Influence of different core materials on the frequency response of a line filter

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Choosing the right Inductor/CMC for your application

- **Many different CMCs**
  - Different size
  - Different shape/designs
  - Different Corematerials

- **Inductors**
  - With ferrite core
  - Without core
Ferrites

- **Ferrite cores**
  - Ferromagnetic material
  - Ceramic subgroup
    - Heat-resistance
    - Hardness
    - Easy to create different shapes

- **Nanocrystalline Material**
  - Metal subgroup
    - Difficult/not possible to create different shapes
      - Metal film that rolled up to a cylindrical core
  - Higher magnetic properties
    - Smaller sizes possible

Mixture of different materials:
Iron Oxide + MnZn or NiZn
Ferromagnetic material

What is ferromagnetic material?

The atoms of magnetic materials are small magnets. These elementary magnets are unordered and there is no magnetic effect.

- Ferromagnetic - $\mu r >> 1$ → magnetic non linear
- Paramagnetic - $\mu r > 1$
- Diamagnetic - $\mu r < 1$

In an external magnetic field, the elementary magnets start to orient, and the material becomes magnetized.

$\mu$ - Permeability
Permeability $\mu$

If a ferromagnetic material is placed in a magnetic field, the magnetic flux becomes concentrated in this material. *The higher the permeability, the greater is the magnetic field bundled in the Material.*

\[
\mu = \frac{B}{H}
\]

\[
\mu = \mu_0 \mu_r
\]

- $\mu_r$ - relative permeability
- $B$ – magnetic induction
- $H$ – magnetic field strength
Permeability $\mu$ - Not constant

The permeability of a material is essentially dependent on:

- The frequency $f$ → Complex permeability
- The magnetic field strength $H$ → Hysteresis curve, Saturation
- The temperature $T$ → Curie temperature
- The material used → MnZn, NiZn, Nanocrystalline, Air
Permeability \( \mu \) - Not constant

The permeability of a material is essentially dependent on:

- **The frequency** \( f \) \( \rightarrow \) Complex permeability
- **The magnetic field strength** \( H \) \( \rightarrow \) Hysteresis curve, Saturation
- **The temperature** \( T \) \( \rightarrow \) Curie temperature
- **The material used** \( \rightarrow \) MnZn, NiZn, Nanocrystalline, Air
Complex Permeability

\[ \mu = \mu' - j\mu'' \]

- \( \mu' \) - ideal inductive component
- \( \mu'' \) - frequency dependent resistive component (represents the losses of the core material)

Main part for filtering - \( \mu'' \)

Need the losses for absorption of the noises (heat)
Permeability $\mu$ - Not constant

The permeability of a material is essentially dependent on:

- The frequency $f$ $\rightarrow$ Complex permeability
- **The magnetic field strength $H$** $\rightarrow$ Hysteresis curve, Saturation
- The temperature $T$ $\rightarrow$ Curie temperature
- The material used $\rightarrow$ MnZn, NiZn, Nanocrystalline, Air
Hysteresis Curve - Saturation

\[ B = \mu H \]
Saturation

Differential Mode

Current flow
Magnetic flux

Source

LOAD

Source

LOAD

$I_{DM}$

$L$

$I_{CM}$

$I_{DM}$

$CMC$
Saturation

WE-PD (Shielded Power Inductor)

WE-FC (CMC Powerline)
Permeability $\mu$ - Not constant

The permeability of a material is essentially dependent on:

- The frequency $f$ → Complex permeability
- The magnetic field strength $H$ → Hysteresis curve, Saturation
- **The temperature $T$** → **Curie temperature**
- The material used → MnZn, NiZn, Nanocrystalline, Air
Curie-Temperature

- Temperature at which the ferrite material loses all its permeability / magnetic properties
- The ferromagnetism disappears and the material becomes paramagnetic
  - reversible
    - Inductance / Impedance drops
Curie-Temperature

Influence of the temperature to the permeability
Temperature behavior – MnZn
Temperature behavior – Nanocrystalline
Permeability $\mu$ - Not constant

The permeability of a material is essentially dependent on:

- The frequency $f$ → Complex permeability
- The magnetic field strength $H$ → Hysteresis curve, Saturation
- The temperature $T$ → Curie temperature
- The material used → MnZn, NiZn, Nanocrystalline, Air
Aircoil vs. Ferritecoil

Simulation rodcore choke with NiZn core and without core

\[ Z_{airc} = R_{Cu} + j\omega L \]

\[ \mu_{Air} \approx 1 \]

\[ L = \frac{\mu_0 \mu_r A_{eff} N^2}{l_{eff}} \]
Simulation vs. Measurement

Simulation
Nizn Core

Measurement
NiZn Core
Comparison Ringcore Materials MnZn/NC/NiZn

- Coresize S
  - Sizes are similar
- Same/similar turns
- Same/similar wire diameter

<table>
<thead>
<tr>
<th>Corematerial</th>
<th>Number of turns</th>
<th>Wirediameter in mm</th>
<th>Inductance in mH</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnZn</td>
<td>12</td>
<td>0,6</td>
<td>1,00</td>
</tr>
<tr>
<td>Nanocrystalline</td>
<td>13</td>
<td>0,5</td>
<td>5,00</td>
</tr>
<tr>
<td>NiZn</td>
<td>13</td>
<td>0,5</td>
<td>0,11</td>
</tr>
</tbody>
</table>
Comparison Ringcore Materials

MnZn/NC/MnZn+NiZn

- Coresize L
  - Sizes are similar
- Same/similar turns
- Similar wire diameter
  
  Different Inductance / Attenuation

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</thead>
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<tr>
<td>MnZn</td>
<td>11</td>
<td>1,3</td>
<td>1,00</td>
</tr>
<tr>
<td>Nanocrystalline</td>
<td>9</td>
<td>1,1</td>
<td>4,00</td>
</tr>
<tr>
<td>MnZn + NiZn</td>
<td>9</td>
<td>1,2</td>
<td>0,22</td>
</tr>
</tbody>
</table>
Comparison Ringcore Materials
MnZn/NC/MnZn+NiZn

- Coresize L
  - Sizes are similar

- Same inductance of 1 mH
  - Different Attenuation
  - Different number of turns needed

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<td>1,4</td>
<td>1,00</td>
</tr>
<tr>
<td>Nanocrystalline</td>
<td>5</td>
<td>1,6</td>
<td>1,00</td>
</tr>
<tr>
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<td>19</td>
<td>0,7</td>
<td>1,00</td>
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Different Shape/Designs

Same material

Both with 1mH

10 dB
Different Shape/Designs
Differential mode attenuation
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