New Induction

New Induction

By Robert J Distinti B.S. EE

This is the first paper in the New Electromagnetism Series. Other Papers in the New Electromagnetism Series include: New Electromagnetism (ne.pdf), New Gravity (ng.pdf), and Rules of Nature (ron.pdf). This material on file with U.S. Patent office. Applications of this technology are patent pending. This material is copyright protected 1999-2004 and is solely the work/discovery of Robert J. Distinti.

ABSTRACT

The purpose of this paper is to introduce a new model for electromagnetic induction to replace Faraday's Law. The new model of induction is superior to Faraday's Law for the following reasons:

1) **Easier to use:** requiring only double line integral to solve an induction problem. Faraday's law requires a triple integral (a line integral and an area integral).
2) **Easier to understand**: The basic equation is no more complex than Coulomb's Law is. The new model is simple enough to be included in a high school physics curriculum. Induction problems can be solved without the need to understand field theory. This is not so with Faraday's Law.
3) **Better suited for numerical integration**: Algorithms written around the new model converge rapidly (see Appendix B). Furthermore, the simplicity of the new model makes possible a general purpose routine that can solve any arbitrary inductance problem by breaking the problem up into fragments (very small lengths) then sum the fragment to fragment effects. Faraday's law requires the computer to determine where the interior of the loop receiving the energy is. Only then can it know what area to perform numerical integration on.
4) **No Ambiguities**: The new model allows one to determine the amount of emf received by any section of a loop. Faraday's Law only yields the NET emf received by a closed loop, we are left to assume that the distribution of emf (emf per unit length) is uniform. Consequently, Faraday's law forces one to assume (incorrectly) that there is no emf generated in any section of a loop when Faraday's law yields a zero result. See NewIndSupFive.doc for example.
5) **No Contradictions**: Faraday's Law affects charges differently depending upon the situation. With the new model, the effect on any charge is determined by one equation regardless of situation.
6) **Applies to Point Charges**: The new model allows a solution to the following problem: Given two point charges sitting on the x-axis separated by a distance, find the component of force acting upon the first charge due to the instantaneous acceleration of the second charge in:
   A) The direction of the y-axis.
   B) The direction of the x-axis.
   Faraday's Law does not enable one to solve this problem.
7) **Explains more**: The new model explains such things as intrinsic inductance and the skin effect in a clear and concise manner. Faraday's Law does not explain these phenomena.

A subsequent paper (titled New Electromagnetism) shows that the new law of induction can model the property of Inertia. Therefore, the new model has been dubbed the Inertial Electric Law (IEL).

Table 1 The New Model For Induction

Name	Point Charge form	Wire Fragment form	Notes
Inertial Electric Law (IEL)	$\mathbf{F} = \frac{-K_M Q_S Q_T \mathbf{a}_S}{\lvert\mathbf{r}\rvert}$	$emf_{TS} = -K_M \left(\frac{dI_S}{dt}\right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{\lvert\mathbf{r}\rvert}$ Note: This model is a superset of the Neumann equation. Neumann is only applicable to closed loops; whereas this model is valid for situations of closed and open loops. See ni_neumann.pdf for more details	$K_M = \frac{\mu}{4\pi}$

Table of Contents

1 Please Read.

The contents of this paper are protected by a number of schemes to include pending patents, trademarks, copyrights, and trade secrets. There is considerable research, publications and products based on the New Electromagnetism models which as yet have not been released. These items are to be released in phases over the next few years.

We publish a small portion of our research for free to allow those who are interested to judge the quality and value of our work. Our freely published papers may be duplicated and distributed without license as long as they are duplicated and distributed intact (all pages without changes).

Document History:
Rev 2: Added Appendix D that includes sample applications of induction that compare Faraday's Law to the new model.
Rev 2.1-2.2: Typographical/grammar fixes.
Rev2.3: Converted to PDF format
Rev2.4: Typographical/Grammar Fixes.
Rev2.5: Reciprocity rule – Changes in blue
Rev2.6: Changed please read; Typographical/grammar fixes
Rev2.7: changed section 4.3 to make more palatable to Physicists
Rev2.8: added references to Neumann's Equation – changes in green
Rev2.9: added references to the Jackson derivation for self induction– changes in green

2 INTRODUCTION

This paper introduces a new mathematical model for the physical phenomenon known as electromagnetic induction. Prior to introducing the new model, the phenomenon of induction is reviewed briefly using Faraday's Law to ensure the reader understands the language of the phenomenon. Once the review is complete, Faraday's Law is examined to expose its shortcomings, ambiguities and contradictions. Finally, the new model of induction is introduced, complete with examples.

This paper is supported by a number of supplements to include PC compatible software. These supplements are detailed in Appendix A.

3 Review of Faraday's Law

Faraday's Law states that the emf induced in a closed loop of wire is proportional to the time rate of change of the number of magnetic flux lines enclosed in the loop. The direction of the emf will be such to create a current that opposes the change in the number of flux lines enclosed by the loop.

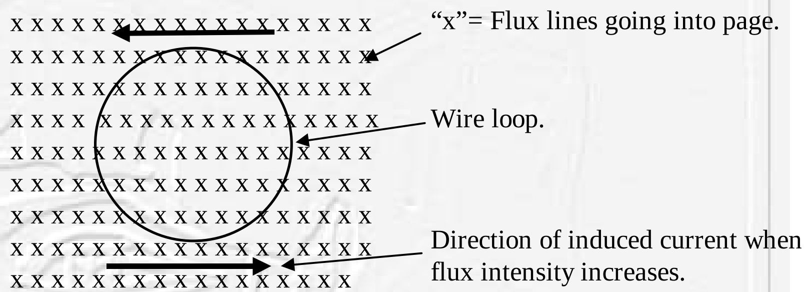


Figure 3-1

The voltage induced in the loop is described by the equation:
$emf = -n(d\phi / dt)$. Where ϕ is the total number of flux lines contained within the loop and "n" is the number of turns in the loop.

There are a number of different types of induction. The "type" of induction is defined by the source of the changing magnetic field. There are currently four types:

1) **Mutual Inductance** (Figure 3-2): Mutual inductance is the emf generated in a loop (target) due to the current change in another loop (source). In this case, the current in the source loop generates the source of the magnetic field. As the current in the source loop changes, the magnetic field generated by the source also changes. If the target is correctly oriented within the field of the source, it will experience the change in magnetic field as well; thus an emf is generated. This type of induction is used to create devices known as transformers. Mutual inductance is represented by a capitol M and is express in the units of Henries (emf in second loop/current change in first loop). Faraday's Law gives excellent results when applied to mutual inductance problems.
2) **Self-Inductance**: In the Mutual Inductance definition, one may observe that the source itself links the magnetic field that it generates. The emf generated in the source by linking its own magnetic field is called Self-Inductance. According to Lenz's Law, the loop will produce (induce) a current to oppose the magnetic field change. As such, the induced current opposes the original current change. This phenomenon is used to construct devices that oppose any change to the current through them; these devices are called inductors. Inductors are used in electronic filters and oscillators. Inductance of this type is represented with a capitol L and is express in the units of Henries (emf/current change). Although Faraday's law is used to explain Self-Inductance, it is not possible to obtain a result because of a division-by-zero condition with the Biot-Savart law. This condition results from the fact that the area containing the flux contacts the current source that generates the flux. This yields a zero distance in the denominator of the Biot-Savart law.
3) **Intrinsic Inductance**: Sometimes called internal inductance; this inductance is the result of changes in the magnetic field produced from the current in the wire itself. It is not the result of magnetic field changes entering the wire from the surroundings. Essentially, the wire itself opposes changes to the current through it. Present theory claims that intrinsic inductance is $\frac{\mu}{8\pi}$ Henries per meter. This relationship is linearly proportional to wire length and independent of wire thickness. This relationship is not derived from Faraday's Law because Faraday's Law is impossible to apply to this phenomenon. Furthermore, simple experimentation teaches that intrinsic inductance is a function of wire thickness.
4) **Motional or Magnet Induction** (**Figure 3-3**): This inductance is produced by a magnetic field moving relative to a loop. This type of induction is harnessed to produce AC electric power. Both Faradays law and the Motional Electric Law ($emf = (\mathbf{v} \times \mathbf{B}) \bullet \mathbf{l}$) give excellent results for this type of induction; however, the Motional Electric Law (MEL) permits a much more detailed analysis of the phenomenon.

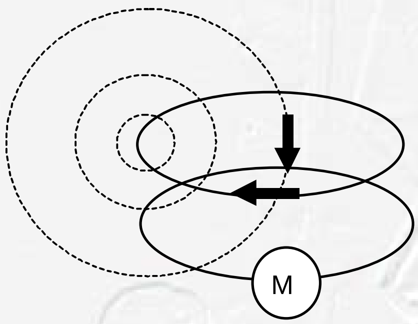


Figure 3-2

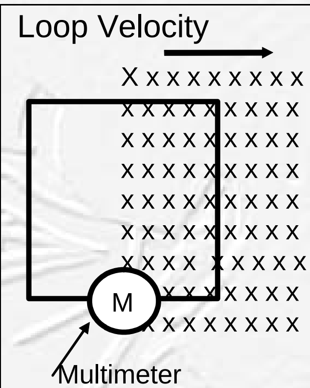


Figure 3-3

4 Evidence for a new model

This section highlights evidence for the existence of an improved model to replace Faraday's Law.

Note: The paper titled "Rules of Nature"--ron.pdf contains much more evidence that a better model then Faraday's Law exists. The "Rules of Nature" now includes the new "Reciprocity Rules" which most peers consider to be strongest argument proof that Faraday's law is not a complete description of induction (this includes Maxwell's version of Faraday's Law). The "Rules of Nature" is a later publication than this paper; in fact, this section became the very nucleus that eventually evolved into the more generally stated Rules of Nature. Newer evidence/arguments for a better model will henceforward be included in the "Rules of Nature", thereby allowing this section to remain historically intact. The "Rules of Nature" is available for free at www.Distinti.com.

For another very strong argument see ni_neumann.pdf

4.1 Faraday's Law and Point Charges

Consider two loops of wire. In the first loop (the source) a changing current is applied that generates a changing magnetic field. Using Faraday's law, it is possible to determine the effect of the changing magnetic field on the charges in the other loop (the target loop). Further suppose that it were possible to immobilize (glue down) all the free charges in the target loop except for one solitary charge. With all of the other charges immobilized, it is still possible to determine the effect on the solitary mobile charge with Faraday's Law. Finally, remove the rest of the target loop leaving just the solitary charge sitting in free space. Without the perimeter of the loop to tell us how much flux is linked, it then becomes impossible to use Faraday's Law. This raises an interesting question: Does nature require a closed area defined by a physical object (such as a conductor) for Induction to work? If so then how does light propagate? Since we know that induction is an integral mechanism of the propagation of light and that light propagates without any such artifices, then there must be another relationship that allows us to determine the effect on the solitary charge mentioned above.

All electromagnetic laws, except induction, can be stated as an interaction between charged particles in free space. For example: Static charges are related by Coulomb's Law; charges moving in a magnetic field are modeled by the Motional Electric Law (MEL); magnetic fields are produced by moving charges (Biot-Savart); the Lorentz Force Equation relates the force on a charged particle to its position and velocity, etc. Why is there no point charge expression for induction?

We know that a changing magnetic field will induce an emf in a conductive loop. If a changing magnetic field is due to a changing current, and a changing current is a condition where charges are accelerating, then why is there no corresponding mathematical relationship for the effects of accelerating charges? Why must induction only work if charges are contained in closed loops of wire?

Nature is full of second order systems, such as the spring-mass-dashpot system, where the properties of position, velocity, and acceleration each contribute a component of force toward the behavior of the system. This is also true for to RLC circuits where charge position and its two time derivatives are used to model circuit behavior. Again, why is there no equation that relates point charge acceleration to some force or field?

Symmetry suggests that there should exist a free space charge equation that relates the force on a charge to charge acceleration.

4.2 Ambiguity

Consider a loop of wire suspended in a uniform magnetic field of increasing intensity; see Figure 4-1. According to Faraday's Law, electrons will flow in such a way to oppose the increase in field intensity at the interior of the loop; therefore, electrons will flow in a clockwise direction as the field intensity increases.

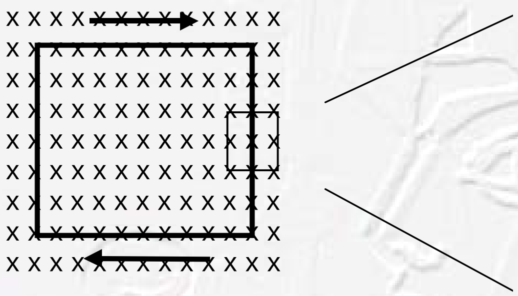


Figure 4-1

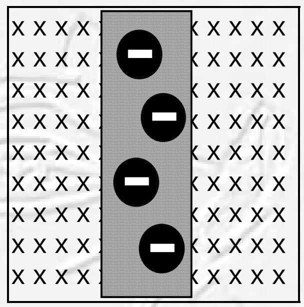


Figure 4-2

Now focus on a very small section of the loop (Figure 4-2). Considering that the electrons in the wire fragment are exposed to an increasing magnetic field and that it is their job to move in the direction to oppose the field changes in the interior of the loop, then the following questions are posed:

1) How do the electrons in Figure 4-2 know that the interior of the loop is to their left?
2) Since the distribution of field lines is uniform, each section of wire is exposed to the same field conditions. If the field affects all sides of the loop in the same way, then why does each side produce an emf in a different direction?
3) Since the field is uniform from the perspective of all electrons, why do electrons behave differently based on what side of the loop they are on?
4) If the flux lines in the center of the loop affect the charges in the wire, then why is there not an effect from flux lines outside the loop?
5) What is the mechanism that relates a change in flux at one point in space to an emf at another point in space?

Ambiguity in a physical law is an indication that the law will eventually be replaced with a better one. As an example, consider Archimedes' principle. Archimedes' principle states that the buoyant force acting on a ship's hull is proportional to the weight of the water displaced. The ambiguity is demonstrated with questions similar to the ones above, such as: How does the hull know how much water it displaces? What is the mechanism whereby displaced water affects the object that displaced it? How does the water know what object displaced it? Etc. Buoyancy is now explained using the concept of pressure as developed by Pascal over two thousand years after Archimedes. This is only one of the historical examples where ambiguous laws are eventually replaced with new laws that reduce or eliminate the ambiguity. In most cases the new laws also explain more phenomena than the original laws could.

This paper will detail a new model for the mechanism of induction that is free of ambiguity. The new law also explains phenomenon that Faraday's Law can not.

4.3 Kirchhoff's Law

Note for Physicists: The first few sentences of this section are for the lesser experienced; take them for what they are worth. Please read this section since it goes beyond just calling E in $-d\phi/dt = \oint \mathbf{E}\cdot d\mathbf{L}$ a non-conservative-electric field.

Kirchhoff's law states that the sum of voltages around a closed loop must equal zero: $V = \oint \mathbf{E}\cdot d\mathbf{L} = 0$.

And yet it is typical to write Faraday's Law in this form $-d\phi/dt = \oint \mathbf{E}\cdot d\mathbf{L}$. This equation is another form of one of Maxwell's four equations for time varying fields. It is more recognizable as $\nabla\times\mathbf{E} = -\partial\mathbf{B}/\partial t$. It describes an absolute and causal relationship between electric and magnetic fields.

If Kirchhoff's law is true and $0 = \oint \mathbf{E}\cdot d\mathbf{L}$ and $-d\phi/dt = \oint \mathbf{E}\cdot d\mathbf{L}$ then $-d\phi/dt = 0$. This seems to show a contradiction in the laws of electromagnetism since $-d\phi/dt = \oint \mathbf{E}\cdot d\mathbf{L}$ is interpreted to say that a changing magnetic field generates an electric field that imparts energy (emf) to a closed loop, yet Kirchhoff's Law states that it is impossible for an electric field (or any conservative field) to add energy to a closed loop

At this point one should ponder the following questions:

1) Is Faraday's Law correct?
2) Is Kirchhoff's Law correct?
3) Are we overlooking something?
4) Is an electric field truly caused by a changing magnetic field?

In order to answer the above questions, let us reexamine what can be studied in the lab.

Note: it is common to say that the E in $-d\phi/dt = \oint \mathbf{E}\cdot d\mathbf{L}$ is a non-conservative electric field (this is covered in more detail in another paper called "Maxwell's Omission" maxomis.pdf). In this discussion we look deeper into the mechanisms of induction to obtain a more detailed understanding of what is going on. In our opinion, it not good science just to change the definition of something in order to avoid contradictions.

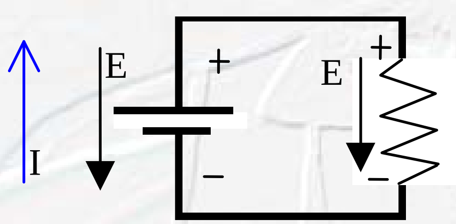


Figure 4-3

An electric field is not the only means by which to move electrons; furthermore, electrons are able to flow around a closed loop even if the sum of the voltages equals zero. This is illustrated by considering the classical circuit of a cell and a resistor (see Figure 4-3). We are told in engineering class that the sum of the voltages around this circuit equals zero ($0 = \oint \mathbf{E}\cdot d\mathbf{L}$) and yet current flows through it. However, this explanation only represents part of the story. In the presence of an electric field, current flows from higher potentials to lower potentials in much the same way that water flows from higher elevations to lower elevations. If an electric field were the only action at work in this circuit, then current would flow through the battery in the same direction as the electric field (E) shown by the left solid black arrow. From experience we know that current (I) flows through the battery in the direction of the blue arrow shown at the far left. The battery uses a chemical reaction to pump charges against the Coulomb forces in much the same way that a pump forces water up hill, against the force of gravity. The chemical reaction in the battery CAN NOT use an electric field (at least directly) to pump the charges otherwise this field would oppose the field of the charges that are separated. This opposing field would leave no net voltage across the terminals of the battery. Instead, the battery adds energy to the charges (energy/charge = voltage) by some means other than an electric field in much the way that a water pump moves water uphill by some means other than a gravitational field.

To illustrate this point further, consider a loop of wire with zero resistance that exists in a non-changing magnetic (call it an applied field). Assume there is no initial current in the wire. Then allow the applied magnetic field to collapse. The collapsing applied magnetic field will impart energy into the loop. Since there is no resistance in the wire, a constant current will flow in the loop forever (which will produce its own magnetic field). Since we are sure that a potential field (electric field) can not add energy to a closed loop, otherwise Kirchhoff's law would be violated; therefore we conclude that a changing magnetic field imparts kinetic energy to the loop. We further conclude that an electric field stores potential energy, and a magnetic field stores kinetic energy. – This point is explored further in the paper "New Electromagnetism."

One may try to prove that these observations are incorrect by citing the example of a voltmeter attached across the gap of an almost closed loop of wire. By exposing the loop to a changing magnetic field the voltmeter produces a reading. Since voltmeters measure voltage using an electric field and since an open loop is a circuit in which current can not flow (by definition), then one may conclude that the direct result of a changing magnetic field on a loop of wire is an electric field. This conclusion is not correct because the properties of an open loop are misunderstood. It is true that no NET current will flow through an open loop; however, that does not mean that there is no charge movement in the loop at all. This is illustrated by the more accurate explanation of the phenomenon:

1) A changing magnetic field imparts kinetic energy to the charges in the wire.
2) These energized charges then race around the loop causing a concentration at one end and depletion at the other end. In essence, the charges convert their kinetic energy to potential energy in the form of an electric field as the depletion/concentration grows.
3) The voltmeter registers voltage due to the electric field caused by the depletion/concentration of charge between the ends of the loop.

Therefore, an electric field is an indirect result of a changing magnetic field.

As a final proof, consider the circuit in Figure 4-4. At $t<t_0$, the capacitor to the left is uncharged and there is no current through the transformer. At $t=t_0$ the current source begins a constant increase in the current through the primary of the transformer (right side). The constant increase in primary current will generate a constant emf across the terminals of the secondary. This will charge the capacitor to a steady voltage.

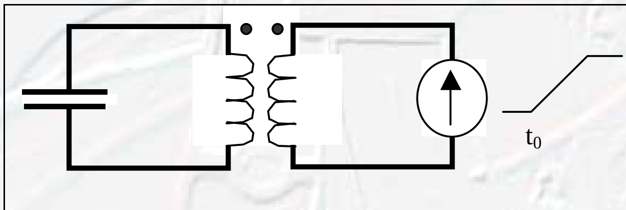


Figure 4-4

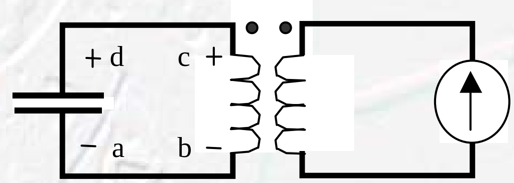


Figure 4-5

If it were correct that the emf across the secondary was due to an electric field, then the polarity of the induced electric field would be as shown in Figure 4-5 at points (b) and (c). Here, the positive terminal of the transformer (c) draws negative charges from terminal (d) of the capacitor and the negative terminal (b) of the transformer supplies negative charges to terminal (a) of the capacitor. How then does the induced electric field move the charges from (c) to (b)? There is no electric field that can force negative charges to repel from the positive terminal (c) and attract to the negative terminal (b). The dilemma we face is the fact that an electric field is a conservative beast and there is no arrangement of an electric field that will force charges around a closed loop. Therefore, the mechanism by which a changing magnetic field moves charges CAN NOT be an electric field. The electric field must be the end result of charges that have been displaced.

This leads to an interesting caveat. In order for a changing magnetic field to generate an electric field, charges must be displaced. If this is so, then does light (electromagnetic radiation) require a charge distribution in free space in order for propagation to occur? This is explored in more detail in a following paper.

It is therefore proven that an electric field is NOT the direct result of a changing magnetic field.

4.4 The Superposition Dilemma

Superposition allows one to analyze a system by computing the separate effects of its sub-components and then summing the "sub effects" together. This concept is of great importance to science and engineering as demonstrated by the following examples:

1) The interference pattern of light is due to the linear summation of the peaks and the valleys of two (or more) coincident light rays. This is superposition in every sense of the word and shows that electric and magnetic fields are linear.

2) The Biot-Savart Law is used to compute the magnetic field intensity at a location from a current carrying wire. This law allows one to compute the effect of every differential length (fragment) of wire separately. The total effect is found by (linear) summation of the fragment effects.

3) Laplace transforms, used extensively in science and engineering, allow one to translate differential equations from the time domain to the frequency domain where the differentials are resolved with simple algebra. After the terms are resolved, the results are transformed back to the time domain. Laplace transforms use superposition; this is why we are told that Laplace transform can only be used on linear differential equations with time invariant coefficients.

4) In Faraday's law, the "n" in "emf = -n($d\phi / dt$)" shows that the emf received by each loop of wire, enclosing the same field, is linearly additive. Although this is old knowledge, it clearly demonstrates superposition is valid with regard to electromagnetic induction.

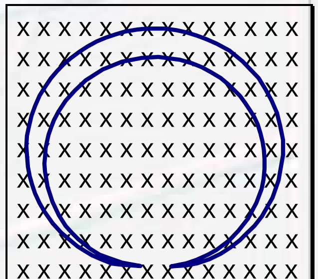


Figure 4-6

Since it is clear that electromagnetic induction is a linear phenomenon, and liner systems are subject to the rules of superposition, then it must be possible to apply superposition to analyze inductance problems. Suppose we were to analyze the power generated in a crescent constructed of two loops like the one shown in Figure 4-6. Which flux lines do you use to compute the induced voltage? The ones contained within the crescent or the ones contained in the body of the loops? Using the superposition theorem, the energy contributed by each loop can be calculated separately. Suppose, using Faraday's Law, we find that the large loop alone generates an open-loop voltage of 1 volt while the small loop generates 0.9 V. Then the gap voltage (of the two loops connected) should then be 0.9V; therefore, without loading the crescent gap, the voltage in the large loop is overpowering the voltage in the small loop by 0.1 volt. If you apply Faraday's law to just the flux contained within the crescent, you should achieve 0.1 volt. Therefore, the flux contained within the crescent represents the net energy of the crescent and the difference in energy between the two loops.

In the above example, it is shown that Faraday's law yields two different answers to the same problem. With Faraday’s Law alone, 0.1 volt (NET) is obtained. Using Faraday’s Law in conjunction with superposition yields 0.9 volt (across the gap). Although both answers are correct, superposition yields a better understanding of the system because it enables one to determine the effects contributed by each component of the system. To further improve our understanding of the system, we should then like to determine the emf generated in each differential length of wire. However, Faraday's Law does not work for linear wire systems since it is impossible to know the amount of flux linked. Furthermore, which way must the charges move in order to oppose the magnetic field changes?

Finally, when applying Faraday's Law to the flux within the crescent, we obtain a single value for emf and are left to assume that the emf is evenly distributed around the crescent. This is clearly a false since superposition teaches that the emf in the outer loop opposes (and is greater than) the emf in the inner loop.

A good model for induction must allow a person to compute the inductive effect on a differential length of conductor. By using such an equation, a person could compute the power generated in a system with varying conductor properties and field intensities.

4.5 Refining the Terminology

The exploration of Faraday's law has made it necessary to view electrical phenomenon in finer detail. The following paragraphs outline the changes necessary to describe electrical phenomena in more explicit terms.

Because it was shown in previous sections that energy imparted to charges is either potential or kinetic, we must refine the terms voltage (V) and electromotive force (emf) in such a manner to reflect this distinction. The terms emf and voltage are redefined as follows:

1) V = Potential energy per charge (joules/coulomb).
2) emf = Kinetic energy per charge (joules/coulomb).

Since force per charge is also a valuable expression and electric fields (force/Charge = **E**) are not the only means by which charges are moved then the following redefinition of **E** is necessary:

1) $\mathbf{E}$ = Any vector field that can be resolved to force per charge (Newton/Coulomb). This is not necessarily an electric field. When required, a subscript is used to distinguish the type of field producing the force per charge phenomenon. The following are examples.
2) $\mathbf{E}_E$ = Vector force per charge field specifically due to an electric field.
3) $\mathbf{E}_M$ = Vector force per charge field, resulting from the actions of a magnetic field.

The above terms affect the classical equations in the following manner:

Relationship between V and $\mathbf{E}_E$.	$V = -\int_a^b \mathbf{E}_E \bullet d\mathbf{L}$ $0 = \oint \mathbf{E}_E \cdot d\mathbf{L}$ (Kirchhoff's Law)
Relationship between emf and $\mathbf{E}_M$	$emf = \int_a^b \mathbf{E}_M \bullet d\mathbf{L}$ $emf = \oint \mathbf{E}_M \bullet d\mathbf{L}$
Kirchhoff's Law	$0 = \oint \mathbf{E}_E \cdot d\mathbf{L}$ or $0 = \nabla \times \mathbf{E}_E$
Faraday's Law	$emf = -n \frac{d\Phi}{dt}$
Maxwell's version of Faraday's law.	$\nabla \times \mathbf{E}_M = -\partial \mathbf{B} / \partial t$ (Note the "M" subscript.)

The following symbols define inductance:

1) M = Mutual inductance: $M = -\frac{emf_2}{\frac{di}{dt}_1}$: The ratio of the emf in a second loop to the current change in the first loop. The emf is caused by the current change.

2) L = Self-inductance: $L = -\frac{emf_1}{\frac{di}{dt}_1}$: The ratio of the back emf in a loop to the current change in the same loop.

Note: In all cases, M and L are positive when the direction of the emf and the direction of the current change are opposite. In previous documents and software algorithms, the opposite convention is used. This and all supporting documents are (or will be) revised with the convention above.

4.5.1 Fragmentary Notation

The remaining sections of this paper make heavy use of the term "fragment". A fragment is a differential length of filamentary conductor. It is to be demonstrated in a later section that any induction problem, involving constructs of wire (such as loops), can be analyzed on a fragmentary level. This section shows fragmentary notation by example only. In Appendix C fragmentary notation is shown in more detail.

1) $d\mathbf{L}_S$ = A source fragment. A fragment is a differential length of filamentary thin conductor. A source is an object that emits energy.

2) $d\mathbf{L}_T$ = A target fragment. A target is an object that produces an effect as a result of energy received from a source.

3) emf_{TS}= Fragmentary emf: The emf induced along a target fragment resulting from the current change through a source fragment. Any given inductance problem (involving conductors) can be resolved to a system of interactions between numerous fragments. The source and target are not necessarily different fragments.

4) $emf_T = \int_S emf_{TS}$ A line integral along the source loop results in the total emf generated in a target fragment.

5) $emf = \int_T emf_T$ Integrating the total emf generated in each target fragment yields the total emf generated in the target loop.

6) $emf = \int_T \int_S emf_{TS}$ Combining lines 4 and 5 into a double line integral result in the total emf generated in the target loop.

7) L_{TS}= Fragmentary Linkage: $L_{TS} = -\frac{emf_{TS}}{\frac{dI_S}{dt}}$: The ratio of the emf in a target fragment to the current change in a source fragment. A fragment is a differential length of wire. The source fragment and the target fragment may be the same.

8) $L = \int_T \int_S L_{TS}$, when the source and target loop are the same.

9) $M = \int_T \int_S L_{TS}$, when the source and target loop are NOT the same.

Do not get L confused with $d\mathbf{L}$; $d\mathbf{L}$ represents a differential vector length, not a differential inductance.

5 New Induction

5.1 Introduction

This section presents the new model for electromagnetic induction as discovered through experimental means. The readers who wish to rerun the experiments to verify these results are welcome to do so. The experiments are described in Appendix A. The new law of induction is described as follows:

> An accelerating charge (the source) will induce a force on other charges (targets) in a direction parallel to the direction of acceleration. The magnitude of the force is inversely proportional to the distance between the source and target. If the source and target are like charges, then the direction of the force is opposite to the direction of acceleration; otherwise, the direction of force is in the same direction.

Because the phenomenon of inertia can be modeled with the new law of induction, the new law has been dubbed the Inertial Electric Law (IEL). The modeling of inertia is discussed in a paper titled "New Electromagnetism" to be available shortly.

The new law of induction is represented in two basic forms. The Point Charge form that relates the inductive effect between charges in free space and the Wire Fragment form that relates the effect between differential lengths of wire (fragments). The point charge form is discussed first.

Equation 1: The Inertial Electric Law – Point Charge form.

$$\mathbf{F} = \frac{-K_M Q_S Q_T \mathbf{a}_S}{|\mathbf{r}|} \quad \text{Where } K_M = \frac{\mu}{4\pi}.$$

In the above equation, $\mathbf{F}$ is the vector force acting upon a target charge Q_T due to the vector acceleration $\mathbf{a}_S$ of a source charge Q_S. The value $|\mathbf{r}|$ is the distance from source to target.

A source is generally defined as the object that creates an effect; while, a target is the object that experiences or reacts to the effect. The source and the target can not be the same.

The new law of Induction can be expressed in a wire fragment form suitable for electrical engineers. A wire fragment is a vector differential length of wire ($d\mathbf{L}$).

Equation 2: The Inertial Electric Law – Wire Fragment form.

$$emf_{TS} = -K_M \left(\frac{dI_S}{dt}\right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|} \quad \text{where } K_M = \frac{\mu}{4\pi}.$$

In the above equation, $\frac{dI_S}{dt}$ is time derivative of the current passing through the source fragment $d\mathbf{L}_S$, emf_{TS} is the kinetic energy per charge absorbed along the length of the target fragment $d\mathbf{L}_T$ resulting from the current change in the source fragment. $|\mathbf{r}|$ is the distance from source to target. To find the total emf received by a target requires a double line integral as demonstrated:

$$. \ emf = \int_T \int_S emf_{TS} = -K_M \int_T \int_S \left(\frac{dI_S}{dt} \right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|}$$

Equation 3: New Induction applied to wire systems

Note: the right side of the above expression looks similar to Neumann's equation which is

$$emf_b = -K_M \left(\frac{di_a}{dt} \right) \oint_a \oint_b \frac{\mathbf{dL}_a \bullet \mathbf{dL}_b}{r}$$

Equation 4: Neumann's Equation applied to wire systems

The closed path restriction ($\oint d\mathbf{L}$) of Neumann's equation limits its usability to only a fraction of the application of the more flexible open path ($\int dL$) model of New Induction. Neumann's equation is derived from Faraday's Law and the classical "transverse only" field model (Biot-Savart) using Green's Theorem. As such, the closed loop restrictions are required otherwise Neumann's equation would violate the classical "Transverse only" model and would suggest that magnetic fields are spherical.

New Induction was developed through experiment (see later chapters) and shows that magnetic fields are spherical (See ni_neumann.pdf, New Magnetism or NIA1 for more details). As such the closed loop restrictions are not necessary. Consequently, Neumann's equation is only a subset of New Induction (See ni_neumann.pdf for more details)

	Point Charge Form	Wire Fragment Form	Notes
Inertial Electric Law (IEL)	$\mathbf{F} = \frac{-K_M Q_S Q_T \mathbf{a}_S}{\lvert\mathbf{r}\rvert}$	$emf_{TS} = -K_M \left(\frac{dI_S}{dt} \right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{\lvert\mathbf{r}\rvert}$	$K_M = \frac{\mu}{4\pi}$

6 Applications and Examples

6.1 Mutual Induction Experiment

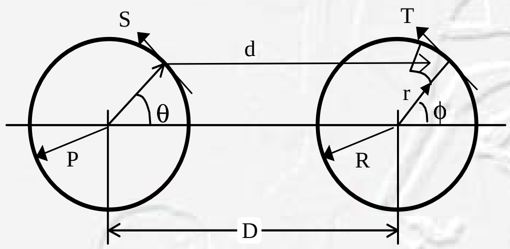


Figure 6-1 Mutually inductive loops

Given a source loop of radius P and a target loop of radius R, where both loops exist in the same plane and are separated by distance D (center to center), compute the mutual inductive linkage (M) between source and target where emf=-M(di/dt). Applying Faraday's Law yields the following equation:

$$M = -\frac{\mu}{4\pi}\int_{\theta=0}^{2\pi}\int_{r=0}^{R}\int_{\phi=0}^{2\pi}\left[\frac{rP\sin\left(\theta+\pi/2-\tan^{-1}\left(\frac{r\sin\phi - P\sin\theta}{r\cos\phi + D - P\cos\theta}\right)\right)}{(r\sin\phi - P\sin\theta)^2+(r\cos\phi + D - P\cos\theta)^2}\right]d\phi dr d\theta$$

Applying the wire fragment IEL yields:

$$M = \frac{\mu}{4\pi}\int_{\theta=0}^{2\pi}\int_{\phi=0}^{2\pi}\left[\frac{RP\cos(\phi-\theta)}{\sqrt{(R\sin\phi - P\sin\theta)^2+(R\cos\phi + D - P\cos\theta)^2}}\right]d\phi d\theta$$

Instead of hammering through solutions for the above equations, a pair of computer algorithms was developed. One algorithm determines mutual inductance using Faraday's law (called FARADAY_M_CIRCLE) and another uses the Inertial Electric Law (called DISTINTI_M_CIRCLE). Both algorithms yield the same result of 4.962e-9 Henries for R = P = 0.1m, D = 0.3m and resolution of simulation dL = 0.001m. The Faraday version took over 25 minutes on a 100mhz 486 machine while the other took less than 20 seconds. The software routines are found in Appendix B.

6.1.1 Collecting Experimental Data

The following apparatus is used to collect data for the mutually inducting loop experiment. The experiment can be run in any laboratory equipped with an oscilloscope and an audio function generator.

Circuit to measure Mutual Inductance.

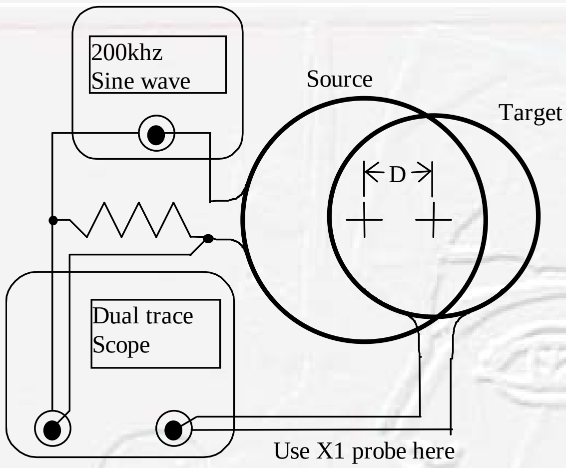


Figure 6-2

$$M_{Total} = -\frac{V_T R}{V_R 2\pi f}$$

$$M_{SINGLE} = -\frac{V_T R}{V_R 2\pi f N_T N_S}$$

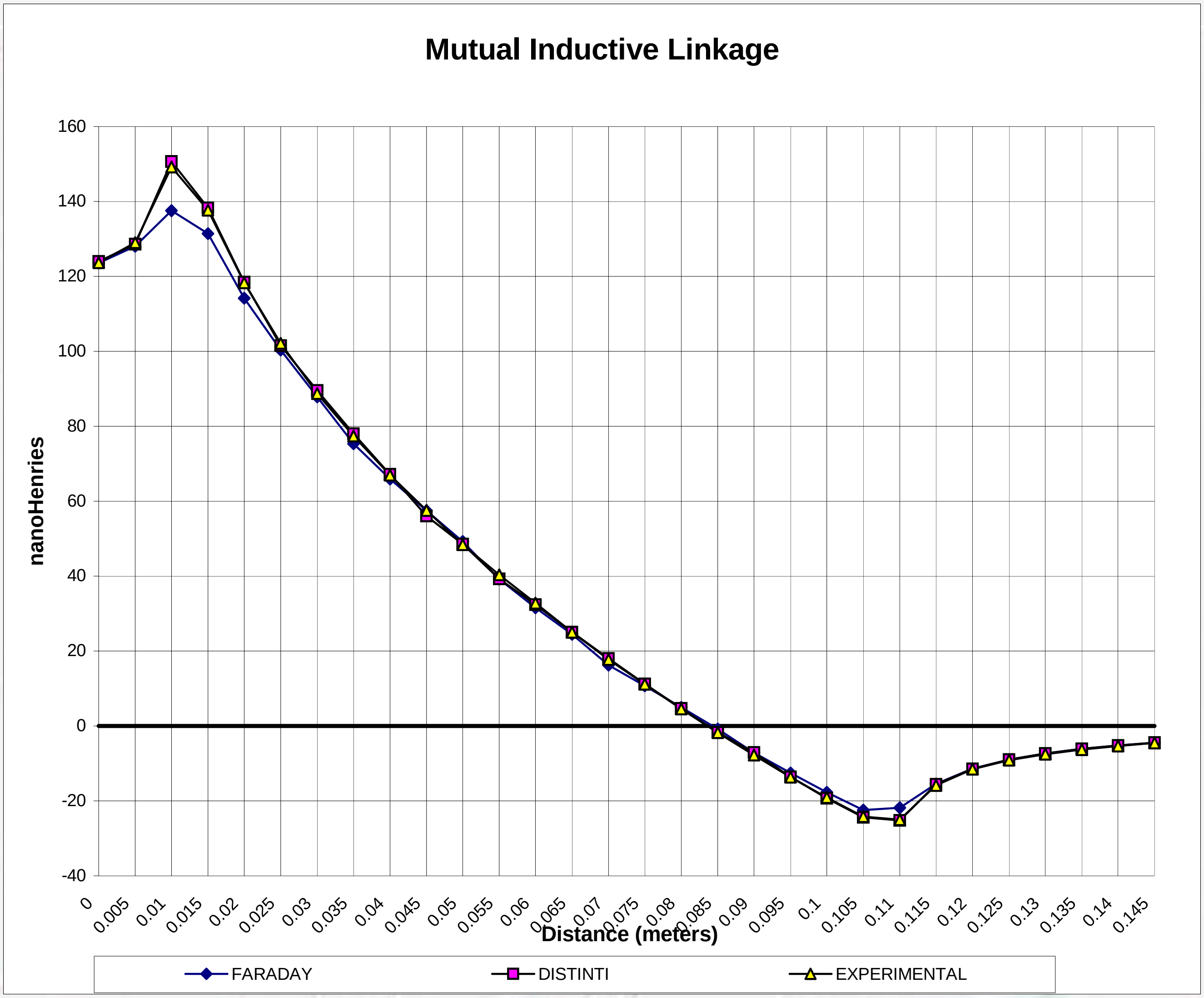
The above equations are automated in the supplemental software package titled NEW_IND.TBK listed in Appendix A.

Equipment needed:
1) Ten turn circular loop of 30 AWG wire with average radius of 6cm.
2) Ten turn circular loop of 30 AWG wire with average radius of 5cm.
3) A sine wave generator with a 600-ohm output impedance capable of 200khz or better.
4) A 33 to 39 ohm resistor.
5) A standard dual trace oscilloscope with at least one X1 probe.

The circuit is constructed according to the diagram above allowing the distance "D" to remain variable. To operate the circuit, a value for "D" is set, then the amplitude of the sine function generator is adjusted such that the voltage (V_R) across the resistor, at 200khz, is 0.8 volts peak to peak. The peak to peak voltage across the target loop (V_T) is then measured and recorded. V_T is recorded as a positive value if V_R is rising when V_T is positive; otherwise, V_T is to be recorded as a negative value — probe orientation is important. The inductive linkage "M" is computed using the equations above. These equations are derived from V=-M(di/dt) by solving for M.

The software routines in Appendix B only compute linkage (M) for single turn loops. The experiment above uses loops of 10 turns; where $N_S = 10$ is the number of turns in the source and $N_T = 10$ is the number of turns in the target loop. Since our objective is to compare experimental data to computer derived linkage, we can either adjust the computer data by multiplying by (N_T*N_S=100) or by dividing the experimental data by 100. Here the experimental data is adjusted by a factor of 100. The equation M_{SINGLE} adjusts the experimental data to yield the single turn linkage that correlates to the results from the software routines.

The following graph compares experimental data to the computer-derived values for Faraday's Law (FARADY_M_CIRCLE) and the IEL (DISTINTI_M_CIRCLE). The plot demonstrates excellent agreement between both theories and the experimental data. The plot is compute with DL=0.0034.



6.2 The Mobius Triangle

Given a strip of paper 20 inches long and 0.5 inches wide; glue thin conductors along the sides of the strip and another along the center of the strip. Next, give the strip a half turn and join the end to form a Mobius strip.

The Mobius strip illustrates the difficulty with Faraday's Law. The conductors along the edge form one conductive loop that contains the surface area of the paper, and the center conductor forms another that we will use as the excitation source. If the center loop were excited by a time varying current, how would one use Faraday's Law to compute the emf induced in the edge conductor? The Mobius strip, by definition, only has one side; therefore, any flux entering the surface area of the paper (contained by the edge conductor) also exits. Can we assume that the surface area of the paper is omitted from our calculations? What exactly is the flux contained by the edge conductor of the Mobius strip?

To simplify the problem, flatten the Mobius strip so that it resembles an equilateral triangle (Figure 6-3). This leaves the arrangement of the conductors as shown in Figure 6-4. If the center wire (red wire) were excited by a time varying current what would be the emf generated in the edge loop (blue loop)? If one were to use Faraday's law, then how many times is the flux in the area enclosed by the center (blue) triangle counted?

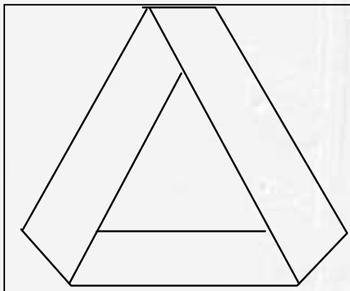


Figure 6-3 The 20 x 0.5 inch Mobius Triangle

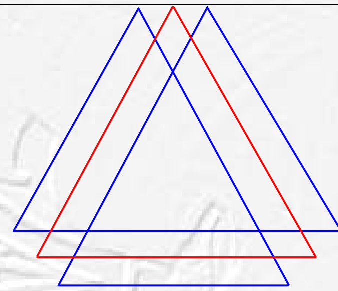


Figure 6-4 Mobius conductor arrangement

The IEL has no such ambiguities, and it readily allows one to solve the problem without deliberating about the contained flux. The IEL allows one to solve induction problems by considering only fragment to fragment effects. The flux contained by the loops is of no consequence. Using the IEL, a general-purpose algorithm was developed to solve induction problems. The algorithm calculates mutual inductance (M) between a source loop and a target loop. The loops are entered as a list of line segments.

Unlike algorithms based on Faraday's Law, this algorithm does not deliberate over area enclosed by the target, nor is there a problem with division by zero when the source fragments impinge on the interior of the target.

The measured inductive linkage for the 20 x 0.5 inch Mobius Triangle is 832nH (measured with the apparatus shown in Figure 6-2 with R = 39 ohms). The computed inductive linkage for the 20 x 0.5 inch Mobius Triangle is 833.6nH (computed with the mentioned software algorithm). This is a difference of 0.2%.

If you would like to run this experiment yourself, the "How-To" details are found in "NewIndSupTwo.Doc" and require that you have "NEW_IND.TBK" installed on your PC.

6.3 Intrinsic Inductance

Intrinsic inductance is the inductance of the wire itself. Intrinsic Inductance is modeled by viewing the current through a wire as a collection of filamentary currents.

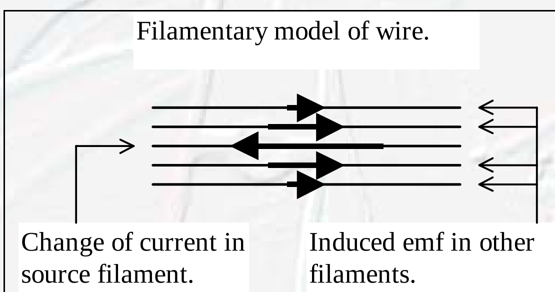


Figure 6-5 Filamentary model of wire

.

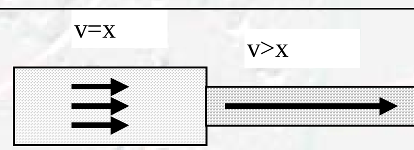


Figure 6-6

Referring to the filamentary model of wire shown in Figure 6-5, suppose that one filament of current (shown at the center) were changing. According to the IEL, this current change would then induce an emf in the opposite direction in all the other filaments.

If one were to increase the current through the wire, then all filaments would experience an instantaneous current increase. The current increases from all filaments would then contribute back emfs to all filaments. The direction of the induced emfs would oppose the current change. This opposition to current change within the wire itself is known as intrinsic inductance.

The IEL allows us to conclude some interesting properties about the nature of intrinsic inductance:

1) Intrinsic inductance is inversely proportional to wire diameter.
2) Intrinsic inductance is weakest near the skin of a conductor. This is called the "Skin Effect" and is the subject of the next section.

The first property is determined by the inspection of Figure 6-6 that shows two conductors of different diameters connected together. If we were to pass current through these conductors, then the current through both conductors must be the same. To obtain the same current through both conductors then one of the following (or both) must be true:
1) The actual charge velocity must be greater in the smaller wire.
2) The charge must be tighter packed in the smaller wire.

If we consider the first case, then greater charge velocities in the smaller wire corresponds to greater charge acceleration in the smaller wire when the current is increased. The IEL teaches us that inductance is proportional to charge acceleration; therefore, the smaller wire must have a greater intrinsic inductance.

If we consider the second case where the charges are more tightly packed, then the average distance between the charges is less in the small wire than it is in the larger wire. The IEL teaches us that the inductive force is inversely proportional to distance; therefore, the smaller wire must have a greater intrinsic inductance.

In either case, the intrinsic inductance increases as wire diameter decreases. Measuring loops constructed of different diameter wire easily proves this conclusion. See Table 2 on page 25 (remember, smaller AWG numbers correlate to thicker wire).

There is no existing derivation of intrinsic inductance based of Faraday's Law. Textbooks on electromagnetism model the phenomenon of intrinsic inductance by considering the magnetic field energy contained within the wire. This derivation yields an expression ($\frac{\mu}{8\pi}$ Henries per meter) that is only a function of wire length. The textbook expression is not correct since experimental results show that intrinsic inductance is a function of both wire length and diameter.

For more information on how New Induction solves self inductance and intrinsic inductance, see the conclusion in the paper found at **http://www.distinti.com/publications/ind_jackson.htm**.

6.3.1 The Skin Effect

The IEL also explains another phenomenon called the skin effect. The skin effect was discovered many years ago when scientist and engineers observed that high frequencies signals tend be passed near the outside (the skin) of a conductor.

The skin effect is demonstrated by considering the wire cross section shown in Figure 6-7. This figure shows a wire cross section divided into very small areas (dA). If we were to increase the current through each of these areas at the same time then what would be the emf induced at any arbitrary point?

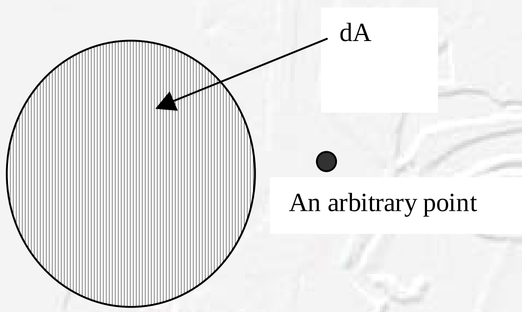


Figure 6-7: Wire Cross Section

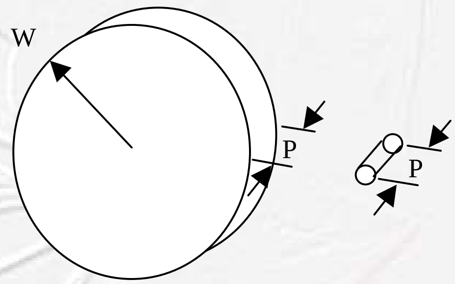


Figure 6-8: Dimensions of wire and fragment

To compute the emf at an arbitrary point resulting from the current change in the wire, we use the wire fragment form of the IEL:

$$emf_{TS} = -K_M \left(\frac{dI_S}{dt} \right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|}$$

For simplicity, assume a uniform cross sectional current density J. To compute the emf received by a target fragment at any arbitrary point we integrate the emf received by the target resulting from the current change through each differential area (dA) of the wire cross section. This way each dA of the wire is treated as a source fragment such that:

$$\frac{dI_S}{dt} = \frac{dJ}{dt} dA, \text{ and}$$

$$emf_{TS} = -K_M \left(\frac{dJ}{dt} dA \right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|}$$

To further simplify, consider only the effect on a target fragment due to a very thin slice of the wire (Figure 6-8) where the length (P) and direction of the target fragment are the same as the cross section.

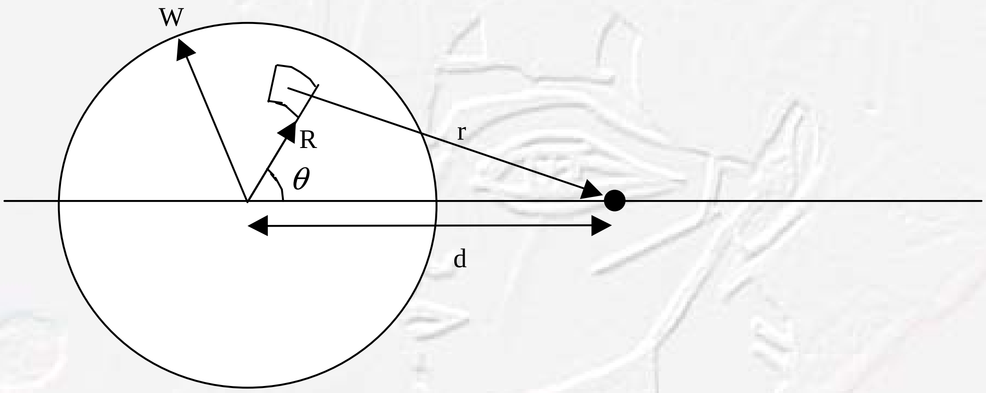
$$emf_{TS} = -K_M \left(\frac{dJ}{dt} dA \right) \frac{\mathbf{P}_S \bullet \mathbf{P}_T}{|\mathbf{r}|}$$

Since Target and fragment are in same direction:

$$emf_{TS} = -K_M \left(\frac{dJ}{dt} \right) \frac{P^2}{r} dA$$

The above equation is the emf received by the target fragment caused by the current passing through any dA of the wire cross section.

The total emf affecting the target fragment is found by integrating the current change at every differential area of the wire cross section. In the following diagram W is the radial dimension of the wire and d is the distance from the center of the cross section to the target fragment.



The equation is expanded as follows:

$$emf_T = -K_M P^2 \left(\frac{dJ}{dt}\right) \int_{R=0}^{W} \int_{\theta=0}^{2\pi} \frac{R d\theta dR}{\sqrt{(d - R\cos(\theta))^2 + (R\sin(\theta))^2}}$$

Equation 5: Intrinsic Point emf.

It is desirable to convert the above equation to the units of inductance. Since inductance is defined as $L = -\frac{emf}{di \ / dt}$, then Equation 5 needs to be divided by the total current change in the system. The total current through the cross section is the area times the current density ($I = J\pi W^2$); therefore, the current change is the time derivative $\frac{dI}{dt} = \frac{dJ}{dt}\pi W^2$. Dividing though yields:

$$L_T = \frac{K_M P^2}{\pi W^2} \int_{R=0}^{W} \int_{\theta=0}^{2\pi} \frac{R d\theta dR}{\sqrt{(d - R\cos(\theta))^2 + (R\sin(\theta))^2}}$$

Equation 6: Intrinsic Point Inductance

A Reminder: The above equation is NOT the total inductance of the wire. It represents the ratio of the emf at a target fragment (note the subscript T) to the current change in a very thin slice of the wire. The target fragment is treated as a point because it is viewed endwise in the diagram above.

Using the above equation, compute the inductance at the center of the wire (d=0):

$$L_{T(center)} = \frac{K_M P^2}{\pi W^2}(2\pi W) = 2\frac{K_M P^2}{W}$$

Since any value of d greater than zero will yield a smaller answer, the above result represents the maximum inductance. Figure 6-9 plots the magnitude of L_T as a function of d superimposed over a wire cross section of radius W.

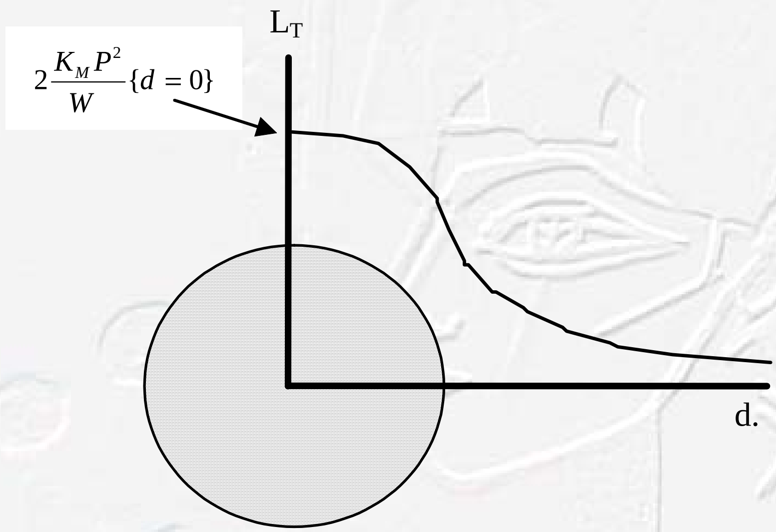


Figure 6-9 Target Inductance as a function of distance

The graph shows that the inductance decreases drastically near the skin of the wire. This correlates with the observed physical phenomenon known as the "Skin effect" for which Faraday's Law gives no explanation.

In the preceding section, logic explained the inverse correlation between intrinsic inductance and wire diameter. In this section the same correlation is observed mathematically by inspection of Equation 6. In Equation 6 the wire radius (W) is in the denominator, this shows that inductance at any given point is inversely proportional to wire diameter.

The equations developed here establish that intrinsic inductance and the skin effect are different aspects of the same phenomenon.

6.3.2 Conclusion

The IEL provides a simple qualitative explanation of intrinsic inductance and the skin effect. Faraday's Law is incapable of explaining either.

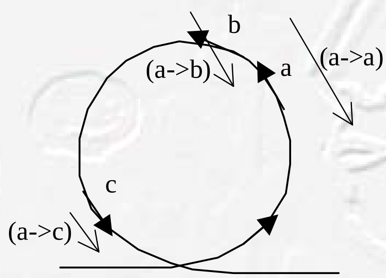
To obtain quantitative results for intrinsic inductance using the IEL, many more factors must be considered. Such factors include the length of the conductor, the shape of the conductor, the properties of the conductor, and the nature of the signal carried by the conductor. The simple fact that inductance is not uniform over the cross section of the wire means that a complete treatment must provide for non-uniform current density and radial current movement. Because such a treatment is a field of research unto itself, it is outside the scope of this work. A paper devoted entirely to intrinsic inductance (and the skin effect) complete with software routines is to be released at a later time.

NOTE: Intrinsic inductance is not expected to be a linear relationship to wire length; it is expected to be a second order polynomial.

6.4 Self Inductance

Note: For more information on how New Induction solves self inductance and intrinsic inductance, see the conclusion in the paper found at **http://www.distinti.com/publications/ind_jackson.htm**.

The discussion of self-inductance is divided into two phases. The first phase discusses loops of a single turn of wire. The second phase discusses multiple turn loops. The purpose of dividing the discussion, is to segment the concept of self-inductance into easy to explain steps. This is needed because the IEL explanation of self-inductance contradicts Faraday's explanation. Although the explanations are in contradiction, the results are the same.



(a->c)=Effect at (c) due to current change through (a).

Figure 6-10 Single Turn loop Inductor

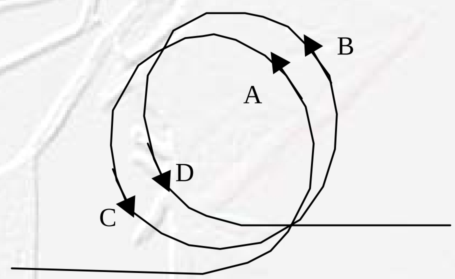


Figure 6-11 Two Turn Loop Inductor

6.4.1 The Single Turn Loop Inductor

Figure 6-10 shows an inductor created with a single turn of wire. Faraday's law claims that the inductance is proportional to the area of the loop; however, the IEL shows that the inductance of this system is predominantly due to intrinsic inductance.

Referring to Figure 6-10, consider that the current in the loop is increasing at a constant rate in the direction shown by the solid arrows. The inductance is computed by summing the fragment to fragment effects (linkage) across the entire system. To get a general idea of the different types of linkage found in this system consider the effect of a single fragment on various other fragments. The following lists the effects of the current change through fragment (a) on other fragments.

1) **Intrinsic Inductance**: Fragment (a) affects itself (a->a). Because the IEL is a 1/r relationship, the effect of a fragment on itself is greater than any other fragment to fragment effect.
2) **Opposite side linkage:** Fragment (a) affects fragment (c) (a->c) on the opposite side of the loop. According to the IEL, the emf generated at (c) is in the same direction as (c) (shown by the thin arrow to the left); therefore, the effect of opposite side linkage reduces the overall inductance of the system. Since fragment (c) is the farthest fragment from (a), the magnitude of the effect is the smallest.
3) **Same side linkage:** Fragment (a) affects fragments on the same side of the loop such as fragment (b). Since a component of the effect (shown by the thin arrow) is in the opposite direction of (b), then the same side linkage adds to the overall inductance of the system.

The above demonstrates the effect of one fragment on a few others. The full inductance is determined by summing the effect of each fragment on all the others. The following table shows experimental data collected for single loop inductors.

Table 2: Measured Inductance of single turn loops

48 inch perimeter shapes	Area (sq. in)	26 AWG wire	22 AWG wire
Circle	183	**2253nH**	**2055nH**
Square	144	**2144nH**	**1950nH**
Equilateral Triangle	111	**2015nH**	**1856nH**
Rectangle 18"x6"	108	**2061nH**	**1875nH**
Flat loop (see note 2)	Close to 0	**360nH**	**275nH**
Twisted (see note 2)	More close to 0	**313nH**	**214nH**

Notes

1) These readings are raw CRIM measurements. They are obtained using the 100mv-calibration scheme detailed in NewIndSupThree.DOC. The fixture inductance is approximately 70nH and crimK for 100mv is 1.137.
2) The "Flat loop" and "Twisted" entries are not tightly controlled shapes. These readings should be considered approximations and used for reference purposes only.

Current theory (prior to the introduction of this work) states that the total inductance of a self-inductor is the intrinsic inductance plus the effect of the self-linked magnetic field changes. The intrinsic inductance (according to current theory) follows the relationship $\frac{\mu}{8\pi}$ Henries per meter. This relationship is independent of wire thickness, which means that the inductance contributed by intrinsic inductance is the same for all loops above since they all have the same wire length. The component of inductance due to the self-linkage of magnetic field lines yields a quantity of inductance that is dependent upon the shape of the loop and not the thickness of the wire. Therefore, according to current theory, the values in the table above should only vary based on the shape of the loop and not the thickness of the wire. According to the experimental results shown in the table above, both the shape of the loop AND the thickness of the wire affect inductance.

New Induction teaches that Intrinsic Inductance is a major source of inductance in the loops above. Furthermore, intrinsic inductance IS dependent on the thickness of the wire.

6.4.2 Multiple Turn Loop Inductors (coils).

Multiple turn loop inductors (coils) are constructed with two or more turns of wire as shown in Figure 6-11. Coils include all the modes of linkage described for single turn inductors with the addition of inter-turn linkage. The linkage between the turns is demonstrated in Figure 6-11 by considering the effect on the fragments (B) and (D) due to fragment (A). The distance between (A) and (B) is much smaller than the distance from (A) to (D). Therefore, the reinforcing effect between (A) and (B) is much greater than the countering effect between (A) and (D). Since the strongest effects are found where the distances between the fragments are the smallest, then intrinsic inductance (The effect of (A) on itself = (A->A)) and the inter-turn-same-side linkage (A->B) are the primary contributors. Considering only these primary contributors we can make a generalization regarding the effect of the number of turns on the overall inductance of the system. The following list shows the number of effects (terms) that contribute to this generalization.

1) Single turn loop = 1 term = (A->A).
2) Two turn loop = 4 terms = (A->A) + (A->B) + (B->A) + (B->B).
3) Three turn loop = 9 terms.
4) Four turn loop = 16 terms.

If the turns in the loop are tightly packed, then (A->B) will be almost as strong as (A->A). From this we deduce that inductance is proportional to the square of the number of turns in the loop. This is only a generalization, to accurately compute the inductance, ALL fragment to fragment effects and the intrinsic inductance must be accounted for.

7 The Search

For an improved explanation of this search and the evidence that suggests that magnetic fields are spherical, see ni_neumann.pdf.

The section describes the methodology used to find the IEL. Although the concepts presented here are simple, the task of explaining them is not. This section is presented at this point so as not to clutter the previous sections that explain the IEL.

The search for the relationship of inductance begins by considering the essence of the problem.

The facts are:
1) The time varying current emits some kind of “stuff” into space.
2) This “stuff” creates emf in conductors that it strikes.

What the “stuff” is and how it propagates will be of interest later. The essence of the problem lies in the fact that a current change causes emf.

To simplify the problem, consider that all wire structures can be decomposed into differential wire lengths (fragments). This allows us to analyze the emf generated in one fragment due to the current change through another fragment. The following diagram illustrates the parameters that are used.

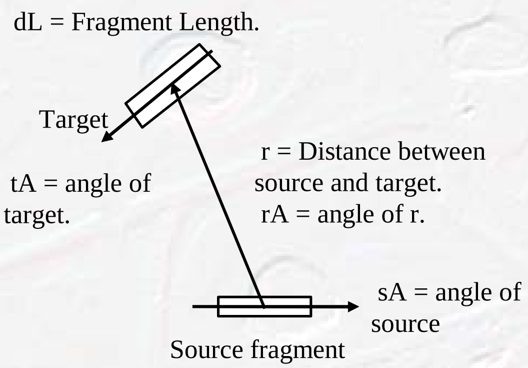


Figure 7-1

NOTE: In the above diagram the term “Angle” is actually direction.

The following are considerations that guide the selection of the experiment to be used:

1) A mutual inductance experiment requires an emitter and receiver. This requires two circuits that need calibration. We want a single circuit to calibrate.
2) We want an experiment where capacitive coupling is minimized.
3) Multi-turn inductors are extremely sensitive to the way the turns are wrapped and bundled. We want loops of one turn only.

The experiment selected is the single turn loop inductor. By measuring the self-inductance (L) of various shaped loops and correlating the measurements to a spatial relationship (called geometry for short) between wire fragments, a new model for induction is realized.

Because intrinsic inductance will be a component of the inductance measured, it must be accounted for. Originally, the assumption was made that intrinsic inductance is a linear relationship to conductor length. Therefore the following equation is used to sum the components that contribute to self-inductance: L=As+Bp. The value (s) is the “raw shape” value. The raw shape value is the total fragment to fragment raw linkage across the shape of the loop. This value is multiplied by the arbitrary constant (A), which should resolve to the constant of relation for induction. The value (p) is the perimeter of the loop. This value is multiplied by the constant (B), which should resolve to the intrinsic inductance per length of wire.

The raw linkage between two fragments is simply a spatial relationship between the two fragments. This spatial relationship is called a geometry for short. Examples of a geometry are: dL*dL*cos(rA-tA)*sin(tA-rA)/r or dL*tan(tA-sA)*csc(rA-sA)/(r*r). As shown by the examples, there are an incredible number of ways to geometrically interrelate two fragments. Because there are over 45,000 ways to interrelate the two fragments, a computer algorithm was developed to perform the search automatically.

The software program that performs this search is called the “Hash-Search” engine. Experimental data for a number of shapes is entered into the system. Then the user selects a range of geometric combinations that are to be searched. When the program is run it performs the following steps:

1) Select a geometry that falls within the range to be searched. In the computer algorithm, the geometries are referenced by four number separated by commas such as 1,3,2,5. The detailed explanation of these numbers is covered in the supplemental document NewIndSupFour.doc that describes the Hash-Search engine.
2) Compute Shape value for each shape using the selected geometry. The shape value is computed by summing the fragment to fragment raw linkage over the entire shape.
3) With the shape value and perimeter, determine the range of the arbitrary constants A and B. The range is determined by performing determents with every combination of experimental data. Due to experimental error, each combination may produces different values for A and B. The min and max of these values are the range of the arbitrary constants.
4) Perform a specially designed iterative form of the “method of least Squares” algorithm to find the values of A and B (within the range determined above) that yield the smallest mean square error and provide the best match among the experimental data set.
5) Take the square root of the mean square error (this is RMS error). If the value is less than or equal to the selected RMS error, then the selected geometry is considered a possibility and listed on the screen.
6) Steps 1 to 5 are repeated for each geometric combination. The number of combination is about 45,000.

The above was run many times for a wide variety of inductor shapes until it was determined that the intrinsic inductance is not a linear function of perimeter. Since the exact relationship of intrinsic inductance is not yet known, a set of shapes must be chosen where the intrinsic inductance is constant among them. The shape that best fits this requirement is the rhombus. The rhombus is parameterized as follows:

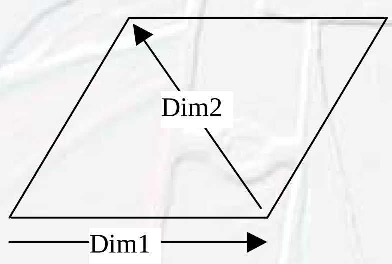


Figure 7-2: The Rhombus

With the Rhombus, the fragment to fragment effects can be changed by changing Dim2. As long as Dim1 is held constant, the intrinsic inductance will remain constant.

The Rhombus experiment yields geometry number 5,0,0,8 as the closest matching relationship for induction. Geometry 5,0,0,8 is $emf_{TS} = -K_M \left(\frac{dI_S}{dt}\right)\frac{\cos(tA - sA)}{r} dL^2$. This simplifies to the dot-product relationship:

$$emf_{TS} = -K_M \left(\frac{dI_S}{dt}\right)\frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|}$$

Equation 7 The IEL for wire fragments

.

The rhombus experiment also yields geometry number 5,0,7,9 as a very close second. This geometry yields the equation $emf_{TS} = K_M \left(\frac{dI_S}{dt}\right)\frac{(d\mathbf{L}_S \times \mathbf{r}) \bullet (\mathbf{r} \times d\mathbf{L}_T)}{|\mathbf{r}|^3}$. It is shown in the paper titled "New Electromagnetism" that geometry 5,0,7,9 is a component of Equation 7. In fact the IEL contains two components, a transverse component and a longitudinal component (see ni_neumann.pdf for more details). Geometry 5,0,7,9 is the longitudinal component. The transverse component and can be derived from existing electromagnetic equations as shown in"New Electromagnetism".

If you ant to see how the different geometries interrelate, see the paper ni_neumann.pdf

Equation 7 is confirmed as the model of induction with the mutual induction experiments shown in previous chapters.

8 Conclusion

This paper introduces an improved model for electromagnetic induction. The new model is easier to use and less ambiguous than Faraday's Law. Furthermore, the new model explains things, such as intrinsic inductance and the skin effect that can not be explained with Faraday's Law. Furthermore, unlike Faraday's Law, the new model is applicable to free space charge distributions. Finally, the new model is far superior for numerical integration (see Appendix B).

The following table compares the difference between Faraday's law and the Inertial Electric Law with regard to explaining natural phenomenon:

Phenomenon	Was explained:	Now explained:
Mutual Inductance	Faraday's Law	IEL
Self Inductance	It is ironic that Faraday's law is used to explain this phenomenon in spite of the fact that it is impossible to solve a self-inductance problem with Faraday's Law.	IEL
Intrinsic Inductance	No valid explanation.	IEL
Motional Inductance	Faraday's Law or Motional Electric law.	Motional Electric Law: $emf_T = (\mathbf{v}_T \times \mathbf{B}) \bullet d\mathbf{L}_T$
Skin Effect	An approximation for skin depth derived from the plane wave equations is: $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$ This approximation is only valid if δ is much smaller than wire diameter.	IEL
The effect of charges accelerating in free space	????	IEL
Inertia	????	IEL – See New Electromagnetism

Anyone wishing to run the experiments highlighted in this paper may download the supplements listed in Appendix A. The experiments are simple enough to run in a high-school electronics lab.

This paper releases the details of the IEL specific to the phenomenon of induction. The effect of the IEL on the rest of electromagnetism is discussed in the paper titled "New Electromagnetism". In "New Electromagnetism" all the laws of electromagnetism are used in conjunction with the IEL to explore the following:

1) Inertia modeled as electromagnetic induction.
2) Deriving the mass of an electron from the IEL.
3) Deriving Einstein's Energy Equation ($E=mc^2$) strictly from electromagnetism.
4) An equation that yields the effective flux velocity about an accelerating charge.
5) Derivation of an improved motional electric law.
6) Derivation of the Transverse component of the IEL from standard equations.

Appendix A Supplements

This paper is supported by a number of documents and software algorithms that contain all information necessary to recreate the experiments found herein.

Any school electronics lab is capable of executing the experiments. The following supplements are to be available shortly following this paper:

All of the software algorithms are embedded in a PC Windows application titled NEW_IND.TBK. This is an Asymetrix Toolbook application supported by a dll written in Borland C++.

1) NewIndSupOne.DOC: Supplement #1 The Rhombus Experiment. Requires NEW_IND.TBK and NewIndSupThree.DOC.
2) NewIndSupTwo.DOC: Supplement #2 The Mobius Triangle Experiment. Requires NEW_IND.TBK.
3) NewIndSupThree.DOC: Supplement #3 The Current Ramp Induction Measuring Circuit (CRIM).
4) NewIndSupFour.DOC: Supplement #4 The Hash-Search Engine. This discusses the geometric hash and search algorithm found in NEW_IND.TBK.
5) The software package NEW_IND.TBK contains many screens for computing and translating experimental data. It also contains support for other experiments not listed. It is expected that NEW_IND.TBK will be updated to include other utilities from time to time.
6) ni_neumann.pdf More in-depth explanation of logic and results of the search for the New Induction model. Includes comparison with Neumann's equation.

Although the above supplements show how to build the experiments, www.Distinti.com now sells high quality pre-assembled components and circuits for the above experiments.

Appendix B Software Samples

The algorithms found at the end of this appendix compute the mutual inductive linkage (M) between coplanar mutually inducting loops. “M” has the units of Henries and relates emf to current change (emf= -M(di/dt)). FARADAY_M_CIRCLE computes the linkage using Faraday’s Law while DISTINTI_M_CIRCLE computes linkage using the Inertial Electric Law. Care should be taken when using FARADAY_M_CIRCLE, since it produces erratic results when the wire of the source loop overlaps the area of the target loop. This is not a flaw of the algorithm but a fundamental problem with Faraday’s Law. These software algorithms are included in NEW_IND.TBK described in Appendix A. They are listed at the end of this section for those who want to see first hand what is going one.

The following are sample data from the routines:

For RS=0.1, RT=0.1, DST=0.3, computed on a 400mhz Pentium 2:

	FARADAY_M_CIRCLE		DISTINTI_M_CIRCLE	
	Result (Henries)	Execution Time	Result (Henries)	Execution Time
DL=0.05	-4.8364656178661e-9	< 1 sec	-4.96144728670049e-9	<< 1 sec
DL=0.01	-4.95655725449012e-9	1 sec	-4.96179776937546e-9	< 1 sec
DL=0.001	-4.96174524445244e-9	4 min 41 sec	-4.96179776937542e-9	3 seconds

For RS=0.06, RT=0.05, DST=0.0, computed on a 400mhz Pentium 2:

	FARADAY_M_CIRCLE		DISTINTI_M_CIRCLE	
	Result (Henries)	Execution Time	Result (Henries)	Execution Time
DL=0.05	3.95624077043048e-8	<< 1 sec	9.58283706159601e-8	<< 1 sec
DL=0.025	7.90632426569373e-8	< 1 sec	1.23998688099642e-7	<< 1 sec
DL=0.01	1.21199931305864e-7	< 1 sec	1.23997758399212e-7	< 1 sec
DL=0.0034	1.23598276844403e-7	1 sec	1.23997758399212e-7	< 1 sec
DL=0.001	1.2396581788485e-7	42 sec	1.23997758399213e-7	1 sec
DL=0.0005	1.23989762757018e-7	5 min 33 sec	1.23997758399214e-7	3 sec

NOTE: A positive result indicates that the emf generated in the target will be opposite to the direction of the current change in the source.

The tables above demonstrate that the IEL (DISTINTI_M_CIRCLE) is superior to Faraday’s Law for numerical integration for the following two reasons:

1) The routine DISTINTI_M_CIRCLE processes faster because it is only a two level deep nested “for“ loop; whereas, FARADAY_M_CIRCLE is three levels.
2) DISTINTI_M_CIRCLE converges much faster than FARADAY_M_CIRCLE. DISTINTI_M_CIRCLE yields extremely accurate results when the resolution (DL = numerical fragment length) is only about ½ the radius of the smaller circle. FARADAY_M_CIRCLE requires about 50 times more resolution (DL = 1/100 the radius) to yield values as accurate.

Note: The above values were computed with the routines: DISTINTI_M_CIRCLE and FARADAY_M_CIRCLE that come with the software sample NEW_IND.TBK. The software routines shown below were cut and pasted from NEW_IND.TBK. The routines below have been edited to enable them to run independent of the NEW_IND.TBK framework. The edits are slight but have not been tested. If you are going to compile these routines then use the values above to ensure your routines were entered correctly.

Input parameter definitions:	**Setup and declarations used by following routines**

RS is radius of source loop.
RT is radius of target loop.
	typedef double n; //type for computations
	typedef long i; //type for iterations (32 bit integer)

DST is distance between loop centers.
DL is differential length for computation.
All values in meters
	typedef double rp; //type for real parameters
	n K = 1e-7; //constant of relation Km=u/(4*pi)
	i s,t,r,x,y,z; //variables for counting and iteration
	/* all other variables are declared as type n*/

```
rp FARADAY_M_CIRCLE(rp RS,rp RT,rp DST,rp DL)
{     Q=0;                                          //Accumulator
      // compute parameterization of source
      s=floor(fabs(2*M_PI*RS/DL));                  // s is source parameterization counter
      dsTheta=2*M_PI/s;                             //incremental source angle
      ds=RS*dsTheta;                                //differential source length
      // compute parameterization of target
      t=floor(fabs(2*M_PI*RT/DL));                  // t is target parameterization counter
      dtTheta=2*M_PI/t;                             //incremental target angle
      dt=RT*dtTheta;                                //differential target length
      r=floor(RT/DL);                               //r is radius parameterization counter
      dr=RT/r;                                      //differential radius
      for (x=0;x<s;x++){                                 // indexes source
            stheta=(x+0.5)*dsTheta;                      //compute source wire fragment pos
            sx=RS*cos(stheta);
            sy=RS*sin(stheta);
            sA=stheta+M_PI_2;                            // source fragment angle
            for (y=0;y<r;y++){                           //indexes target radius
                  rr=(y+0.5)*dr;                         //target radial position
                  dA=rr*dtTheta*dr;                      // the differential target area
                  for (z=0;z<t;z++){                     //indexes target angle
                        ttheta=z*dtTheta;
                        tx=rr*cos(ttheta)+DST;
                        ty=rr*sin(ttheta);
                        rx=tx-sx;
                        ry=ty-sy;
                        dd=rx*rx+ry*ry;                  //distance squared
                        rA=atan2(ry,rx);
                        if (dd!=0) Q=Q-dA*ds*sin(rA-sA)/dd;
      }     }     }
      return -K*Q;
}
```

```
rp DISTINTI_M_CIRCLE(rp RS,rp RT,rp DST,rp DL)
{     Q=0;                                          //Accumulator
      // compute parameterization of source
      s=floor(fabs(2*M_PI*RS/DL));                  // s is source parameterization counter
      dsTheta=2*M_PI/s;                             //incremental source angle
      ds=RS*dsTheta;                                //differential source length
      // compute parameterization of target
      t=floor(fabs(2*M_PI*RT/DL));                  // t is target parameterization counter
      dtTheta=2*M_PI/t;                             //incremental target angle
      dt=RT*dtTheta;                                //differential target length
      dL2=ds*dt;                                    //length product
      for (x=0;x<s;x++){                            //indexes source
            stheta=(x+0.5)*dsTheta;                 //compute source position
            sx=RS*cos(stheta);
            sy=RS*sin(stheta);
            sA=stheta+M_PI_2;                       //compute direction of source fragment
            for (z=0;z<t;z++){                      //indexes target
                  ttheta=z*dtTheta;                 //compute target position
                  tx=RT*cos(ttheta)+DST;
                  ty=RT*sin(ttheta);
                  tA=ttheta+M_PI_2;                 //compute target direction
                  rx=tx-sx;
                  ry=ty-sy;
                  d=sqrt(rx*rx+ry*ry);              //compute distance
                  if (d>(DL/4)) Q=Q-dL2*cos(tA-sA)/d;    //Geometry 5,0,0,8
            }
      }
      return -K*Q;
}
```

Appendix C Fragmentary Notation

This section will graphically illustrate fragmentary notation. Fragmentary notation replaces differential notation for wire fragments. A simple comparison between differential notation and fragmentary notation is observed using the Biot-Savart law. In differential notation, the Biot-Savart law is:

$$d\mathbf{B} = \mu \frac{(Id\mathbf{L} \times \hat{\mathbf{r}})}{4\pi|\mathbf{r}|^2}$$

Since $d\mathbf{B}$ represents the contribution of $\mathbf{B}$ at a point in space due to current moving through a Fragment ($I_S d\mathbf{L}_S$), then the equation can be rewritten using fragmentary notation such that:

$$\mathbf{B}_S = \frac{K_M (I_S d\mathbf{L}_S \times \hat{\mathbf{r}})}{|\mathbf{r}|^2}$$

In fragmentary notation the subscript “S” on the left side of the equation shows that $\mathbf{B}_S$ is the result of a single fragment $d\mathbf{L}_S$. The elements on the right side that represent or are related to the fragment “S” are also marked with the subscript “S”.

The IEL of New Induction is a Fragment to Fragment effect; therefore, two subscripts are used.

The following figures are used to illustrate the use of fragmentary notation. In the following figures, the source loop is on the right and a target loop is on the left. The source loop is excited by a time varying current source that induces emf in the target loop.

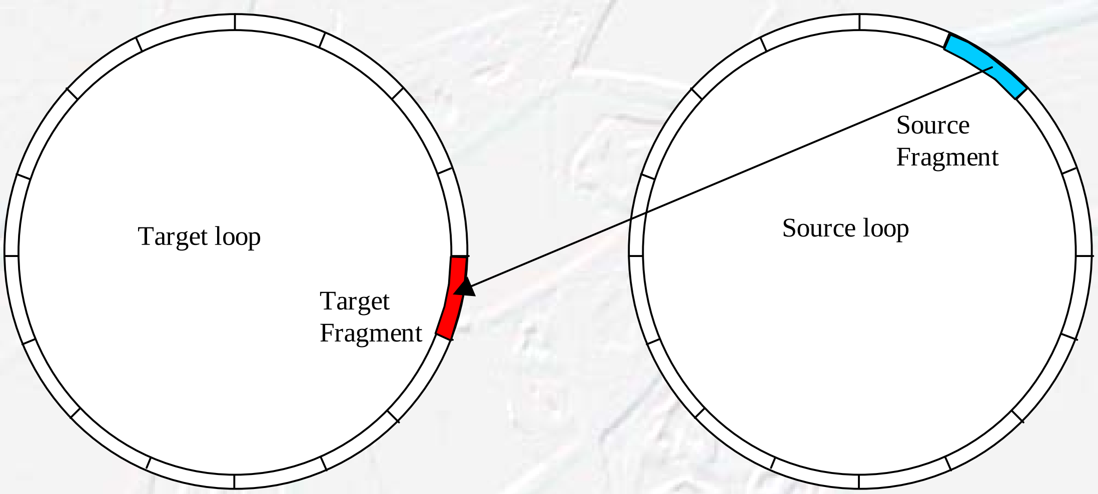


Figure C-1 emf_{TS}

Figure C-1 shows the elementary fragment to fragment effect. Here the emf generated in the target fragment is due to the effect of a single source fragment. The wire fragment form of the IEL represents this interaction: $emf_{TS} = -K_M \left(\frac{dI_S}{dt} \right) \frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|}$.

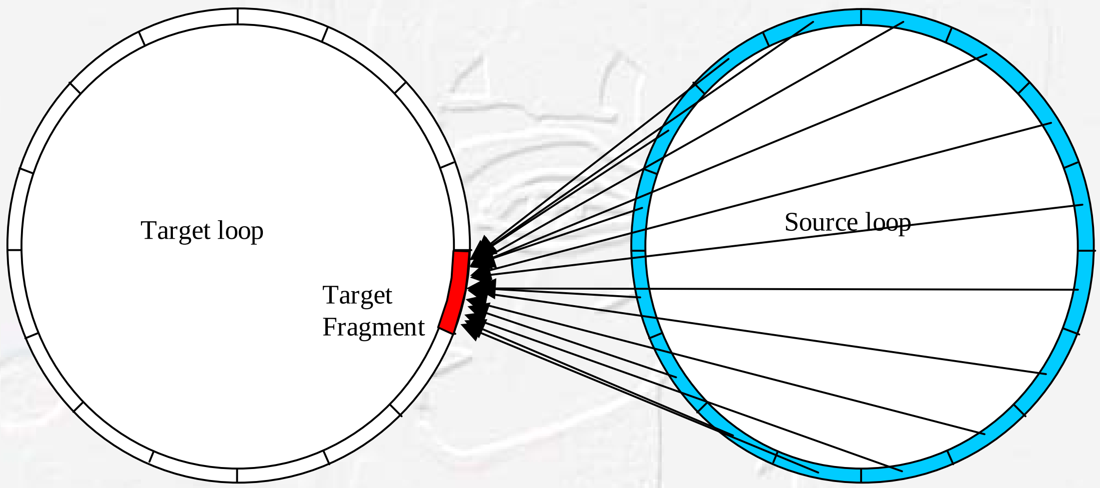


Figure C-2 emf_T

If emf_{TS} is integrated along the source loop then $emf_T = \int_S emf_{TS}$. Here emf_T represents the total emf received by a target fragment due to the effect of all source fragments as shown in Figure C-2.

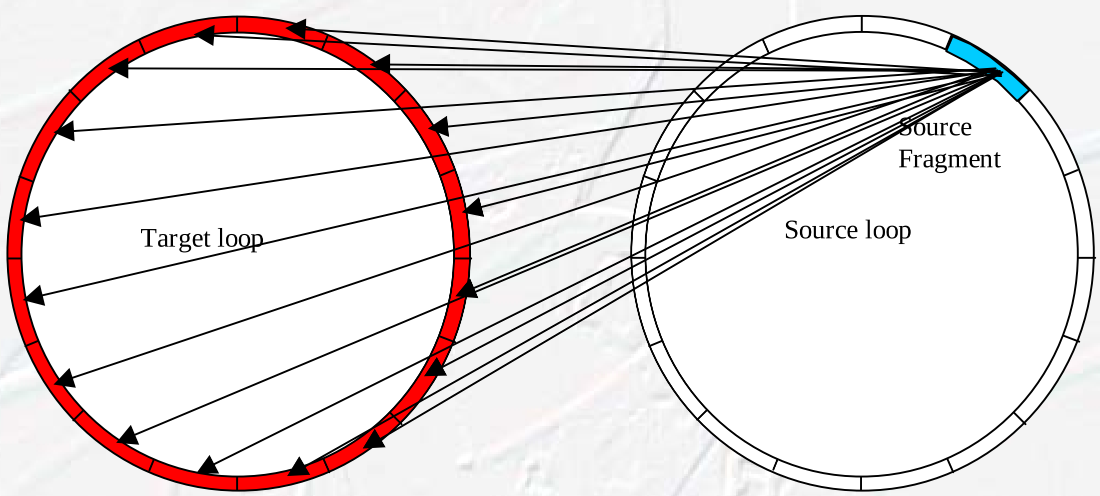


Figure C-3 emf_S

If emf_{TS} is integrated along the target loop then $emf_S = \int_T emf_{TS}$. Here emf_S represents the emf received in the target loop due to the effect of a single source fragment as shown in Figure C-3.

Figure C-4 *emf*

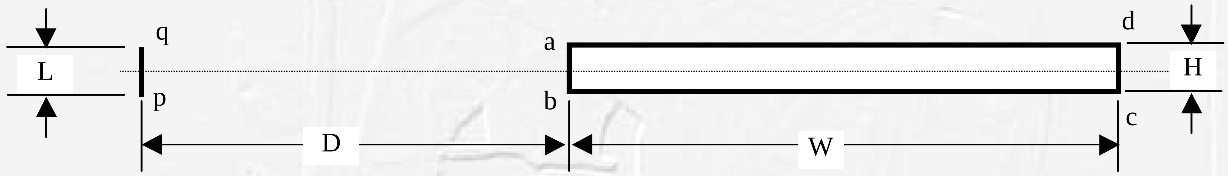
If emf_{TS} is integrated along both the target and source loops then $emf = \int_S \int_T emf_{TS}$. Here emf represents the total emf received by the target loop due to the effect of the entire source loop. This is illustrated in Figure C-4 ; the arrows are not shown for convenience.

In the papers “New Induction” and “New Electromagnetism”, only the subscripts “T” and “S” are used in fragmentary notations.

Appendix D Sample Applications

In this paper, the comparisons between Faraday's Law and the IEL are numerical in nature. This section was added to compare the two laws with algebraic results. The following pages were extracted from a promotional flyer sent out to major institutions.

D.1 Sample application #1



Given the above system where conductor segment (pq) carries a time changing current (di/dt); find the emf induced in the conductive loop (abcd). For simplicity, assume that the length D is much much greater than L and H. The direction of di/dt is from p to q (toward top of page).

USING FARADAY'S LAW

1) Writing down the two equations required :

$$d\mathbf{B} = \mu \frac{(Id\mathbf{L} \times \hat{\mathbf{r}})}{4\pi|\mathbf{r}|^2} \text{ and } emf = -N\frac{d\Phi}{dt}.$$

2) Because D >> H we can say $B = -\mu \dfrac{(IL)}{4\pi r^2}$.

The minus sign comes from resolving the cross product.

3) Replace I with di/dt: $\dfrac{dB}{dt} = -\dfrac{di}{dt}\dfrac{\mu L}{4\pi r^2}$

4) The quantity $d\Phi/dt$ is found by integrating dB/dt over the area enclosed by the loop.

$$\frac{d\Phi}{dt} = -\int_W \int_H \frac{di}{dt}\frac{\mu L}{4\pi r^2} dH dW.$$

5) The integration can be simplified by realizing that the field intensity for this problem varies little as a function of height; therefore, only integration along the width is required. This yields:

$$\frac{d\Phi}{dt} = -\frac{di}{dt}\frac{\mu LH}{4\pi}\int_D^{D+W}\frac{1}{r^2}dr.$$

$$\frac{d\Phi}{dt} = \frac{di}{dt}\frac{\mu LH}{4\pi}\left(\frac{1}{D} - \frac{1}{D+W}\right)$$

6) Since $emf = -N\dfrac{d\Phi}{dt}$ and there is only one turn in the loop (N=1) then :

$$emf = -\frac{\mu LH}{4\pi}\left(\frac{di}{dt}\right)\left(\frac{1}{D} - \frac{1}{D+W}\right).$$

Lenz's law is then used to determine the direction of the induced emf in the loop.

USING THE INERTIAL ELECTRIC LAW

1) Writing down the wire fragment form of the IEL:

$$emf_{TS} = -\frac{\mu}{4\pi}\left(\frac{dI_S}{dt}\right)\frac{d\mathbf{L}_S \bullet d\mathbf{L}_T}{|\mathbf{r}|}.$$

2) From the IEL we see that only line segments (ba) and (cd) are affected.

3) The emf contributed by (ba) is

$$emf = -\frac{\mu}{4\pi}\left(\frac{di}{dt}\right)\frac{LH}{D}.$$

4) The emf contributed by (cd) is

$$emf = -\frac{\mu}{4\pi}\left(\frac{di}{dt}\right)\frac{LH}{(D+W)}.$$

5) Since the directions of both emfs are downward, they oppose each other in the loop; therefore, the total emf is the difference between the two:

$$emf = -\frac{\mu LH}{4\pi}\left(\frac{di}{dt}\right)\left(\frac{1}{D} - \frac{1}{D+W}\right).$$

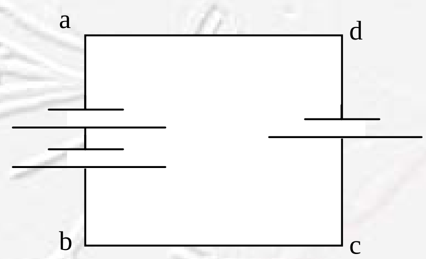
The direction of the emf is ccw around the loop for positive values of di/dt.

D.2 Sample application #2

In the above problem (Sample #1) what is the potential difference developed between the corners of the loop. Assume minimal resistance and capacitance in the loop.

<table>
<tr>
<td>FARADAY'S LAW

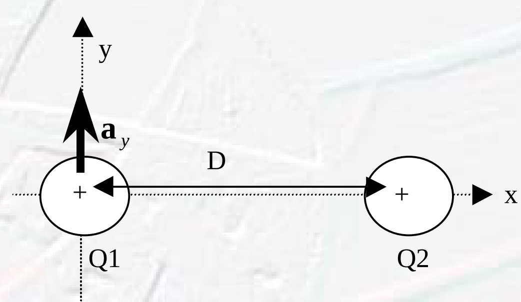
UNSOLVABLE</td>
<td>IEL

1) The following is an effective circuit diagram from above


2) In the above diagram the potential difference between 'a' and 'd' is zero and the potential difference between 'b' and 'c' is zero. The potential difference between (ad) and (bc) is the lesser of the two emfs, which is:
$$emf = -\frac{\mu}{4\pi}\left(\frac{di}{dt}\right)\frac{LH}{(D+W)}$$</td>
</tr>
</table>

D.3 Sample application #3

Given two positive charges (Q1 and Q2) resting on the x-axis separated by a distance (D). If, at t=0, Q1 is accelerated ($\mathbf{a}_y$) in the positive y direction, what is the component of force affecting Q2 due only to the acceleration of Q1 at t=0?



<table>
<tr>
<td>FARADAY'S LAW

UNSOLVABLE</td>
<td>IEL
1) Writing down the point charge form of the IEL
$$\mathbf{F} = \frac{-\mu Q_S Q_T \mathbf{a}_S}{4\pi|\mathbf{r}|}$$
2) Substituting variables yields the answer:
$$\mathbf{F} = \frac{-\mu Q_1 Q_2 \mathbf{a}_y}{4\pi D}$$
The direction of force on Q2 is in the –y direction.</td>
</tr>
</table>

