Modeling AND SiMULATION OF MagNETIC TRANSMISSION LINES

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# Abstract

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# Abstract

Magnetic Transmission Line is the dual counterpart of Electric Transmission Line. Its theory, encompasses a diverse range of applications including Transformers, Dynamic Machines, Microwave Generators, Tuners, Couplers, Isolators, Power Dividers etc. Intrinsically, Magnetic Transmission Line is made from a non-conducting magnetic material, with a high permeability. It transmits Magnetic Flux which acts as the Magnetic charge. Time varying magnetic flux results in a Magnetic Displacement Current inside the Transmission Line, which has the units of Volts. This produces a gradient Magnetic Field; with Fields Lines that spread radially outwards. The magnetic voltage due to this Magnetic Field is measured in Amperes. Although, the operation of a Magnetic Transmission Line does not involve electric charges, Magnetic Displacement Current produces an Electric Field with closed Field Lines encircling the Magnetic Transmission Line. Together, the Electric and Magnetic Fields transmit Energy along the direction of propagation. These relations will be modeled using Maxwell’s Equations and magnetic circuits to study the time and frequency domain behavior of Magnetic Transmission Lines. Furthermore, Finite Difference Time Domain Electromagnetic Field Simulations will be carried out in MEEP Simulator for anisotropic, inhomogeneous, non-linear Magnetic Transmission Lines.

# Introduction

Magnetic Transmission Lines are designed to transmit electromagnetic energy using strong magnetic fields. They are made of magnetic materials with very high magnetic permeability and a strong affinity for magnetic flux. When an external magnetic field is applied, atomic spins tend to align parallel to it. This large scale cooperation enhances the Magnetic Flux Density inside the magnetic material. When the applied field is varied, the changing Magnetic Flux Density transmits the magnetic information across the magnetic material. This phenomenon is called Magnetic Transmission.

It is important to note that charge carriers are not involved in magnetic communication. Isolated Magnetic charges do not exist and magnetic conduction current can never flow in a Magnetic Transmission Line. Magnetic Transmission is only possible through Magnetic Displacement currents. These result from the alignment of magnetic dipoles in response to a stimulating Magnetic Force. This driving force is called Magnetomotive Force.

Moreover, Magnetic Transmission Lines do not involve the flow of Electric charges. Magnetic materials are very poor electric conductors; hence electric currents cannot transmit information across a Magnetic Transmission Line. Changing Magnetic Fields produce Electric Fields which are transmitted through electric displacement currents. These currents result from the alignment of bound electric charges present inside the Magnetic Material. Induced Electric Fields cause shifting of electron cloud surrounding the atomic nucleus. This polarization is responsible for transmitting Electric information across the Magnetic Material. Together, the Electric and Magnetic Fields transmit Electromagnetic Energy along the direction of propagation.

The following sections will elaborate on the subject of Magnetic Materials. A brief account on the losses in Magnetic Transmission Lines will be given as well.

## Nature of Magnetic Materials

The basic building blocks of magnetic materials are fictitious magnetic poles which can be considered as magnetic charge carriers. Poles can have either positive or negative charge. This is responsible for the magnetic field around the pole. Hence like poles repel each other and unlike poles attract each other. The force between poles is proportional to the strength of the poles (m) and inversely proportional to the square of distance (r) between them:

In nature, magnetic monopoles always exist in a pair called magnetic dipole. Magnetic dipole can result from the motion of an electron in an orbit around a nucleus; or its spin (either clockwise or anticlockwise) around an axis. This is similar to a current flowing in a loop. The identification of poles is dictated by the Flemming’s right hand rule. The magnetic moment () of an orbiting/ spinning electron is proportional to the spectroscopic splitting factor (g) i.e. the ratio between mechanical angular momentum and magnetic moment, electron charge (q), associated quantum number (n) and Planck’s constant (h). It is inversely proportional to the electron mass (m) and speed of light (c).

Two dipoles attract each other if unlike poles are close to each other. On the other hand, two dipoles repel each other if like poles are closer. Hence, an external magnetic field can cause a mechanical torque and mechanical moment on a magnetic dipole. This moment tries to turn the dipole in the direction that decreases the overall energy of the system. In equilibrium state, the resultant moment due to both poles is zero.

In an unmagnetized material, the magnetic dipoles are randomly oriented hence their fields cancel out. When an external Magnetic Field H is applied, the magnetic dipoles rotate to decrease the energy of the system. In this way, the electrons try to occupy the energy levels with the lowest energy.

Atoms contain orbitals with a fixed amount of energy for accommodating electrons. An electron with clockwise spin can pair with an electron having anticlockwise spin. The clockwise spin can cancel the effect of anticlockwise spin hence no magnetic moment will result. Only unpaired spins contribute to the net moment. The resulting spin and orbital moments add up to produce a net Magnetization Vector Field M inside the magnetic material. This field is proportional to the magnetic susceptibility of the material ):

The Magnetic Field inside a magnetic material can be represented by a flow of M and H lines. The number of lines passing through a region of space is called Magnetic Flux (equivalent to magnetic charge). Magnetic Flux Density represents the number of flux lines per unit area:

Iron, Nickel and Cobalt contain 4, 3 and 2 unpaired electrons per atom respectively. Hence, the effect of Magnetization/ Polarization is very strong in these special elements and their alloys. A large scale cooperation between magnetic dipoles causes an enhanced Magnetic moment. Due to the high magnetic susceptibility, they are used in the production of Ferromagnetic and Ferrimagnetic materials.

The parallel alignment of magnetic dipoles causes the creation of magnetic domains to reduce the magnetic potential energy stored in the Magnetic Flux Lines. The Magnetic energy consists of the following:

* Magnetostatic Energy: The energy needed to place the magnetic poles in a specific geometric configuration e.g. magnetized state. Magnetostatic Energy is proportional to the width of the magnetic domain. The expression is given in (5)
* Magneto-crystalline Anisotropy Energy: For crystalline structures with repeating atomic units, the domain magnetization tends to align along one direction more easily than other directions. Magneto-crystalline Anisotropy Energy is greater in hard direction as compared to the easy direction.
* Magnetostrictive Energy: Magnetization and Demagnetization can cause changes in the dimensions of the magnetic materials. These stresses are caused by shifting of atomic planes e.g. during alignment of domains. Magnetostrictive Energy represents the elastic potential energy stored in the constricted atomic configuration.
* Domain Wall Energy: A Domain wall is a region where the Magnetization in one domain gradually changes to the direction of a neighboring domain. Domain Wall Energy represents the energy in the transition region.

Naturally, the size and direction of magnetic domains is chosen to minimize the overall magnetic energy of the system. If an unmagnetized material is placed in an external magnetic field, the domains may have to align in a hard direction for Magnetization of the material. Work will be done to align the domains in the special configuration so that the preferable domains grow in size while the unfavorable domains shrink. This will involve displacement of atomic planes and domain boundaries. Hence the overall stored magnetic energy of the system will increase during magnetization.

B-H Loop

## Magnetic Losses

## Summary

# Topic 1

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## Conclusion

# Conclusions

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# Appendix