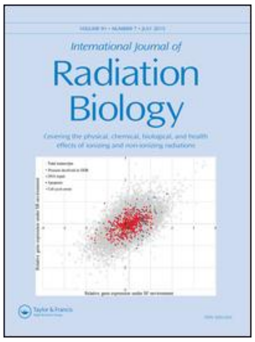

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LETTERS TO THE EDITOR

Comments on DNA as a fractal antenna

Blank and Goodman (2011) proposed in this journal that DNA acts as a 'fractal antenna'. "Since DNA can interact with EMF [electromagnetic fields] over a wide range of frequencies and does not appear to be limited to an optimal frequency", they write, "it has the functional properties of a fractal antenna".

Blank and Goodman justify their claims by listing some reported biological effects of ELF (extremely low frequency, here referring to powerline frequencies of 50 or 60 Hz) and microwave fields (about 1 GHz), many of which are controversial in their interpretation. Their point seems to be that 'fractal' antenna properties of DNA confer sensitivity to electromagnetic fields at these two very different frequency ranges. Their argument is hardly rigorous, and indeed it is circular if it also argues for the plausibility of effects of electromagnetic fields on DNA over a wide frequency range.

But this conjecture is inconsistent with functional properties of fractal – or any other – antenna. At 50/60 Hz and 1 GHz, the wavelength λ of electromagnetic radiation in tissue is about 750 m and 0.04 m, respectively (assuming dielectric properties typical of soft tissue such as brain and muscle, Gabriel et al. 1996). Any antenna that could be fitted into the nucleus would be electrically tiny at these frequencies. As discussed below, such antennas would also be very inefficient in absorbing energy from an incident wave.

Best (2003) showed that the electrical characteristics of fractal antennas approach those of ordinary dipole antennas when their electrical length is small, i.e., when their physical size is less than $\lambda/2\pi$. A small fractal antenna has no advantage in performance, and may even be much worse, than other antennas of similar length (Best 2003).

And such small antennas, regardless of design, are very inefficient at collecting energy. The famous Chu-Wheeler theory shows that the minimum quality factor Q of an electrically small antenna (regardless of design) is given by:

$$Q_{min} = \left(\frac{\lambda}{2\pi a}\right)^3 + \left(\frac{\lambda}{2\pi a}\right) \tag{1}$$

where 'a' is the smallest sphere that could encompass the antenna. Assuming for sake of argument that a = 1 μm, this leads to Q values of order of 10^{11} at 1 GHz and 10^{24} at 60 Hz (designers of practical antennas typically aim for values of 100 or less). Q is inversely proportional to the radiation resistance of the antenna (smaller Q is better) and these high Q values correspond to extremely low efficiencies in collecting energy from an incident wave. And their efficiency is many orders of magnitude lower at 60 Hz than at 1 GHz.

To be sure, the geometric complexity of fractal antennas increases their bandwidth compared to dipoles and other simple types, provided that they are not electrically small. One firm (Fractal Antenna Systems, Waltham, MA, USA) sells a fractal antenna (http://www.fractenna.com/downloads/FractalAntenna_UASM.pdf) that is designed to operate between 0.38 and 4 GHz. It is approximately 0.3 m square, compared to a length of 0.36 m for a simple half-wave dipole antenna tuned to operate at 0.4 GHz. If industry could make sub-micron sized fractal antennas that work efficiently between 50 Hz and 1 GHz, it would certainly do so.

By any reasonable definition, DNA is not an antenna at all at these frequencies. DNA has an electrical conductivity of the order of 1 S/m (Wang 2008), similar to that of the surrounding medium, and consequently has low electrical contrast with the surrounding medium. Both the DNA and surrounding media are electrically very lossy.

Granted, the scientific literature contains references to 'molecular antennas' in connection with photosynthesis, and to fractal properties of DNA in connection with the statistical properties of base pair sequences. Neither has anything to do with absorption of electromagnetic energy by DNA at the frequencies considered here.

The interaction of DNA and other macromolecules with electric and magnetic fields is, of course, a well studied subject. Any reasonable theory for the interaction of such fields with DNA would have to consider the strength of interaction in relation to random thermal effects which swamp out small perturbations, the intrinsic mechanical properties of the molecule, and rates of energy transfer from the molecule to its environment. That would require a more rigorous and quantitative theory than Blank and Goodman offer in their paper. Loose and implausible conjectures about DNA as a fractal antenna do not substitute for careful discussion of these matters.

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Declaration of interest

The author reports no conflicts of interest. The author alone is responsible for the content and writing of the paper.

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Author's reply:

Sir,

Implicit in Foster's analysis is the idea that fractal antennas are limited solely to the metallic types in current industrial devices. He is not open to the possibility of any other type of fractal antenna; specifically that the DNA molecule in the cell nucleus, though very different from a metallic wire, can have the properties of a fractal antenna. As Benoit Mandelbrot, the leader in this field, showed in his 1982 book 'The Fractal Geometry of Nature', fractals occur in many places in Nature as well as in mathematics. Blank and Goodman's paper shows that the DNA molecule in the cell nucleus is one of these places.

The evidence in support of this idea is extensive. In the cell nucleus, the DNA molecule is a coiled coil (several times over) that demonstrates self-similarity, the essential structural property of a fractal. The DNA molecule has been shown to react with electromagnetic radiation over a range of frequencies, the essential functional property of a fractal antenna. In addition, consistent with the properties of an antenna, the DNA molecule conducts electrons within the core of the double helix --as has been demonstrated by the Bartlett group at Caltech, as well as other research laboratories.

In his discussion of the properties of DNA, Foster cites Wang's review. However, that review deals with impedance spectroscopy of DNA suspensions where there is only a surface reaction to electromagnetic fields (due to the ions adsorbed on the DNA surface) and not to electronic conduction within the core of the double helix (as occurs in an antenna).

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