Magnetic Permeability

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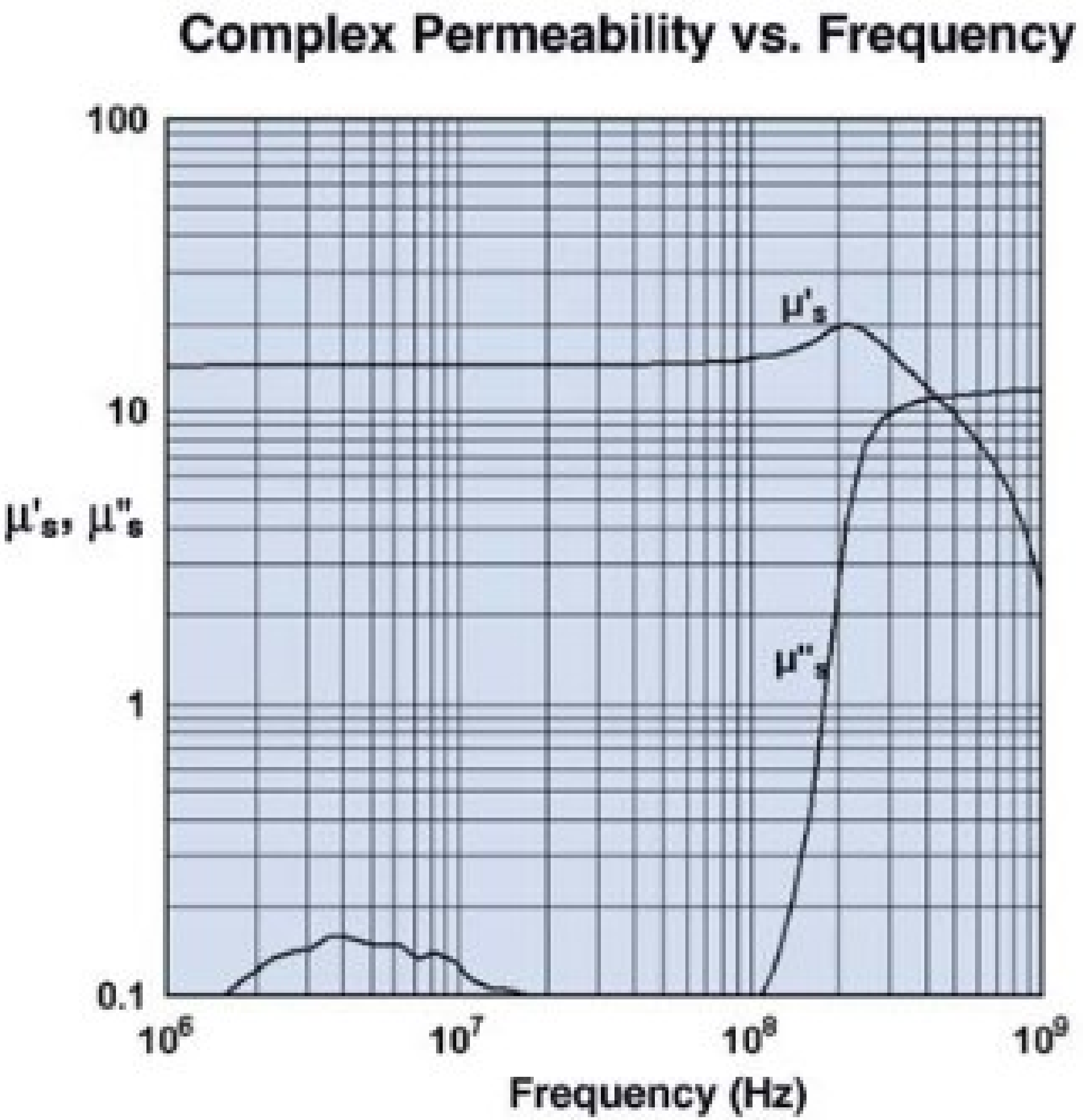
Background

- Scalar μ and complex μ
- **B = μ H**
- $\mu_r = \mu_r' - j\mu_r''$
- $\mathbf{Z_f/Z = \mu_r}$
- $\mathbf{Z_F = j\mu_r'\omega L + \mu_r''\omega L}$

Commercial Specification Example

Fair-Rite:



Measured on an 18/10/6mm toroid using the HP 4284A and the HP 4291A.

H and B

H symbolizes the magnetic field strength generated by a current flowing through a neighboring conductor (could be a coil)

B is the magnetic flux density generated by

- Current flowing through neighboring conductors
- Increase of density caused by magnetic material.

Magnetic Permeability μ

Magnetic material with a positive magnetic permeability increases the magnetic flux caused by a current through a neighboring conductor

Note: Magnetic flux is related tot the number of magnetic field lines that goes through a surface

μ represents the increase of the magnetic flux B in respect to the original magnetic field strength H (The latter which is caused by a current through a neighboring conductor.)

This can be expressed in a formula where μ is a multiplier which multiplies H to get B.

$$\mathbf{B = \mu H}$$

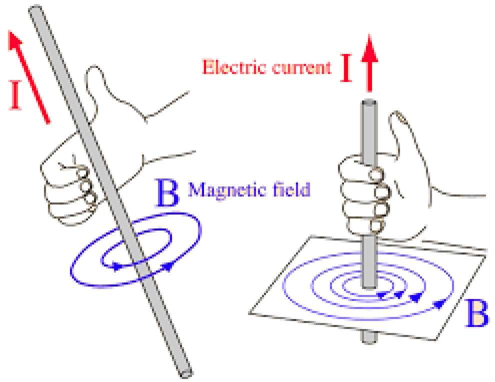
Note: μ is the Greek letter for M which you can imagine to stand for Multiply

Magnetic Induction

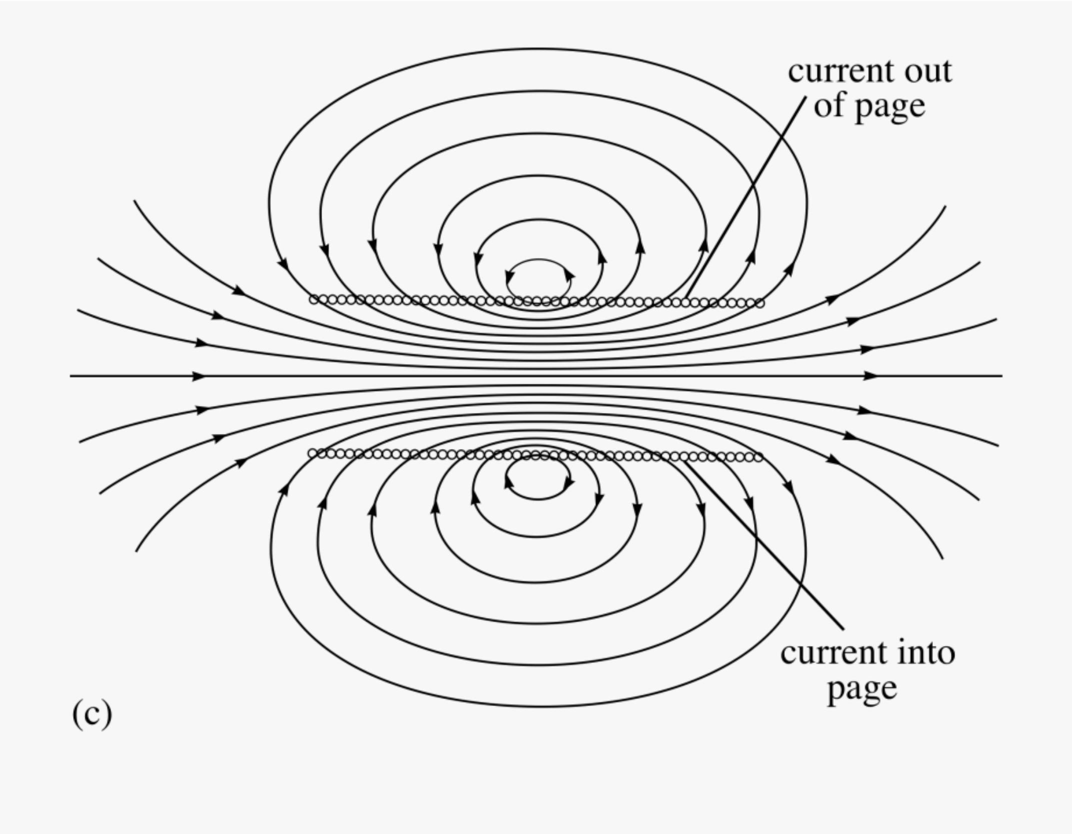
Magnetic Inductance is the property of a current to produce magnetic field lines.

Examples

- Straight wire
- Solenoid
- Toroid



In case a wire is wound around magnetic material with high permeability μ, its inductance is increased by the value of μ



The *Magnetic Permeability* μ

μ is the relation (quotient) between the applied magnetic field strength H and the resulting Magnetic Flux density B due to the effect of the presence of magnetic material.

$\mu = B/H \Rightarrow B = \mu H$

μ is the Greek character for our Latin character mM

- Multiplication
- Magnetization

It indicates how many more magnetic field lines are present because of the magnetic material, in respect to the original field H

H and *B* in Vacuum

H is expressed in A/m

B (flux density) is expressed in Tesla or kg/s/A (or N/m/A)

B=μH

μ in vacuum (i.e. without magnetic material present) μ is defined as μ_0

$$\mu_0 = B/H$$

μ_0 = magnetic permeability in vacuum

μ_0 en μ_r

μ in vacuum is defined as μ_0

In the presence of magnetic material μ can be larger or smaller than μ_0

μ_r is the relative permeability of material with permeability μ in respect to μ_0 therefor:

$$\mu = \mu r\, \mu_0$$

How can we determine μ_r ?

- Impedance of a coil without magnetic material $Z = j\omega L$
- Impedance of same coil but wound on magnetic material with permeability $\boldsymbol{\mu_r}$ is: $Z_F = j\omega\, \boldsymbol{\mu_r} L$
  - $Z_F/Z = \boldsymbol{\mu_r}$
- Z_F of coil on Ferrite material is easily measurable
- Z of same coil without Ferrite can be calculated with the formula: $L = \mu_0 N^2/ C$

(C is a constant which is dependent of the form of the coil)

- For a toroid $C = 2\prod/h \cdot \ln(d_o/d_i)$
  - Taylor => ln x = (1-x) – (x-1)2/ 2 + …
  - http://www.qsl.net/in3otd/electronics/magnetics/theory.html

Alternative toroid calculation

If Ur > 10 the following approximation can be used for a closed magnetic circuit :

- $L = N^2 \mu \cdot s / l$
- $\mu = \mu_0 \, \mu_r$
- $s = (D1 - D2) * h/2\pi$
- $l = (D1 + D2) / 2$

(all dimensions in meters)

Easy calculation with COIL32application

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ENTER THE INPUT DATA:

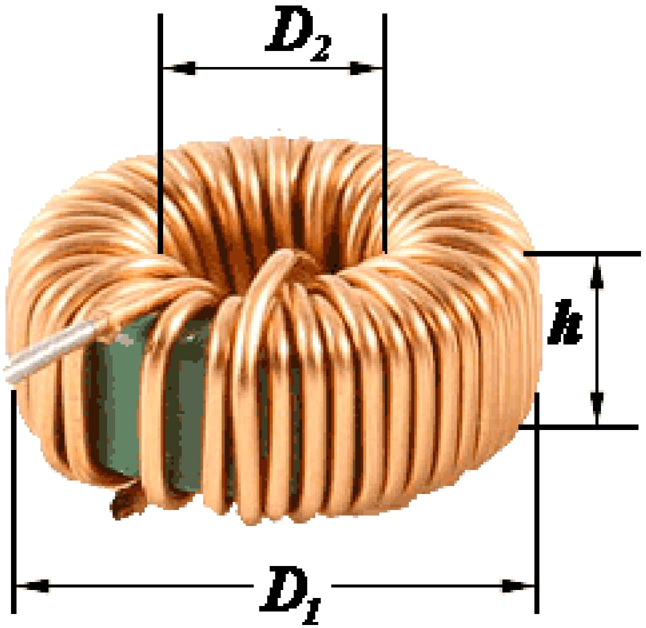
Select units: mm/cm

N =	20		– **Number of turns**
L =	200	µH	– **Measured inductance**
D_1=	22	mm	– Outer diameter of ring
D_2=	11	mm	– Inner diameter of ring
h =	5	mm	– Height of ring

Calculate

RESULT:

μ =	722	– Initial magnetic permeability
A_L=	500	– Inductance factor of the core [nH/N^2]



https://coil32.net/online-calculators/determine-toroid-core-permeability.html

To download CoiL32

Visit the site www.rfseminar.nl

Selectr Topics -> “Coil calculation with COIL32/COIL64”

Selecte “ONLINE CALCULATORS”

Select “Determine Toroid Permeability”

Follow instruction

ON9BOG's rule of thumb:

Product of μ and frequency in MHz less than <3750

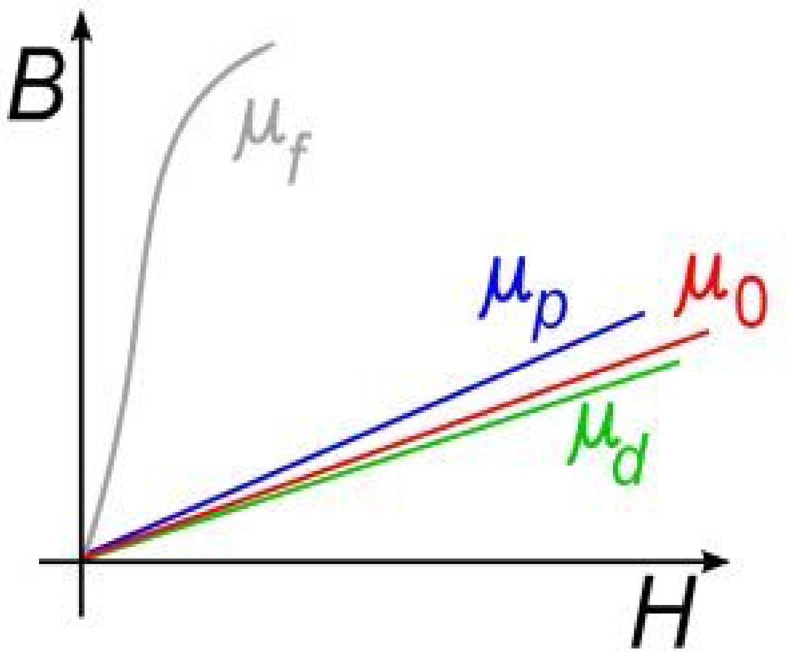
B maximum 10 mT (3C65 < 15mT)

Different kinds of magnetism

Para- and Dia-magnetism

- Diamagnetic materials are repelled by a magnetic field (μ_r<1)
- Paramagnetic materials are attracted by a magnetic field (μ_r>1)

Permeabilities of ferromagnets, paramagnets, free space, and diamagnets



μ is dependent on many factors

Such as:

Magnetic field strength

Temperature

History (hysteresis)

Frequency

μ is complex

Complex does not mean ‘complicated’ but just that ‘it consists of multiple items.’ e.g.:

- Real part is in phase with reference,
- Imaginary part is 90^0 out of phase in respect to reference

In general **μ** is a complex entity meaning that B can be out of phase with H

As $\boldsymbol{\mu_r}$ is a complex number, we can separate it in two components:

$$\boldsymbol{\mu_r = \mu_r' - j\, \mu_r''}$$

$$\mu_r = \mu_r' - j\mu''_r$$

Z is impedance without magnetic material

Z_F = impedance with magnetic material

$\boldsymbol{\mu_r} = Z_F/Z$

$Z_F = \mu_r Z$

$Z_F = (\mu_r' - j\mu_r'')j\omega L$

$Z_F = j\mu_r'\omega L - j\, j\, \mu_r''\omega L$

$$\boldsymbol{Z_F = j\mu_r'\omega L + \mu_r''\omega L}$$

$\mu_r = \mu_r' - j\mu_r$

$Z_F = j\mu_r'\omega L + \mu_r''\omega L$

- The quotient Im/Re determines Q

μ_r' determines the imaginary part of a coil on magnetic material

- In other words: it tells us how well it behaving as an inductivity.

μ_r'' determines the real part of a coil on magnetic material

- In other words it tells us how lossy it is

Rule of thumb:

- If you require an ideal coil, use material with high μ_r'
- If you need it for fighting RFI μ_r'' must be high

Permeability isfrequency dependent

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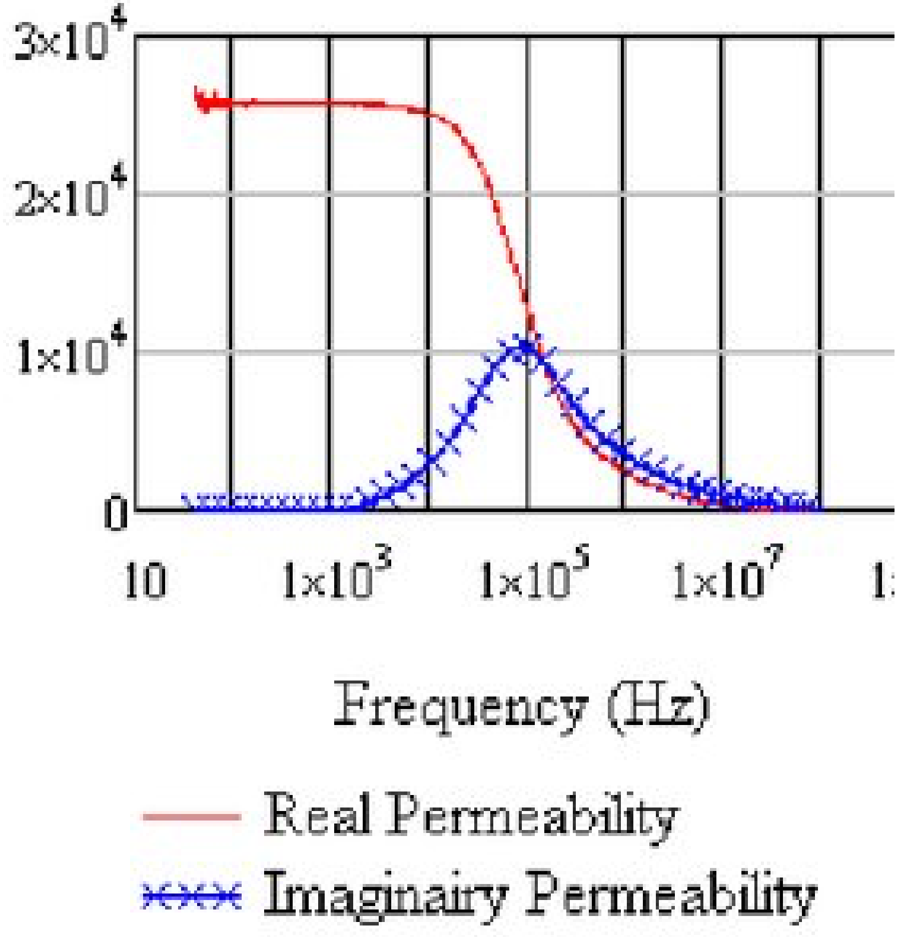
- Permeability μ_r'-jμ_r'' is complex
- Permeability is frequency dependent
- Important for HF
- $\mu_r = \mu_r' - j\,\mu_r''$
- μ_r' is in red
- j μ_r'' is in blue



Tips for use

Study frequency dependence of graphs of complex μ

If graph not available, measure it with a VNA equipped with a dedicated Measurement Cell (see other presentations on www.rfseminar.nl).

Be aware of shifting of graphs with multiple windings

Determine Q at desired frequency range Q = Im/Re

- High Q for tuned circuits and filters
- Low Q for damping interfering HF