CH9 Conducted Emissions and Susceptibility

▲Reglatory agencies impose limits on conducted emissions for the reason that are placed on the commercial power system net.

▲The commercial power distribution system represents a large "antenna"system from which there conducted emission can radiate quite efficiently.

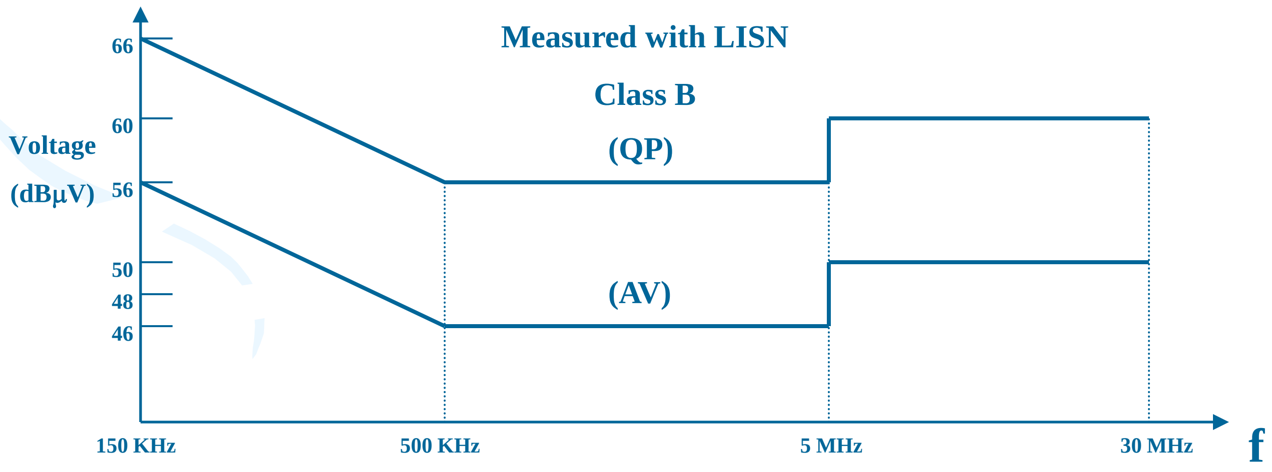
▲Susceptibility(C.S) = A product must be reasonably insensitive to disturbances that are present on the power system net in order insure reliable operation of the product.

Conducted Emission: Regulation

Limits for conducted disturbance at the mains ports of Class B ITE		
Frequency range MHz	Limits dB(μV)	
	Quasi - peak	Average
0.15 to 0.5	66 to 56	56 to 46
0.5 to 5	56	46
5 to 30	60	50

Notes

1. The lower limit shall apply at the transition frequencies
2. The limit decreases linearly with the logarithm of the frequency in the range 0.15 MHz to 0.50 MHz



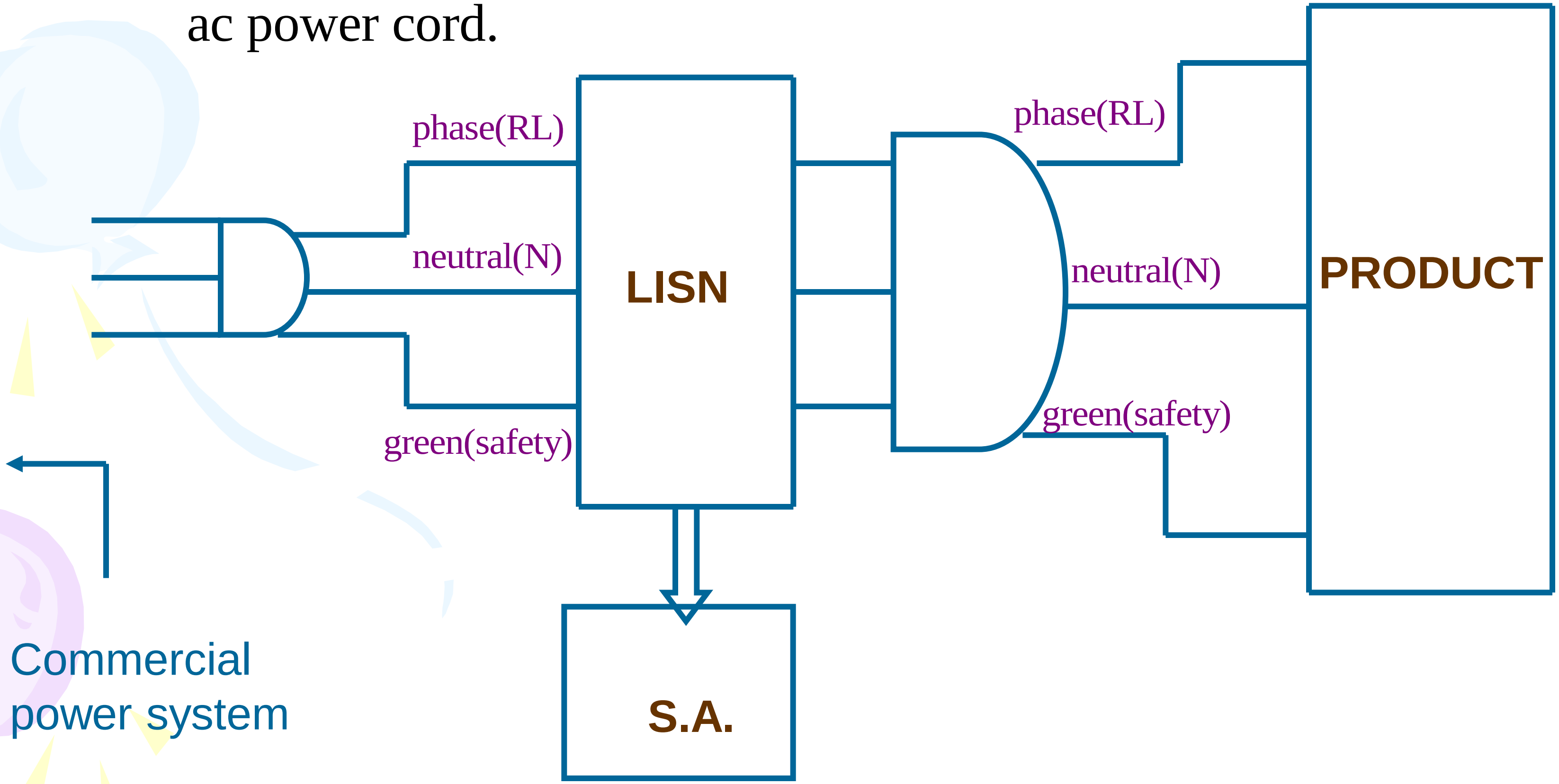
9–1 measurement of conducted emission

a.FCC 450KHz ~30MHz

CISPR22 150KHz~30MHz

b.LISN : (Line Impedance Stabilization Network)

is inserted between the commercial power outlet and products ac power cord.



9–1–1 The line impedence stabilization network(LISN)

a.**why use LISN ?**

(1)the impedence seen looking into the ac power system wall outlets varies considerably over the measurement frequency range.

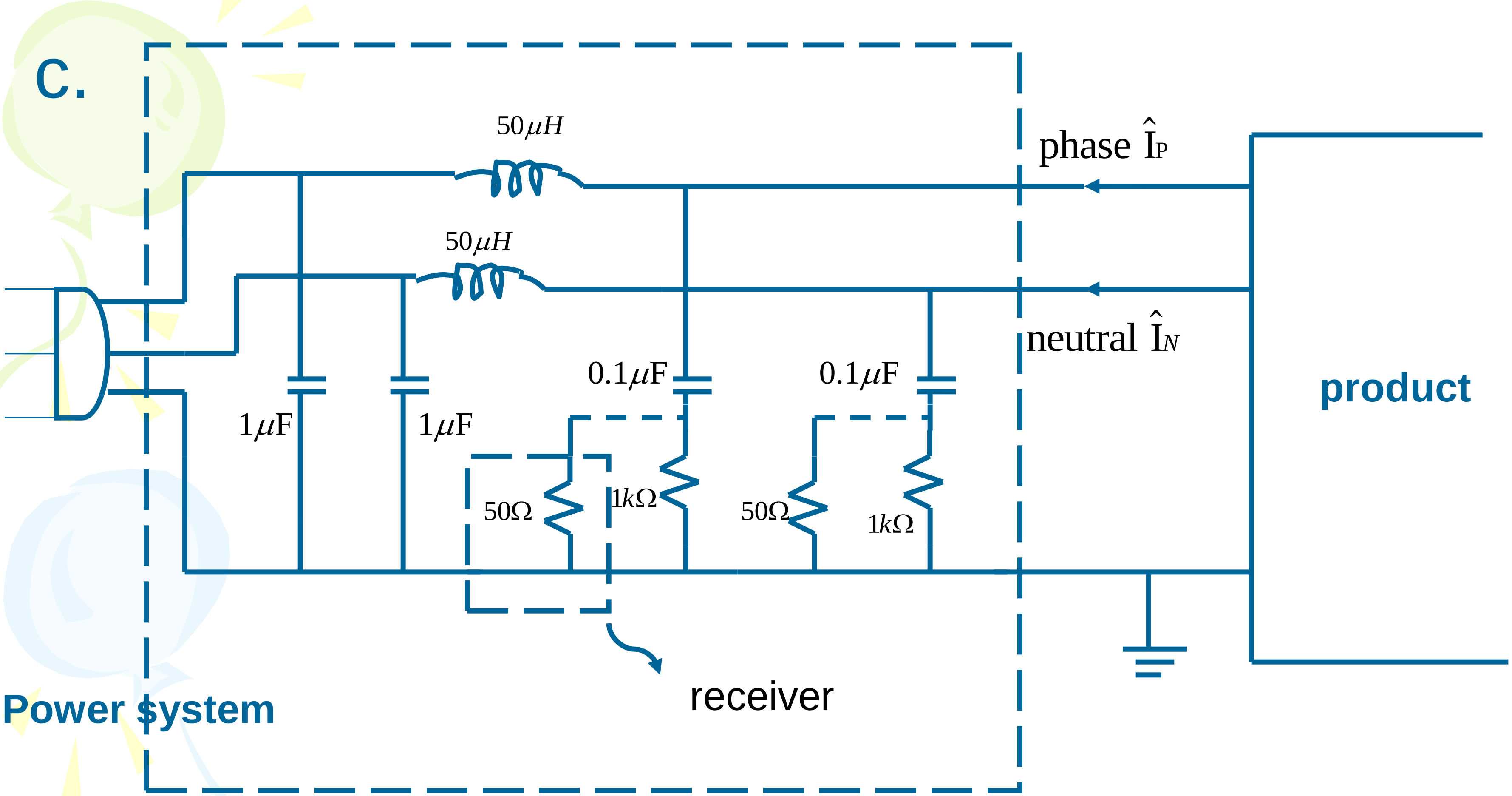
(2)The measured data should be correlatable between measurement sites.

b.**Three objectives for using LISN**

(1)present a constant impedance to the product's power cord outlet over the frequency range of the conducted emission test.

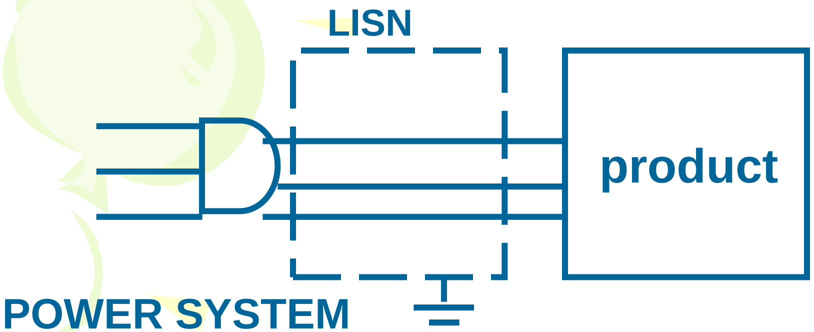
(2)prevent the conducted noise on the power system net from contaminating the measurement.

(3)pass the 60Hz power required for operation of the product.



Element	Z_{60Hz}	Z_{450kHz}	Z_{30MHz}
50μH	18.8mΩ	141.3Ω	9.42kΩ
0.1μF	26.5kΩ	3.54Ω	0.053Ω
1μF	2.7kΩ	0.354Ω	0.0053Ω

<1> for 60/50Hz system , the equivalent circuit of LISN is

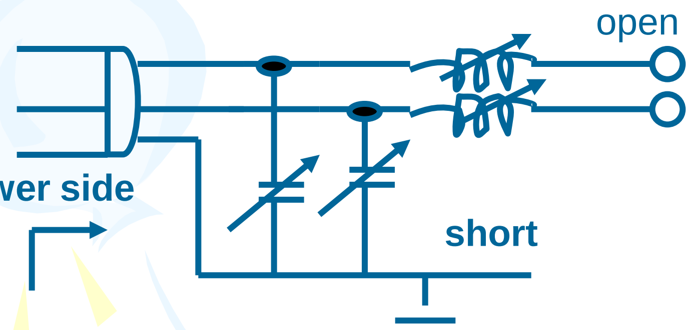


$$\begin{cases} L = & \rightarrow short \\ C = & \rightarrow open \end{cases}$$

→ power flow pass the LISN

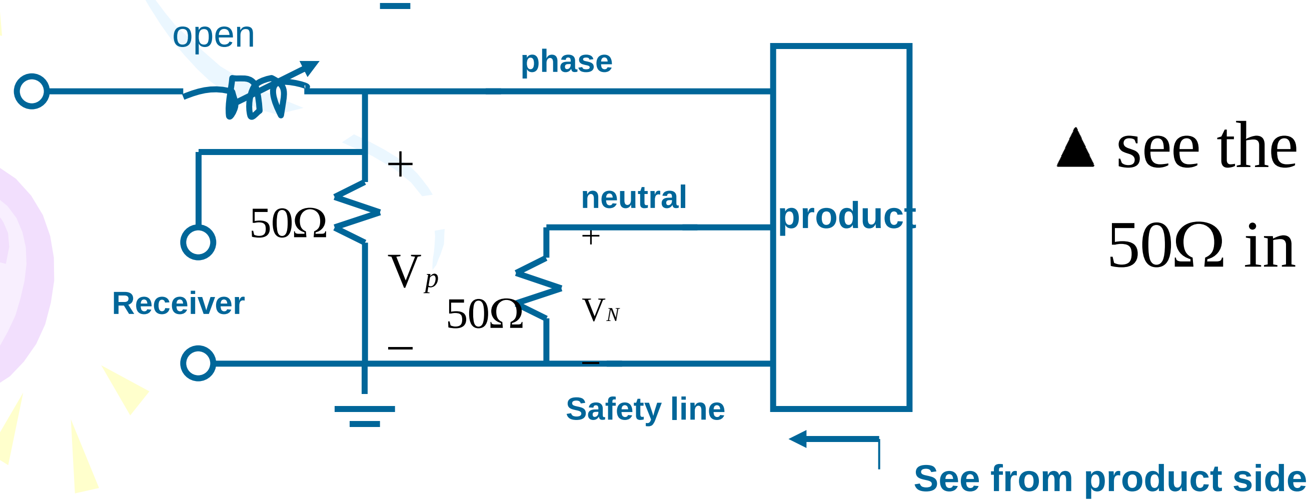
< 2 > for 400kHz < f <30MHz

(1)



▲ prevent the current noise from flowing into receiver (S.A.)

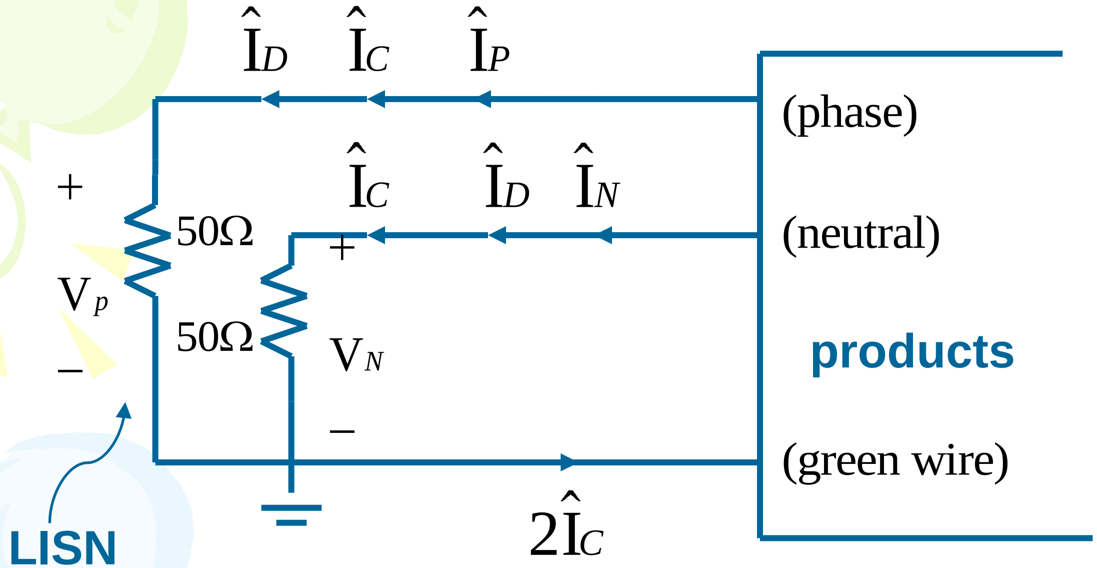
(2)



▲ see the stable 50Ω in this freq range.

9-1-2 Common and Differential-Mode Currents

a.



<1> $\hat{I}_P = \hat{I}_C + \hat{I}_D$

$\hat{I}_N = \hat{I}_C - \hat{I}_D$

⇒

$$\hat{I}_D = \frac{1}{2}(\hat{I}_P - \hat{I}_N)$$

$$\hat{I}_C = \frac{1}{2}(\hat{I}_P + \hat{I}_N)$$

<2> The measured voltages are

$$V_P = 50(\hat{I}_C + \hat{I}_D)$$

$$V_N = 50(\hat{I}_C - \hat{I}_D)$$

<3>As opposed to radiated emissions

1.$\hat{I}_C$ can be of the order or exceed $\hat{I}_D$ in conducted emission.

2.$\hat{I}_D$ here is not the funtional 60Hz power line currents.

3.Generally,$\hat{I}_C$ or $\hat{I}_D$ dominates in the C.E. .

$$\therefore \left.\begin{aligned} \widehat{\mathbf{V}_P} &= \mathbf{50\hat{I}_C} \\ \widehat{\mathbf{V}_N} &= \mathbf{50\hat{I}_C} \end{aligned}\right\} \qquad \text{for} \quad \hat{\mathbf{I}}_C \gg \hat{\mathbf{I}}_D$$

and

$$\left.\begin{aligned} \widehat{\mathbf{V}_P} &= \mathbf{50\hat{I}_C} \\ \widehat{\mathbf{V}_N} &= \mathbf{50\hat{I}_C} \end{aligned}\right\} \qquad \text{for} \quad \hat{\mathbf{I}}_D \gg \hat{\mathbf{I}}_C$$

b. power supply filters contain components each of which is intented to reduce either $\hat{\mathbf{I}}_C$ or $\hat{\mathbf{I}}_D$.

9-2 Power supply filters

a.There are no electronic products today that comply with the conducted emission regulatory requirements without the use of power supply filter.

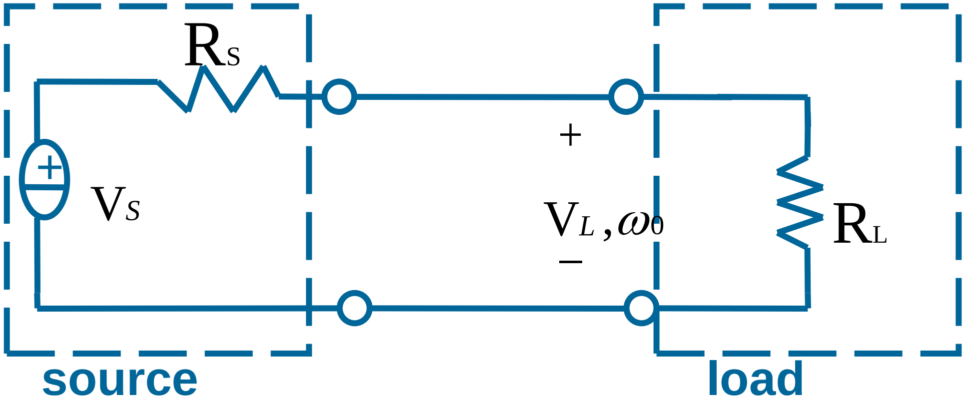
b. Bsaic properties of filters

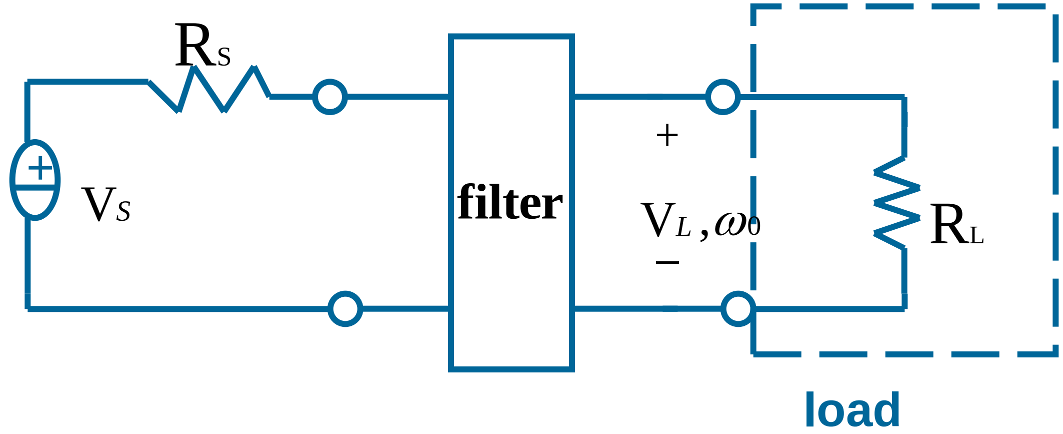
<1>Insertion Loss

$$IL = 10\log_{10}\left(\frac{P_L,\omega_0}{P_L,\omega}\right)$$

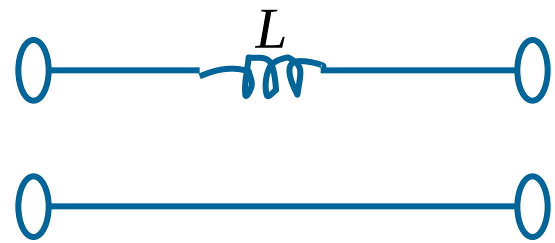
$$= 10\log_{10}\left(\frac{V_L^2,\omega_0/R_L}{V_L^2,\omega/R_L}\right)$$

$$= 20\log_{10}\left(\frac{V_L,\omega_0}{V_L,\omega}\right)$$





<2>Example: Filter (low pass) $\Longrightarrow$



1. $$V_{L,\omega 0} = \frac{R_L}{R_S + R_L} V_S$$

2. $$V_{L,\omega 0} = \frac{R_L}{R_S + j\omega L + R_L} V_S = \frac{R_L}{R_S + R_L} \frac{1}{1 + j\omega L \big/ R_S + R_L} V_S$$

3. $$IL = 20\log_{10}\left|1 + \frac{j\omega L}{R_S + R_L}\right| = 20\log_{10}\sqrt{1 + (\omega\tau)^2}$$

$$= 10\log_{10} 1 + (\omega\tau)^2 \qquad \text{where} \quad \tau = \frac{L}{R_S + R_L}$$

(3) I.L. is dependent on the source and load impedance.Maunfactures provide freq.response plots of I.L.of a particular filter,with RL=Rs=50Ω.

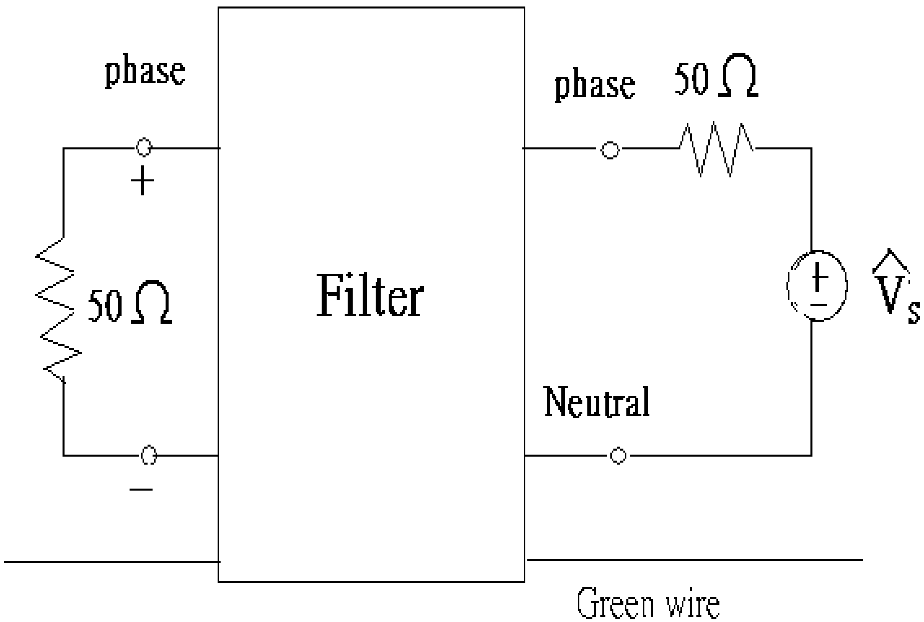
(4)But when the filter is used in the product and is tested for C.E.,what is RL and Rs?：

RL=50Ω (impedance of LISN)

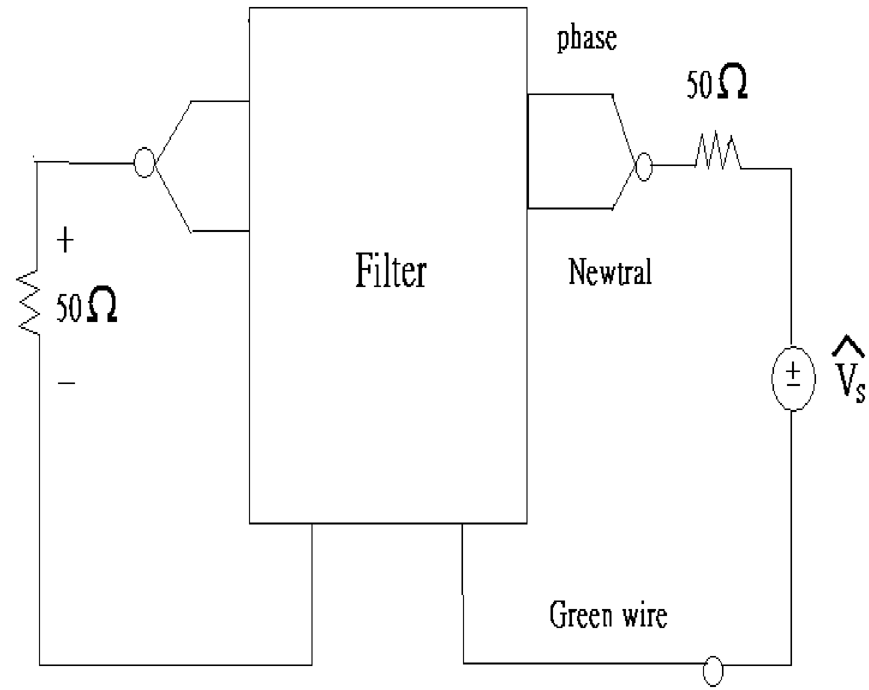
RS=? (Looking back into product power input)

So,the data sheet is just for reference.

(5) Manufactucers typicallty give separate I.L. test for $\hat{I}_c$ and $\hat{I}_d$

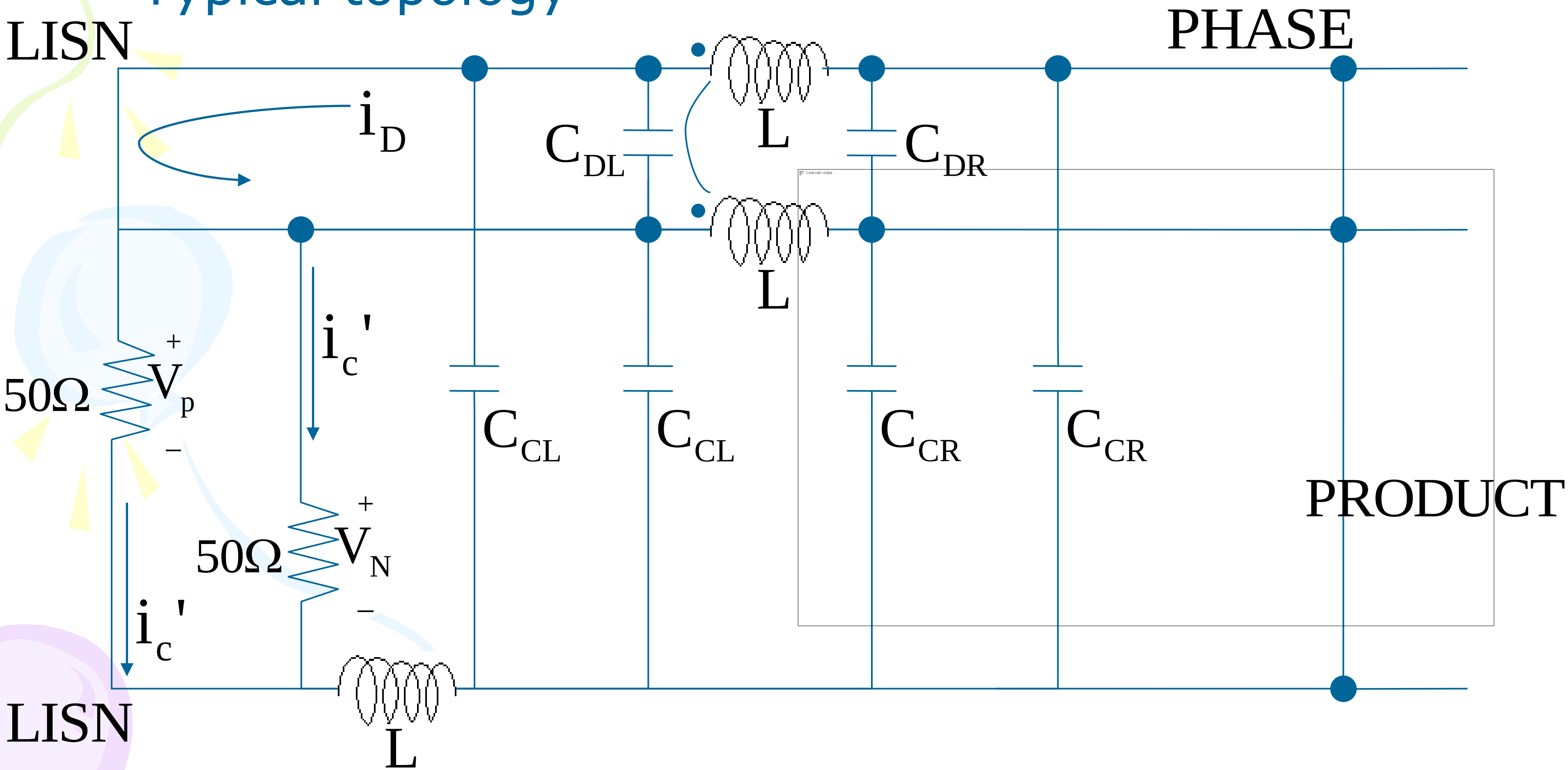


($\hat{I}_D$ test set-up)



9.2.2 A Generic Power Supply Filter Topology

- Typical topology



(b).Effect of the filter elements on common-mode and differential-mode currents

(1). Green wire inductor LGW: Block the commond-mode currents.

(2). C_{DL} ,C_{DR} (X-caps): to divert the differential-mode currents.

(3). C_{CL}, C_{CE} :to divert the common-mode currents.

1. The C_{CL}, C_{CR} can be limited by the leakage current specified by UL (Underwriter Lab) for preventing the shock hazard.

Ex: UL limints the the leakage current < 1mA for 60Hz in 120V power system.

$$C_C < \frac{1}{2}\times 10^{-3}(A)/120(V)\times 2\pi\times 60\left(Hz\right) = 5526\,pF.$$

2. Typical value for C_C and C_D.

$C_C \approx$ 2200 pF , $C_D \approx$ 0.047 μF. $C_D >> C_C$

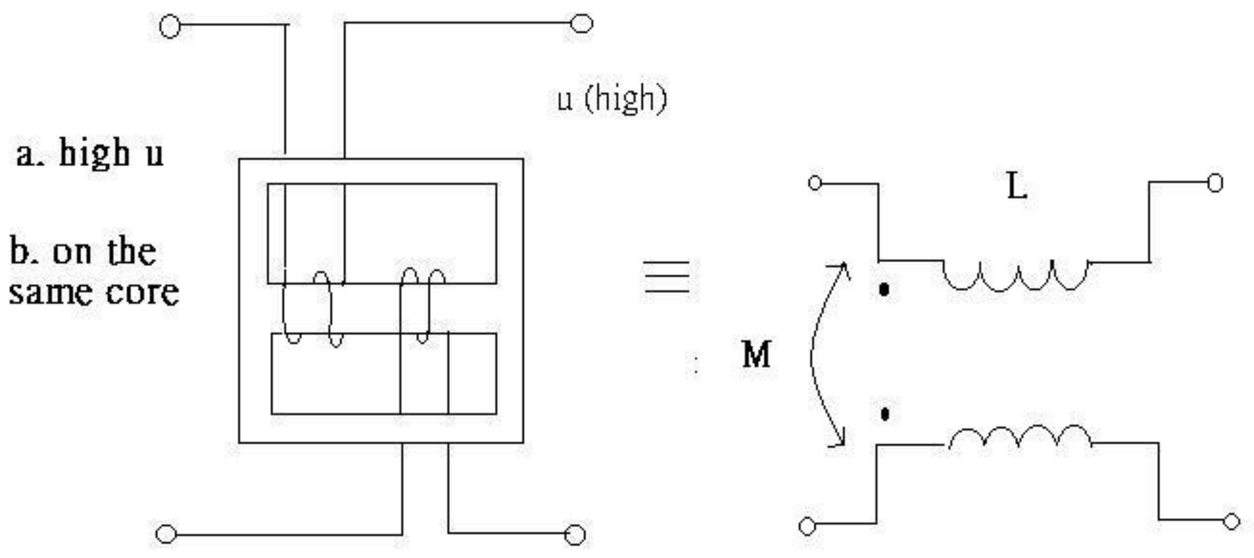
3. The valid freq. for C_C to divert common-mode current.

C_C = 2200pF.

at 1.45MHz, Z_C = 50Ω, C_C is valid for f > 1.45MHz.

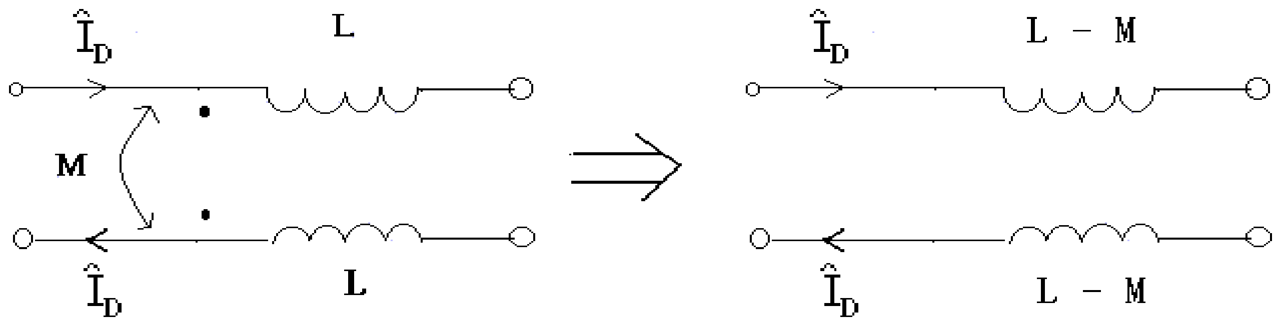
(4) Common-mode choke: to block the common-mode current

1.



$$K : M \big/ \sqrt{L_1 L_2} \cong \frac{M}{L} : 1 \Rightarrow M \cong L$$

2.



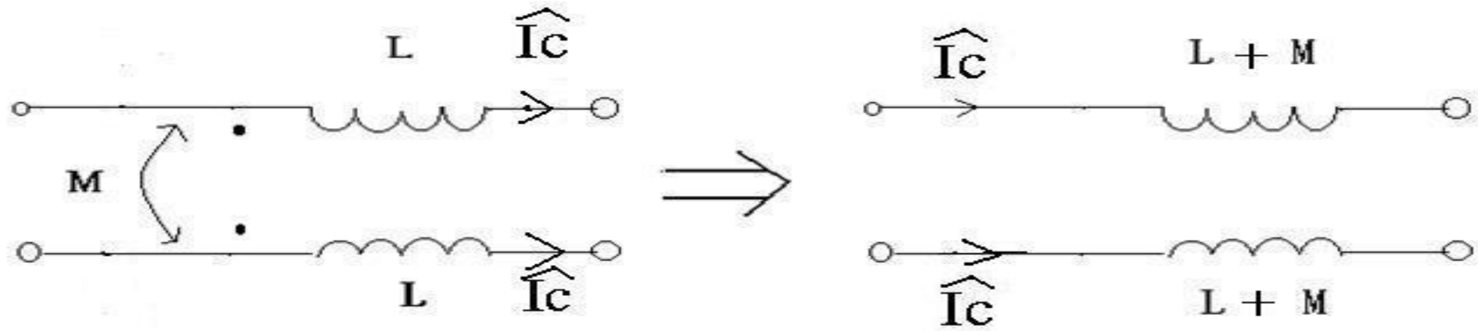
$$\hat{V} = j\omega L \hat{I}_D - j\omega M \hat{I}_D$$

$$= j\omega(L - M)\hat{I}_D$$

$\Rightarrow$ Leakage indutance.

is due to the magnetic flux that leaks out the core and does not couple between the winding.

3.



$$\hat{V} = j\omega L \hat{I}_c + j\omega M \hat{I}_c$$

$$= j\omega(L+M)\hat{I}_c$$

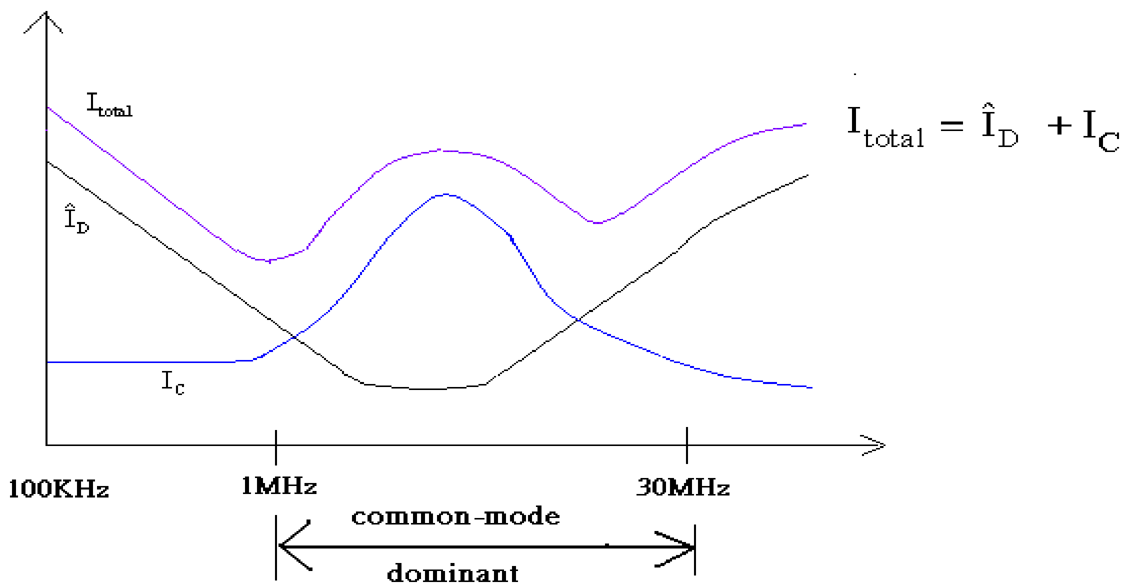
Note: typically, $L \approx M = 1mH$.

$$\therefore j\omega\left(L + M\right) = 56549\Omega. \quad f : 450KHz$$

$$= 3.77M\Omega. \quad f : 30MHz$$

(c).Separation of C.E. into common-and differential-mode currents for diagnostic

(1)



(2) At some freq. range,the I_C is dominant.
At some freq. range,the $\hat{I}_D$ is dominant.

(3) Approach to solve the C.E. problem:

1.Check out the freq. point that can not comply the regulations.

2.Determine if it is due to $\hat{I}_C$ or $\hat{I}_D$.

3.If $\hat{I}_C$, => then change the component values of C_C,LGW,or L in chock.

4.If $\hat{I}_D$,=> then design the values of C_{DR} ,C_{DL}.

Conducted Emission : Line Filter Design

How to design the values of the C and L ?

The **key** is to understand the contribution of the common-mode and differential-mode Noise on the conducted emission.

A Diagnostic tool that can separate the total C.E. into its C.M. and D.M. components at each frequency is useful for the filter design

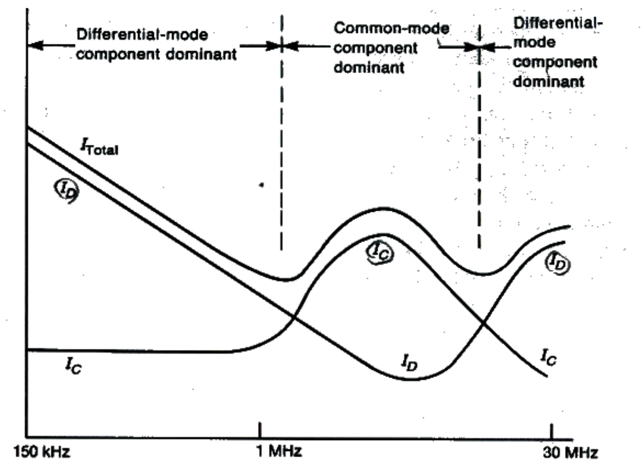


FIGURE 9.13 Illustration of the important observation that one component of current may dominate the other over a particular frequency range of the conducted emission test. In order to reduce the total conducted emission, the dominant component must be reduced.

Conducted Emission : Line Filter Design

Device to separate the C.M. and D.M. noise

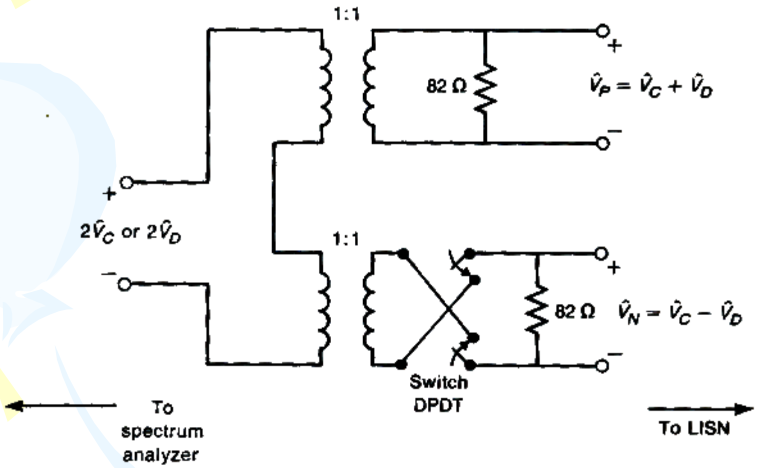


FIGURE 9.14 Schematic of a device to separate the common-mode and differential-mode conducted emission contributions.

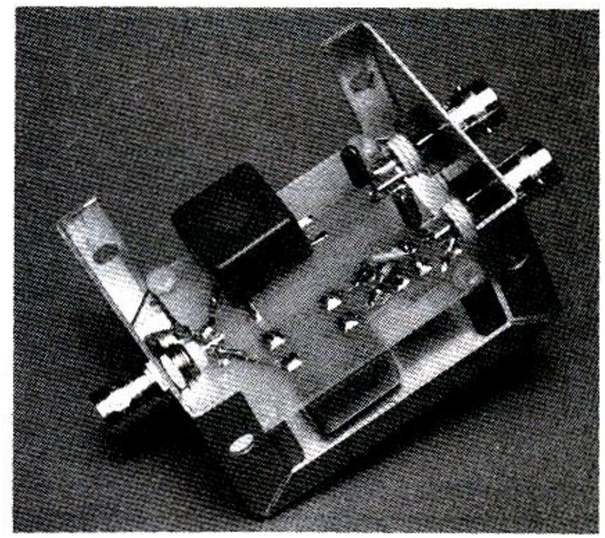


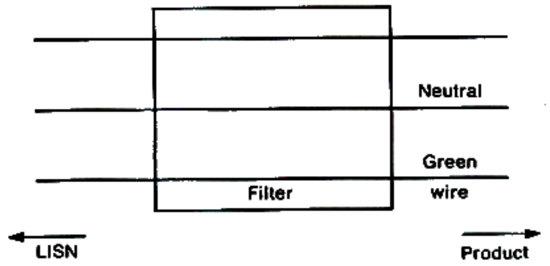
FIGURE 9.15 Photograph of the device of Fig. 9.14.

$$2V_c = V_p + V_n$$
$$2V_d = V_p - V_n$$

Conducted Emission : Line Filter Design (example)

SMPS + filter

No filter



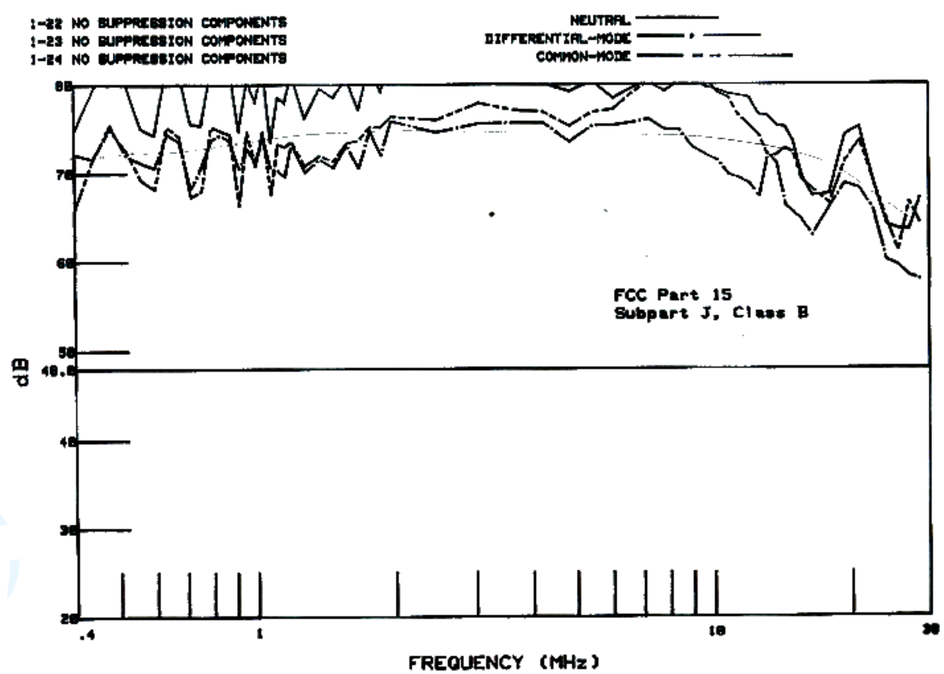


FIGURE 9.16 Measured conducted emissions of a typical product separated into differential- and common-mode components with no power supply filter.

Conducted Emission : Line Filter Design (example)

Add Y capacitances

3300pF < 50Ω at 1MHz

Both common-mode and differential-mode noise is reduced.

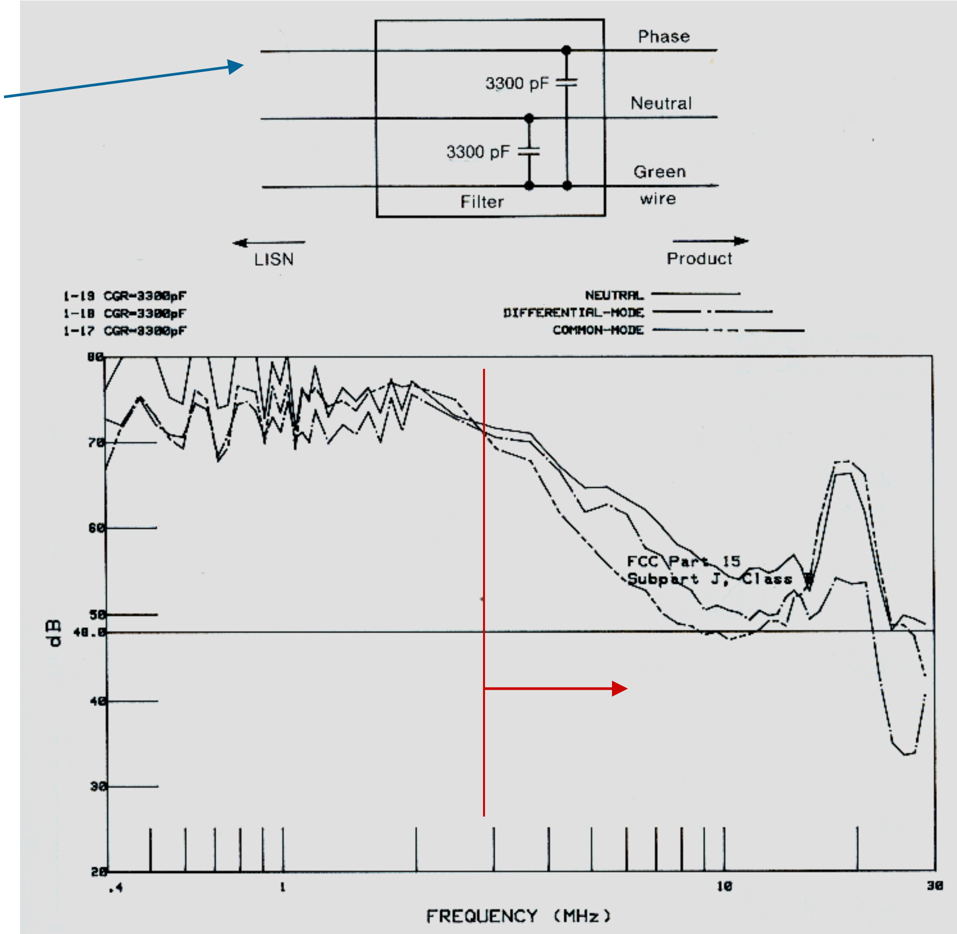


FIGURE 9.17 Measured conducted emissions of a typical product separated into differential- and common-mode components with 3300 pF line-to-ground capacitors added.

Conducted Emission : Line Filter Design (example)

Add X capacitance

0.1uF < 50Ω at 20KHz

Differential-mode noise is decreased significantly

Common-mode noise is unchanged

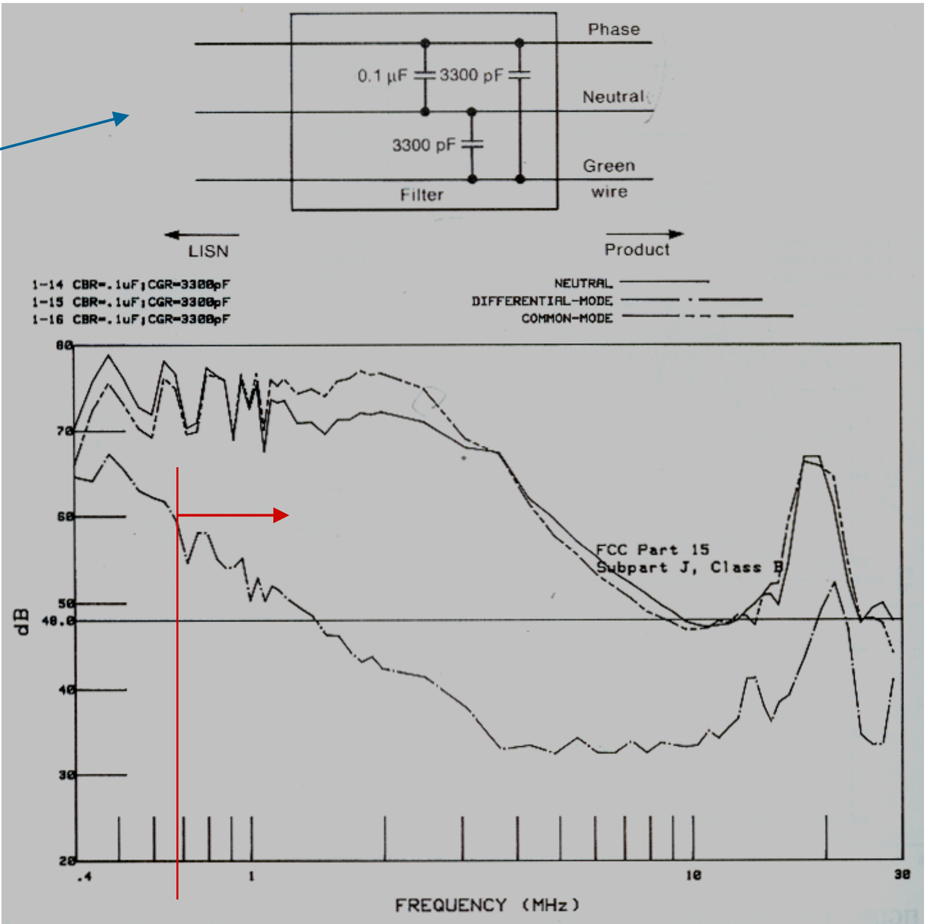


FIGURE 9.18 Measured conducted emissions of a typical product separated into differential- and common-mode components with a 0.1 μF line-to-line capacitor added.

Conducted Emission : Line Filter Design (example)

Add 1mH Green wire inductance

1mH > 50Ω at 8KHz

Common-mode noise is decreased significantly

Differential-mode noise is unchanged

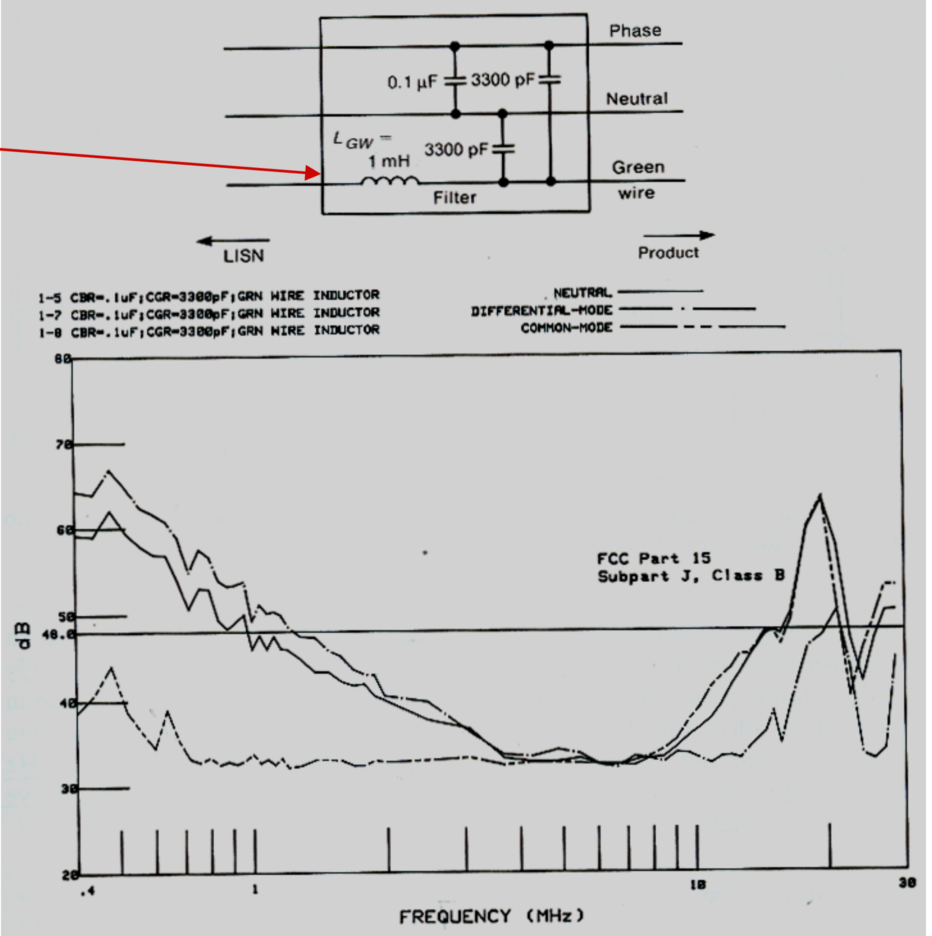


FIGURE 9.19 Measured conducted emissions of a typical product separated into differential- and common-mode components with a Green Wire inductor added.

Conducted Emission : Line Filter Design (example)

Add common-mode choke(28mH)

Differential-mode noise is decreased significantly

Common-mode noise is unchanged

Why ?

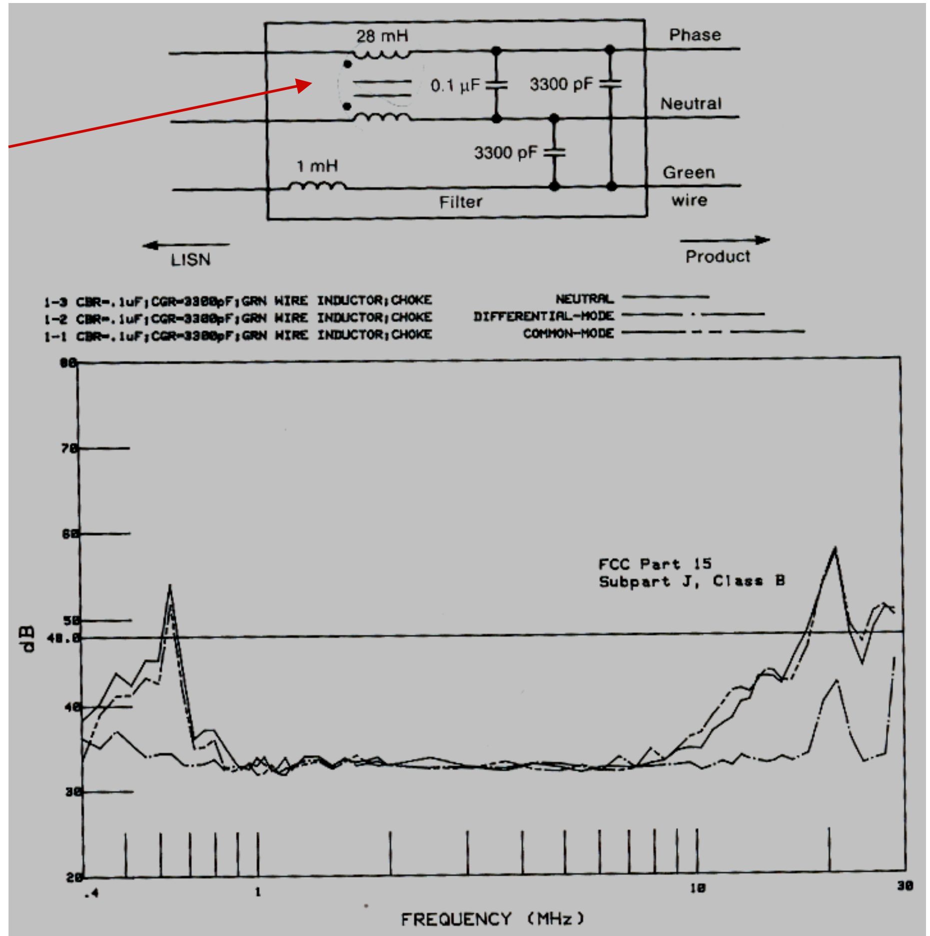


FIGURE 9.20 Measured conducted emissions of a typical product separated into differential- and common-mode components with a common-mode choke added.

Conducted Emission : Line Filter Design

Parasitic effect for C and L

"Common mode filter project by means of internal impedance measurement",
IEEE EMC Symposium, 2000

Real impedance behavior of the C and L

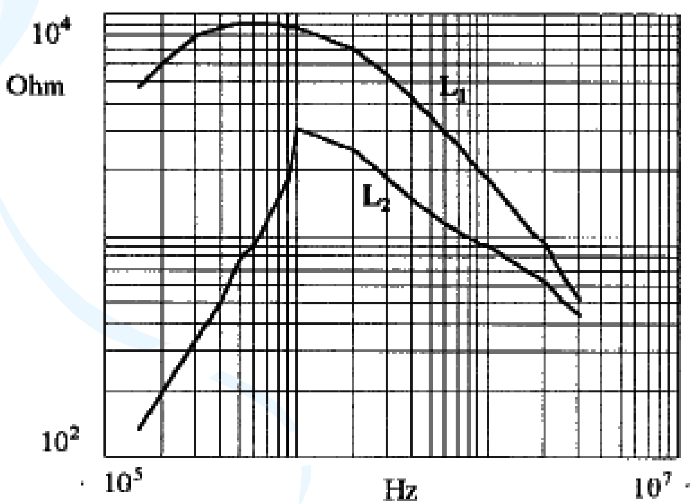


Figure 2: measure of the high frequency impedance of inductors L_1 and L_2

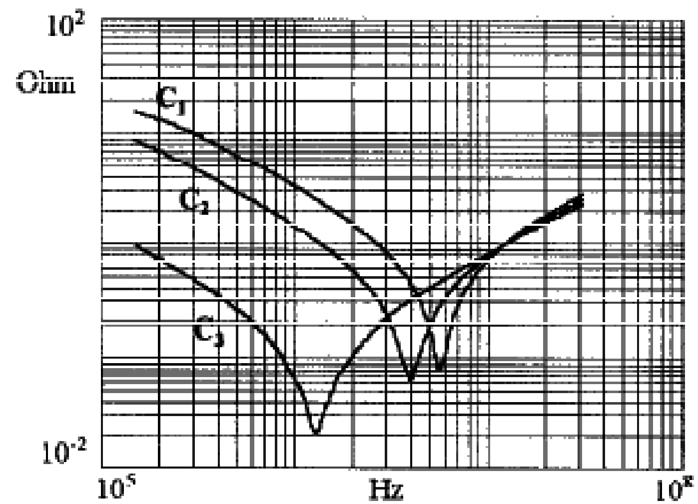


Figure 3: measure of the high frequency impedance of capacitors C_1, C_2 and C_3

Conducted Emission : Line Filter Design

Equivalent model for C

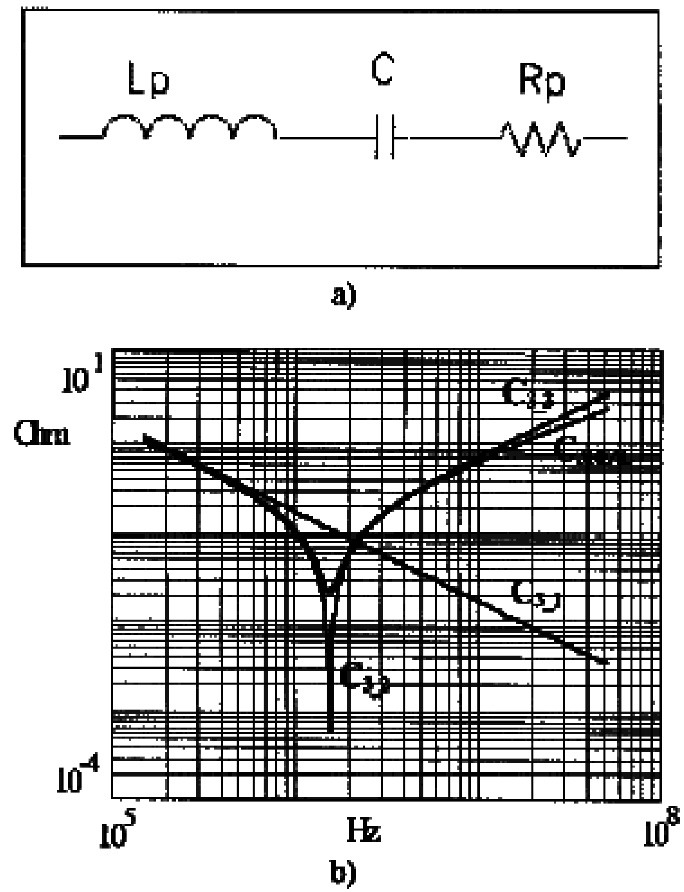


Figure 4: a) equivalent electric model of C_3; b) comparison between the measured impedance C_{3REAL} and different approximations: C_{3-1} only capacitance C, C_{3-2} with L_p added; C_{3-3} whole electric model

Conducted Emission : Line Filter Design

Equivalent model for L

All winding capacitance

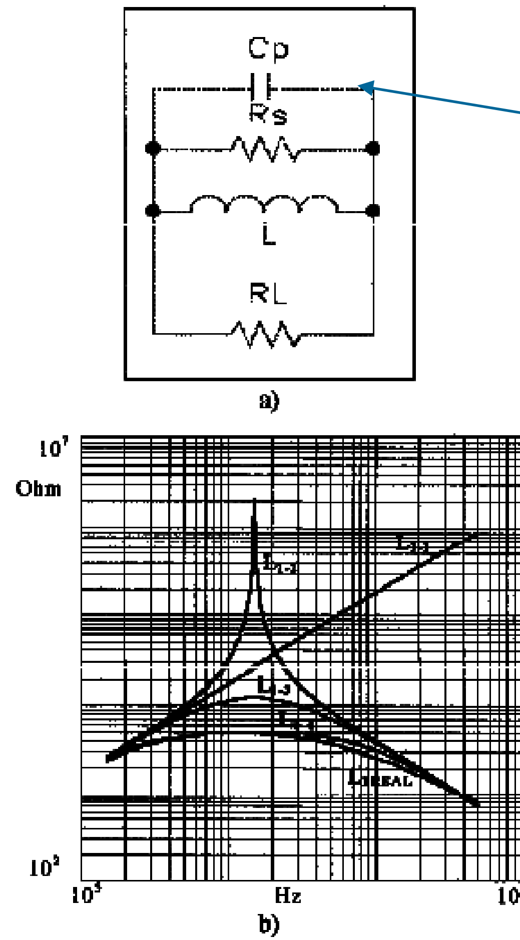


Figure 5: a) equivalent electric model of L_1; b) comparison between the measured impedance L_{1REAL} and different approximations: $L_{1\text{-}1}$ only inductance L; $L_{1\text{-}2}$ with C_p added; $L_{1\text{-}3}$ and $L_{1\text{-}4}$ with R_s and R_L included respectively