Integrated Common Mode and Differential Mode Choke Improves Efficiency and Reduces Cost

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Conducted Noise

- **Differential Mode Noise**: Conducted on the line and neutral in opposite directions.
- **Common Mode Noise**: Conducted on both line and neutral in the same direction.
- Each type of noise requires a different filter solution.
The simplest DM Filter involves the placement of a single winding inductor in the line path and a capacitor from line to neutral. Effectively blocking noise from moving through the system.

The DM inductor (because it is in the line path) sees both the noise and a net DC offset due to the current being supplied to load so the inductor must be able to handle the peak currents without saturating.
**Differential Mode Inductor**

### Physical Model

- Design must provide required inductance/impedance with low enough resistance (DCR) to handle rms current and adequate saturation to handle peak line current.
- Typical design is with powdered iron core or gapped ferrite core.

### Reluctance Model

Flux (I) = \( N \cdot I_{\text{line}} / \text{Req} \)

\( \text{Req} = \frac{\text{le}}{(\text{perm} \cdot A_e)} \)

Inductance (L) = \( N \cdot \text{Flux}(I) / I_{\text{line}} \)

\[ = N^2 \cdot \text{perm} \cdot A_e / I_e \]

Therefore \( \text{Flux}(I) = L \cdot I_{\text{line}} / N \)

Or Flux Density \( (B_{pk}) = L \cdot I_{\text{line}} / (N \cdot A_e) \)

**Design Example:** Require a 350uH, 2A differential mode choke.

Use 75 perm powdered iron, OD=0.8” with 54T of 23GA wire

\[ \text{Ind} = 350\mu\text{H}, \ \text{DCR}=180\text{mOhms (PowerLoss = 720mW)} \] and size is 23.0 x 23.0 x 9.0 mm (4.76cm³)
Common Mode Filter

- The simplest CM Filter involves the placement of a dual winding magnetic in the line and neutral path and a capacitor from line to ground. Effectively blocking noise from moving through the system.

- The currents (line and neutral) pass through the CM magnetic in opposite directions and therefore create no net DC flux and no possibility of saturating the CM magnetic core.
**Common Mode Inductor**

**Physical Model**

- Design only needs to provide the required inductance / impedance with low enough resistance (DCR) to handle rms current. No saturation issues.

- Typical design is with an ungapped 5-10K perm ferrite core

**Reluctance Model**

Flux (I) = N * \( I_{\text{line}} / R_{\text{eq}} - N * I_{\text{neutral}} / R_{\text{eq}} \) = 0 (no net dc flux in CM)

* So the line/neutral see no impedance

However, the CM noise signal enters the component from the same direction and sees an inductance of:

Inductance (L) = \( N^2 \) \( \text{perm} \) \( A_e / l_e \)

**Design Example:** Require a 1.60mH, 2A common mode choke.

Use 5K perm ferrite core, OD=0.6” with 25T of 26GA wire per winding

Ind = 1.6mH per side, DCR=65mOhms (PowerLoss = 520mW) and size is 19.0x19.0x8.0 mm (2.89cm³)
Integrated CM and DM Inductor

• The two separate magnetics in the EMI filter account for 1.24W of loss, 8.9cm² of PCB space and take up 7.65cm³. Goal is to combine the DM and CM filter into a single component.

• Combining the DM and CM has the potential benefits of reducing losses, board space, volume and cost but careful design must be done to ensure that the component does not saturate.
Although not shown previously any ‘real’ mutual wound magnetic (CM chokes, Transformers) will have some amount of leakage inductance (uncoupled flux) which effects the coupling of the magnetic.
Integrated CM and DM Inductor

The integrated CM and DM Inductor is almost identical in terms of reluctance model and equivalent schematic to the 2-phase coupled inductor sometimes used in dual phase voltage regulators.

“Designing Coupled Inductors”, By John Gallagher, Power Electronics Technology, April 2006

\[ L_{\text{OPEN}(1-4)} - L_{\text{OPEN}(2-3)} = L_M + L_K \]

\[ R_{\text{OPEN}(1-4)} = R_{\text{OPEN}(2-3)} = R + (R_C || R) \]

\[ L_{\text{OPEN}(1-4)} = L_{\text{OPEN}(2-3)} = L_M + L_K = N^2 \frac{(R + R_C)}{2R R_C + R^2} \]

\[ 2 \times L_K = \frac{N^2}{(R_C + 0.5R)} \]

\[ L_M = \frac{R_C}{(2R R_C + R^2)} \]
**Integrated CM and DM Inductor**

It is now possible to design the static values:

DM Inductance = \(2 \times L_k = 2 \times \frac{N^2}{(R + 2 \times R_c)}\)

CM Inductance = \(L_m = \frac{N^2 \times R_c}{2 \times R \times R_c + R_c^2}\)

But need to determine flux to check saturation

Reluctance Model resembles electrical circuit used in Millman's Theorem so;

\[
\begin{align*}
\phi_1 &= \left(\frac{(R + R_c)}{(R^2 + 2R R_c)}\right)(N \times I_{11}) - \left(\frac{R_c}{(R^2 + 2R R_c)}\right)(N \times I_{12}) \\
\phi_2 &= \left(\frac{-R_c}{(R^2 + 2R R_c)}\right)(N \times I_{11}) + \left(\frac{(R + R_c)}{(R^2 + 2R R_c)}\right)(N \times I_{12}) \\
\phi_3 &= \phi_1 + \phi_2
\end{align*}
\]

Assume, coupling of \(p = \frac{L_m}{L_k}\)

\[
\begin{align*}
\phi_1 &= \left(\frac{L_k}{N}\right) \times I_{11} + \left(\frac{pL_k}{N}\right) \times (I_{11} - I_{12}) \\
\phi_2 &= \left(\frac{L_k}{N}\right) \times I_{12} + \left(\frac{pL_k}{N}\right) \times (I_{12} - I_{11}) \\
\phi_3 &= \left(\frac{L_k}{N}\right) \times (I_{11} + I_{12}) = \left(\frac{L_k}{N}\right) \times I_{OUT}
\end{align*}
\]

Check:

If coupling is very good (\(L_k\) approaches zero) then dc flux goes to zero and no saturation (same as CM)

If coupling is very bad (\(L_m\) approaches zero) then dc flux approaches \(L_k/N \times I\) (same as DM)

How does the CMDM compare with separate components?
Previously showed a DM Choke (350uH, 2A) and a CM Choke (1.6mH, 2A)

DM Choke:  Copper Loss = 720mW,  Volume = 4.76cm³, Footprint = 5.29cm²
CM Choke:  Copper Loss = 520mW,  Volume = 2.89cm³, Footprint = 3.61cm²
Total        = 1240mW,                      = 7.65cm³                    = 8.90cm²

Pulse CMDM

2 * Lk = DM Inductance = 350uH and capable of supporting 2.2A
Lm = CM Inductance = 1.6mH
DCR (per winding) = 110mOhms
Size:  25 x 20 x 12 mm

CMDM Choke:  Copper Loss = 880mW,  Volume = 6.00cm³, Footprint = 5.0cm²
CMDM Choke reduces:
  • Power Loss by 30%
  • Component Volume by 22%
  • Component Board Area by 44%
  • Component Cost by 21%