Trees, Fractals and Solar Power

Posted by Simon Winder on Jan 6, 2012 in Physics, Technology

The Wall Street Journal recently ran a story about Aidan Dwyer, a 13 year old, who has created a stir with his science project which purported to show that if solar cells are arranged in space like leaves on a tree rather than on a flat surface, they collect more solar energy. His project write-up can be found here. The internet response has ranged from praise and offers of business capital to aggressive attacks and charges that his experiment ispseudoscience.

Unfortunately Aidan did not measure the right quantity (power) when performing his experiments, so in the original form they are not conclusive. What aspects of his ideas might be valid and what might be suspect?

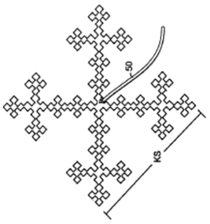
Aidan is excited about the ideas of Fibonacci series and golden ratios. I remember getting into those things for the first time as a child. It is true that plants grow by building cells from a rotating meristem and this creates logarithmic spirals, Fibonacci branchings and interesting fractal patterns. I do not believe that directly these have any relevance to efficient light collection. However he is right in that plants have evolved to be efficient at collecting light. I think that the particular details of the way that leaves are arranged to fill space are a red herring. What I think is important and is missed in the discussion is that plants create bushy 3D structures with many crevices and these pockets allow light to be trapped and eventually absorbed.

If one considers a flat solar panel, it is hard to ensure that the light is efficiently collected. A surface that absorbs light over a wide wavelength range with no reflection is going to look matte black. If it was 100% efficient it would not scatter back any light at all. It is extremely difficult to manufacture solar panels to have that property. There is always some reflection. If instead of using a flat panel, solar cells were placed in a corrugated 'VVVVV' formation where the angle of the 'V' is very acute, then light going in from different angles would have multiple chances to be captured as it bounced around in the depths of the crevice. An interesting related effect can be seen when multiple razor blades are stacked together in parallel. If the blades are sharp and you look at the row of edges, it is pitch black. In fact razor blade companies often sell stacked razor blade sets to physics laboratories for use as laser beam dumps. A block of 375 single-edged blades makes a 1.5 inch square target. When light hits this arrangement, it falls into the narrow crevices and is lost.

If we look at a picture of a bush, we can see that while the leaves themselves reflect some green light, the depths of the bush are very dark. Light bounces around and is eventually absorbed. The fractal arrangement of leaves, even on those plants where the leaves do not actively track the sun, is efficient at creating pockets where the light, no matter from which direction it arrives, has lots of opportunity to be absorbed by the leaves.

This observation leads to a potential application to solar panels. If the panels are built in a 'V' formation or a more complicated fractal-like structure, then the absorption opportunities are higher. One might imagine a flat solar panel which is nevertheless made by etching many deep crevices into a metal structure, or made from a sponge-like substance where on a microscopic scale there are many angles and pits within which light can reflect and be absorbed. This structure would then be coated with the necessary layers that build up a solar cell, allowing the photoelectric effect to produce electrons which can then be efficiently gathered. There are many possible geometries. I think that this is where the real engineering opportunities reside, rather than in the more esoteric contemplation of Fibonacci series.

As an example of nature's use of multiple reflections, consider the vision of a cat. In the cat's eye, light comes in and passes through the sensitive receptors in the retina, and then reflects off a natural reflective coating on the back of the eyeball. It then heads back through the receptor layer. This arrangement gives cats great dark vision because there is twice the opportunity for light to be absorbed in the receptors. It also makes cat's eyes reflective at night. In humans however, the back of the eyeball is coated with a black pigment instead. This ensures that no light is scattered back towards the photo receptors because we rely on very sharp spatial vision and reflected light would blur the image that we see.



Another area where fractals may in the future be important for solar technology relates to an alternative way of gathering energy. Rather than using the photoelectric effect where photons cause electrons to be liberated from metal atoms, it may soon be possible to use terahertz antenna technology instead. Light is electromagnetic radiation just like radio waves and microwaves. We can use antennas to capture or produce light providing the antennas are the correct size. However the wavelength of light is around 600 nanometers, so this needs very tiny devices. With current advances in nanotechnology, constructing these structures and depositing them on a large collecting surface is becoming possible. You can read more about research in this area here and here. The main technology that is still needed to make this work correctly is very fast rectification to convert the terahertz electrical currents into a DC supply. I expect that this problem will be overcome soon.

Cell phones today make use of a new technology called fractal antennas. The metal strips in these antennas for microwave transmission are arranged in space-filling fractal pattens. The reason for this is it allows the antenna to have a very wide frequency bandwidth for transmitting and receiving. The fractal acts like many antennas of a wide variety of sizes. This technology may also be useful to solar collection where we wish to absorb solar energy over a wide range of wavelengths from the infra-red at around 1.5 microns to the ultraviolet at 300 nanometers. There is some exciting work to be done in this area and lessons from nature are always welcome.