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Replacing Biot-Savart Rule of Magnetic Field by a "Magnetic Auvert Rule" to Evaluate Field Surfaces and Field Curves around Circular and Square Current Loops Modeled as Electrical Segments

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Abstract

Around a straight wire carrying a steady current, magnetic field lines are classically represented by concentric circles, each point on a given circle having the same field magnitude. For finite electrical segments, the Biot-Savart law is normally used to compute and plot these curves, but that approach becomes cumbersome for complex wire geometries. The author proposes replacing the Biot-Savart formulation with a new **Magnetic Auvert rule** to evaluate a scalar magnetic potential and the corresponding magnetic field vectors. This rule makes it possible to compute and draw magnetic field lines and surfaces for arbitrary geometries composed of fixed electrical segments, enabling field visualization around circular, square, and more general current configurations.

Keywords

Biot-Savart Law, Magnetic Auvert Rule, Magnetic Surface, Magnetic Field Line, Magnetic Field Curve, Electrical Segment, Scalar Field, Right-Hand Rule

1. Introduction

The first documented observations of an interaction between a steady electric current and a compass were reported by Ørsted [1]-[3]. He asked Ampère to verify his findings, and Ampère repeated the experiments, concluding that a current in a wire produces a magnetic field that influences a compass placed anywhere around it [4]. Consequently, Ampère proposed that the magnetic field lines around a straight wire form concentric circle, as illustrated in **Figure 1** [5]-[7].

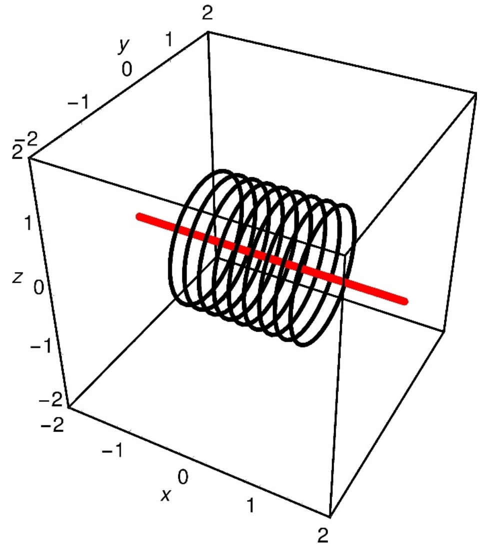

Figure 1. Classical representation of circular magnetic field curves around an infinitely straight electrical wire. The "red" wire is at the center of "black" magnetic field circles. Each circle has the same magnetic field value by having the same distance to the wire.

Following these results, the classical theory of magnetism was developed and published [8].

When the straight conductor of **Figure 1** is replaced by a circular loop, the resulting current geometry is non-classical and requires different magnetic field curves, as illustrated in **Figure 2**. These non-circular field lines arise from the "Magnetic Auvert rule" proposed in this article.

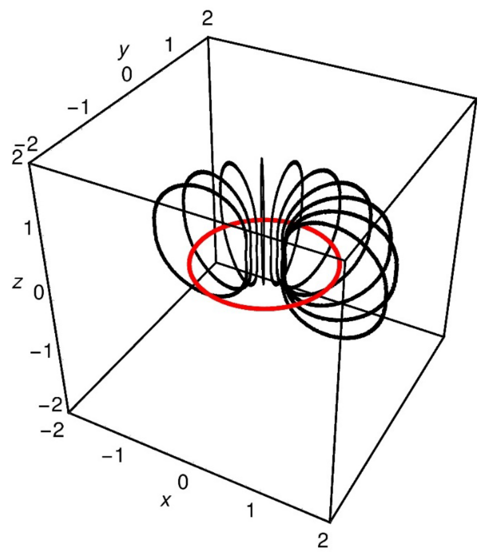

Figure 2. Non-classical representation of nearly circular magnetic field curves around a "red" circular wire flowing with a static electrical current. "Black" curves are nearly circular forming specific magnetic field curves induced by the circular wire. In a single black curve, each point has the same magnetic field value along it. In each of the ten curves, the same magnetic field value is also used.

The present article introduces the "Magnetic Auvert rule", a new procedure for computing magnetic fields around assemblies of short current segments. After presenting the rule and its mathematical formulation, an application section examines several conductor geometries, including circular and square loops.

To simplify the expressions used throughout, the vacuum permeability and permittivity are set to unity.

All figures and numerical illustrations for the "Magnetic Auvert model" were produced with Mathematica [9], GIMP [10], and reference material from Wikipedia [11].

2. Theoretical Description of the Magnetic Auvert Rule

This section presents a theoretical model that enables the computation and visualization of the magnetic field produced by one or two current-carrying segments. Using the Magnetic Auvert rule, we evaluate a scalar magnetic potential, derive the corresponding magnetic field vectors, and plot the resulting field lines and surfaces for single and paired electrical segments.

2.1. Field around Short Electrically Active Segments

2.1.1. Scalar Field around One Segment

In this paragraph, one segment is the source of the magnetic field. Unfortunately, the field value proposed has a strong difference from the historical value proposed by Biot and Savart [12].

The center of the small segment is placed at ($x = 0$, $y = 0$) with length l. Distance D is between point p with the center of the segment l. The magnetic field value "MF" is the field value induced at point p by the small segment. Point h is the orthogonal projection of point p onto the segment axis.

In **Figure 3**:

- I is the value of the electrical-current flowing through the segment.
- l is the length of the segment.
- D is the distance between point p and the middle of the segment.

In **Figure 3**, the scalar field value at point p corresponds to a non-vector physical quantity, and this value is $I{\cdot}l/D^2$ (A/m).

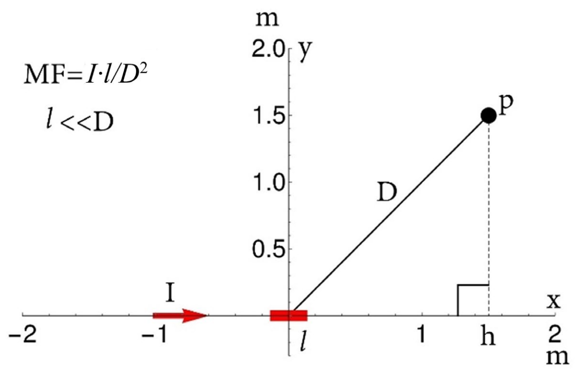

Figure 3. Scalar field definition of the magnetic field induced at point p by a small electrical segment l with current I.

Historically, Jean-Baptiste Biot and Félix Savart who had discovered their first relationship in 1820 have given a field definition composed of vector operations [C12].

The main difference between the two models lies in the non-vector definition introduced by the Magnetic Auvert rule.

Under our rule, the magnetic field value depends linearly on the current I and is proportional to the segment length l.

To keep consistent physical units in I/r the field is expressed in **A/m**.

The formula applies when the distance from point p to the segment is at least ten times the segment length; otherwise, the segment must be subdivided.

In a previous paper the segment represented part of an electrical line [13]. Here, we extend the method to multiple segments to describe various wire geometries.

2.1.2. Magnetic Auvert Rule Defining Three Orthogonal Vectors

In this paragraph, the concept of scalar field is replaced by the concept of magnetic vector field. Therefore, a specific definition of three vectors is used with a strong modification by the author [13] from the Biot-Savart rule [12].

At point p, in **Figure 4**, three mutually perpendicular vectors A, C, and M are defined and have equal magnitudes equal to the scalar field value from **Figure 3**, expressed in A/m.

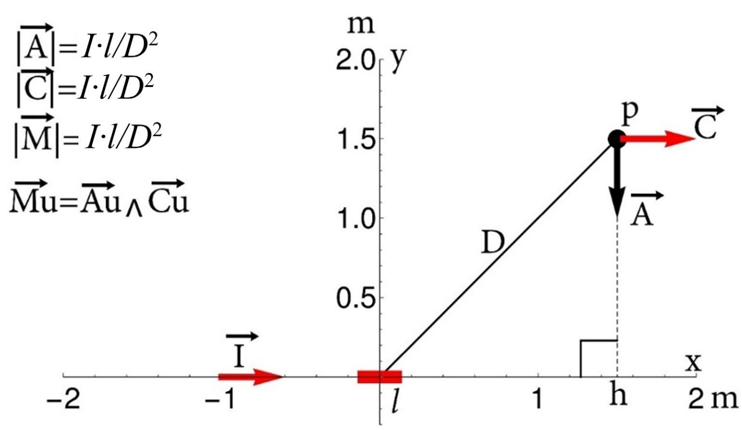

Figure 4. Definition of three orthogonal vectors at point p.

Vector C is parallel to the current I and to the segment. Vector A points from p toward the segment's axis (the shortest line connecting p to the segment). Vector M is orthogonal to both vectors A and C, oriented along the out-of-plane direction (the z axis) and cannot be drawn within the xy plane.

The x and y axes are given in meters.

2.1.3. Magnetic Auvert Rule with Two Electrically Active Segments

In this paragraph, two segments are used and vectors A and C are evaluated at point p.

Vector At and vector Ct, are calculated in **Figure 5**. Then, vector M depending on At and Ct, will be described in the next paragraph.

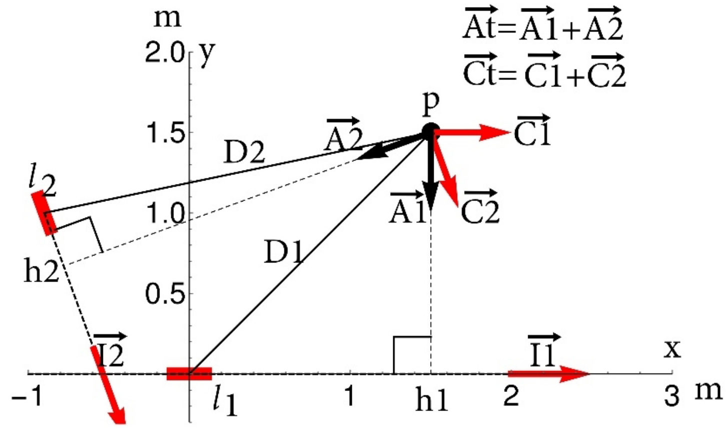

Figure 5. With two electrical segments, two vectors A and C at point p, are studied. Vectors $A1$ and $A2$ are perpendicular to current $I1$ and $I2$. Vector $C1$ and vector $C2$ run in the same direction as currents $I1$ and $I2$ going through segments $l1$ and $l2$. Addition of vectors A gives vector At. Addition of vectors C gives Ct.

2.1.4. Magnetic Auvert Rule to Calculate Magnetic Field Vectors

The field value is now evaluated with a particular interaction with vectors At and Ct.

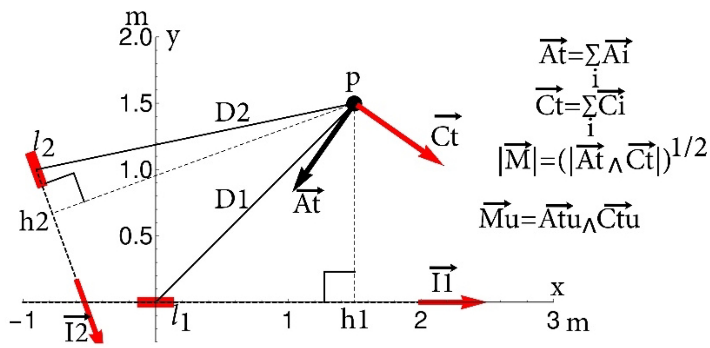

Figure 6. Resultant vectors At and Ct, defining vector M at point p.

After summing the contributions from two segments, the resultant vectors at point $\boldsymbol{p}$ are $At = A1 + A2$ and $Ct = C1 + C2$, as shown in Figure 6. The vector $\boldsymbol{M}$ is orthogonal to the xy plane and cannot be drawn there. Its magnitude is defined from the cross product of $\boldsymbol{At}$ and $\boldsymbol{Ct}$: the magnitude of $\boldsymbol{M}$ equals the square root of the magnitude of the cross product of At and Ct. Its direction is given by the unit vector along the cross product. By definition, vector M is tangent to both the field curve and the equipotential surface at point p.

All three vectors share the same physical units (A/m).

Extending this procedure to many segments allows computation of the magnetic field magnitude and the drawing of magnetic field curves, as shown in the applications section.

3. Classical Magnetic Field Model versus Magnetic Auvert Model

This chapter compares both models in the case of an infinite electrical wire in which the concept of scalar field is used.

The classical model discovered by Orsted and Ampère in 1820, is composed of a long electrical wire on the x axis, and a check point at a distance r from the wire. In this classical model, the field magnetic value is proportional to the current in the wire and inversely proportional with the distance r. In these conditions, the field value is zero at an infinite distance of the wire and at an infinite value when the check point is at a zero distance with the wire.

In the magnetic Auvert rule, the segment is elongated to infinity, and the scalar field value described in **Figure 3**, is given by the following integration. Parameter dx replace the length of the segment I.

$$|M| = I\int_{-\infty}^{+\infty} \mathrm{d}x \Big/ \left(x^2 + r^2\right) = \pi I/r \tag{1}$$

The main difference of this formula against the Biot = Savard rule is that the integration is without vector.

Also in **formula 1**, the value I/r obtained after the integration, is proportional with a constant factor, between the classical model and with the Magnetic Auvert rule. Due to this proportionality, both models are fully compatible.

4. Applications

Mainly in this chapter, electrical wire geometries form loops with circles or squares.

4.1. Magnetic Field around a Circular Wire with Electrical Current

4.1.1. Planar Magnetic Field Curves around a Circular Wire

In **Figure 7**, a circular conductor (red) of radius 1 m carries a steady current $\boldsymbol{I} = 1$ **A**. Black curves represent magnetic equipotential curves: the highest potential is near the red loop and decreases with distance from the loop. Far from the loop, the vertical straight lines coincide with the loop's symmetry axis. In the Magnetic Auvert model, this vertical symmetry axis corresponds to the vector sum of all vectors $\boldsymbol{C}$ contributions from all the segments composing the circle; this sum is zero. Therefore, the magnetic potential vanishes along that vertical line.

All field magnitudes are expressed in **A/m**.

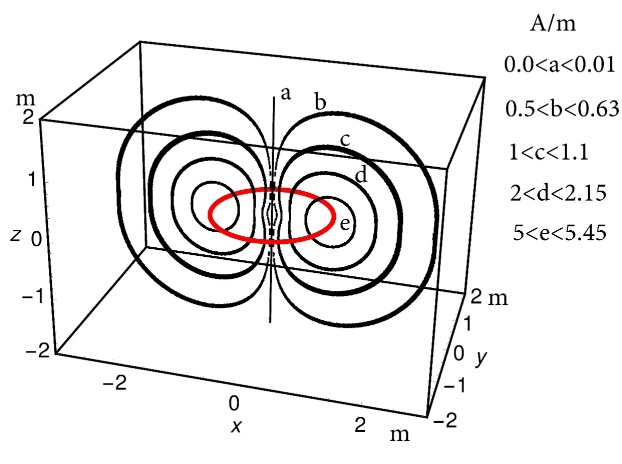

Figure 7. Magnetic Field Curves around a red current loop.

4.1.2. Magnetic Potential Surface around a Circular Electrical Loop

In this paragraph, magnetic field curves are identical by a rotation around the vertical strait line having points at equidistance from the circular electrical loop.

In Figure 8, circular conductor (red) carries a steady current $I = 1$ A. The plotted surface corresponds to the equipotential value of 2 A/m and has been cut in half to reveal the loop.

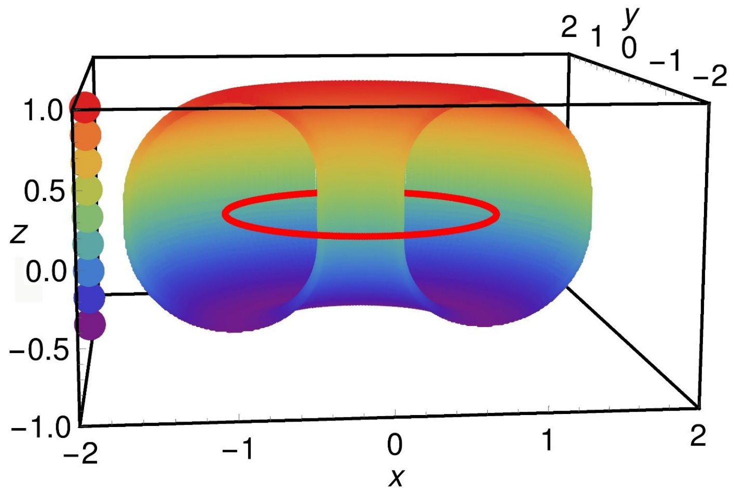

Figure 8. Equipotential surface at 2 A/m around a 1 m radius current loop.

Color shading encodes the surface height z, facilitating visual tracking of elevation across the magnetic surface. The outer portion of the surface is nearly circular, while the region near the center of the electrical loop along the symmetry axis becomes almost planar, approaching a straight line.

In the Magnetic Auvert model the vertical symmetry axis is a locus of vanishing scalar potential because the vector sum of all vector C contributions from the loop's segments is zero.

All field magnitudes are expressed in A/m.

4.1.3. Magnetic Field Curves around a Circular Wire

In this paragraph, separated magnetic curves are drawn by a medium size of the angular rotation.

In Figure 9, black curves show magnetic field curves where the magnetic field equals **2 A/m** around the red circular conductor. Although such equipotential curves can be drawn continuously around the entire loop. Only nine representative curves are shown on one half of the circle for clarity. Increasing the number of curves produces a dense pattern that converges to the equipotential surface illustrated in Figure 8.

4.2. Magnetic Field around a Square Wire with Electrical Current

4.2.1. Magnetic Field Curves around an Electrical Square Wire

In this chapter, the segments are not forming a red circle but a red electrically active square.

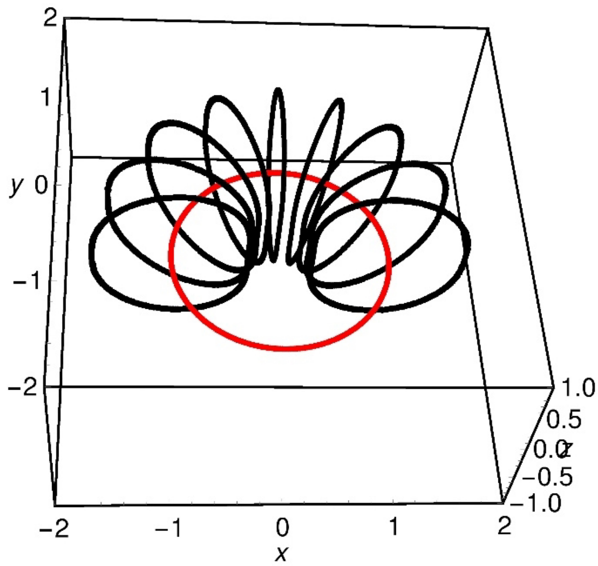

Figure 9. Magnetic field lines at constant value 2 A/m around a current loop.

In **Figure 10**, square conductor (red) composed of four segments of length **2 m** carries a steady current $\boldsymbol{I} = 1\ \mathbf{A}$. Black curves represent magnetic equipotential curves: the potential is highest near the square and decreases with distance. Centered in the square, the equipotential curves approach straight vertical lines that coincide with the symmetry axis of the square.

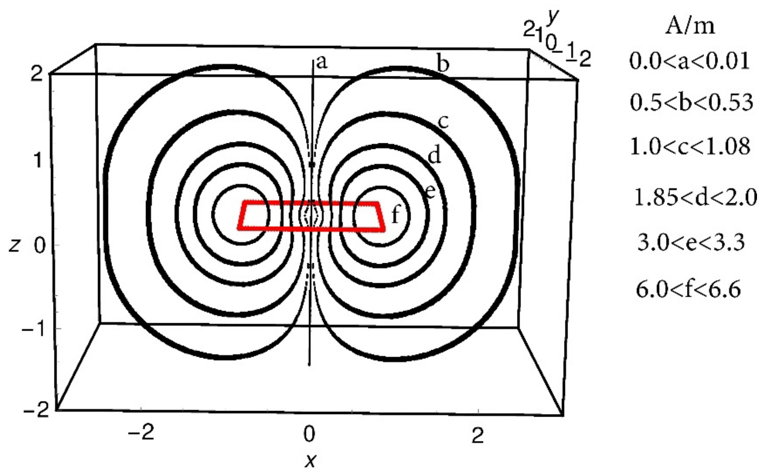

Figure 10. Magnetic field lines around a square current loop.

In the Magnetic Auvert model the vertical centered axis ***a*** is the vector sum of the four vectors C contributions from the square's segments; this sum vanishes, so the magnetic potential is zero along axis *a*.

All field magnitudes are expressed in A/m.

4.2.2. Magnetic Field Surface with Constant Field Value around Square Current

The rotation about the ***z* axis** cannot be applied directly to a square loop, so the equipotential surface in Figure 11 is constructed by sampling many discrete orientations around the loop and assembling the resulting contours. For each orientation we compute the magnetic potential at a grid of points in the plane, extract the contour corresponding to the chosen constant value, and record the contour height z given by the Magnetic Auvert rule. Repeating this for a dense set of angles produces a continuous equipotential surface that follows the square's symmetry while capturing the local curvature near each segment and the nearly planar behavior near the vertical symmetry axis.

The procedure generalizes by increasing the angular sampling density and the planar grid resolution; higher resolution yields a smoother surface that converges to the ideal equipotential as shown in Figure 11.

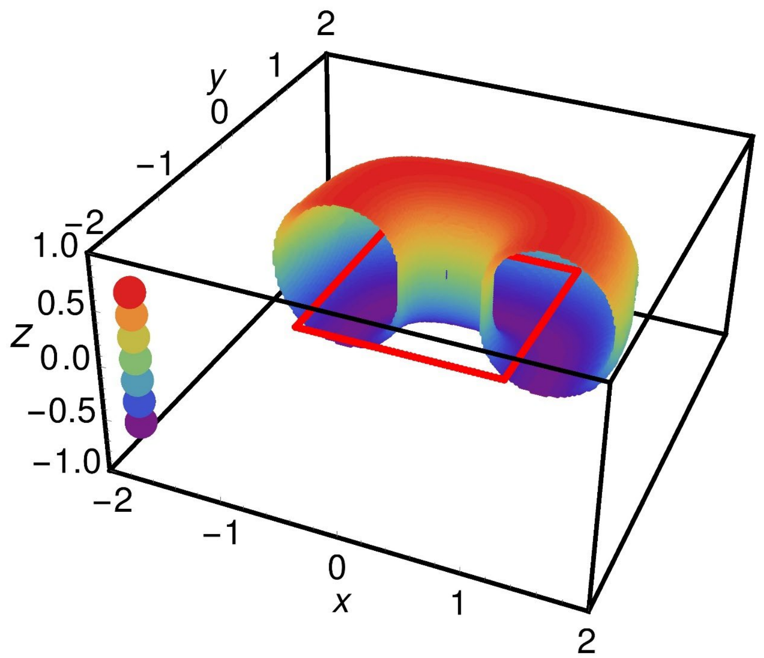

Figure 11. Equipotential surface at 3 A/m around a square current loop.

In Figure 11, a square conductor (red) composed of four segments of **2 m** carries a steady current $I = 1$ **A**. The plotted surface represents the equipotential value of **3 A/m** and has been cut away to reveal the loop. Color shading encodes the surface height z, making it easy to follow elevation changes across the magnetic surface.

Because a square lacks continuous rotational symmetry about the z axis, the surface is constructed by sampling many discrete orientations and assembling the resulting contours; this yields a surface that reflects the square's fourfold symmetry, with nearly planar behavior near the vertical symmetry axis.

By comparing Figure 8 and Figure 11, a small difference is visible in the angular aspect between both colored surfaces. This difference is due to the angles necessary to form the field surface around the square.

4.2.3. Non-Similar Magnetic Field Curves around an Electrical Square Wire

In this paragraph, separated and different curves but with equal magnetic values are drawn.

In Figure 12, five different equipotential curves (black) at **3 A/m** are shown around the red square conductor to preserve visibility of the loop. Two curves located above the square's corners are identical by symmetry; the three other curves above the midpoints of the sides are similar but slightly different from the corner curves. These five curves lie in four planar symmetry planes of the square; the remaining equipotential curves are generally nonplanar and form a three-dimensional pattern. Rendering the full set of nonplanar curves requires point-by-point evaluation along each line and specialized plotting routines beyond simple planar contour extraction.

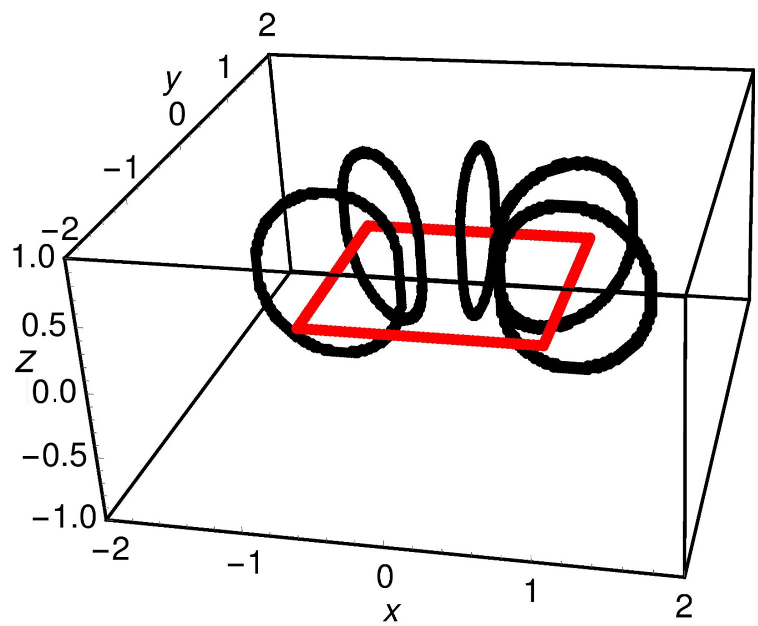

Figure 12. Representative equipotential curves at 3 A/m around a square current loop.

4.3. Two Electrical Circular Wires with Same Directions for the Electric Current

With two electrically active circular loop, the magnetic field pattern is not a simple point-by-point sum of each loop's curves. Although each loop contributes its own equipotential contours, the resultant field at any point depends on the vector combinations.

4.3.1. Magnetic Field Curves around Two Electrically Active Circular Loops

In Figure 13, two parallel circular conductors (red) carry currents in the same direction. Black curves show equipotential curves: the field magnitude is higher close to the loops and decreases with distance. The vertical symmetry axis *a* (at *x*

= y = 0) is the locus where the vector sum of all vectors C contributions from both circles vanishes; consequently, the magnetic potential is zero along axis a.

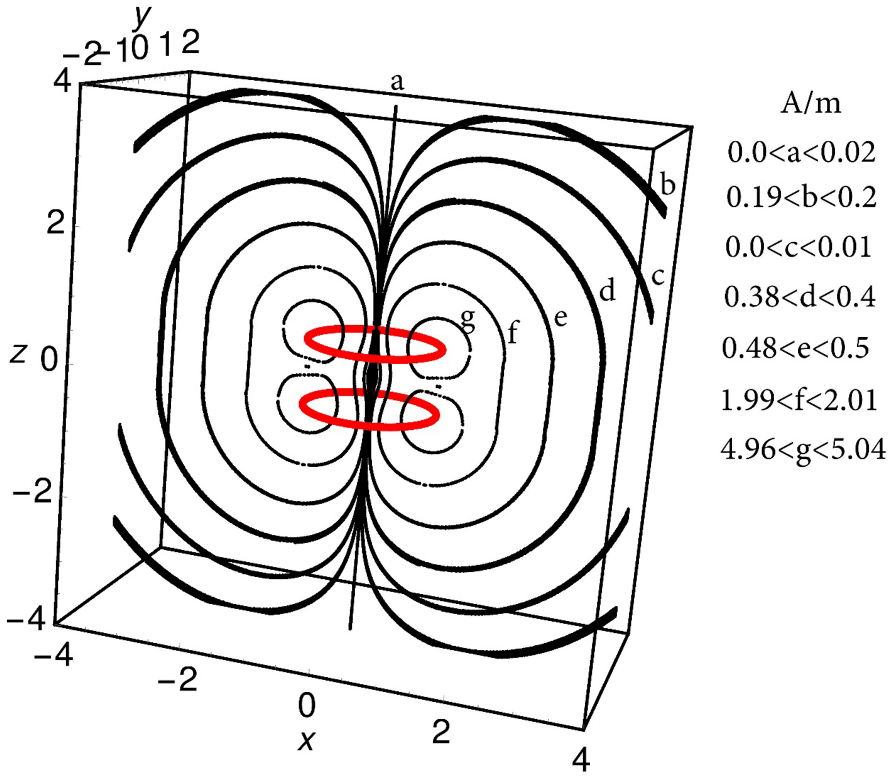

Figure 13. Magnetic field curves for two identical, parallel with same electrical direction for two electrically active loops (red).

In the theoretical part of this article, the magnetic field is the consequence of the addition of all vectors A, and with an addition of all vectors C. The vector M is then derived from those resultant vectors rather than being summed independently. This formulation differs from the classical presentation based directly on Ampère's vector law and its usual vector superposition.

4.3.2. Equipotential Surface Surrounding Two Parallel and Circular Electrical Loops

In **Figure 14**, the magnetic field surface is surrounding two red electroactive circles in the same current direction.

The plotted surface corresponds to the equipotential value 2 A/m and has been cut in half to reveal the loops.

Color shading encodes the surface height z, allowing visual tracking of elevation across the magnetic surface. The surface is built by sampling a representative contour (the 2 A/m curve) at many orientations around the pair of loops and assembling the resulting contours into a continuous surface. At each point the resultant vectors At and Ct are computed from all segment contributions, and the out-of-plane component M is derived from their cross product; therefore, the combined surface is not a simple overlay of two single-loop surfaces but reflects the interaction between the loops' contributions.

All field magnitudes are expressed in **A/m**.

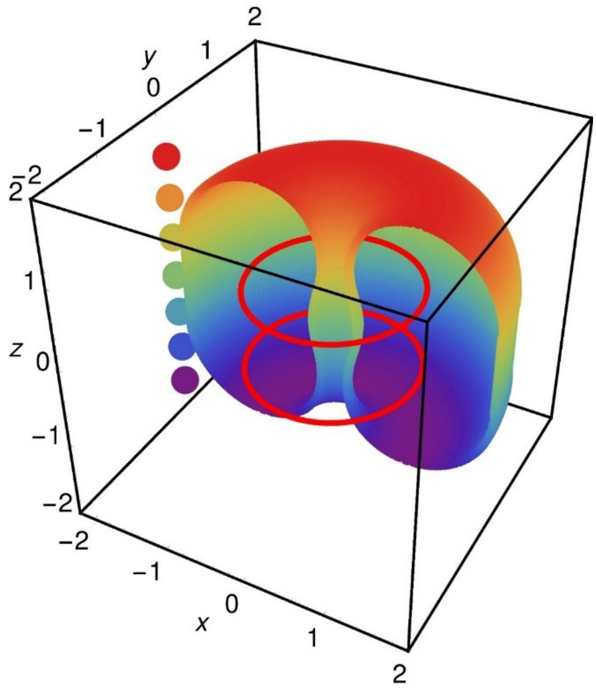

Figure 14. Equipotential field surface at 2 A/m around two circles with same electrical current of 1 A.

4.3.3. Magnetic Field Curves with Two Electrically Active Circles

For clarity, this section shows a limited, representative set of curves so the interior structure remains visible; the full pattern is obtained by densely sampling contours and assembling the three-dimensional equipotential surface.

In **Figure 15**, only eleven curves are drawn to keep the interior of the loops visible. The curves are generated by rotating a single reference contour in discrete angular steps and assembling the resulting traces.

By construction the equipotential curves do not intersect one another; this non-intersection property is a fundamental characteristic of all magnetic curves evaluated in this article.

All field magnitudes are expressed in **A/m**.

4.4. Magnetic Fields around Two Circular Wires with Opposite Electrical Current

4.4.1. Planar Magnetic Fields Curves with Two Circular Loops in Opposite Electrical Directions

In this paragraph, the difference between both circles is in their own color: red and blue.

Figure 16 shows the cross section in the plane $y = 0$, for two circular conductors carrying currents in opposite directions. Black curves are equipotential at selected constant field values: the field magnitude is higher close to each electrical loop and decreases with distance.

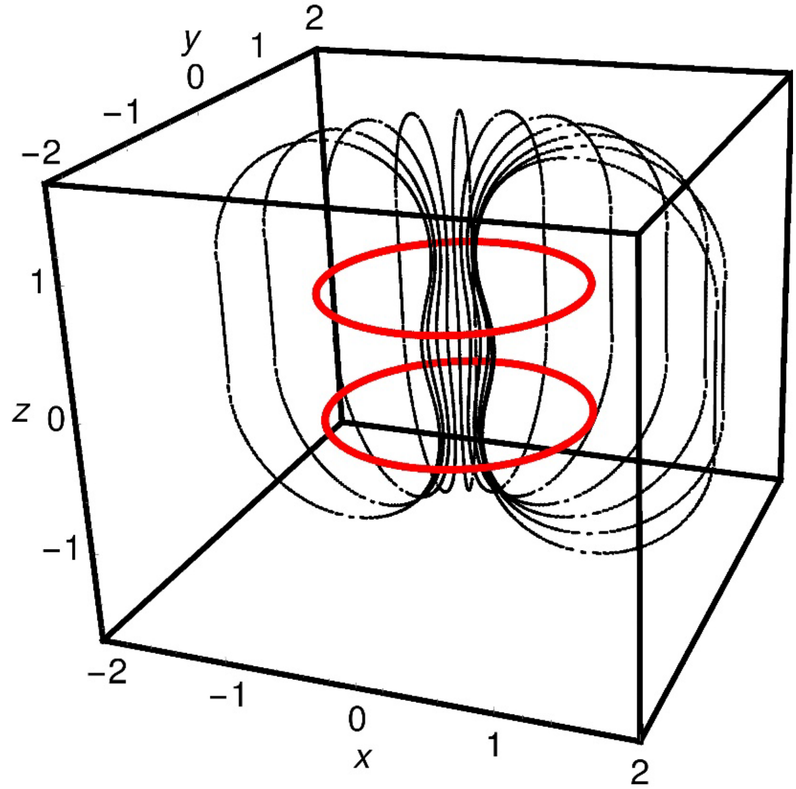

Figure 15. Representative of eleven magnetic equipotential curves (black) at 2 A/m for two parallel current loops with same electrical direction.

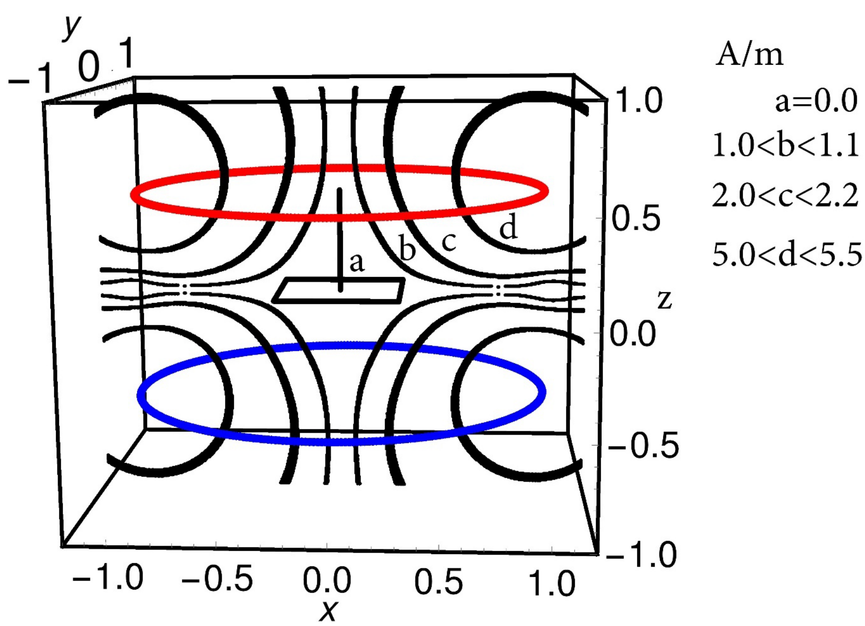

Figure 16. Planar section $y = 0$ of the magnetic field curves for two electrical circular loops in opposite current directions.

Where a xy point is equidistant from the two loops (for example along the vertical line through point ***a***), the vector sum of the local vectors C contributions cancels and the magnetic scalar potential vanishes; this is visible as the zero-value locus along the axes passing through ***a***.

The pattern exhibits four symmetric groups of three similar curves above and below the loops; these groups reflect some local geometry changes by the currents.

All field magnitudes are expressed in **A/m**.

4.4.2. Magnetic Field Surfaces around Two Circular Wires with Opposite Current Directions

In Figure 17, two parallel circular conductors (red and blue) carry currents in opposite directions. Each colored surface represents the equipotential value **1 A/m** and has been cut away where needed to reveal the loops. The horizontal plane $z = 0$ forms the boundary between the two domains: for $z > 0$, the field domain is associated with the red loop, and for $z < 0$, it is associated with the blue loop.

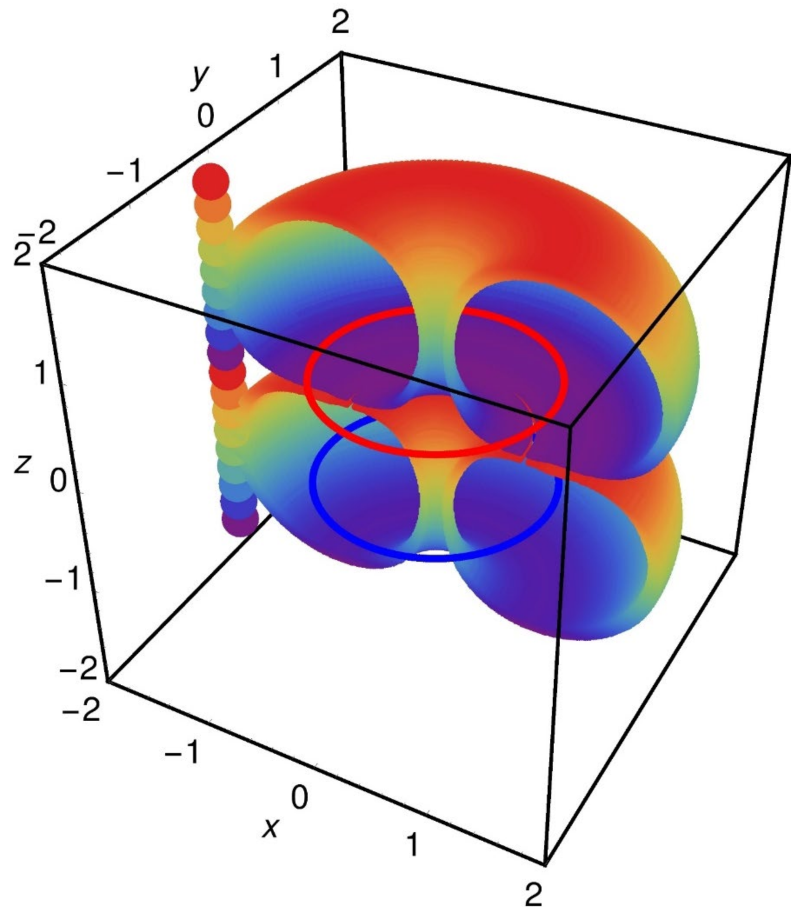

Figure 17. Equipotential surfaces at 1 A/m for two antiparallel current loops.

The plane $z = 0$, is a locus of zero magnetic scalar potential that extends to infinity, consistent with the observation that the field vanishes at large distance. Equipotential surfaces do not intersect one another; only the zero-field surface can serve as a boundary between the two domains.

According to these two magnetic surfaces, several magnetic curves can be drawn as described in the next paragraph.

4.4.3. Magnetic Field Curves around Two Circular Wires with Opposite Current Directions

In **Figure 18**, nine magnetic equipotential curves (black) at 1 A/m are shown around two parallel circular conductors (red) carrying currents in opposite directions. Only nine curves are drawn to keep the interior of the loops visible. Each curve is generated by rotating a reference contour extracted from the planar section shown in **Figure 16** and tracing the resulting path in space. Increasing the number of rotational samples reconstructs the full equipotential surface; with fewer samples the interior structure remains easier to inspect. By construction these equipotential curves do not intersect one another; this non-intersection property holds for all magnetic curves produced with the Magnetic Auvert model.

All field magnitudes are expressed in **A/m**.

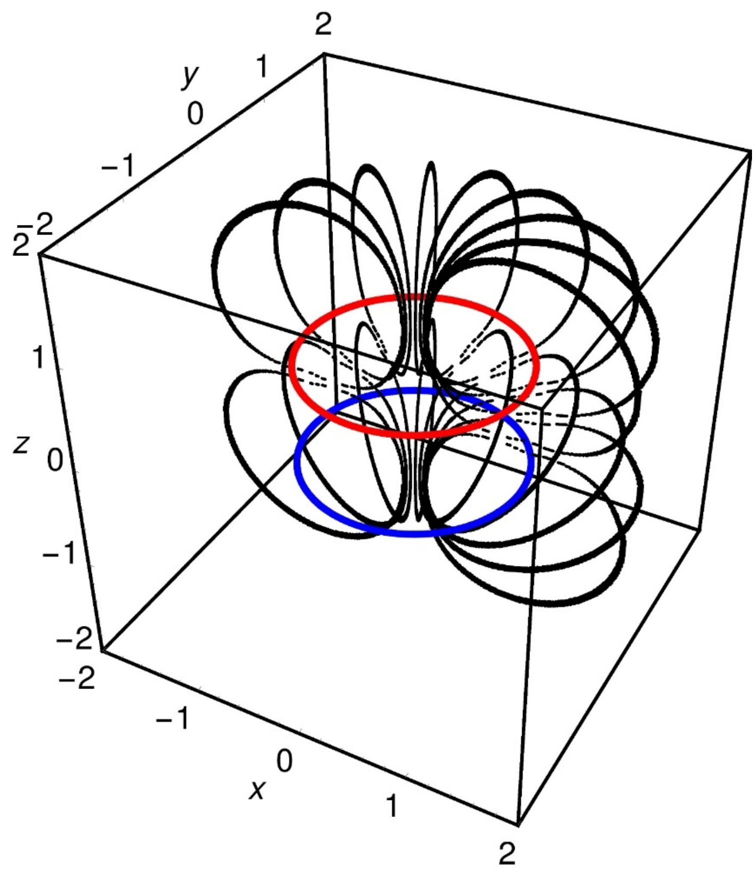

Figure 18. Representative equipotential curves at 1 A/m for two antiparallel current loops.

4.4.4. Orientations of Magnetic Field Curves with Two Electrical Loops in Opposite Current Directions

This paragraph illustrates one of the most complex configurations discussed in this article: field directions with two circular electrical currents flowing in opposite directions and following the right-hand rule [14] [15].

In Figure 19, Electrical directions in Magnetic loop are shown clockwise for the blue circle and anticlockwise for the red circle. For the magnetic black curves, arrows follow the classical right-hand rule. When black circles are nearer to one colored circle, they are with arrows in the classical right-hand rule direction with the nearest part of the colored loop.

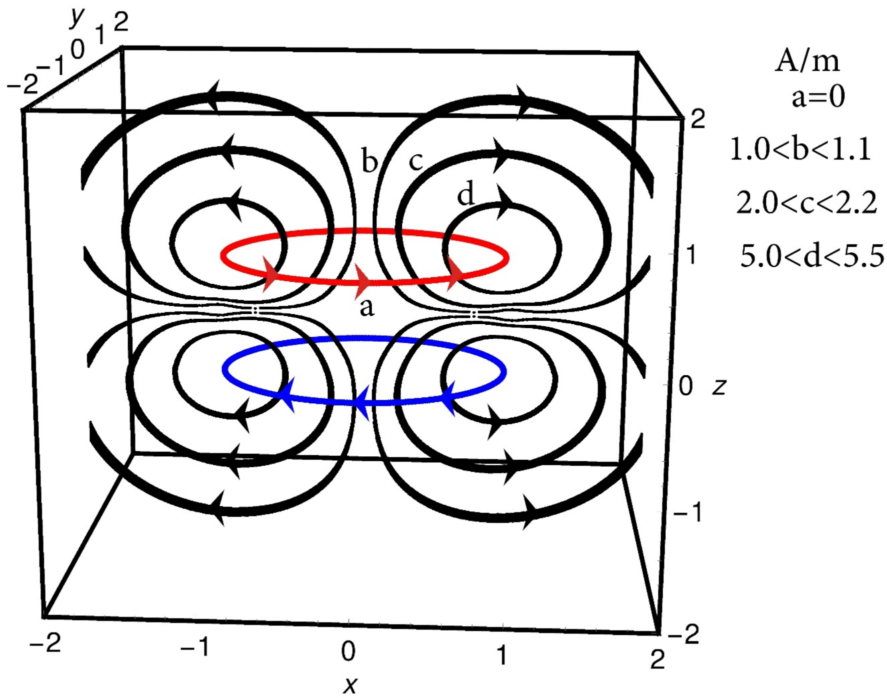

Figure 19. A planar cross section ($y = 0$) of magnetic curves around two circular electrical loops in opposite current directions.

In Figure 19, a black magnetic field curve has the same potential value all along it. It cannot go at an infinite distance. Therefore, every non-zero curve must be back and close to itself.

Linear axes with $x = y = 0$ and plane with $z = 0$, follow a zero-field value. These borders are between two groups of magnetic curves. They have no direction because the magnetic field value is zero.

Although the magnetic field directions remain the same on both sides of the boundary, the zero-field region prevents a strong border even if directional field representation is identical on both sides of it.

This result is a key distinction between the proposed model and the classical theory of magnetic fields, which predicts a non-zero field value at the center of a circular electrical current.

5. Conclusion

The Magnetic Auvert model proposes a revised evaluation of the magnetic field around arbitrary current geometries by computing three local vectors—A, C, and the derived out-of-plane component M—at every point. This formulation enforces additivity for the vector contributions A and C, removes discontinuities at segment boundaries, and yields continuous iso-potential surfaces and non-intersecting magnetic field curves for single and multiple conductors. The model reproduces familiar symmetry features (zero-potential axes and separatrix planes) while allowing straightforward numerical construction of equipotential contours and surfaces for complex assemblies. Readers can apply the method to any conductor configuration by summing segment contributions, extracting contours at chosen field values, and assembling rotated samples to form full three-dimensional surfaces.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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