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# P3 8 Should've put an electric ring on it

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**Abstract**

This paper investigates the viability of generating a man-made magnetic field around Earth using a circular wire loop along the equator. Calculations show that producing a field equal to Earth's would require a current of $1.29 \times 10^9$ A, corresponding to a current density of $4.11 \times 10^8 \mathrm{Am}^{-2}$ and ohmic heating per unit volume of $2.71 \times 10^9 \mathrm{Wm}^{-3}$.

## Introduction

Life on Earth is sheltered from excessive UV radiation from the Sun due to the Earth's magnetic field, protecting life from both radiation damage and keeping the atmosphere from photolytic degradation as on Mars. It is driven by the convection of the liquid iron in the Earth's core, however over the period of which humans have been measuring the magnetic field it appears to be decreasing over the last 20 years. While this is thought to be a part of a oscillating cycle [1], it begs the question of what were to be done if the magnetic field were to be completely depleted. We decided to investigate using a wire loop around the Earth to generate the field to replace the Earth's field.

## Theory and Equations

The first thing we use is a rearrangement of the Biot-Savart law[2], with approximations of the Earth's surface magnetic field $B_E = 4.5 \times 10^{-5}$ T, the radius of the wire loop is $r = R_E = 6.378 \times 10^6$ m, we can find the current needed to pass through our wire using the following:

$$I = \frac{2B_E(x^2 + R_E^2)^{\frac{3}{2}}}{\mu_0 R_E^2} \tag{1}$$

Where $x = R_E$ is our distance above the plane of the loop of wire. This gives us a current of $1.29 \times 10^9$ A. We can use this to find the magnetic dipole moment[2] of this current loop $\mathbf{m}$ and compare it to the Earth's.

$$\mathbf{m} = I\mathbf{A} \tag{2}$$

With $\mathbf{A} = \pi R_E^2$ as the vector area of the loop in $\mathrm{m}^2$ and $I$ is the current we calculated earlier, we get $1.65 \times 10^{23}\,\mathrm{A\,m}^2$, 2.58 times Earth's magnetic moment of $6.4 \times 10^{22}\,\mathrm{A\,m}^2$[4].

We can also use the differential form of Ampere's law to find the current density of the wire:

$$\frac{\nabla \times B}{\mu_0} = J = \frac{I}{\pi r_w^2} \tag{3}$$

Where our wire radius $r_w = 1$ m we get a current density of $J = 4.11 \times 10^8\,\mathrm{A\,m}^{-2}$.

We can then use this to find the Joule heating of our wire per unit volume with $P = I^2 R$, where $R = \rho\frac{L}{A}$ and $I = \frac{J}{A}$. $\rho$ is our wire's resistivity which we presume to be silver's $1.6 \times 10^{-8}\,\Omega\,\mathrm{m}$[5].

$$\frac{P}{V} = J^2 \rho \tag{4}$$

This gives an ohmic heating of approximately $2.71 \times 10^9\,\mathrm{W\,m}^{-3}$.

## Discussions

The values calculated are extreme in nearly every manner to be considered, though theoretically possible and achievable. The current is smaller than largest current ever made of $2 \times 10^6\,\mathrm{A\,cm^{-2}}$ ($2 \times 10^{10}\,\mathrm{A\,m^{-2}}$) by Oakland Laboratory [6], so this is achievable, however this required the usage of superconducting wires. Over planetary distances, this would be unfathomably expensive and difficult to install. The ohmic heating itself is another major concern. For reference, Sizewell C's power output is $\approx 3.2 \times 10^9\,\mathrm{W}$ [7], so the power output supporting six million homes [7] is given off every $m^{-3}$. Even if cooling were provided by the oceans, the impact would still be significant; in reality, no known material could survive long under such extreme ohmic heating.

The entire output needed to supply the wire would be $V\rho J^2 = 3.41 \times 10^{17}$ W which is energy requirements needed to be considered a type 1 civilisation on the Kardashev scale [8] or in terms of solar input towards Earth:

$$\frac{P}{1361\pi R_E^2} = 1.96 \tag{5}$$

Approximately 2× the solar power reaching Earth is needed.

## Conclusion

There are some plausible components to this thought experiment, however, the sheer scale and currents required are not currently available for humanity within the near foreseeable future. The current output is extremely large and while achievable, it would require superconductor materials with coolant systems to balance the heating output. In this calculation, resistivity of silver was used, however this can only cope with the current outputs when using silver nanowires [9]. In addition, the heating output being so enormous would be an incredibly difficult challenge to overcome in order to safely restore the Earth's magnetic field. The viability is poor and it would be likely far easier to insert a dynamo into orbit to shield the Earth rather than using this hypothetical wire.

## References


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