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Inductance of a Coil

Self Inductance of a Coil

Inductance is the name given to the property of a component that opposes the change of current flowing through it and even a straight piece of wire will have some inductance. Inductors do this by generating a self-induced emf within itself as a result of their changing magnetic field.

In an Electrical Circuit (http://amazon.com/dp/0415662869/?tag=basicelecttut-20)

, when the emf is induced in the same circuit in which the current is changing this effect is called **Self-induction**, (L) but it is sometimes commonly called back-emf as its polarity is in the opposite direction to the applied voltage.

When the emf is induced into an adjacent component situated within the same magnetic field, the emf is said to be induced by **Mutual-induction**, (M) and mutual induction is the basic operating principal of transformers, motors, relays etc. Self inductance is a special case of mutual inductance, and because it is produced within a single isolated circuit we generally call self-inductance simply, **Inductance**.

The basic unit of measurement for inductance is called the **Henry**, (H) after Joseph Henry, but it also has the units of **Webers per Ampere** (1 H = 1 Wb/A).

Lenz's Law tells us that an induced emf generates a current in a direction which opposes the change in flux which caused the emf in the first place, the principal of action and reaction. Then we can accurately define **Inductance** as being: "a coil will have an inductance value of one Henry when an emf of one volt is induced in the coil were the current flowing through the said coil changes at a rate of one ampere/second".

In other words, a coil has an inductance, (L) of one Henry, (1H) when the current flowing through it changes at a rate of one ampere/second, (A/s) inducing a voltage of one volt, (V_L) in it. This mathematical representation of the rate of change in current through a coil per unit time is given as:

$$\frac{di}{dt} \quad (A/s)$$

Where: *di* is the change in the current in Amperes and *dt* is the time taken for this current to change in seconds. Then the voltage induced in a coil, (V_L) with an inductance of L Henries as a result of this change in current is expressed as:

$$V_L = -L\frac{di}{dt} \quad (V)$$

Note that the negative sign indicates that voltage induced opposes the change in current through the coil per unit time (di/dt).

From the above equation, the inductance of a coil can therefore be presented as:

Inductance of a Coil

$$L = \frac{V_L}{(di/dt)} = \frac{1\,\text{volt}}{1A/s} = 1\,\text{Henry}$$

Where: L is the inductance in Henries, V_L is the voltage across the coil and di/dt is the rate of change of current in Amperes per second, A/s.

Inductance, L is actually a measure of an inductors "resistance" to the change of the current flowing through the circuit and the larger is its value in Henries, the lower will be the rate of current change.

We know from the previous tutorial about the **Inductor (http://www.electronics-tutorials.ws/inductor/inductor.html)**, that inductors are devices that can store their energy in the form of a magnetic field. Inductors are made from individual loops of wire combined to produce a coil and if the number of loops within the coil are increased, then for the same amount of current flowing through the coil, the magnetic flux will also increase.

So by increasing the number of loops or turns within a coil, increases the coils inductance. Then the relationship between self-inductance, (L) and the number of turns, (N) and for a simple single layered coil can be given as:

Self Inductance of a Coil

$$L = N\frac{\Phi}{I}$$

Where:

L is in Henries

N is the Number of Turns

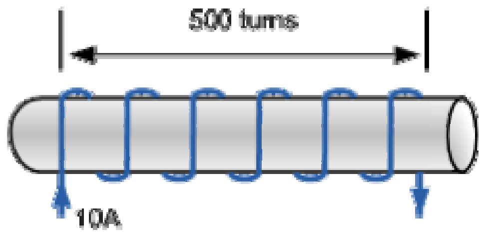
Φ is the Magnetic Flux Linkage

I is in Amperes

This expression can also be defined as the flux linkage divided by the current flowing through each turn. This equation only applies to linear magnetic materials.

Inductance Example No1

A hollow air cored inductor coil consists of 500 turns of copper wire which produces a magnetic flux of 10mWb when passing a DC current of 10 amps. Calculate the self-inductance of the coil in milli-Henries.



$$L = N\frac{\Phi}{I} = 500\frac{0.01}{10} = 500mH$$

Inductance Example No2

Calculate the value of the self-induced emf produced in the same coil after a time of 10mS.

$$emf = L\frac{di}{dt} = 0.5\frac{10}{0.01} = 500V$$

The self-inductance of a coil or to be more precise, the coefficient of self-inductance also depends upon the characteristics of its construction. For example, size, length, number of turns etc. It is therefore possible to have inductors with very high coefficients of self induction by using cores of a high permeability and a large number of coil turns. Then for a coil, the magnetic flux that is produced in its inner core is equal to:

$$\Phi = B.A$$

Where: Φ is the magnetic flux linkage, B is the flux density, and A is the area.

If the inner core of a long solenoid coil with N number of turns per metre length is hollow, "air cored", then the magnetic induction within its core will be given as:

$$B = \mu_o H = \mu_o \frac{N.I}{\ell}$$

Then by substituting these expressions in the first equation above for Inductance will give us:

$$L = N\frac{\Phi}{I} = N\frac{B.A}{I} = N\frac{\mu_o.N.I}{\ell.I}.A$$

By cancelling out and grouping together like terms, then the final equation for the coefficient of self-inductance for an air cored coil (solenoid) is given as:

$$L = \mu_o \frac{N^2.A}{\ell}$$

Where:

L is in Henries

μ_o is the Permeability of Free Space ($4.\pi.10^{-7}$)

N is the Number of turns

A is the Inner Core Area ($\pi.r^2$) in m^2

l is the length of the Coil in metres

As the inductance of a coil is due to the magnetic flux around it, the stronger the magnetic flux for a given value of current the greater will be the inductance. So a coil of many turns will have a higher inductance value than one of only a few turns and therefore, the equation above will give inductance L as being proportional to the number of turns squared N^2.

As well as increasing the number of coil turns, we can also increase inductance by increasing the coils diameter or making the core longer. In both cases more wire is required to construct the coil and therefore, more lines of force exists to produce the required back emf. The inductance of a coil can be increased further still if the coil is wound onto a ferromagnetic core, that is one made of a soft iron material, than one wound onto a non-ferromagnetic or hollow air core.

If the inner core is made of some ferromagnetic material such as soft iron, cobalt or nickel, the inductance of the coil would greatly increase because for the same amount of current flow the magnetic flux generated would be much stronger. This is because the material concentrates the lines of force more strongly through the the softer ferromagnetic core material as we saw in the **Electromagnets (http://www.electronics-tutorials.ws/electromagnetism/electromagnets.html)** tutorial.

Ferrite Core

So for example, if the core material has a relative permeability 1000 times greater than free space, $1000\mu_o$ such as soft iron or steel, then the inductance of the coil would be 1000 times greater so we can say that the inductance of a coil increases proportionally as the permeability of the core increases. Then for a coil wound around a former or core the inductance equation above would need to be modified to include the relative permeability μ_r of the new former material.

If the coil is wound onto a ferromagnetic core a greater inductance will result as the cores permeability will change with the flux density. However, depending upon the ferromagnetic material the inner cores magnetic flux may quickly reach saturation producing a non-linear inductance value and since the flux density around the coil depends upon the current flowing through it, inductance, L also becomes a function of current flow, i.

In the next tutorial about Inductors (http://amazon.com/dp/0962852546/?tag=basicelecttut-20)

, we will see that the magnetic field generated by a coil can cause a current to flow in a second coil that is placed next to it. This effect is called **Mutual Inductance (http://www.electronics-tutorials.ws/inductor/mutual-inductance.html)**, and is the basic operating principle of transformers, motors and generators.

« The Inductor (http://www.electronics-tutorials.ws/inductor/inductor.html) | Mutual Inductance (http://www.electronics-tutorials.ws/inductor/mutual-inductance.html) »

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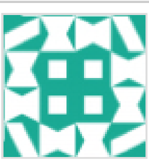
18 Responses to “Inductance of a Coil”



ahmad asrar

Hi wayne.i found your tutorial extremely conceptual.my question goes like this:currrent and voltage in inductor are phase shifted by pi/2 rad. Max current flows through circuit when voltage is min i.e zero in this casethats right.but the thing i am confused about is how can there be a max current when voltage is zero.i mean when voltage is zero and inductor is in its max charged state,what is then the driving force for the current to make it flow.whenever we want to establish a current in circuit,there must be some driving force behind it which in this case seems to be nothing to me.thankyou

May 27th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6933)

Reply (/inductor/inductance.html?replytocom=6933#respond)

Wayne Storr (http://www.electronics-tutorials.ws)

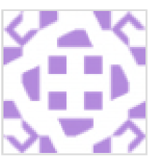
As explained above, an inductor is NOT a voltage or power source like a battery but instead is a very long piece of wire wrapped into the shape of a coil. Inductors are used in circuits with other components and pass a current through them like a resistor. The difference is that an inductor opposes the flow of a changing current (its inductance) due to the self-generated back emf produced by a changing magnetic field, (Lenz's Law).

At some point this current will reach its maximum value determined by the impedance of the load connected after the inductor. As the current stops increasing, it effectively becomes a steady state current, and no back-emf is created by the inductor, the only emf in the circuit is that of the source. At this point the voltage drop across the inductor is zero (except for wire resistance) and maximum current flows through it until there is a change once again in the value of the current.

As stated, an inductor generates a back-emf whose size depends on the rate of change of current, so a pure inductor with an applied AC voltage will have an AC back-emf, which will be out of phase with the applied voltage by 90 degs (pi/2) as you have stated.

May 27th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6936)

Reply (/inductor/inductance.html?replytocom=6936#respond)



Matt

The first equation given is wrong. First equation says that L = V di/dt which would give units of volt Amp/s but the units listed are volt/(amp/s). The units here are correct but the correct equation is V/(di/dt). Otherwise the equation listed later for the voltage or emf induced would not be emf = L di/dt. di/dt. We cannot have an equation that when rearranged gives di/dt on both sides. If we say di/dt = I and L = V*I then V = L/I it would be impossible to have L = V*I AND V = L*I in order for both equations, which are really the same equation to be correct, 1/I must be in one of the equations. Simple mistake, but when the purpose of the information is to educate, it's important for the info to be correct so people who are just learning this don't get their info wrong and build up an incorrect base of knowledge. It's much harder to correct knowledge once it's learned that way then it is to just simply check your work, more than once before posting.

March 8th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6226)

Reply (/inductor/inductance.html?replytocom=6226#respond)

Wayne Storr (http://www.electronics-tutorials.ws)

Thanks Matt. 🙂

Reply (/inductor/inductance.html?replytocom=6228#respond)

March 8th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6228)

Huwei Wu

It's a very good tutorial which helps me rethink lots of basic knowledge again. I have a question after reading the tutorial. Since you write a equation L=Nphi/I dose that mean L can be measured by DC current? Inductance of a coil theoretically should be independent with Current(ac/dc) only depends on physical dimension and geometry. So how can we measure the L? After we wrapping a coil, how much we should say the L of the coil is?

Reply (/inductor/inductance.html?replytocom=6201#respond)

March 6th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6201)

Wayne Storr (http://www.electronics-tutorials.ws)

Hello Huwei, Yes you are correct that the inductance of a coil is a function of its physical characteristics. But self-inductance, or simply inductance, is also the property of a coil whereby a change of current induces a back emf in the coil where: v = L x (the rate of change of current). In terms of the electromagnetic field theory, the inductance L is given by: L = Nphi/i.

Reply (/inductor/inductance.html?replytocom=6203#respond)

March 6th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6203)

Tempest Juvano

why is copper the best conducting material? in the experiment to study biot savart's law, what is the effect of different materials used as the current carrying inductor coil?

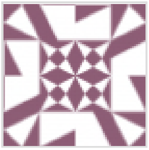
Reply (/inductor/inductance.html?replytocom=5746#respond)

January 30th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-5746)

Wayne Storr (http://www.electronics-tutorials.ws)

Because copper is a very good conductor of electrical current as its ampacity is better than aluminium. The four main conducting metals used are aluminium, copper, gold and silver. Out of the four, copper is the cheapest, has the lowest resistivity of any metal but silver making it ideal for use where space is limited as a smaller cross-sectional area of copper can be used for the same current flow, plus its DC resistance is very low. Copper is also more flexible than aluminium, easily available and reasonably resistant to corrosion. Coils and inductors made from gold or silver are available but naturally expensive for everyday use.

January 30th, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-5747)
Reply (/inductor/inductance.html?replytocom=5747#respond)



Sony

I would like to confirm if my understanding on Inductance is correct.
Inductance is the property which helps in developing a magnetic field around a coil when a current flows through it regardless of DC or AC.
In AC, back emf is generated due to changing magnetic field around the coil. Hence do we relate inductance and back emf as inductance has caused magnetic field first ?

December 27th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-5386)
Reply (/inductor/inductance.html?replytocom=5386#respond)

Wayne Storr (http://www.electronics-tutorials.ws)

Self-Inductance, or simply Inductance is the property of a conductor regardless of whether the conductor is in the form of a straight wire or of a coil of wire, (although the effect of self-inductance is much greater in a coil than a straight wire) that resists the flow of current. Inductance is the ability of the conductor or coil to store energy in the form of an electromagnetic field with the unit of inductance being the Henry, (symbol L).

It is this changing magnetic field, produced by a changing current, that produces a self-induced voltage of reverse polarity across the conductor called the back-emf (which is determined by the inductance and the rate of change of the current). It is this self-induced back-emf voltage which opposes the flow of current through the conductor or coil. For a DC supply, once the circuit current is stable and non-changing, the back-emf is zero. For an AC supply, the back-emf reverses polarity every half cycle.

December 27th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-5388)
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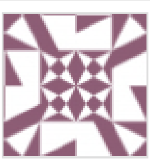


Sony

Thanks a lot for the detailed explanation !!!

December 27th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-5394)
Reply (/inductor/inductance.html?replytocom=5394#respond)

sharanya

good tutorial btw if we are given a circuit with only the inductor coil which itself is of a good resistance in dc then we would be considering it as a LR circuit right. I know its a silly doubt but i just wanted to confirm

June 5th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-978)

Reply (/inductor/inductance.html?replytocom=978#respond)

Wayne Storr (http://www.electronics-tutorials.ws)

Hello Sharanya, It depends upon what information is given and how you want to analyse the circuit. If only inductance is given in Henries, then its analysed as a pure coil. If a DC resistance and inductance is given then you can analyse it as an LR Circuit (http://www.electronics-tutorials.ws/accircuits/ac-inductance.html).

June 5th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-980)

Reply (/inductor/inductance.html?replytocom=980#respond)

Robert Maute

Good tutorial, except for one misleading little error. Unless I am greatly mistaken, N is incorrectly defined in the text at one point as “turns/metre”, whereas N should be just turns (total), not turns per metre. N is defined in the same tutorial both before and after the incorrect definition as “Number of turns”, meaning total number of turns. N as total number of turns (not turns per metre) also agrees with my physics textbook.

April 25th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-529)

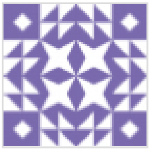
Reply (/inductor/inductance.html?replytocom=529#respond)

Wayne Storr (http://www.electronics-tutorials.ws)

Hello Robert, Yeah your right. What I meant to say was a coil with N number of turns per metre length. Thanks for spotting the error and letting me know. 🙂

April 26th, 2014 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-532)

Reply (/inductor/inductance.html?replytocom=532#respond)



Udara sandaruwan

Hi.. A Transformer.. secondary consuming power is 600VA with 12V supply. If the primery voltage is 240V calculate the current through the primery?? My mail is uadarasandaruwan@gmail.com (mailto:uadarasandaruwan@gmail.com) please mail the answer friend.

Reply (/inductor/inductance.html?replytocom=6140#respond)

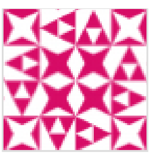
March 2nd, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6140)

Wayne Storr (http://www.electronics-tutorials.ws)

I do not send private email messages and I am not your teacher friend. This is basic stuff you should know. Anyway, the answer is 2.5A

Reply (/inductor/inductance.html?replytocom=6141#respond)

March 2nd, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-6141)



jaan

Secondary voltage = 12 v
Primary voltage =240 v
K=12/240=0.05
sepdown transformer 20 : 1
Secondary power cons..600VA
Seconday curren = 600/12 A :- 50A
Primary current =0.05*50 =2.5A

Reply (/inductor/inductance.html?replytocom=7153#respond)

June 21st, 2015 (http://www.electronics-tutorials.ws/inductor/inductance.html/comment-page-1#comment-7153)

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