Lecture 10 Inductors

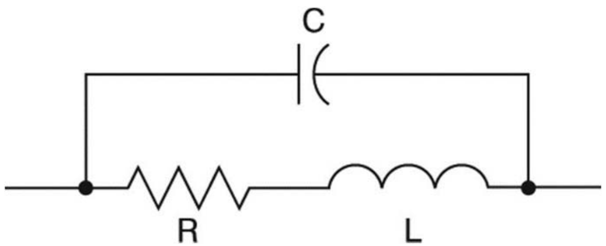
1. Inductors as A Circuit Element
2. Inductor Types
3. Inductor Applications
4. Inductor Modeling
5. Coding Example

1. Inductors as A Circuit Element

- Inuctor: magnetic energy storage device

- In practice, the magnetic energy can be stored only for short time.

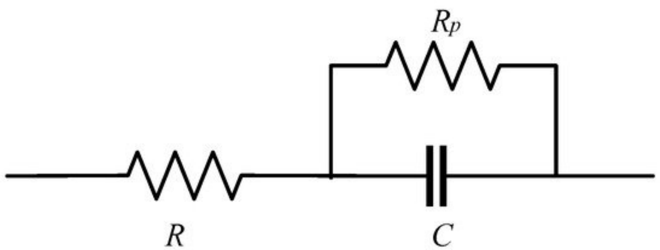
- Wire ohmic loss consumes the energy when the current flows in the inductor.



$$I(t) = I_0 e^{-t/(L/R)}$$

$$R = 20\ \Omega,\ L = 3\ \mu\text{H} \rightarrow L/R = 0.15\ \mu\text{s}$$

- In contrast, in a capacitor the charge flows out very slowly.



$$V(t) = V_0 e^{-t/(R_p C)}$$

$$R_p = 10\ \text{G}\Omega,\ C = 33\ \text{nF} \rightarrow R_p C = 330\ \text{s}$$

- Equations for Inductors

$$L = \frac{\Lambda}{I} = \frac{N\Phi}{I} \text{ (inductance)}$$

$$V = -L\frac{dI}{dt} \text{ (back emf: induced voltage across the inductor)}$$

$$P = -VI = LI\frac{dI}{dt} \text{ (power)}$$

$$W = L\int_0^{I_0} IdI = \frac{1}{2}LI_0^2 \text{ (stored energy)}$$

Types of Inductors

- A diverse electronic component used in a wide range of applications requires various types of inductors. These are of different shapes, sizes including the wire wound and multilayer inductors. Different types of inductors include **high-frequency inductors, power supply line inductors or power inductors and inductors for general circuits**. Differentiation of the inductors is based on the type of winding as well as the core used.

Different Types of Inductors

- Air Core Inductors
- Ferro Magnetic or Iron Core Inductors
- Ferrite Core Inductors
- Toroidal Core Inductors
- Bobbin based Inductors
- Multi Layer Inductors
- Thin Film Inductors

Air Core Inductors

- In this inductor, core is completely absent.
- These inductors offer high reluctance path for the magnetic flux, hence less inductance.
- The air core inductors have larger coils to produce higher flux densities.
- These are used in high frequency applications including TV and radio receivers.

Ferro Magnetic or Iron Core Inductors

- Due to their higher magnetic permeability these have high inductance property.
- These are high power inductors but limited in higher frequency capacity due to the hysteresis and eddy current losses.

Ferrite Core Inductors

- These are the different types of inductors which offer advantages of decreased cost and low core losses at high frequencies.

- Ferrite is a metal oxide ceramic based around a mixture of Ferric Oxide Fe2O3.

- Soft ferrites are used for the core construction to reduce the hysteresis losses.

Toroidal Core Inductors

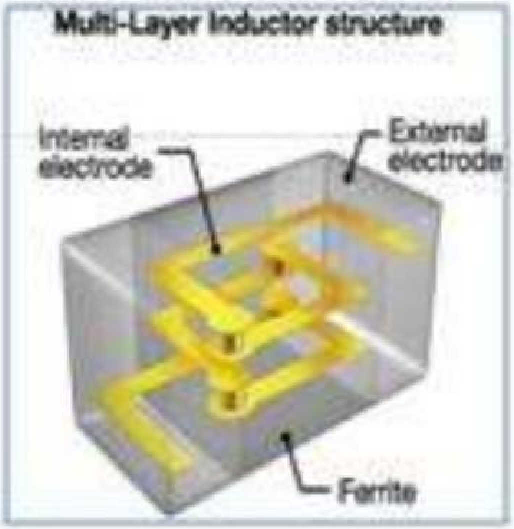
- In these inductors, a coil is wounded on a toroid circular former.
- Flux leakage is very low in this type of inductor.
- Special winding machines are required to design this type of inductor.
- Sometimes ferrite core is also used to decrease the losses in this design.

Bobbin based Inductors

- In this type of Inductor coil is wounded on the bobbin.
- Bobbin wound inductor designs vary widely in terms of power rating, voltage and current levels, operating frequency, etc.
- These are mostly used in switch mode power supplies and power conversion applications.

Multi Layer Inductors

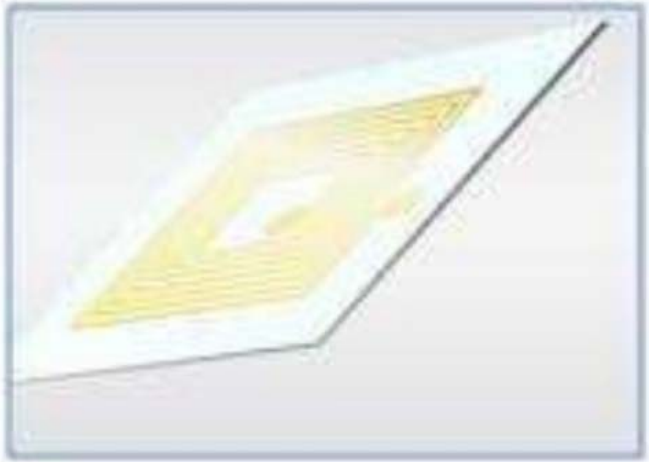
- A multilayer inductor contains two conductive coil patterns.
- It is arranged in two layers in the upper part of a multi-layered body.
- The coils are connected electrically in a consecutive manner in series to two more conductive coil patterns disposed in the lower part of the multi-layered body.
- These are mainly used in mobile communication systems and noise suppression applications.



Thin Film Inductors

- These are completely different from the conventional chip-type inductors wound with copper wire.

- In this type of inductors , tiny inductors are formed using thin-film processing to create the chip inductor for high-frequency applications, which ranges from about nano Henry.



Factors affecting the Inductance of an Inductor

- Capability of producing magnetic lines is referred as inductance. Standard unit of inductance is **Henry**. The amount of magnetic flux developed or inductance of different types of inductors depends on four basic factors discussed below.

  - **Number of turns in a coil**
  - **Material of the Core**
  - **Cross section area of the Coil**
  - **Length of the Coil**

Power loss in an Inductor

- Power dissipated in inductor is mainly due to the two sources
  - Inductor Core.
  - Inductor Windings.

Power loss in an Inductor

Inductor core:

- Energy loss in inductor core is due to the hysteresis and eddy current losses.
- Magnetic field applied to the magnetic material is increased, goes to the saturation level and then decreases.
- While decreasing it doesn't traces the original path and it causes the hysteresis losses.
- Smaller value of the hysteresis coefficient of the core materials results in the low hysteresis losses.

Power loss in an Inductor

Inductor core:

- The other type of core loss is eddy current loss.
- These eddy currents are induced in the core material due to the rate change of magnetic field according to the Lenz's law.

- Eddy current losses are much less than the hysteresis loss.
- These losses are minimized by using the low hysteresis coefficient materials and laminated core.

Power loss in an Inductor

Inductor core:

- In inductors, losses occur not only in the core, but also in the windings. Windings have their own resistance.
- When the current passes through these windings, heat losses (I^2*R) will takes place in the windings.
- Skin effect causes the current to concentrate on the surface of conductor than centers.
- The effective area of the current carrying area decreases.

Power loss in an Inductor

Inductor core:

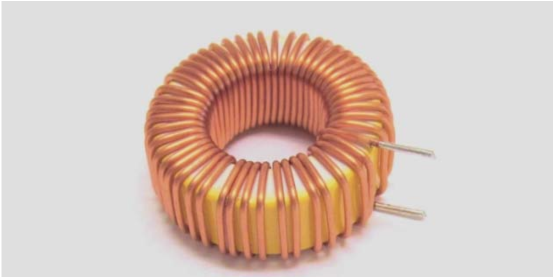
- Eddy currents induced in the windings causes the current to be induced in the neighbouring conductors which is called proximity effect.
- Due the overlapping conductors in the coils.
- Proximity effect causes to increase the resistance of the conductor higher than in case of the skin effect.
- Windings losses are reduced with the advanced winding technologies like shaped-foil and litz wire windings. http://www.elprocus.com/different-types-of-inductors/

Applications

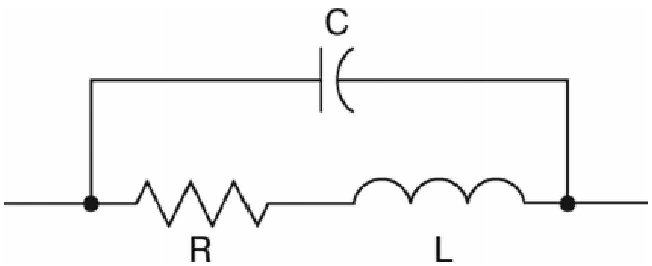
- Inductors have a wide variety and important applications in electronics.

- High power applications
- Transformers
- Suppressing noise signals
- Sensors
- Filters
- Radio frequency
- Energy Storage
- Isolation
- Motors

4. Inductor Modeling



A 6-turn coil (AWG 20.5) wound on a ferrite toroid (Philips 4B1 nickel-zinc) of outer diameter 14 mm, inner diameter 9 mm, and height 5 mm. This will be referred to as Inductor 1.



$$Z(\omega) = \frac{R + j\omega L}{1 - \omega^2 LC + j\omega RC}$$

Due to the effect of the ferrite core material,

R : frequency-dependent

L : frequency-dependent

C : assumed to be frequency-independent

Low frequency values:

$R = 20\ \Omega$, $L = 3.5\ \mu\text{H}$, $C = 0.7\ \text{pF}$

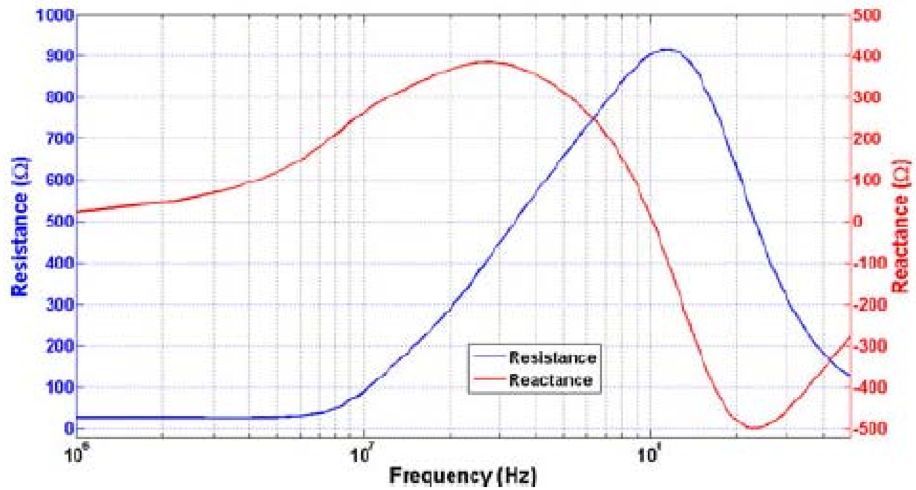
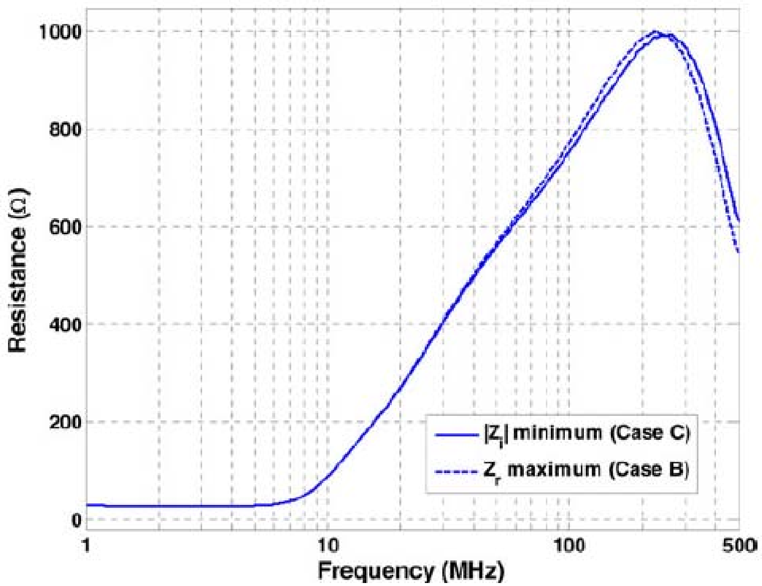
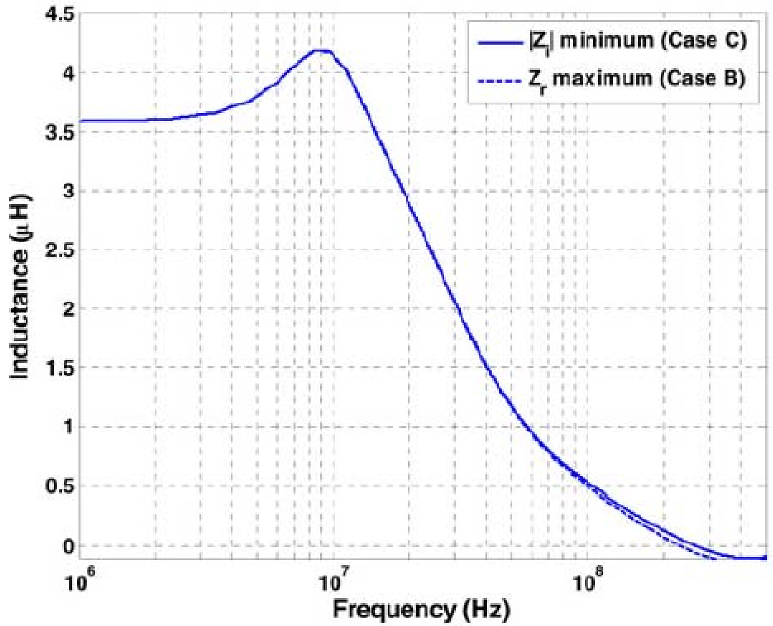


Fig. 4. Measured impedance of the 4B1 toroidal inductor.

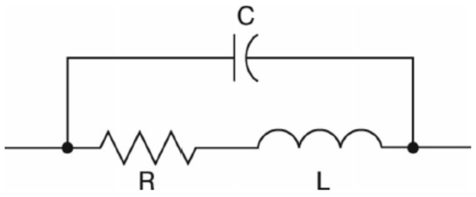


Resistance (Ω)
Frequency (MHz)
1000
800
600
400
200
0
1
10
100
500
|Zi| minimum (Case C)
Zr maximum (Case B)



Inductance (μH)
Frequency (Hz)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
10^6
10^7
10^8
|Zi| minimum (Case C)
Zr maximum (Case B)

5. Coding Example



$$Z = \frac{R + j\omega L}{1 - \omega^2 LC + j\omega RC} = R_{eq} + j\omega L_{eq} \text{ (inductor impedance)}$$

R_{eq} : equivalent resistance

L_{eq} : equivalent inductance

Use the low-frequency values R = 20 Ω, L = 3.5 μH, C = 0.7 pF to calculate the

1) impedance Z,

2) equivalent resistance R_{eq}, and

3) equivalent inductance L_{eq} at f = 1, 10, 100, 200, 400 MHz

Fin

(End)