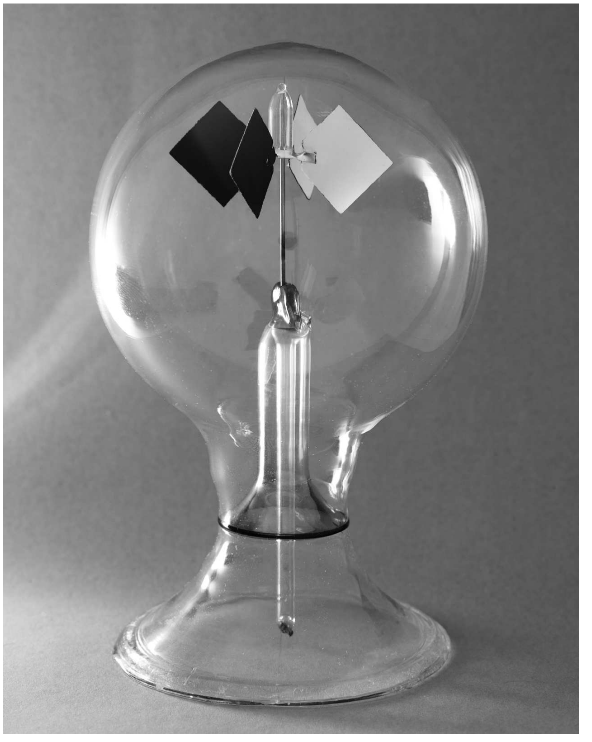

Figure 9x.92. Crookes Radiometer, invented in 1873, and responsible for a decade's worth of argument over the cause of its "backwards" rotation. These things are the very devil to photograph: low light (so it doesn't twirl), wait for it to stop jiggling (and in a favorable orientation), and (worst of all) its shiny surface reflects everything it sees back into the camera; spent a couple of frustrating hours before getting this portrait.

You can buy components for ready-to-go fiber power systems (Fig. 9x.93). For example, the Lumentum L4-2486-005 fiber-coupled diode laser puts out up to 2 W at 830 nm into a 60/125 μm fiber; when coupled to a Broadcom AFBR-POC406L photovoltaic "optical power converter" it generates 6 V at 120 mA at the receiving end.[64] Figure 9x.94 shows the datasheet's photovoltaic *I–V* characteristic (their lower-voltage AFBR-POC404L puts out comparable power – 650 mW – into 3 V loads).

These power levels are altogether adequate for operat-

[63] Oddly enough, they spin *backward*: You'd think light bouncing off the shiny side would impart twice as much momentum as light absorbed by the dark side, so the shiny side should be in retreat. But it goes the other way. The reason is far more complicated than the simplistic explanation seen in some textbooks (which at least acknowledge the paradox; others just get it completely wrong).

[64] The Lumentum products originated with JDS Uniphase, who also manufactured photovoltaic converters. You can read about these products in the Lumentum Technical Note 30175827-900-0314 (poweroverfiber-tn-pv-ae).

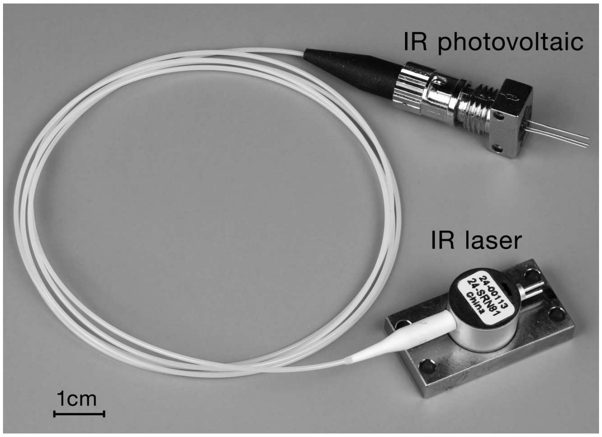

Figure 9x.93. JDSU's 2 W power-over-fiber laser (now available from Lumentum) delivers 500 mW at 3 Vdc or 5 Vdc when coupled to a power-conversion photovoltaic.

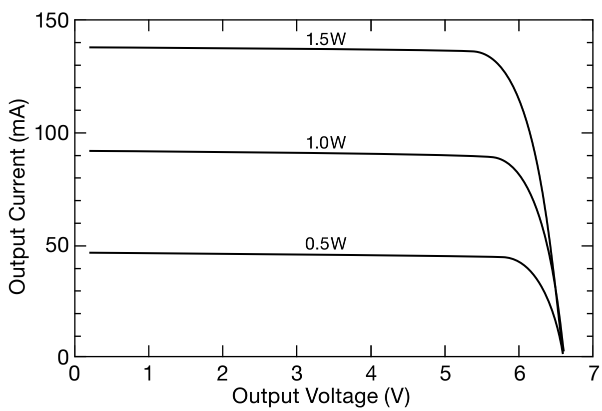

Figure 9x.94. Output current versus voltage for the Broadcom AFBR-POCx06L 6 V photovoltaic power converter, from their datasheet.

ing small analog or digital systems. But if the reader finds them, uh, anemic, take a look at the web page of Powerlight Technologies (http://powerlighttech.com/power-over-fiber-2), where you'll learn that "PowerLight Power Over Fiber technology uses high-intensity light to transfer up to kilowatts of power via fiber optic cable. Whether tethered above ground or undersea, unmanned aerial vehicles (UAVs) and unmanned undersea vehicles (UUVs) using our technology can last longer, go farther and maneuver more."

Returning to laboratory-instrumentation power levels, Tektronix uses power-over-fiber (and a return signal-over-fiber path) in their remarkable IsoVu™ probe system (Fig. 9x.95): one fiber sends power to the remote probe, two more exchange digital control signals, and an analog pair is used to send an optical "carrier" which is returned bearing wideband (to 1 GHz) analog signals back from the probe head (Fig. 9x.96). The result is complete galvanic isolation, with the ability to probe signals with extraordinary common-mode rejection (160 dB at low frequencies, falling to 110 dB at 800 MHz). That's necessary if, for example, you want to see high-speed gate-source voltage differences on a flying MOSFET. And the complete isolation means you can probe signals sitting atop high-voltage electrodes, or otherwise floating at nasty potentials.[65]

Figure 9x.95. Tektronix IsoVu probing system: completely isolated, with power and signals over fiber. (Copyright© Tektronix. Reprinted with permission. All Rights Reserved.)

Just for the fun of it, we decided to cobble together a fiber power link. First stop: eBay, where we bought[66] a JDSU 2486-L3 830 nm 2 W laser with 3′ 60/125 μm ST-terminated fiber.[67] While at eBay we also got some 40 mm square (25×35 mm active area) monocrystalline[68] 2 V photovoltaic stacks ($17.60 for ten of them, cheap!). We chose

65 As is often the case, every silver lining has a cloud: these things are not inexpensive – they start at +41 dB$.

66 Starlight Photonics Inc., aka "Junktronix."

67 JDSU's products are now part of Lumentum, who sell these laser sources as their L4-2486-xxx; however, they do not sell matching photovoltaics.

68 Interestingly, *amorphous* silicon photovoltaics do not work with infrared, they cut off completely above 800 nm.

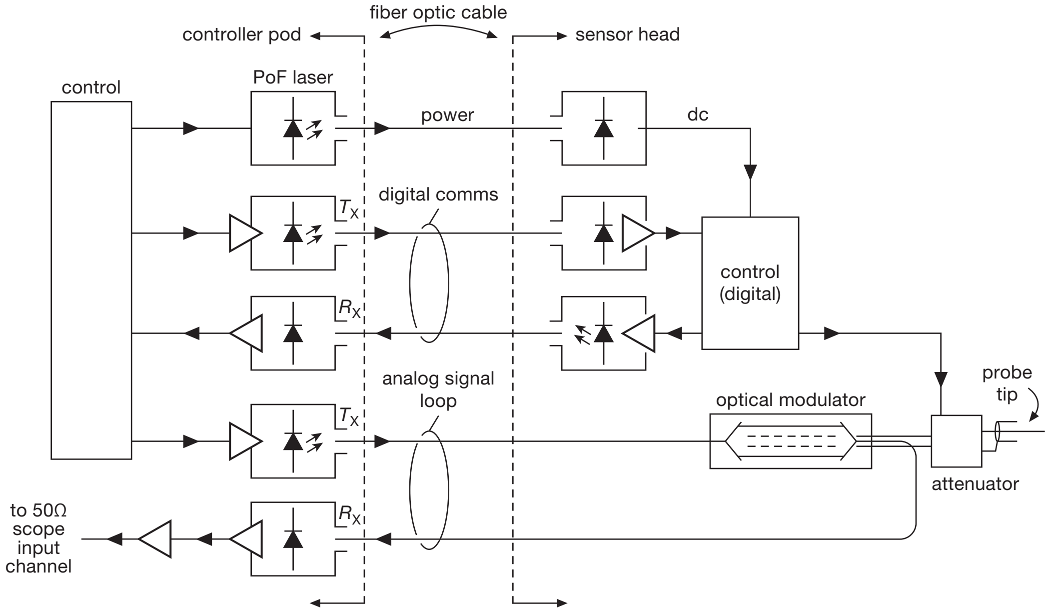

Figure 9x.96. Five fibers carry digital signals, analog signals, and power in the IsoVu isolated probing system. Most of the secret sauce resides in the wideband, high-impedance, low-power, linearized optical modulator (a Mach–Zehnder electro-optic interferometer), which elegantly eliminates the need for a power-hungry wideband front-end amplifier.

the latter because they were a hundred times cheaper than those nifty Broadcom photovoltaics. Not as compact or pretty – we put the PV cell at one end of a 6″ long 2.5″ mailing tube, with an ST feedthrough at the other end – but it worked well enough, putting out 150 mA at 2 V.[69]

This got us thinking about power transfer with *LED* sources (instead of lasers), for applications where the compactness of fiber is not needed. So we fished through our junkbox(es), where we found a collection of high-power LEDs in the form of "chip on board" (COB) arrays, some of which are shown in Figure 9x.97. These are widely available in many colors, and they put out an impressive amount of light. The red ones (625 nm) we had on hand are rated at 100 W (dc input), with roughly 25% conversion efficiency to optical power output. When we placed our 4-cell 25×35 mm photovoltaic about 25 mm away from the LED (the latter running at its maximum rated 4 A) we measured an open-circuit voltage of 2.6 V and a short-circuit current of 400 mA; the corresponding figures for a larger 10-cell photovoltaic (65 mm square) were 6.2 V and 200 mA. Figure 9x.98 shows curves of the measured photovoltaic output voltage versus load current, for a range of LED drive currents; and Figure 9x.99 demonstrates that this crazy stuff really works.

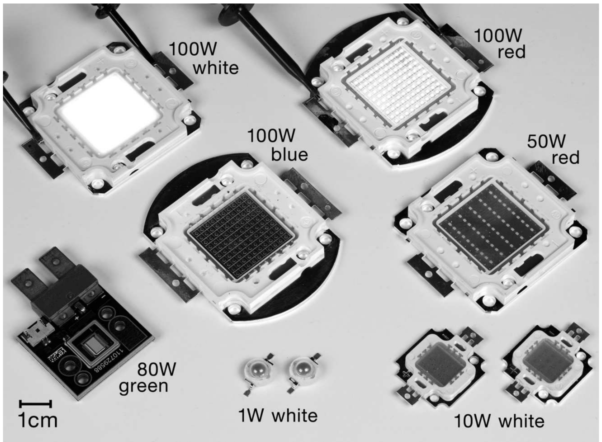

Figure 9x.97. "Chip-on-board" (COB) LED arrays are available in many colors as well as white (yellow phosphor over blue LEDs); they are inexpensive ($15 or so for the 100 W variety) and are used for area lighting. The green "photonic lattice" emitter at lower left (available in matching red and blue) is used in place of halogen or arc lamps in digital projectors; it puts out 2000 lumens from a 0.12 cm^2 emitting area. To photograph the powered COBs at top we had to run the current *way* down – at full blast these things are painful to look at.

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[69] Photovoltaics intended for conversion of ∼800 nm laser light use GaAs rather than silicon, because the bandgap is better matched, producing conversion efficiencies in the neighborhood of 40–50%.

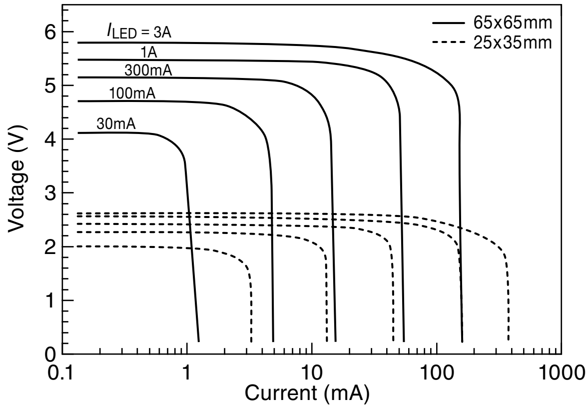

Figure 9x.98. Measured output voltage versus load current for two monocrystalline silicon photovoltaics ("solar cells"), measured at half-decade steps of LED drive current. For variety we plotted *V* versus *I*, rather than the other way around as in Fig. 9x.94.

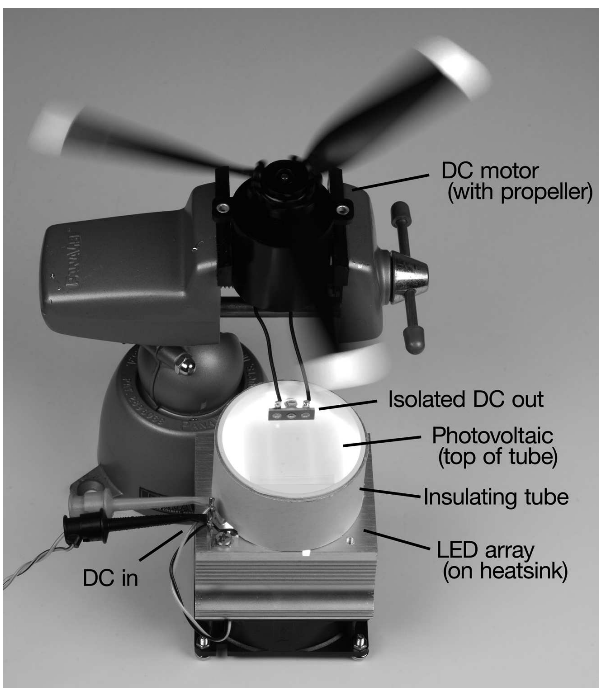

Figure 9x.99. "Photomotive force!" (just kidding). We coupled a red LED array to a silicon photovoltaic, which produced far more dc output than needed to spin this 3-bladed propeller.