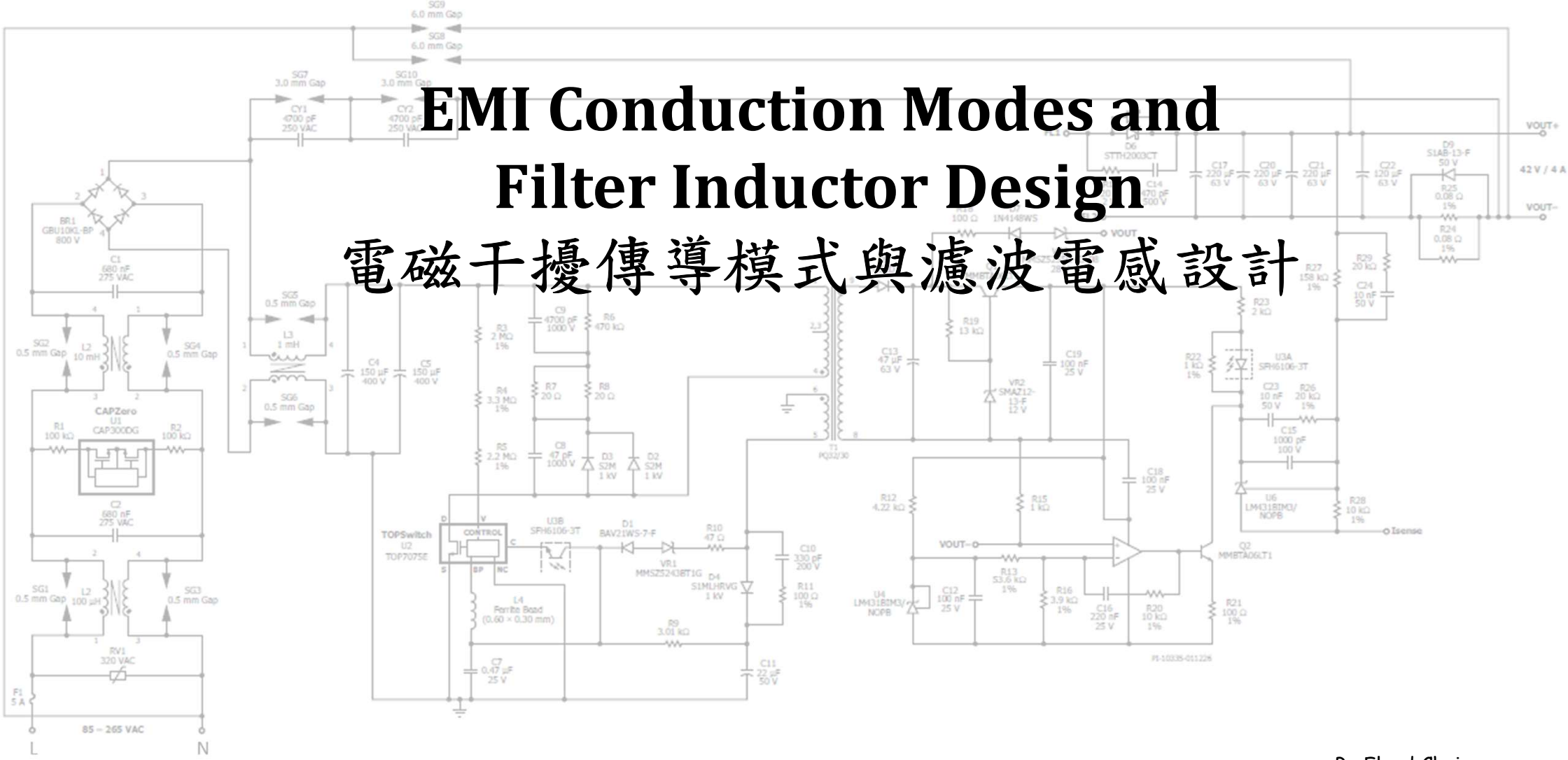
EMI Conduction Modes and Filter Inductor Design

電磁干擾傳導模式與濾波電感設計



By Floyd Chui
English translated by Yamily Peng
September 2026

OUTLINE

- **Understanding signal modes 訊號傳導模式的兩大類型**
- **Common-mode-choke design 共模電感的雙繞組設計**
- **Differential-mode-choke design 差模電感設計考量**
- **Dual mode choke theory 共差模雙功能電感原理簡介**
- **EMC/EMI busbar filter for EV 車用匯流排濾波器案例**
- **Q & A**

• 訊號傳導模式的兩大類型 Understanding signal modes

Signal transmission can be classified into two major categories based on its current propagation mode: differential mode (DM) and common mode (CM). Differential mode is also referred to as "symmetric mode" or "normal mode", while common mode is also known as "asymmetric mode" or "ground leakage mode". Consequently, noise generated by electromagnetic interference (EMI) is also divided into two types: ***differential mode noise*** *and* ***common mode noise.***

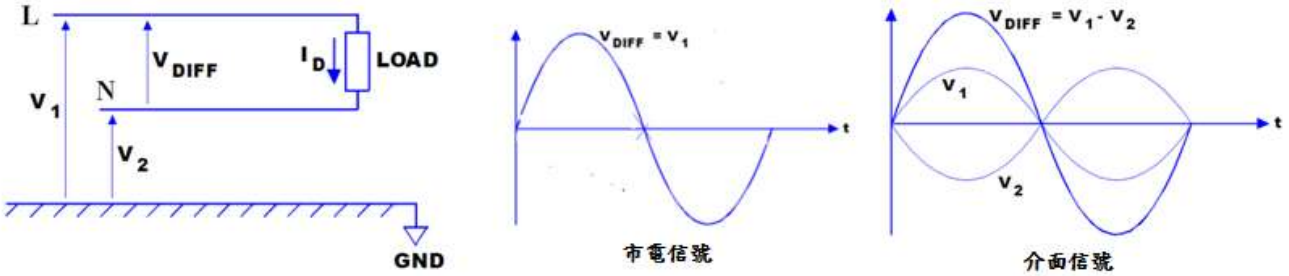
訊號的傳導可以藉由其電流行進的模式分成兩大類:差模（Differential mode；DM）和共模（Common mode；CM）。差模也稱作「對稱模式（symmetric mode）」或「正常模式（normal mode）」；而共模也稱作「非對稱模式（asymmetric mode）」或「接地洩漏模式（ground leakage mode）」，所以電磁干擾產生的雜訊也分成兩類：

差模雜訊和 **共模雜訊**。

A. Pure Differential Mode Signal 純差模信號：

In terms of the mains power signal transmission, $V_{DIFF}=V_1$ and V_2 approaches 0, creating a loop where current flows from a high potential through the load to a low potential. In electronic interface signal transmission, $V_1=-V_2$; they are equal in magnitude but 180° out of phase, resulting in $V_{DIFF}=V_1-V_2$. Because V_1 and V_2 are symmetrical with respect to the ground, no current flows through the ground wire, and all differential mode current（I_{DIFF}）flows entirely through the load. The AC power signal provided by utility companies operates in this differential mode transmission pattern. The overall concept is illustrated in the diagram below:

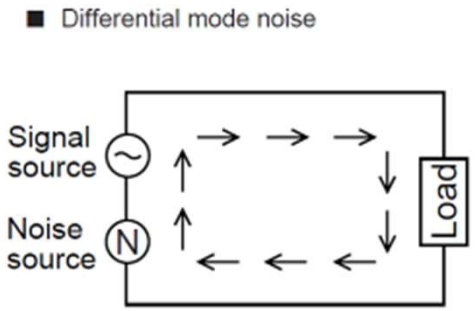
在市電電源信號傳輸方面，$V_{DIFF}=V_1$，V_2趨近於0，是由高電位經負載流向低電位形成迴路；而在電子介面傳輸信號方面，$V_1=-V_2$，大小相等，相位差是180°，$V_{DIFF}=V_1-V_2$，因為V_1和V_2對地是對稱的，所以地線上沒有電流流過，所有的差模電流（I_{DIFF}）全流過負載。電力公司所提供的交流電力信號即是走差模的傳導模式。整體說明如下圖所示：



Differential Mode Noise 差模雜訊

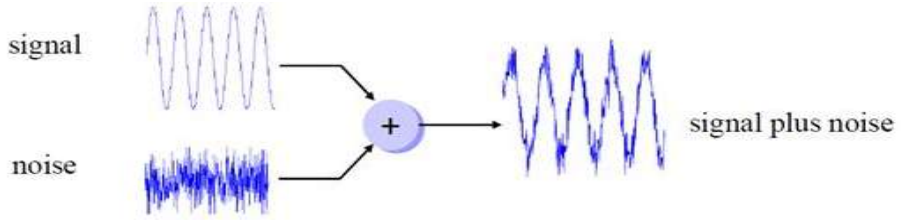
Differential mode signals are typically what we intend to transmit, representing the most fundamental loop for a circuit to send signals. The "byproduct" generated by this loop is called differential mode noise, which occurs when the current directions in the two power supply lines are opposite to each other. As shown in the diagram below:

差模訊號通常是我們所要的，為一電路傳送訊號最基本之迴路，此迴路所產生的「副產品」，稱之為差模雜訊，為兩條電源供應線路的電流方向互為相反時發生的。如下圖所示：



We must understand that noise can never be completely eliminated; however, through proper grounding, shielding, and filtering, its interference can be minimized as much as possible. For a good circuit design, prevention is always better than modifying the circuit after problems arise. Implementing noise prevention measures right at the PCB layout stage is the primary task in building a highly reliable, low-noise electronic system. Below is a schematic diagram showing the signal and noise before and after overlapping:

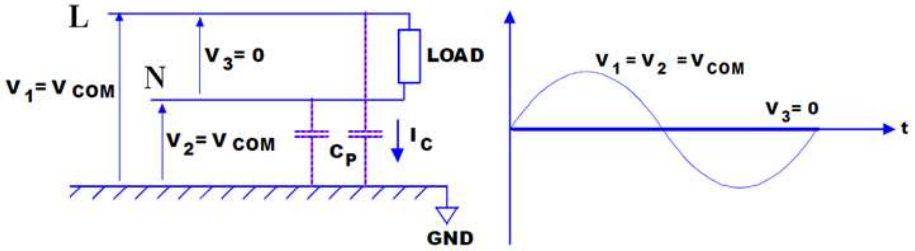
我們應當瞭解，雜訊是不可能完全被去除的，但是經由適當的接地(grounding)、屏避(shielding)與濾波(filtering)，則可將其干擾儘量降低。對於一個良好的電路設計，預防勝於發生問題後的電路修改。在電路板的佈局即開始做好雜訊防治的工作，是建構高可靠度低雜訊電子系統的首要工作。以下為信號(signal)與雜訊(noise)疊加前後的示意圖：



B. Pure Common Mode Signal 純共模信號：

$V_1=V_2=V_{COM}$; they are equal in magnitude and have a 0 ° phase difference, resulting in $V_3=V_1-V_2=0$. Because there is no common mode potential difference across the load, no common mode signal current flows through the load. All common mode currents flow toward the ground wire through the parasitic capacitance between the conductors and the ground. When transmitting signals via wires, since common mode signals do not carry information, they are mostly "unwanted" signals. The overall concept is illustrated in the diagram below:

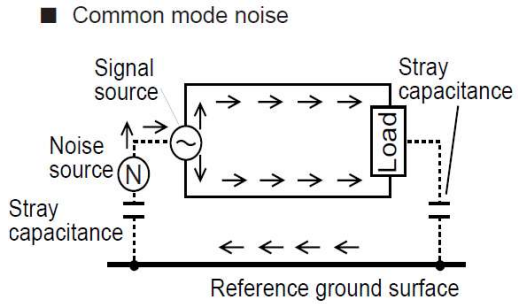
$V_1=V_2=V_{COM}$，大小相等，相位差為0°，$V_3=V_1-V_2=0$。因為在負載(LOAD)兩端沒有共模電位差，所以沒有共模信號電流流過負載。所有的共模電流都通過導線和地之間的寄生电容流向地线。在以導線傳輸訊號時，因为共模信號不攜帶信息，所以它多半是“不想要”的信號。整體說明如下圖所示：



Common Mode Noise 共模雜訊

Common mode noise is an unwanted side effect or a "byproduct" of differential mode circuits. Factors such as parasitic capacitance in twisted pairs, magnetic leakage from various components, temperature fluctuations, and various environmental noises can all be regarded as common mode interference. Common mode noise occurs when the current directions in all power supply lines are the same. As shown in the diagram below:

共模訊雜訊是我們不要的副作用或是差模電路的「副產品」，如絞線中的寄生電容、各元件之漏磁、溫度的變化各種環境噪聲的影響都可以視作為共模干擾。而共模雜訊是當所有的電源供應線路的電流方向相同時發生的。如下圖所示：

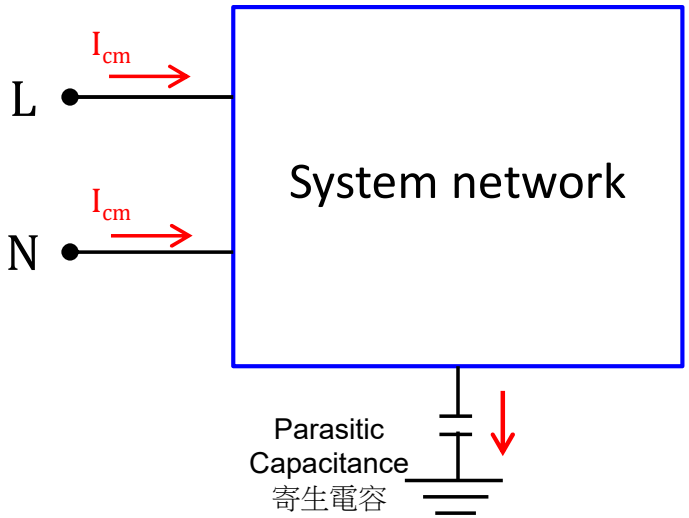


In summary, a simple way to distinguish between common mode and differential mode signals is to look at the path of the signal current through the L/N lines of the circuit:

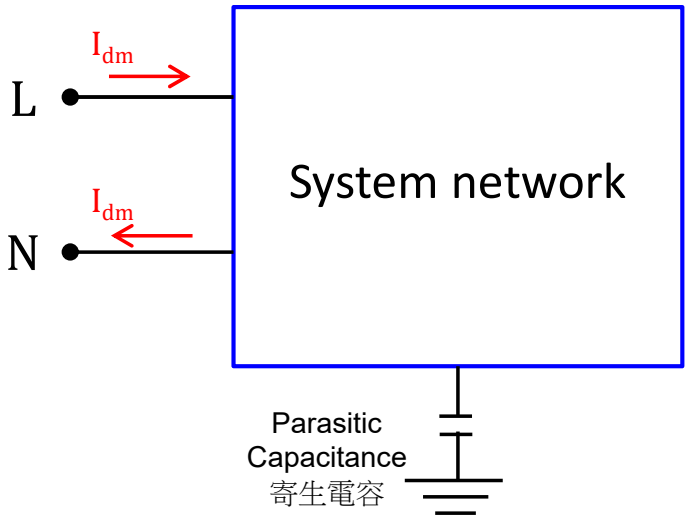
總結訊號共模和差模的簡單區分，可以單純從該訊號電流流經電路 L/N 的方式來簡單判斷：

(L 俗稱火線，電壓呈現正負變化； N 為中性線，電壓恆維持接近 0)

Common Mode 共模



Differential Mode 差模



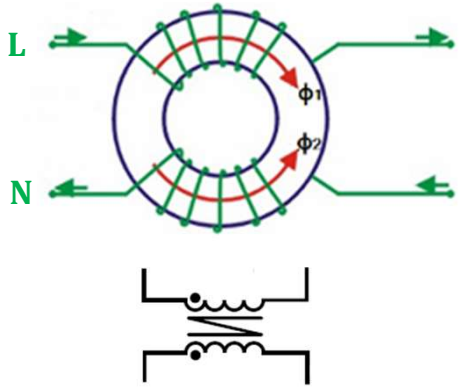
• 共模電感的雙繞組設計 Common-mode choke design

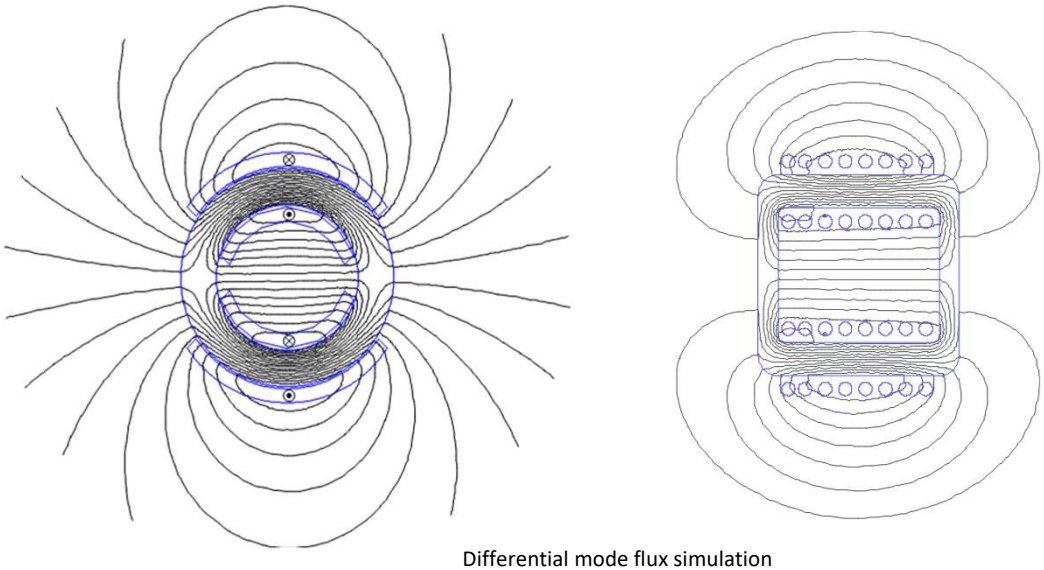
Common-mode Choke Introduction 簡介

A Common-mode Choke consists of identical coils wound symmetrically around a closed magnetic core (as shown in the diagram below). When the signal current or power supply current flows through the two windings in opposite directions, the generated magnetic fluxes ϕ1 and ϕ2 oppose and resist each other. Consequently, even under large current signals at the mains power input, the Common-mode Choke (referred to as CMC for short) is less prone to the core flux saturation, and the choke features a low impedance.

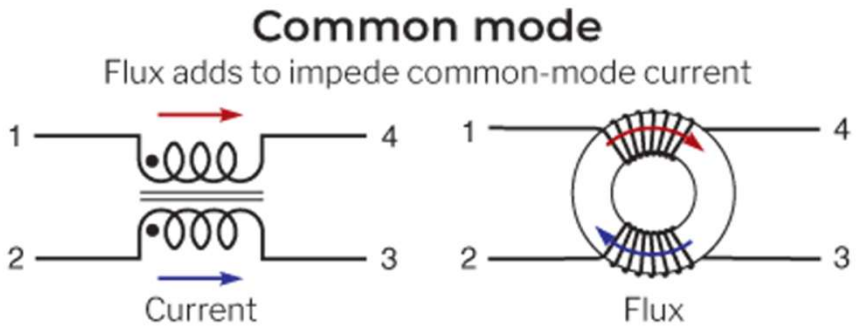
Choke中文翻譯為扼流圈，是電感的另一種名稱，特別是針對變動中電流信號的節制所需的應用場合會特別以Choke來稱呼。
Common-mode Choke叫做共模扼流圈，顧名思義是對共模電流雜訊做出節制的電感。
Common-mode Choke是一個在封閉磁環上對稱繞製、匝數相同的線圈(如下圖所示)，當信號電流或電源電流在兩個繞組中，流過電流方向相反，產生的磁通量ϕ1和ϕ2相互抵抗，即使是市電輸入端的大電流信號下，Common-mode Choke (簡稱CMC)也不易有鐵芯磁飽和的問題，且扼流圈呈現低阻抗。

Mains Differential Mode Current市電差模電流

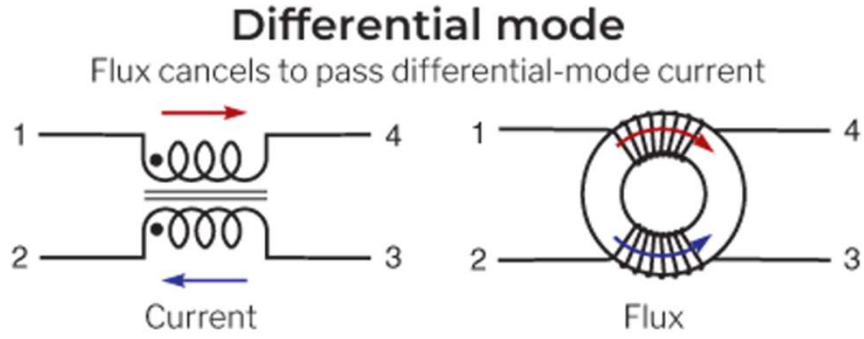




Differential mode flux simulation
by FEMM 4.2



The specific polarity of the dual-winding configuration ensures that when common-mode signal currents flow into their respective coil paths, they induce magnetic flux in the same direction, thereby generating high reactance. The choice of magnetic core material is primarily determined by the frequency band where common-mode noise occurs, selecting material characteristics that match and provide high impedance within that specific frequency range.
特定極性的雙繞組繞法，使得共模訊號電流各自流入所屬線圈路徑時，引發順向磁通，進而產生高電抗！
磁芯材質的選用主要根據共模雜訊發生頻段來選擇匹配該頻段高阻抗的材質特性。



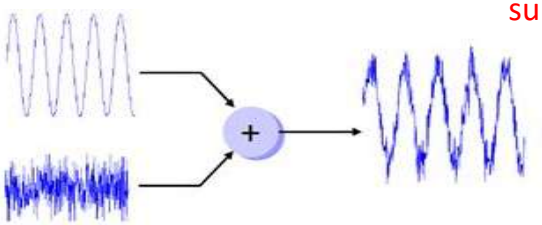
The specific polarity of the dual-winding configuration ensures that when differential-mode signal currents flow into their respective coil paths, they induce magnetic fluxes in opposite directions, resulting in low reactance! Since the mains current provided by power plants operates in differential mode, the power signal experiences almost no impact from reactance when flowing into a common-mode inductor.
特定極性的雙繞組繞法，使得差模訊號電流各自流入所屬線圈路徑時，引發彼此逆向的磁通，造成低電抗！
電廠提供的市電電流走的是差模模式，故電力信號流入共模電感幾乎不受電抗影響。

A CMC is essentially a bidirectional filter: on one hand, it filters out external common-mode electromagnetic susceptibility (EMS) on the signal line, while on the other hand, it suppresses electromagnetic emissions (EME) generated by the system itself, preventing it from affecting the normal operation of other electronic equipment within the same electromagnetic environment.
CMC實質上是一個雙向濾波器：一方面要濾除信號線上外來共模電磁干擾(EMS)，另一方面又要抑制系統本身向外發出的電磁干擾(EME)，避免在同一電磁環境下影響其他電子設備的正常工作。

• 差模電感的設計考量 Differential-mode choke design

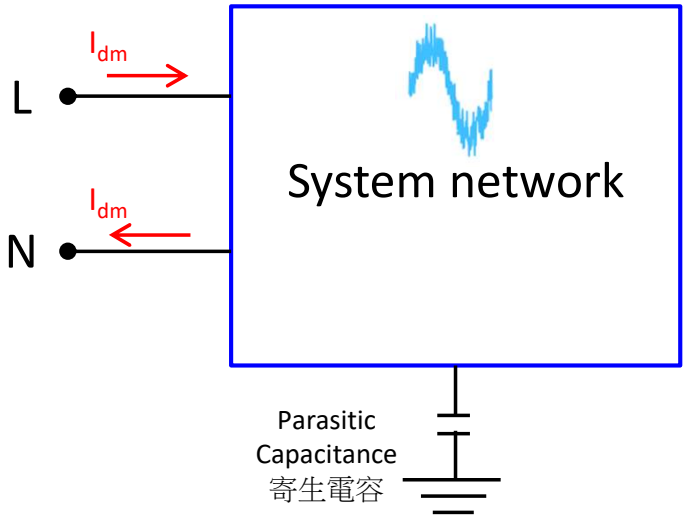
Differential-Mode Power Signal
差模電力訊號

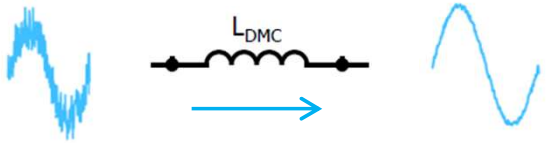
Differential-Mode (DM) Noise
差模雜訊



Differential Mode (DM) Noise superimposed on the Power Signal
差模雜訊疊加在電力訊號上

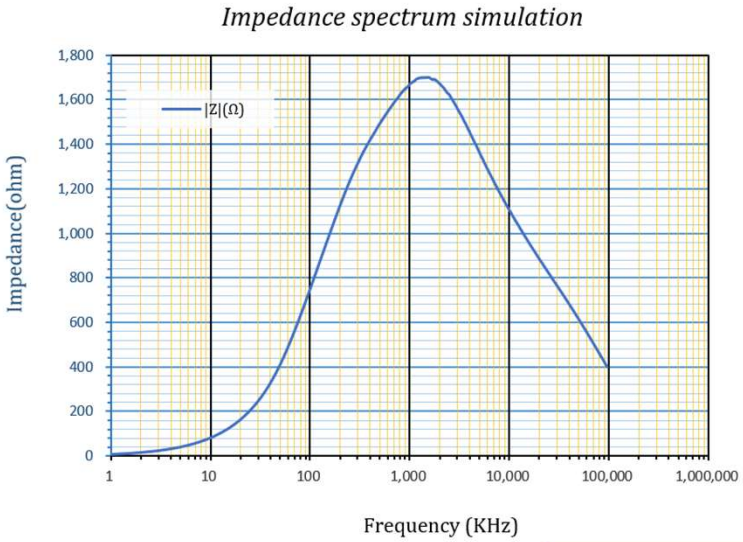
Differential Mode 差模





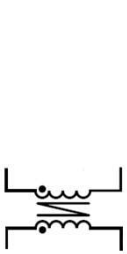
When the power current signal is at its peak or trough, the magnetic core of the differential-mode inductor must not experience magnetic saturation; otherwise, the inductance will drop instantly, resulting in low reactance and rendering the inductor unable to effectively suppress differential-mode noise.
在電力電流訊號處在波峰或波谷時，差模電感的磁芯不能因而磁飽和，否則電感會瞬降，造成低電抗，進而無法有效抑制差模雜訊。

- *The selection of magnetic core materials must ensure that magnetic saturation does not occur under peak current conditions. Since the mains power is a 50–60 Hz sine wave, core loss is not a primary consideration.*
  磁芯材質的選擇必須考量電流峰值條件下不能磁飽和，而市電為50~60Hz的弦波，故磁芯損耗非主要考量。
- *The frequency band spanning the impedance peak of a differential-mode choke must match the noise frequency band that is targeted for suppression.*
  差模電感阻抗峰值的頻段需與擬重點抑制的雜訊頻段匹配。

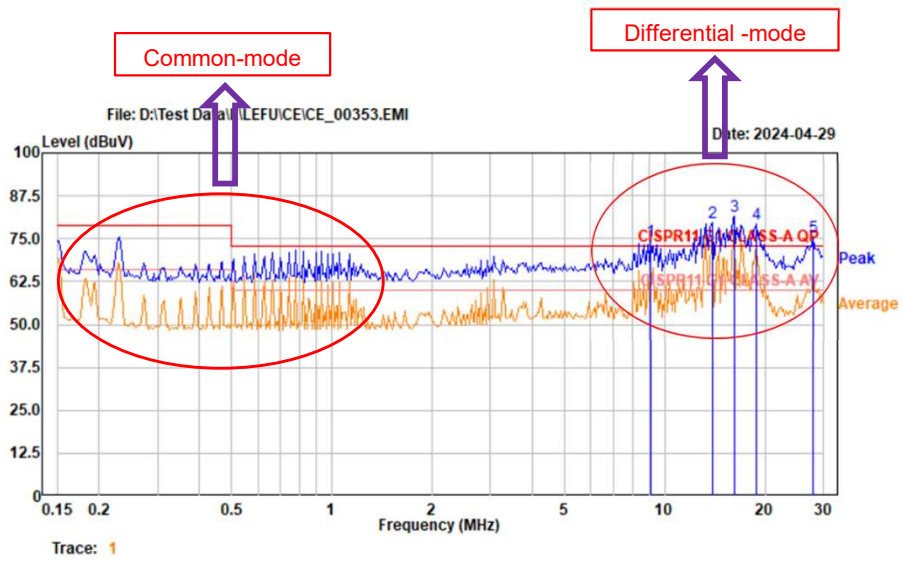


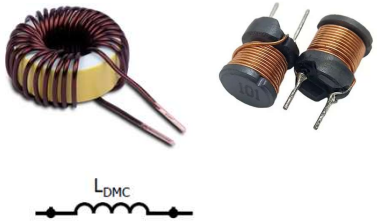
The high-impedance frequency band in the impedance spectrum must match the noise frequency band that is targeted for suppression.

阻抗頻譜中高阻抗的頻段須與擬重點抑制的雜訊頻段匹配！









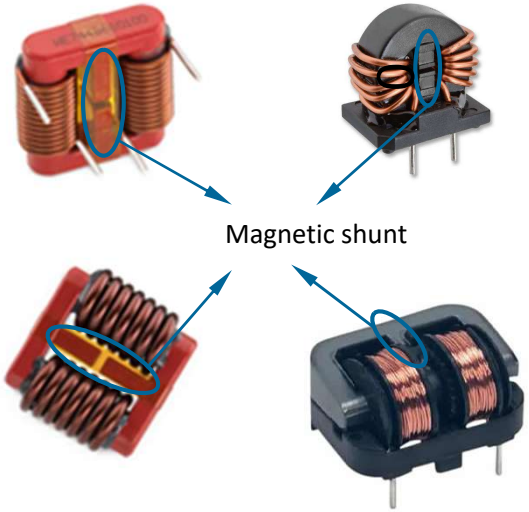
Conduction EMI test

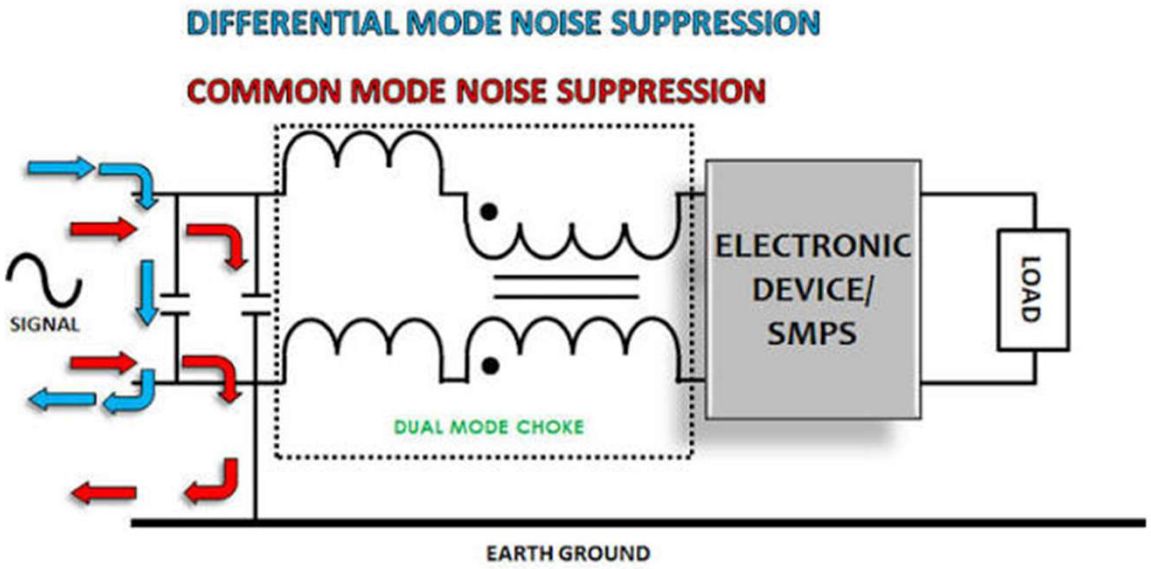
• 共差模雙功能電感原理簡介 Dual mode choke theory

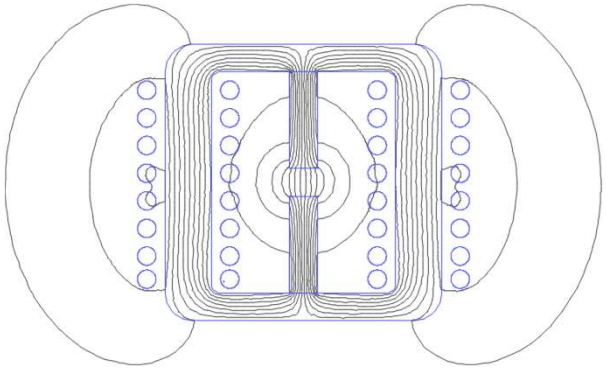
Based on the primary function of a common-mode choke design, a high-reluctance magnetic shunt is integrated into the core circuit. This shunt guides a portion of the opposing magnetic flux induced by differential-mode currents back to the opposite poles of their respective coils. Consequently, the forward flux from common-mode noise bypasses this high-reluctance shunt, preserving high common-mode impedance. Meanwhile, the guided shunt- flux successfully generates the required differential-mode impedance.

基於共模電感為主要功能設計的前提下，於該磁芯磁路中另闢一條**具高磁阻的磁叉路**(magnetic shunt)，誘導差模電流所引發兩相抵抗的磁場部分進入該磁叉路，回流至各自線圈的另一磁極。如此，既可兼顧共模雜訊所引發之順向磁通不會流入高磁阻的磁叉路，而保有高共模阻抗的性能，又能將差模信號所引發的抵抗磁通部分導引至磁叉路，進而產生所需的差模阻抗。

Dual mode chokes







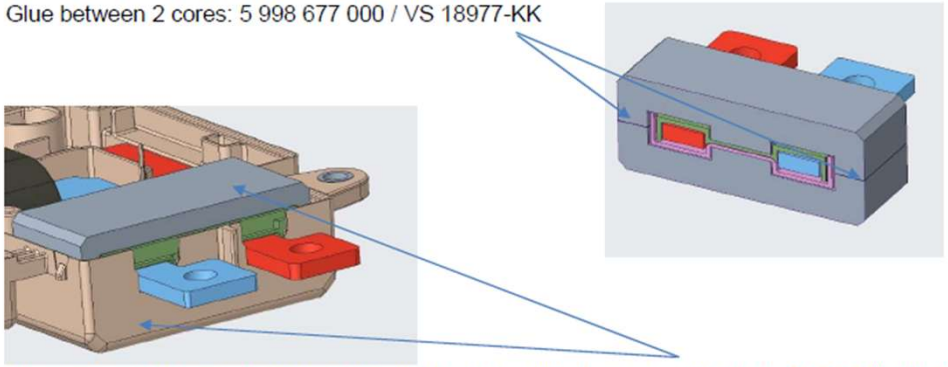
Differential mode flux simulation
by FEMM 4.2

• 車用匯流排濾波器 – Dual mode choke application

Ferrite EE-core with gap on center post

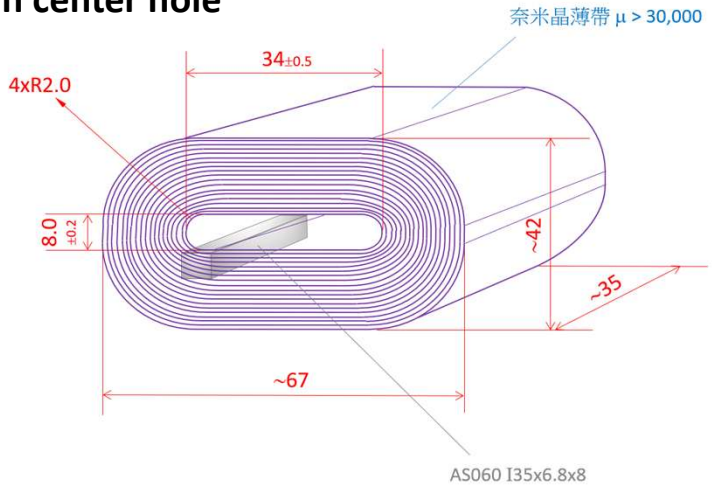
As an "E-shaped" ferrite core, it will be assembled / glued together with two identical parts.
It will form a stack-up with plastic isolation parts and copper busbars – this subassembly will then be mounted / glued in an EMC-Filter plastic housing, see pictures:

Glue between 2 cores: 5 998 677 000 / VS 18977-KK



Glue on top / bottom side of cores for attachment on filter housing: 5058 199 282 / DOWSIL 7091 Adhesive Sealant

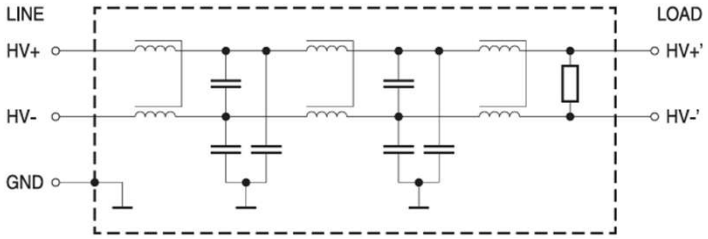
Nanocrystalline ribbon wound core with dust stick-core in center hole

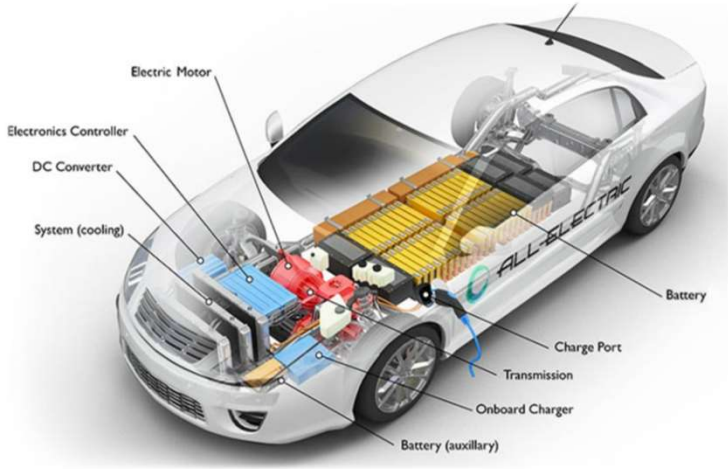


2- line BUSBAR filter for high voltage DC inverters



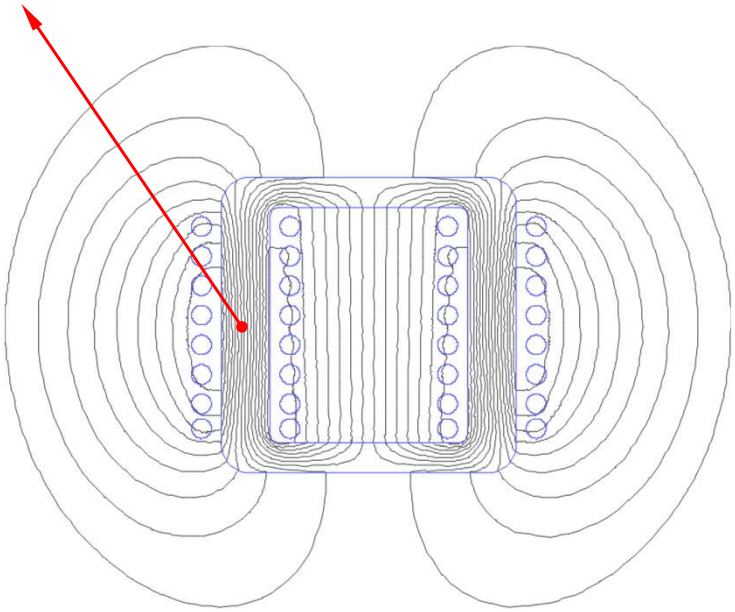
Typical circuit diagram





Q & A

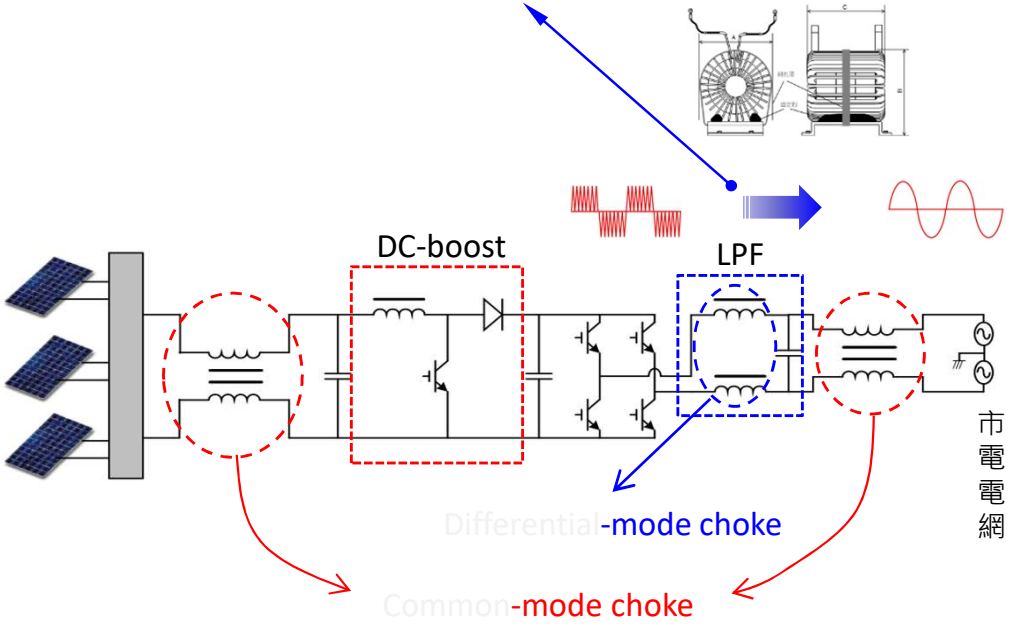
Flux saturation issue to be concerned?



Differential mode flux simulation
by FEMM 4.2

Common-mode choke with AC current from the mains
市電AC電流進入共模電感

Core loss issue to be concerned?



Grid connected PV Inverter circuit
併網型光伏逆變電路

Thank you for listening!

