Trilogy of Magnetics

Design Guide for EMI Filter Design, SMPS & RF Circuits

Basic principles

I Basic principles

1 Basic principles of inductive components

The basis for understanding inductors is provided by magnetism and a few fundamental electromagnetic field laws, revealing clear and fundamental knowledge of inductors and ferrites. The most important phenomena and laws are from basic physics lessons:
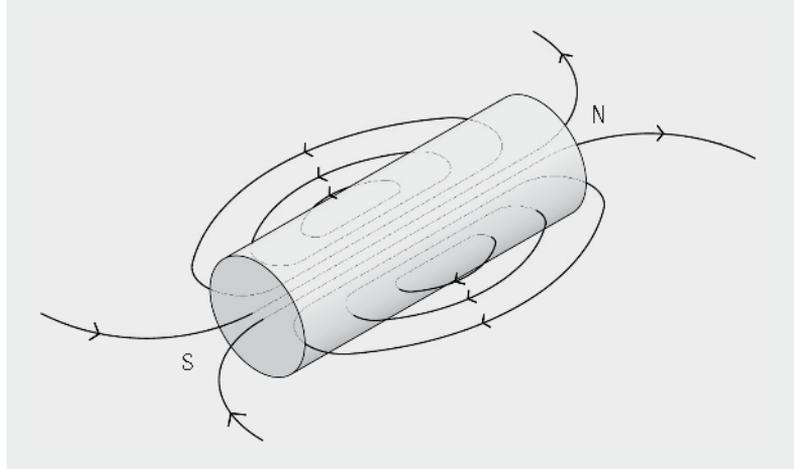
Fig. 1.1:   Bar magnet

- Every magnet has a north and south pole (The earth is an enormous magnet!)
- If an existing magnet is divided, a new one is created. The magnet created also has a north and south pole. This division can be performed down to the molecular level without losing the magnetic effect.
- Every magnet is surrounded by a magnetic field, which is represented by the field line model.
- Magnetic field lines are closed loops. They have neither a beginning nor end.
- There are magnetizable materials (e.g. iron) and non-magnetizable materials (e.g. aluminum).

Ferromagnetic materials

The following analysis concerns a class of magnetizable materials, the ferromagnetic materials.
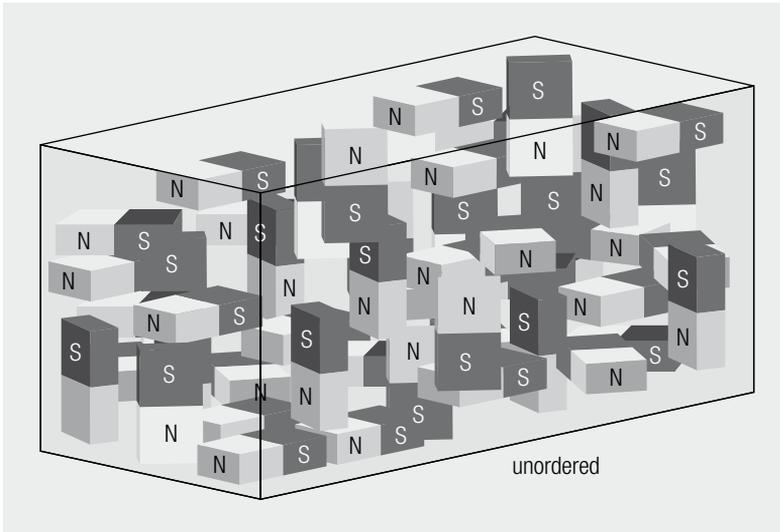
Fig. 1.2:   Elementary magnets

Every magnetic material is composed of a finite number of the smallest elementary magnets, configured randomly in the unmagnetized state. Therefore the sum of the magnetic effect is zero. These orientate themselves under the influence of an external magnetic field.
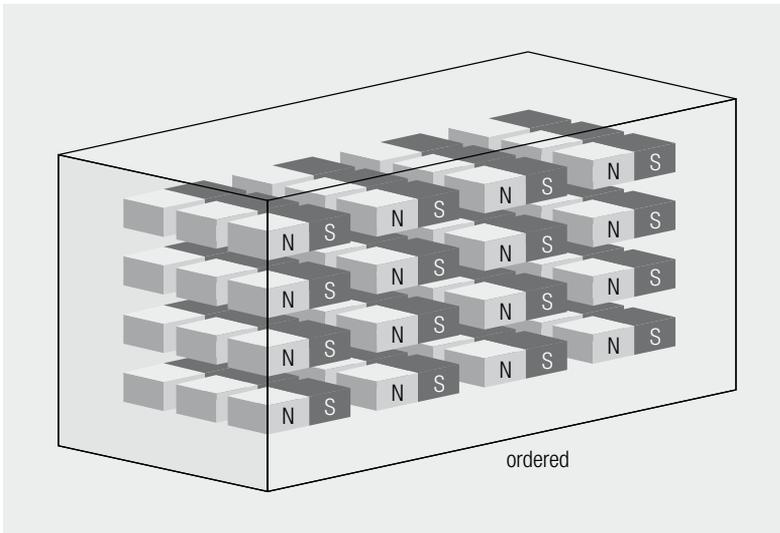
Fig. 1.3:   Saturation

If all elementary magnets are oriented in the magnetic field, one speaks of **saturation** of the material.

Saturation

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Once the externally applied magnetic field is removed, two effects can occur:

a) The material becomes unmagnetized once again: One speaks of a soft magnetic material

b) The material remains magnetized: One speaks of a hard magnetic material

1.1 Ampère's Law and magnetic field strength H

A magnetic field is created around an electric conductor passing a current. This magnetic force field is a vector quantity perpendicular to the generating current. Field lines represent the magnetic force field. For a current carrying conductor, these form closed concentric circles.

Integrating in a counter clockwise direction along a field line, the H and each distance increment (dr) are always in the same direction. A complete circulation provides the magnetic boundary potential:
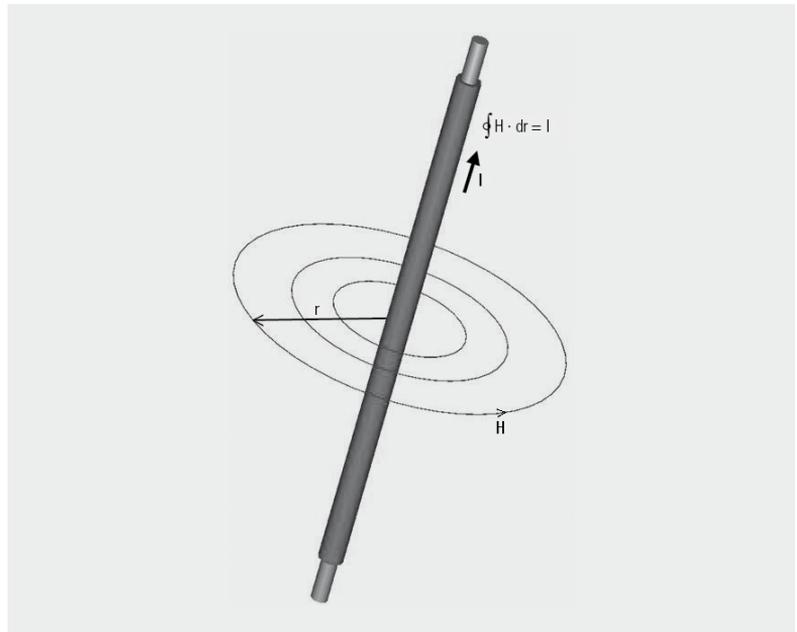
Fig. 1.4: Magnetic field strength H of a long conductor

If several conductor currents pass through the enclosed area, the sum of the currents must be on the right side of the equation (observing their directional signs):

$$\oint H \cdot dr = \sum_{v} I_v \qquad (1.1)$$

The magnetic field is measured by means of the magnetic field strength H and is defined by the currents generating the field.

The field strength of any conductor configuration may be determined from the Biot-Savart Law:
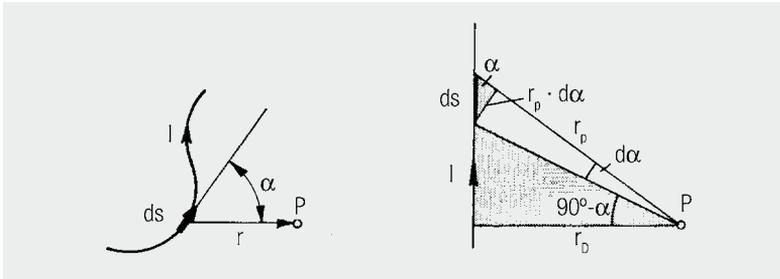
Fig. 1.5:   BIOT SAVART's Law: Describing the field strength outside a straight current conductor

Accordingly, the small section (ds) of the conductor carrying current (I) makes the contribution:

$$dH = \frac{I \cdot \sin \alpha \cdot ds}{4 \cdot \pi \cdot r^2} \qquad (1.2)$$

where (α) is the angle between the direction of the line element (ds) and its connection (r) to the point (P) at which the field strength (dH) exists.

The field strength (H) results from integrating over the entire length of the conductor.

The contour integral of H along a closed line is equal to the total current through the area across this closed path. The magnetic field strength is given by the total current through the surface enclosed by the magnetic field line and the length of this field line.

If it is assumed that the same currents flow in N discrete conductors, as in the case of a coil, the equation simplifies to:

$$\oint_l \vec{H} \cdot \vec{ds} = N \cdot I \qquad (1.3)$$

N   =   number of conductors within the closed path l
I   =   current per conductor

The unit of magnetic **field strength (H) is A/m**.

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Examples of typical conductor arrangements of the magnetic field strength (practical formula):

1.1.1 Straight current conductor

Straight conductor

$$H = \frac{I}{2 \cdot \pi \cdot r}$$
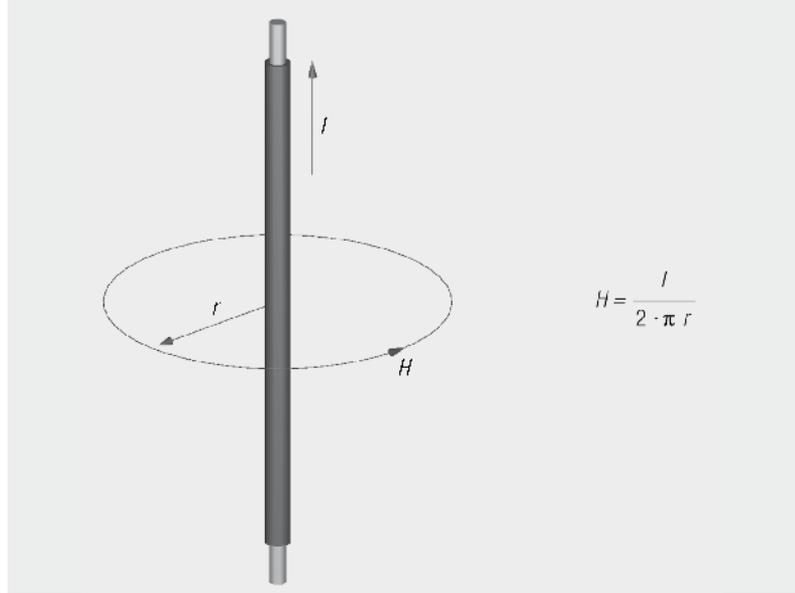
Fig. 1.6: Magnetic field strength (H) of a straight conductor

Toroidal coil

1.1.2 Toroidal coil

$$H_m = \frac{N \cdot i}{2 \cdot \pi r}$$

$N = Winding\ turns$
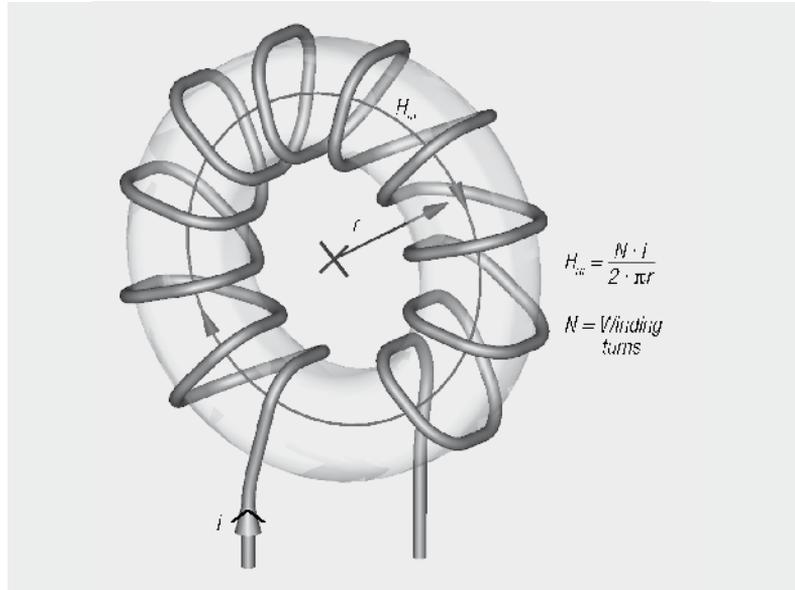
Fig. 1.7: Magnetic field strength H of a toroidal coil

1.1.3 Long solenoid
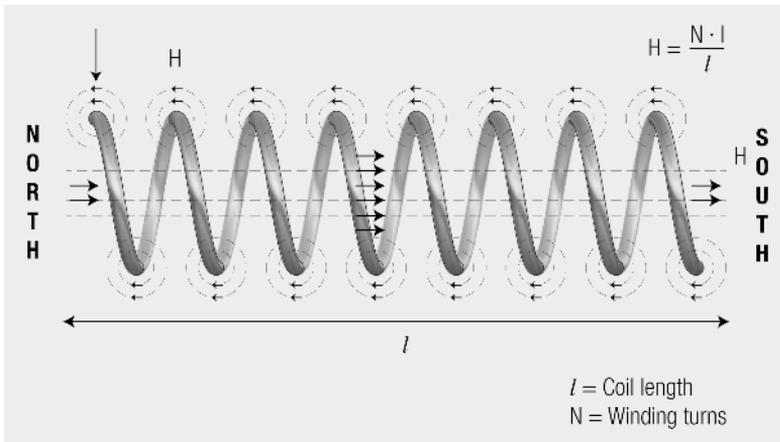
Fig. 1.8:   Magnetic field strength H in a solenoid

This illustration shows the size of the magnetic field strength (H) inside a long solenoid to be dependent on the current I, the coil length l and the winding turns N.

Example:

Ferrite sleeve 742 700 9 on a conductor with dc current of I = 10 A
Sleeve dimensions:
OD = 17.5 mm; ID = 9.5 mm; l = 28.5 mm
($\rightarrow$ average diameter = 13.5 mm and r_a = 6.75 mm)
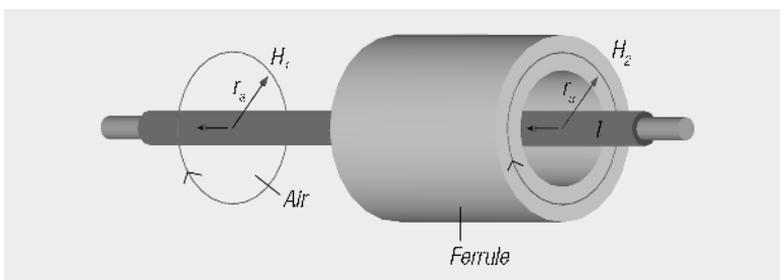
Fig. 1.9:   Field strength in air and in a ferrule

Question:
What size has the field strength H_1 in air and field strength H_2 in ferrule (centered conductor)?

Answer:
The field strengths H_1 in air and H_2 in the ferrule are the same.