Mixed-Mode EMI and It's Implications to Filter Design

By
Dan Chen

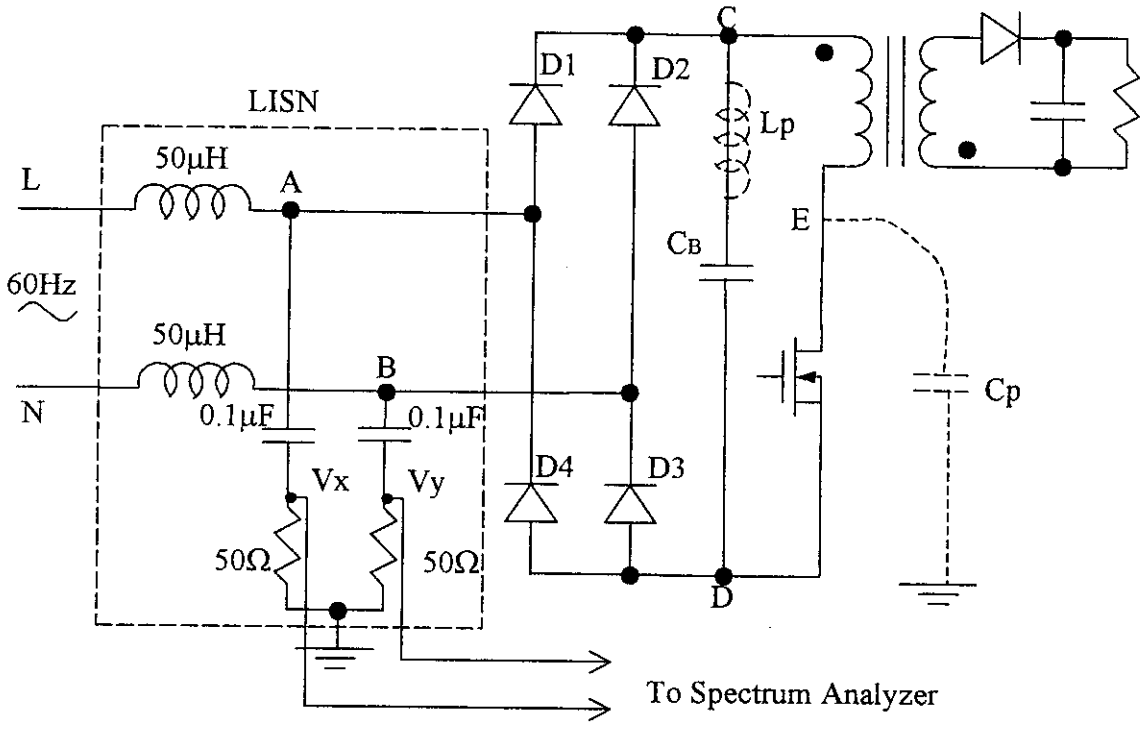
EMI

-Differential Mode (DM)

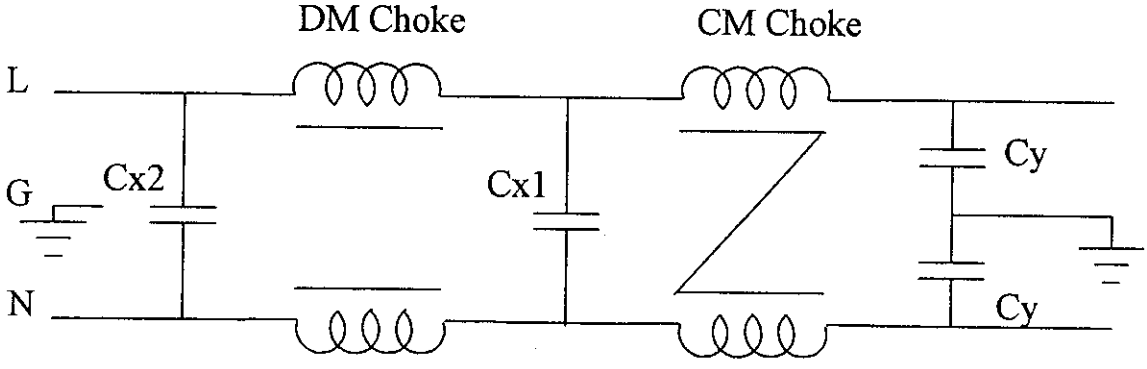
-Common Mode (CM)

- *Mixed Mode*

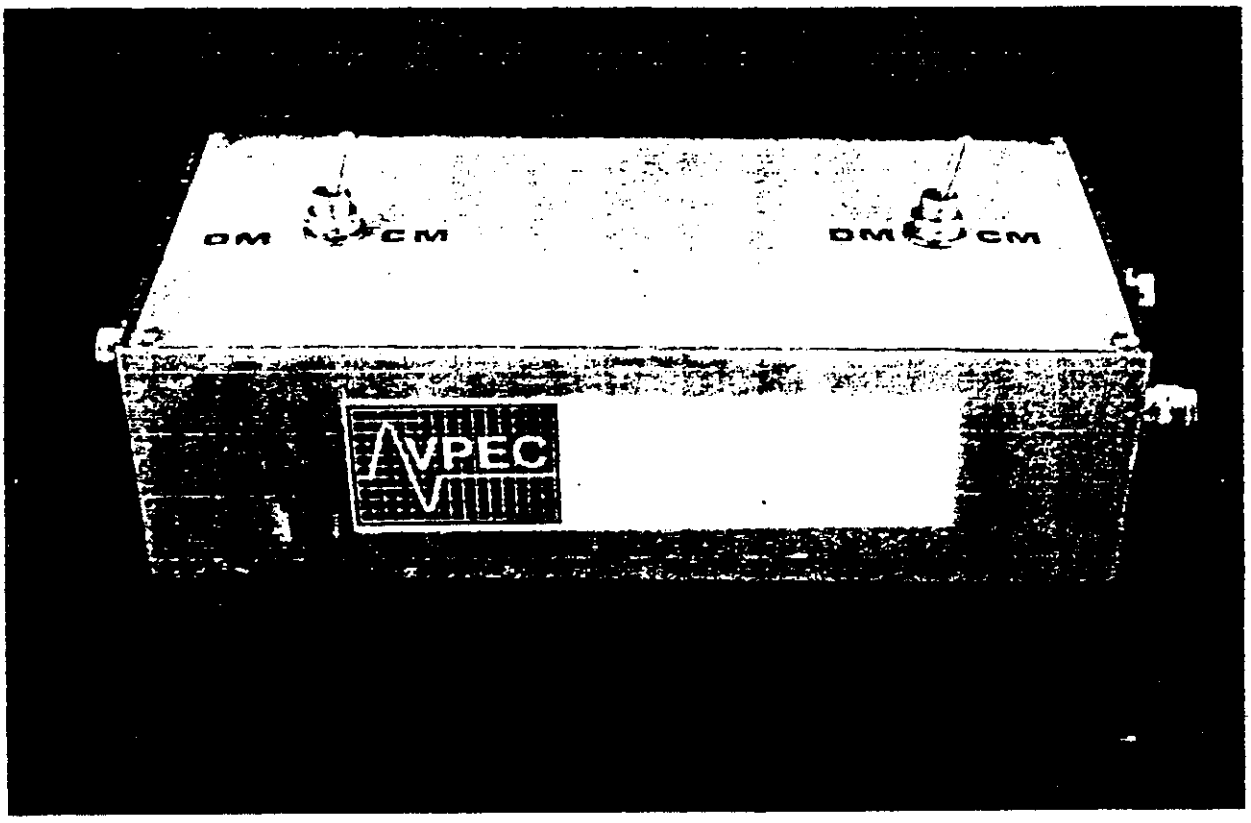
Review of Conventional EMI Theory



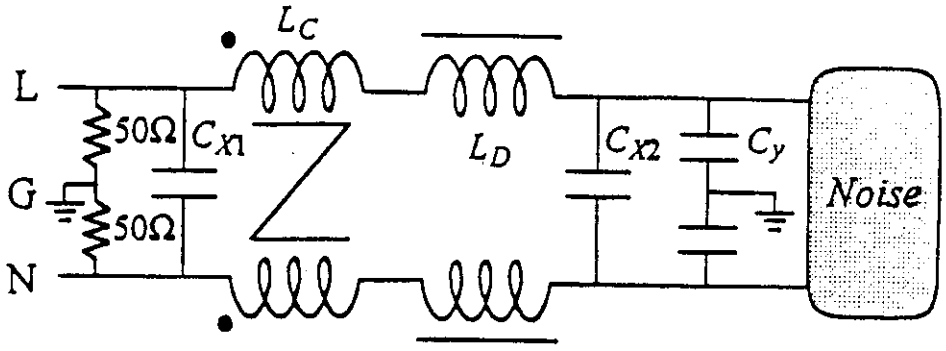
CM Noise: $\frac{V_x + V_y}{2}$ DM Noise: $V_x - V_y$

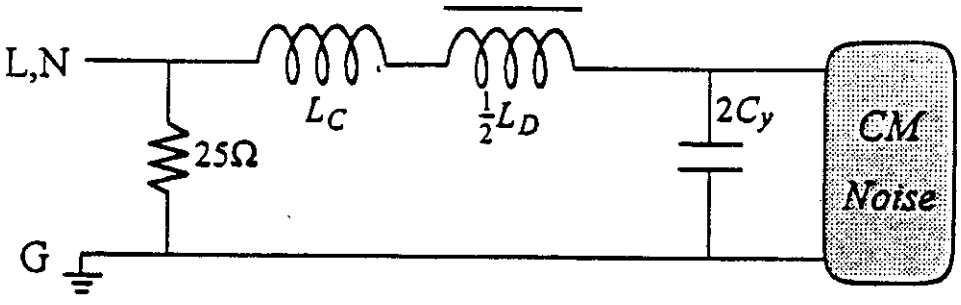


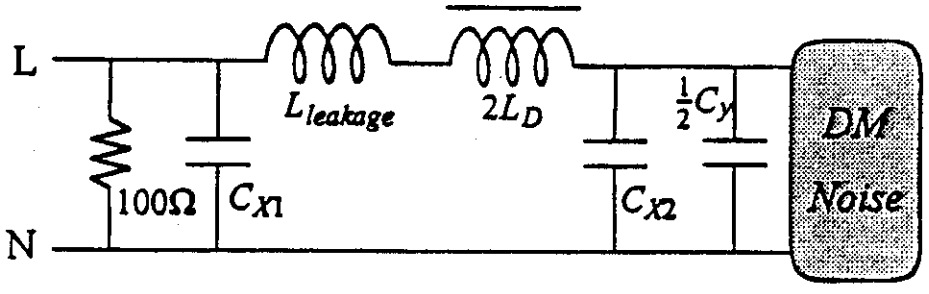
Composite EMI Filter


DM
CM
DM
CM
VPEC

Filter Equivalent Circiuts







Tests Using a Noise Separator

Test # 1: No filter is inserted.

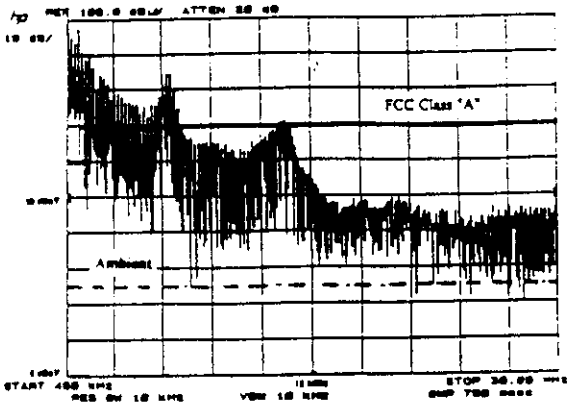


Figure 5(a) Total Noise

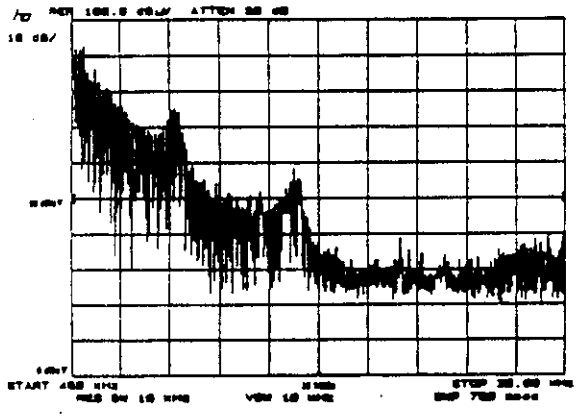


Figure 5(b) DM Noise

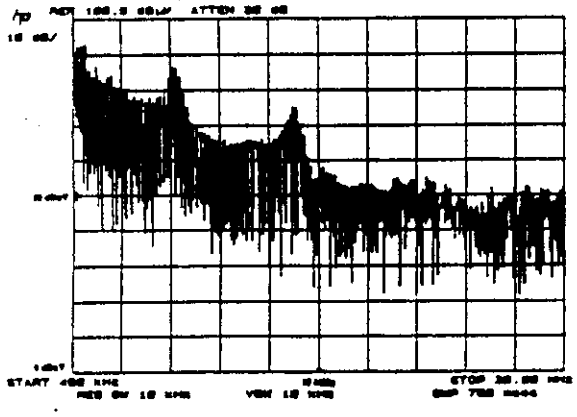


Figure 5(c) CM Noise

Test # 2: "Tests Using Noise Separator"

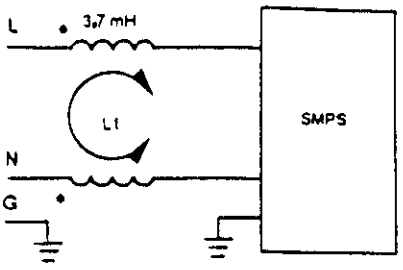


Figure 6(a) Test 2 Diagram

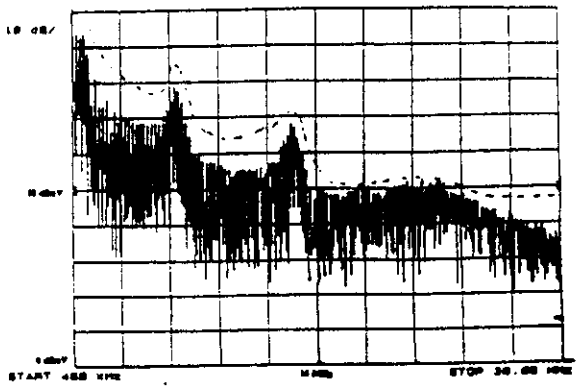


Figure 6(b) Total Noise

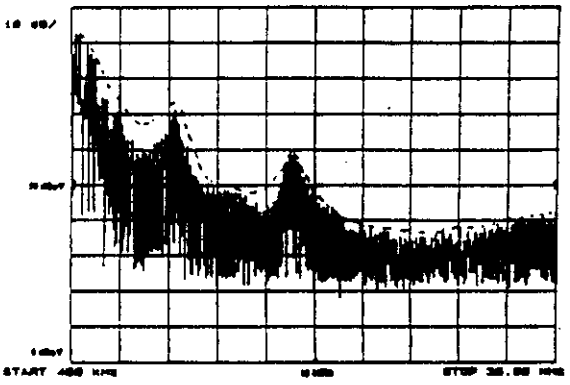


Figure 6(c) DM Noise

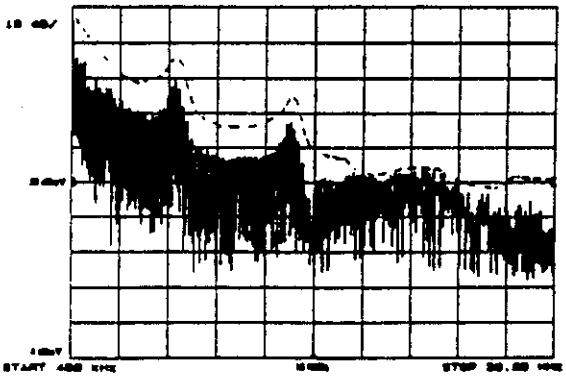


Figure 6(d) CM Noise

Test # 3:

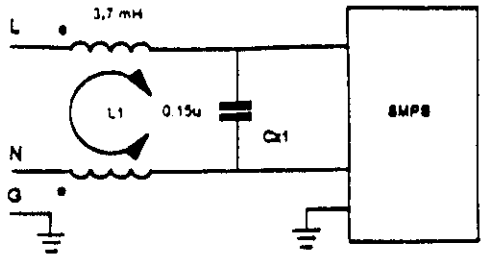


Figure 7(a) Test 3 Diagram

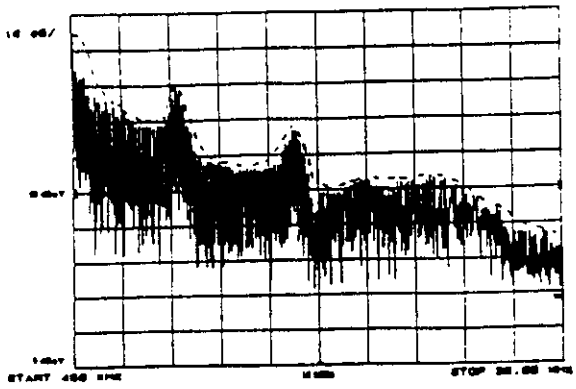


Figure 7(b) Total Noise

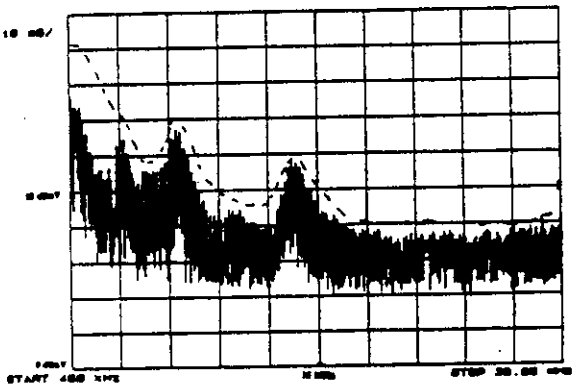


Figure 7(c) DM Noise

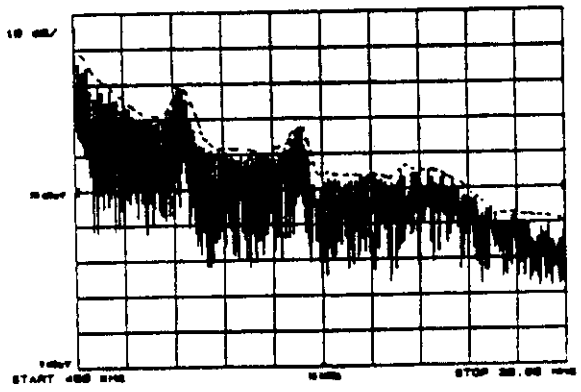


Figure 7(d) CM Noise

Test # 4:

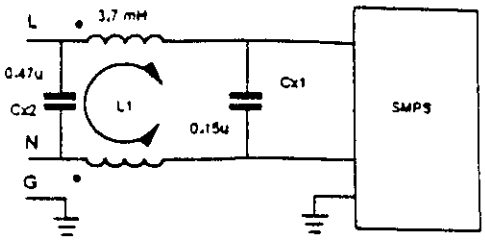


Figure 8(a) Test 4 Diagram

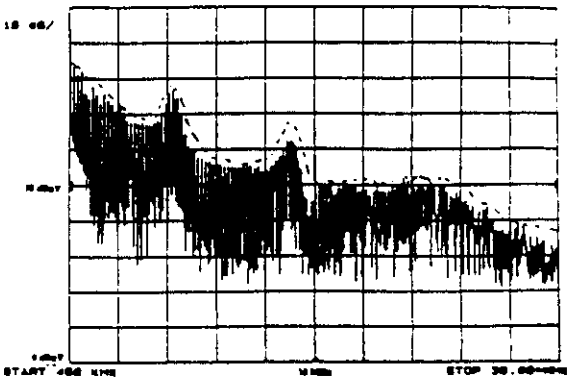


Figure 8(b) Total Noise

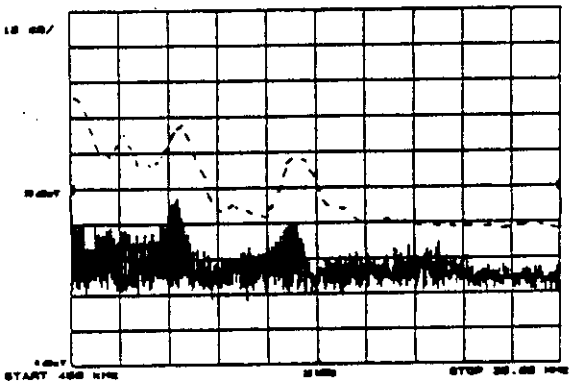


Figure 8(c) DM Noise

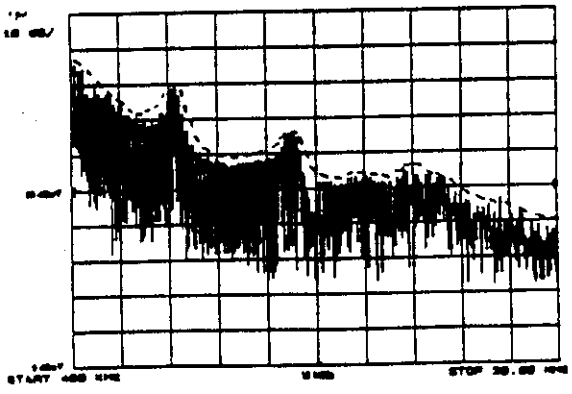


Figure 8(d) CM Noise

Test # 9:

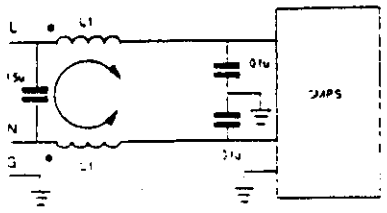


Figure 13(a) Test 9 Diagram

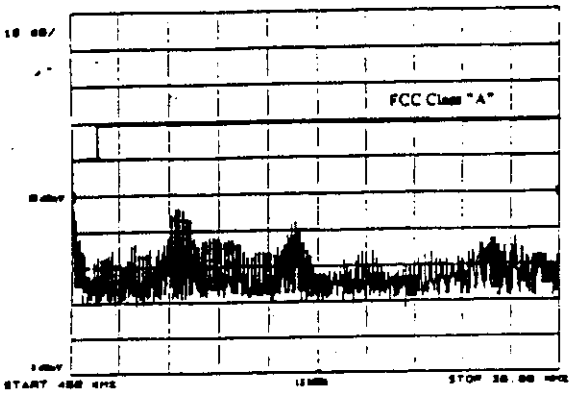


Figure 13(b) Total Noise

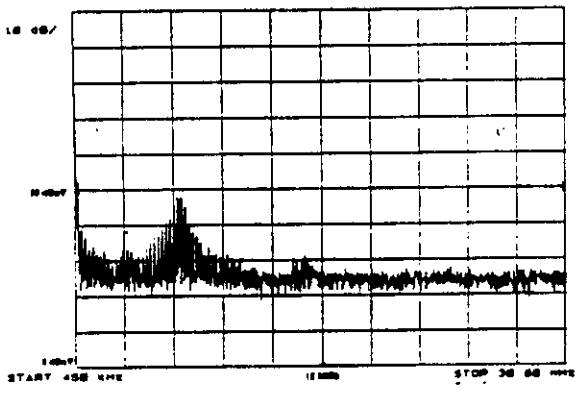


Figure 13(c) DM Noise

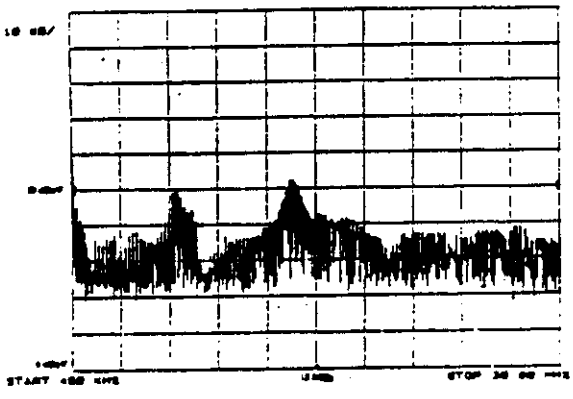


Figure 13(d) CM Noise

Test # 10:

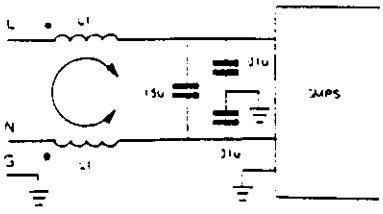


Figure 14(a) Test 10 Diagram

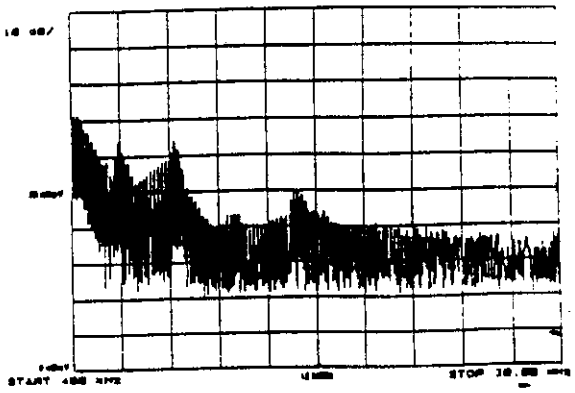


Figure 14(b) Total Noise

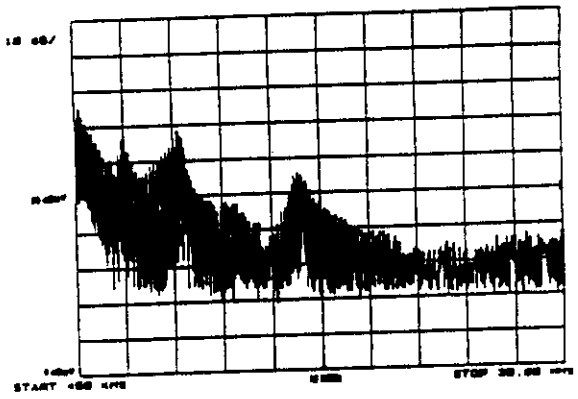


Figure 14(c) DM Noise

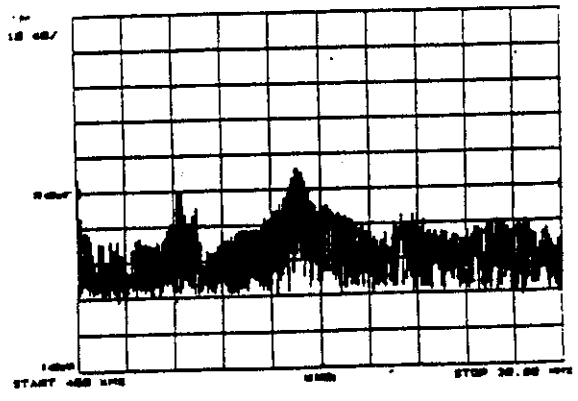


Figure 14(d) CM Noise

Mixed-Mode EMI Noise in Offline Converters

- Formerly called Non-Intrinsic Differential-Mode (NIDM) Noise

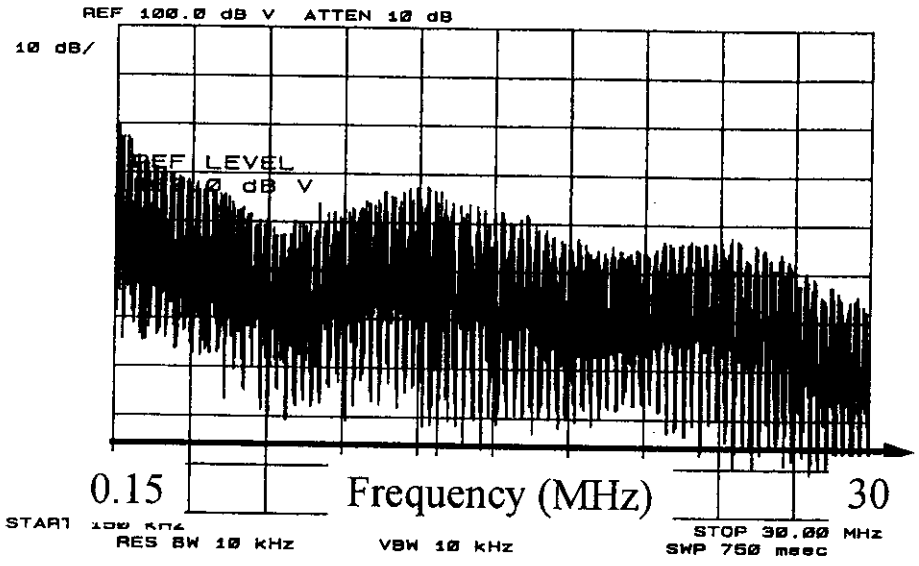
- Caused by dv/dt coupling through unbalanced noise current path

- Can be effectively attenuated by balancing noise current path (using an X capacitor)

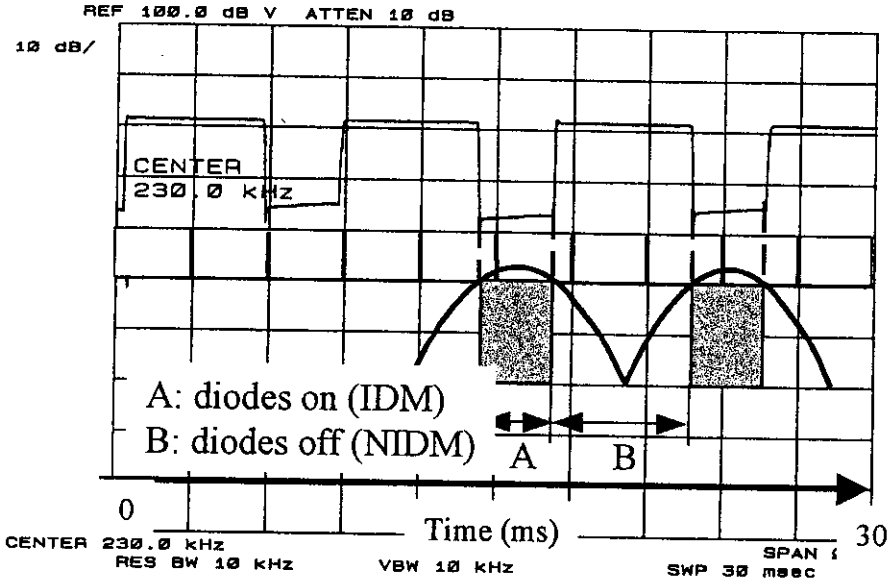
- Tools for investigation:

  - DM/CM Noise Separator
  - Zero-Span Mode of Spectrum Analyzer

Mixed-Mode EMI Noise

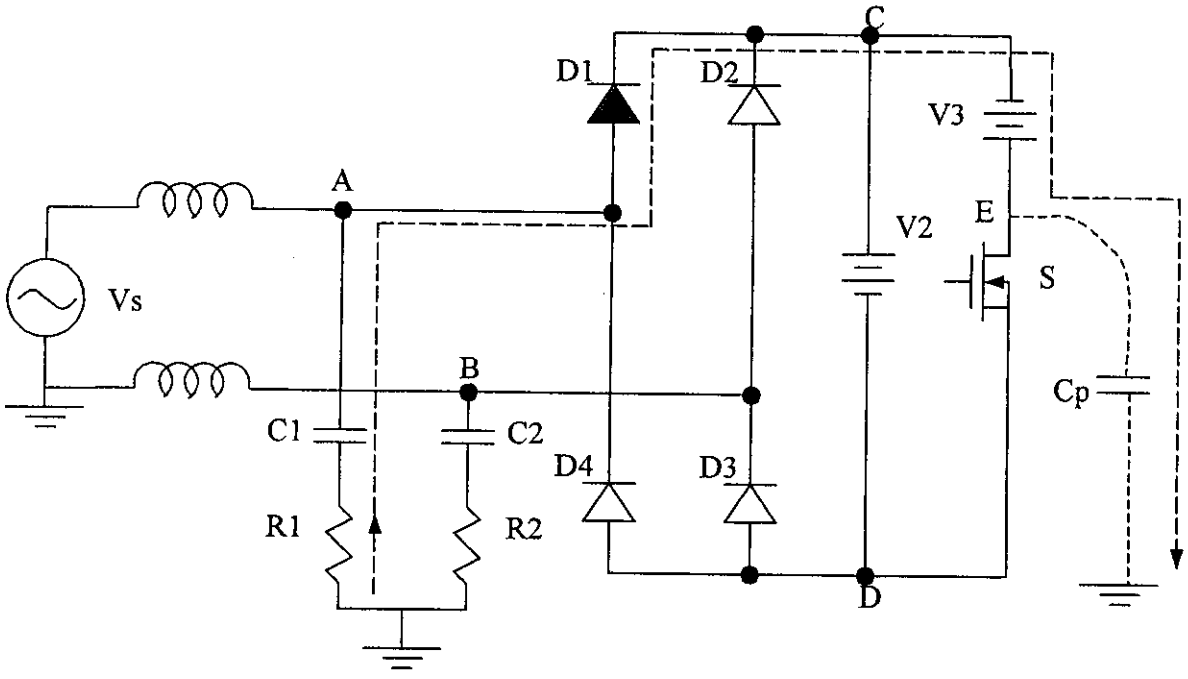


Regular EMI spectrum

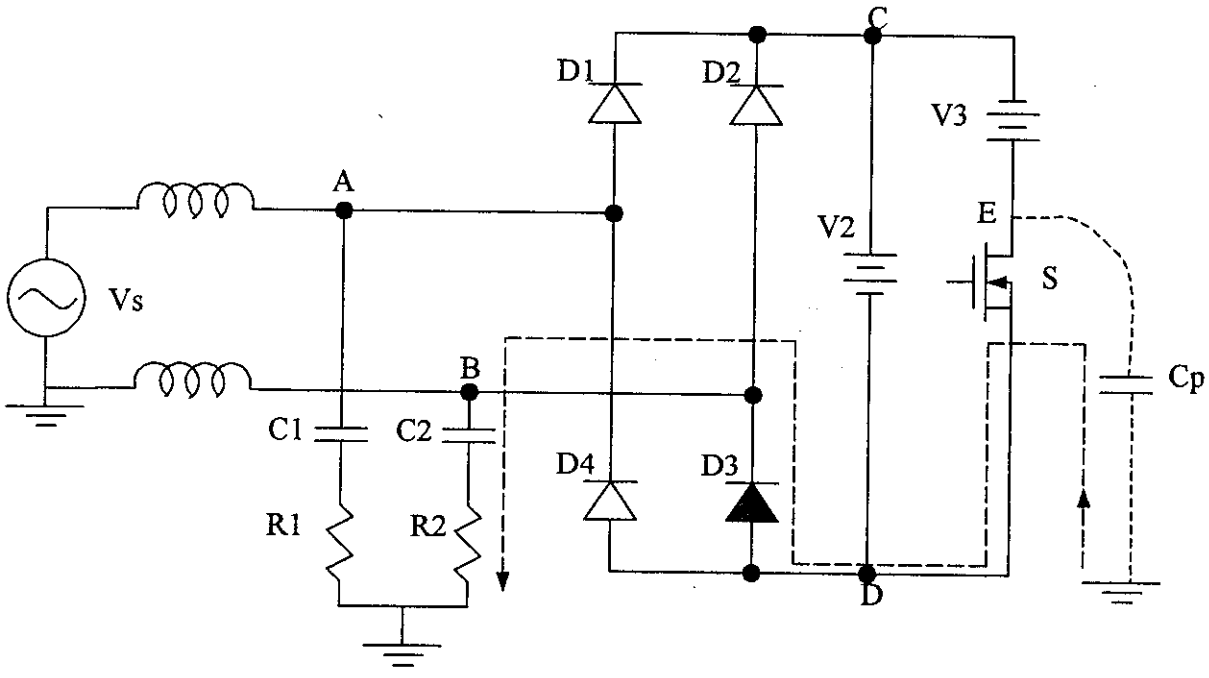


Zero-span mode

Mechanism of Mix-Mode Noise Coupling

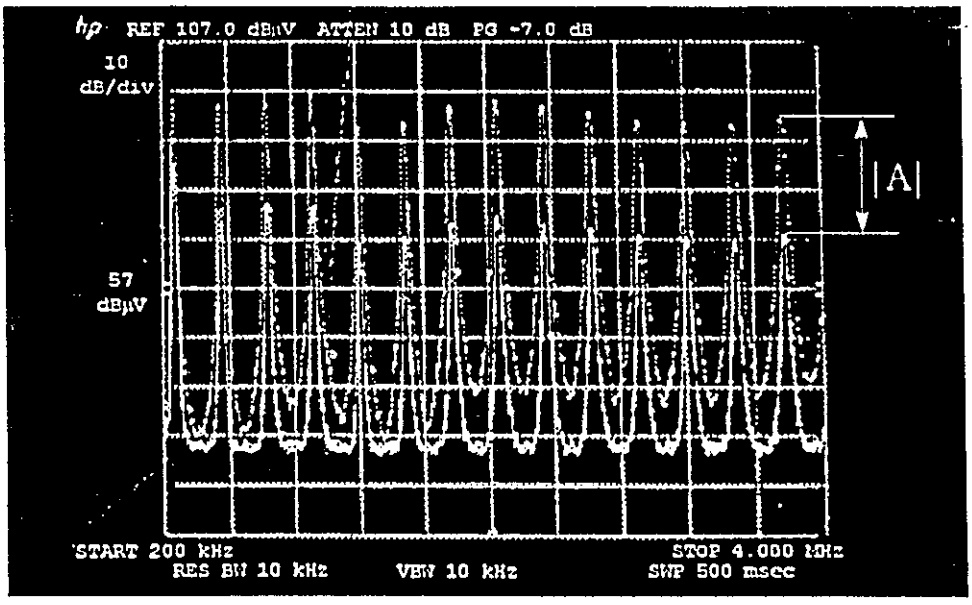


Diodes off, MOSFET turned off, Cp charged

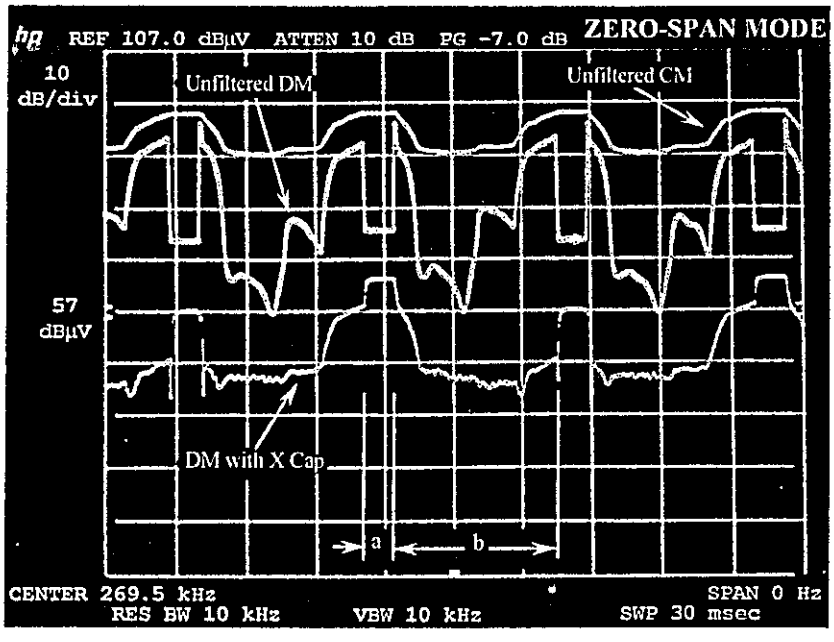


Diodes off, MOSFET turned on, Cp discharged

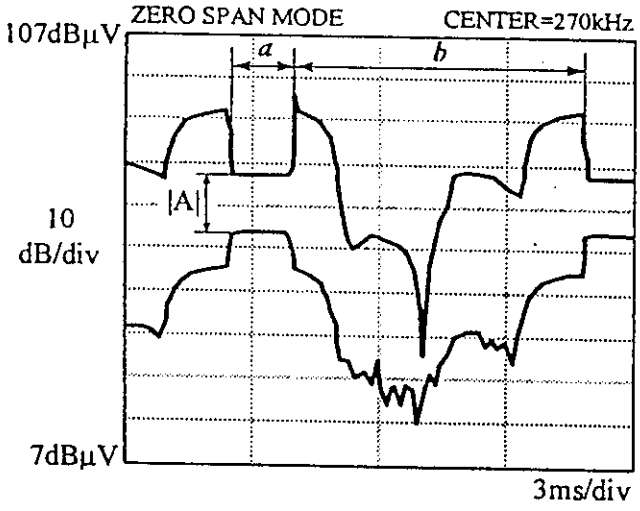
EMI Measurement of an Off-line Power Supply



- Sweep in the time-domain reserves only maximum values.



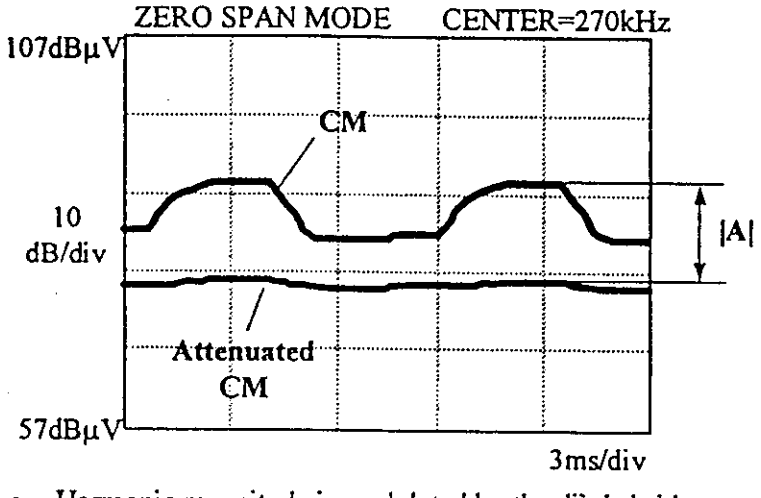
EMI Measurement of an off-line Power Supply (Using Zero Span Mode)



- *a*: Diode Bridge ON; *b*: Diode Bridge OFF
- |A| must be measured for every harmonic.

DM

MODULATED CM HARMONIC MAGNITUDE



- Harmonic magnitude is modulated by the diode bridge.
- Only peak values are useful.

CM

↑

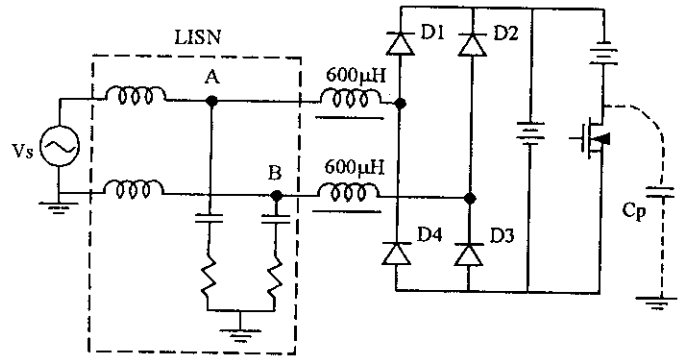
a: Rectifier On"

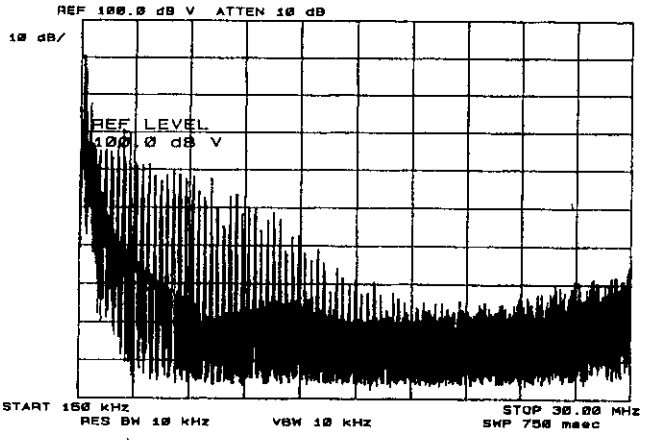
b: Rectifier "Off"

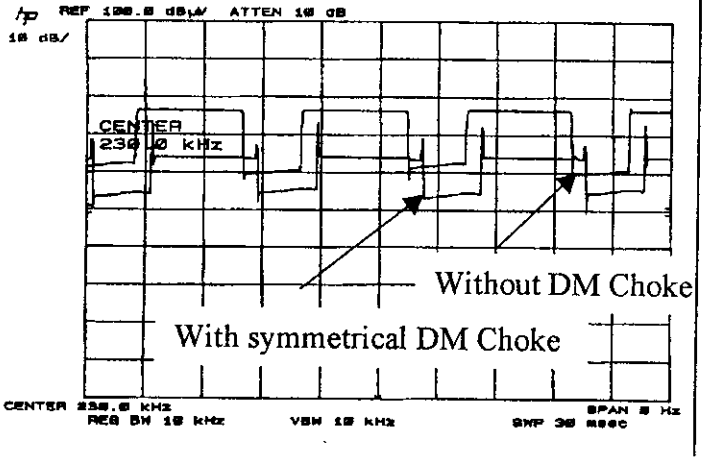
Implications of Mixed-Mode EMI Noise

Symmetrical Vs. Asymmetrical DM Chokes

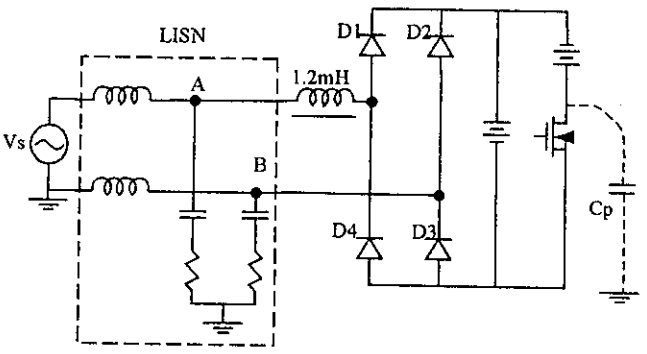
Symmetrical Choke

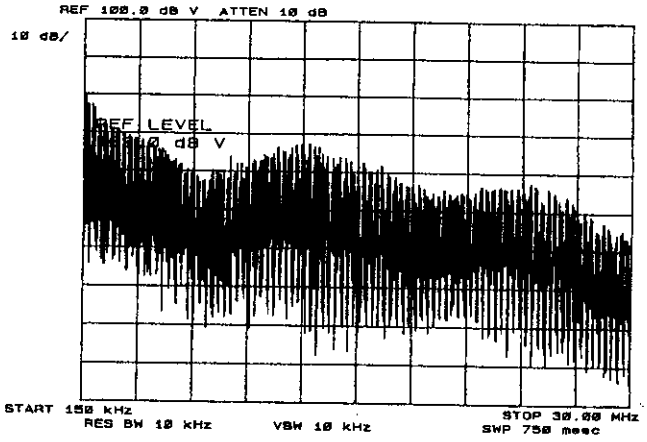


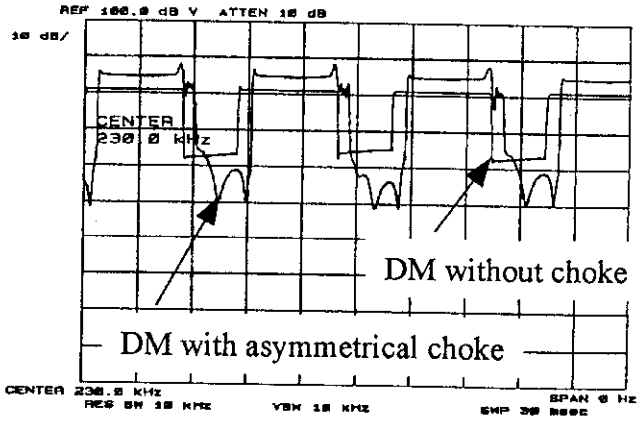




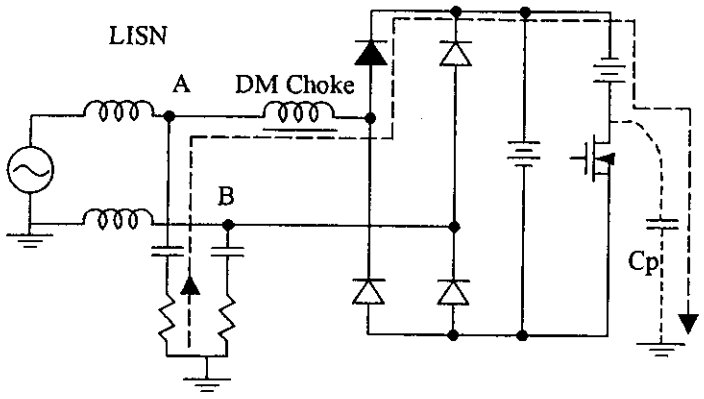
Asymmetrical Choke

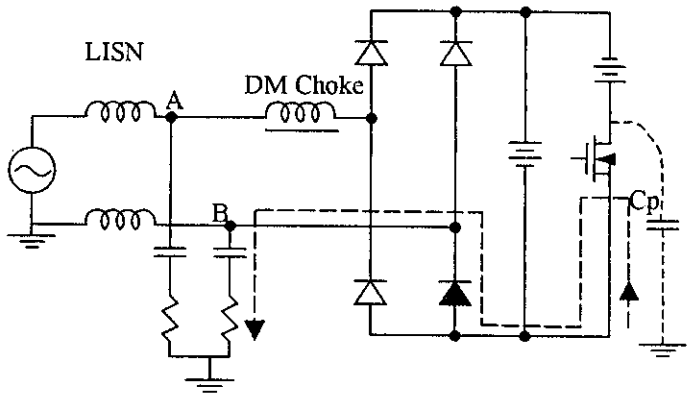


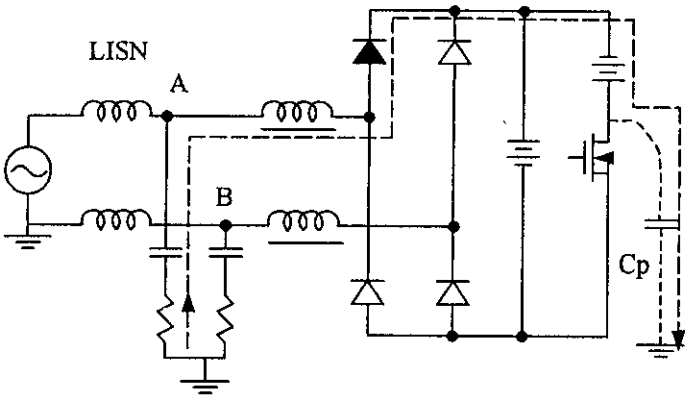


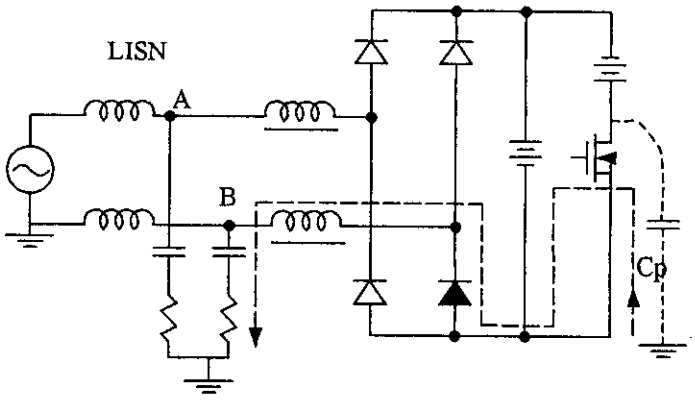


Symmetrical Vs. Asymmetrical DM Chokes

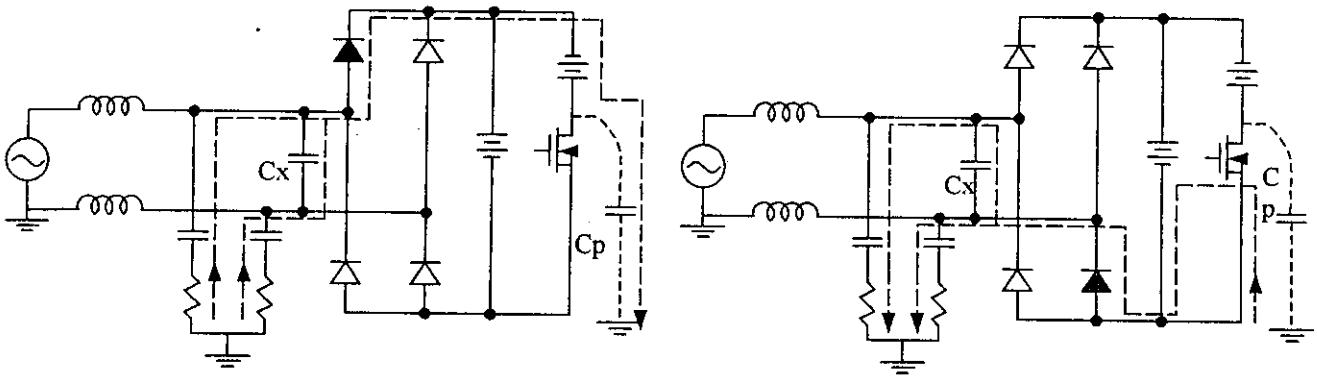


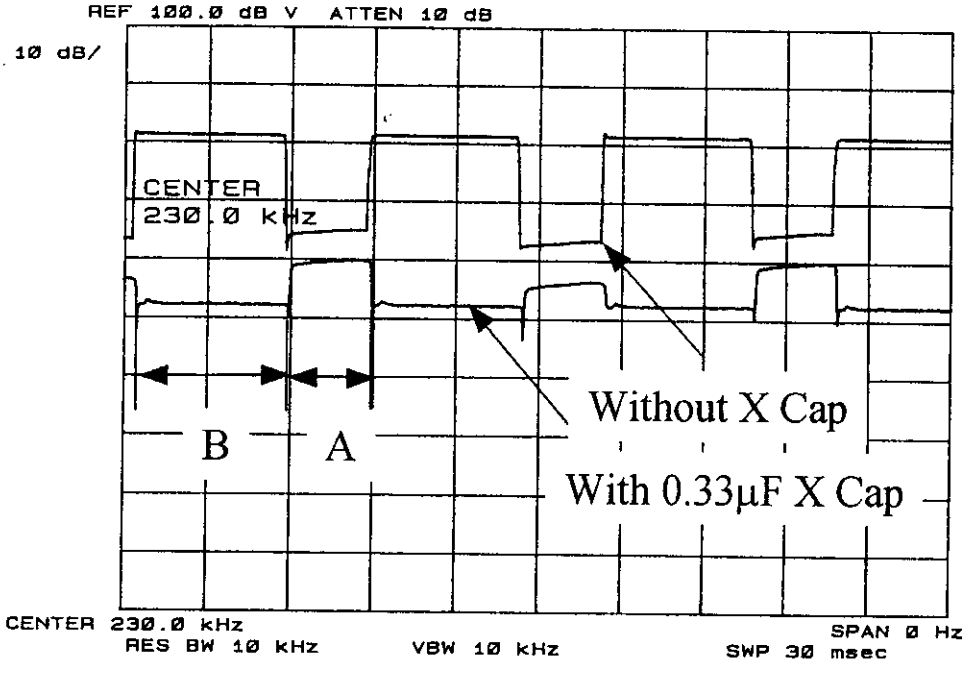






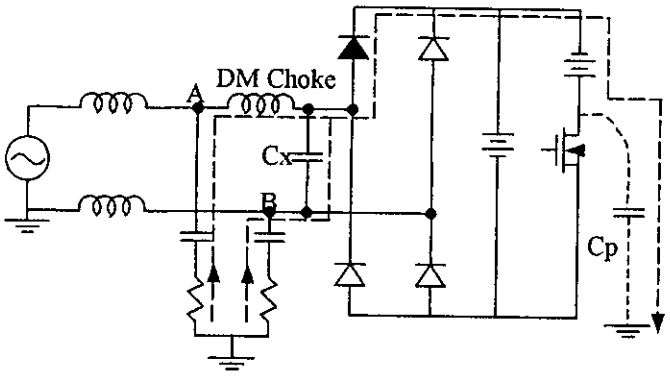
Using X Cap to Balance MM

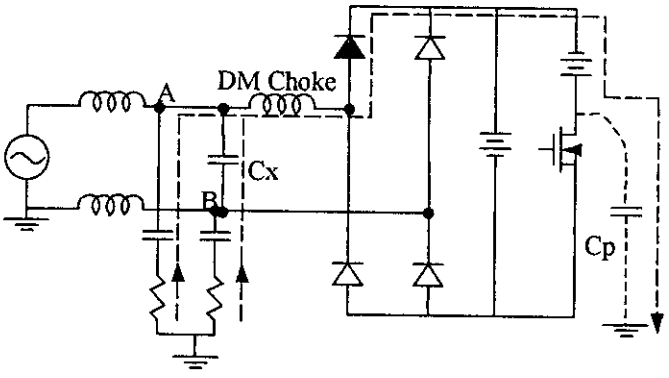


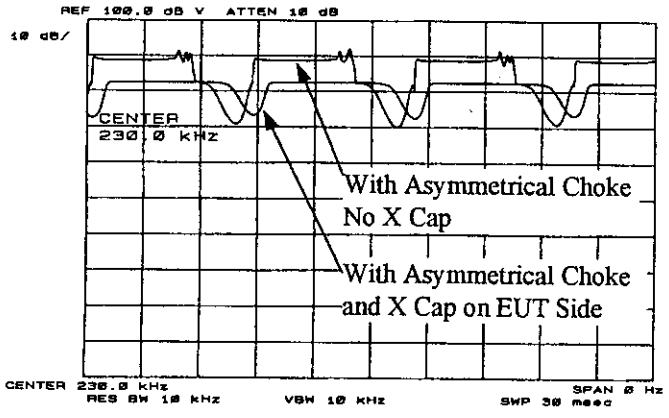


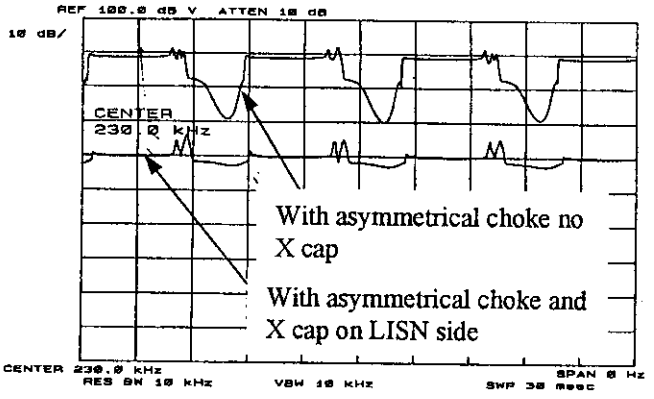
Which Side Should the X Cap Be Placed?

Asymmetrical Choke



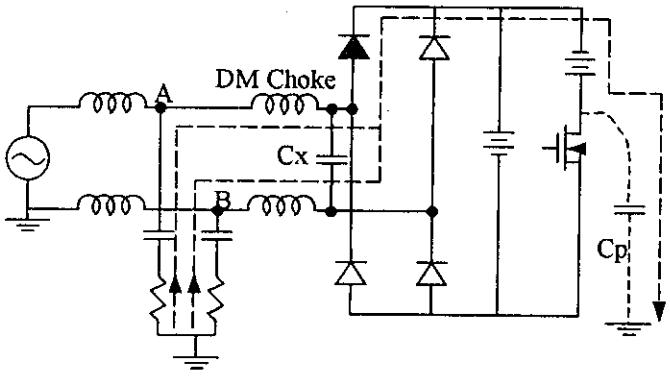


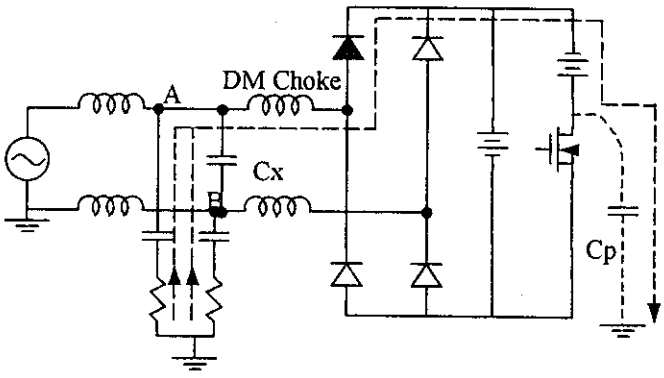


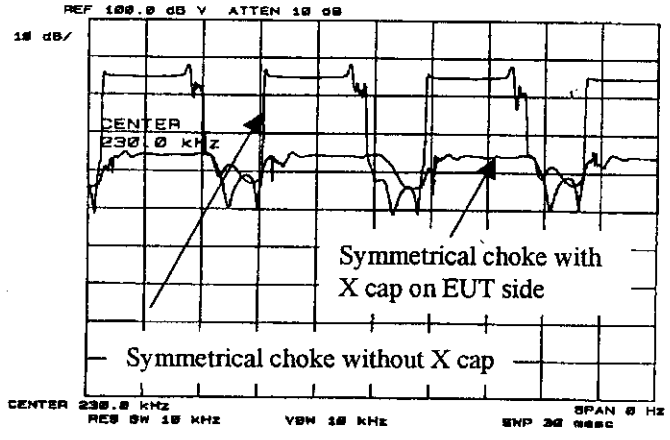


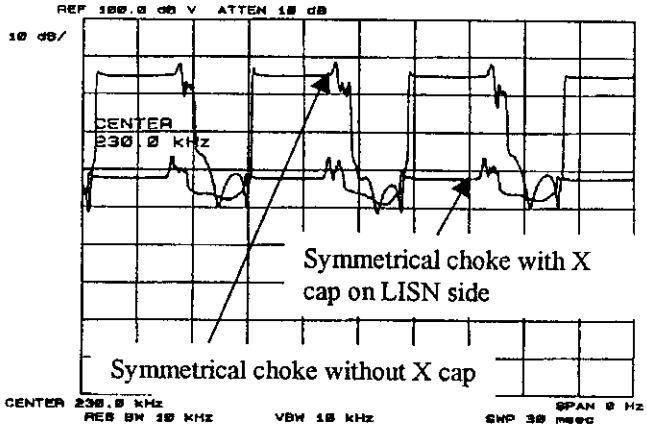
Which Side Should the X Cap Be Placed?

Symmetrical Choke

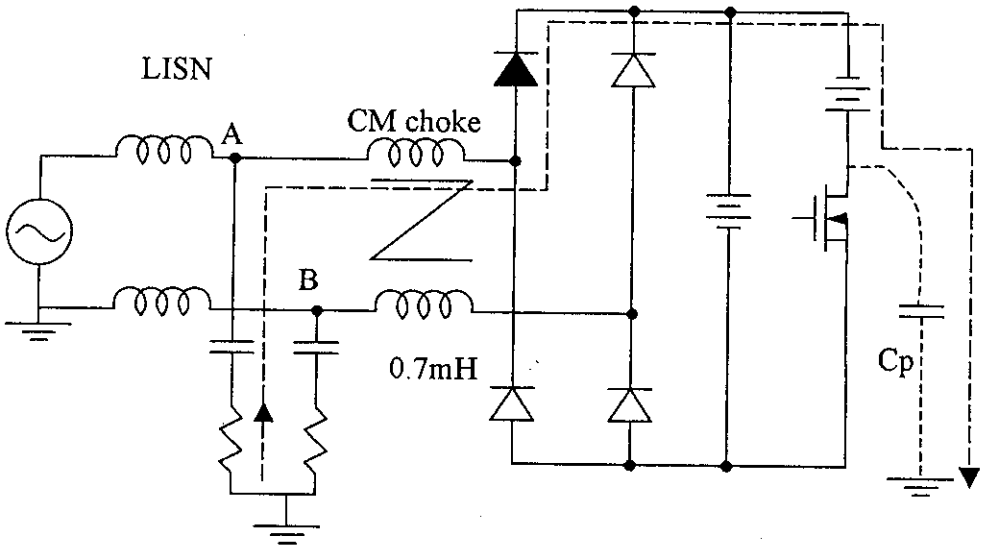


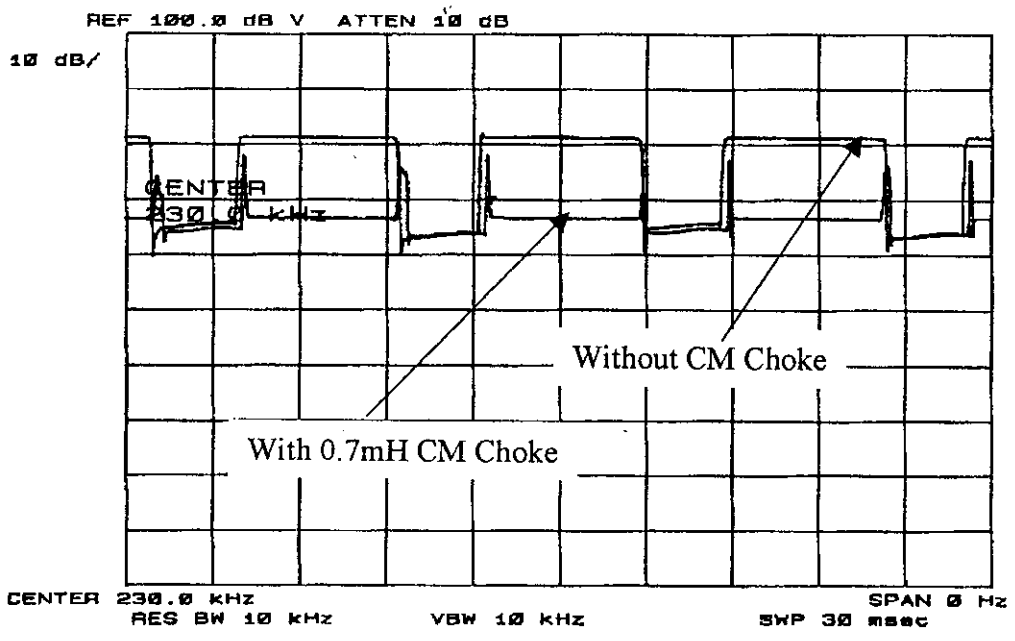




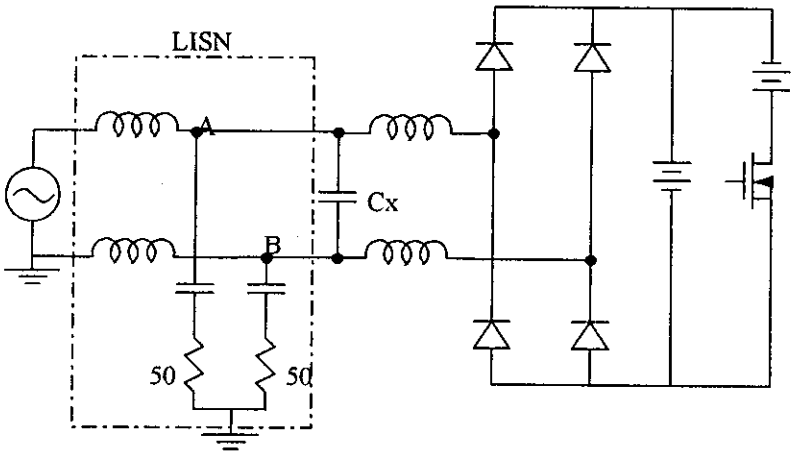


Effect of CM Choke on MM Noise

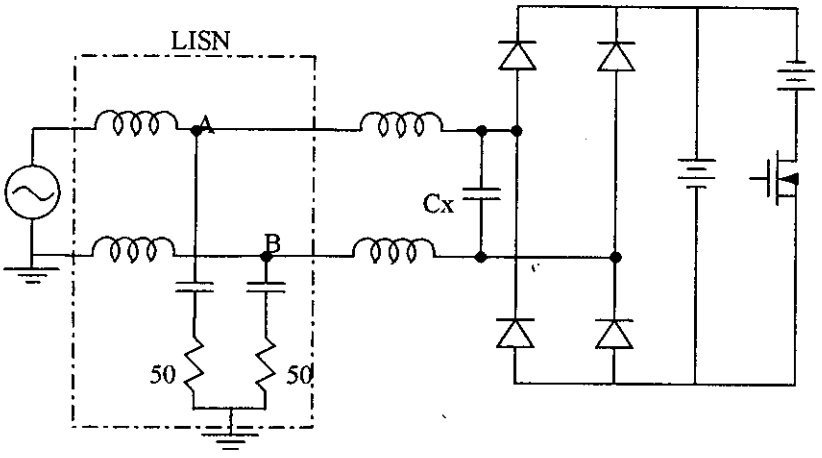




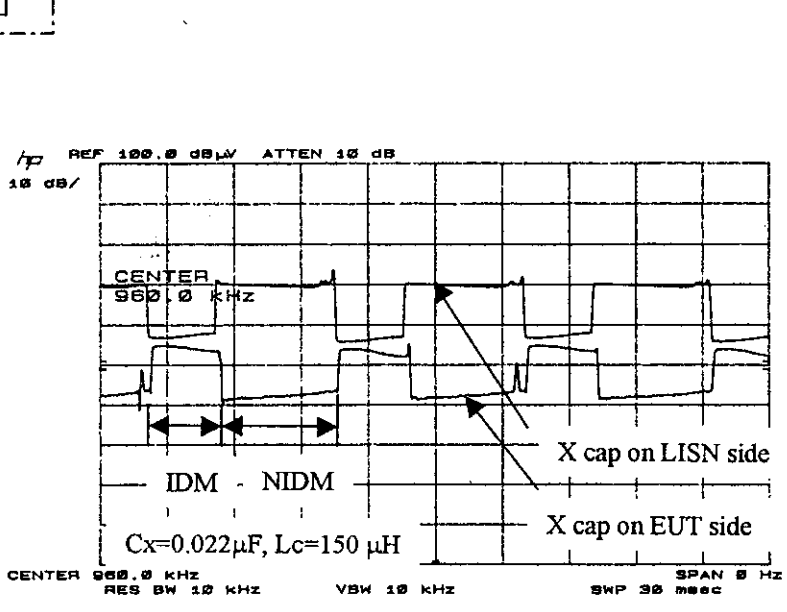
How Much C Is Needed to Balance the Current



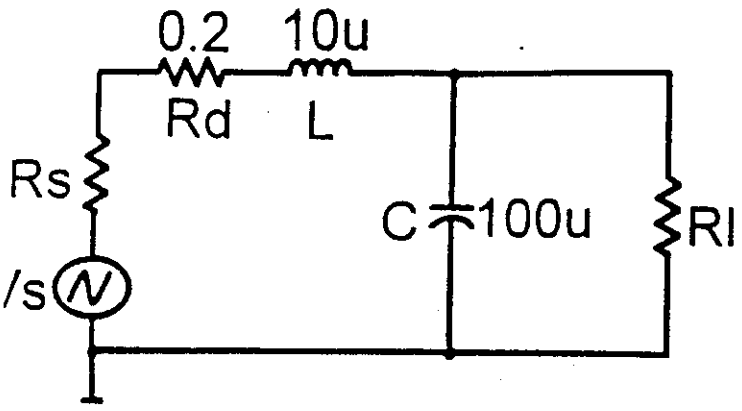
$$\frac{1}{2\pi f C_X} \ll 50\ \Omega$$



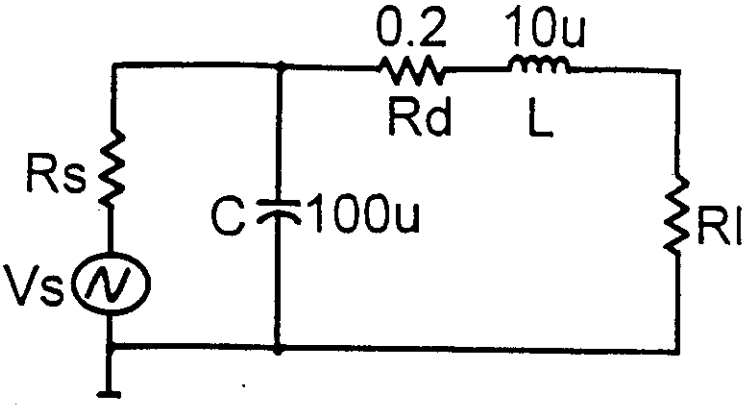
$$\frac{1}{2\pi f C_X} \ll \left|50\Omega + j2\pi f\left(L_{DM} + L_{CM}\right)\right|$$



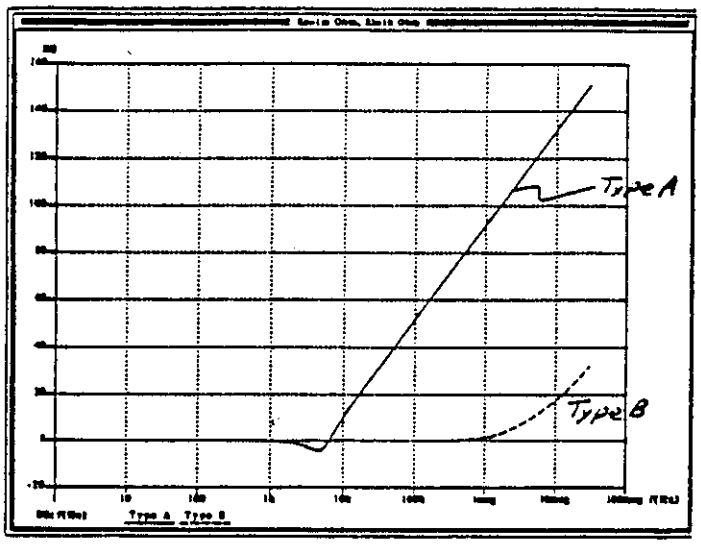
Impedance Effects on Filter Attenuation



Filter Type A



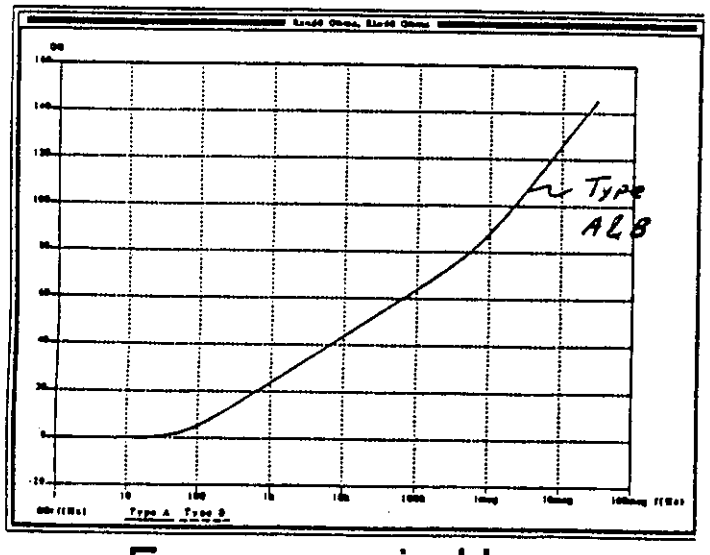
Filter Type B



Attenuation in dB

Frequency in Hz

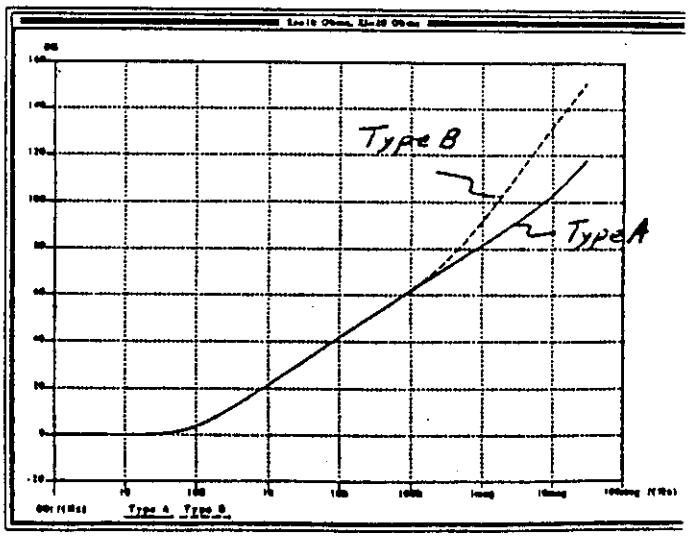
Rs=1m Ohm, Rl=1K Ohm



Attenuation in dB

Frequency in Hz

Rs=Rl=50 Ohm

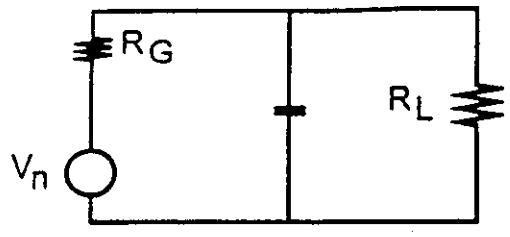


Attenuation in dB

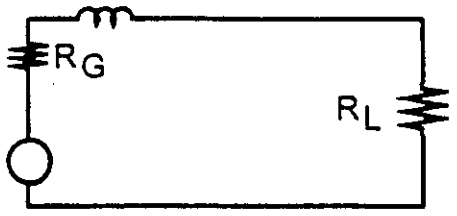
Frequency in Hz

Rs=1K Ohm, Rl=20 Ohm

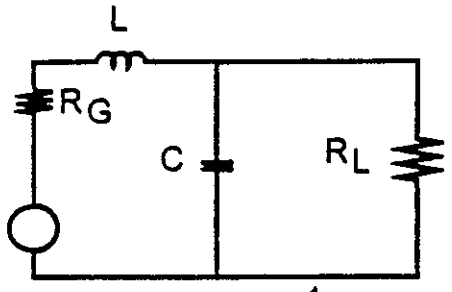
Effectiveness of a Filter



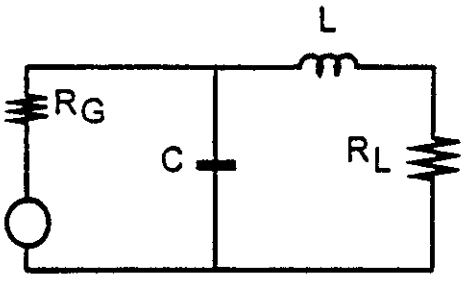
effective if $\frac{1}{wc} << R_L, R_G$



if $wL << R_L, R_G$

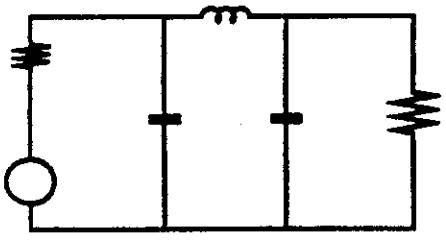


if $wL >> R_G$ & $\frac{1}{wc} << R_L$

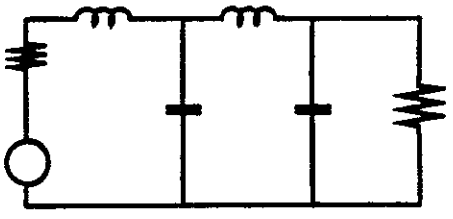


if $wL >> R_L$ & $\frac{1}{wc} << R_G$

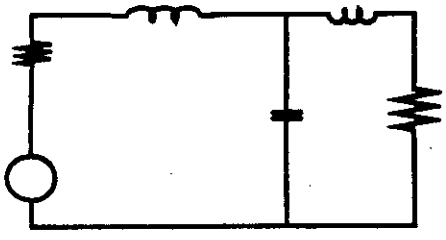
Higher-Order Filters



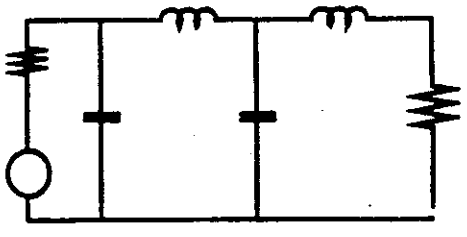
(π)



(LCLC)

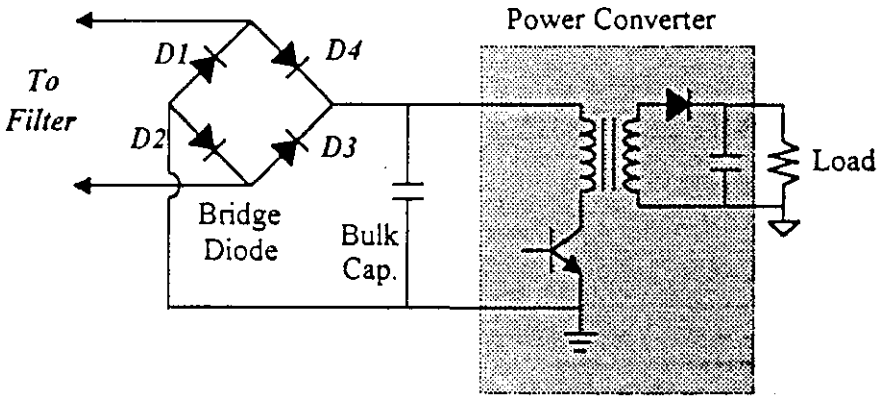


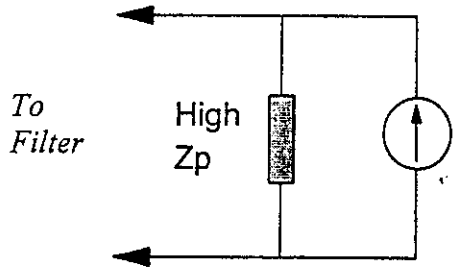
(T)



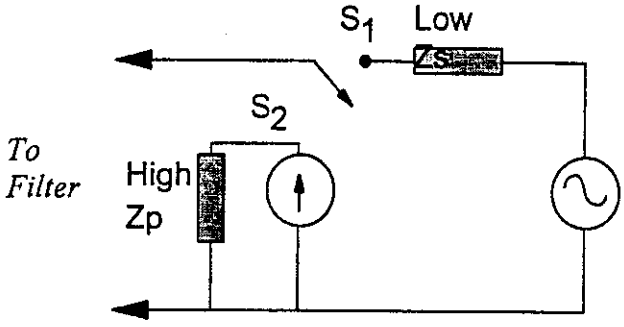
(CLCL)

Noise Source Impedance





CM Noise Equivalent Circuit



DM Noise Equivalent Circuit

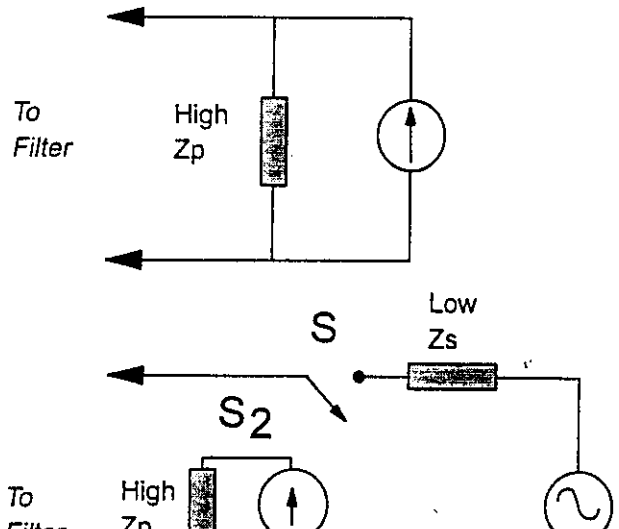
When rectifier diodes "on" $\Longrightarrow$ S_1 "on", S_2 "off"

When rectifier diodes "off" $\Longrightarrow$ S_1 "off", S_2 "on"

- Practically difficult to measure*

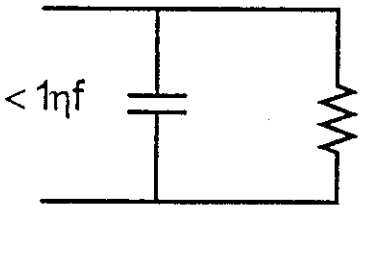
* Ref [2]

Experimental Source Impedance



CM:

Z_p:

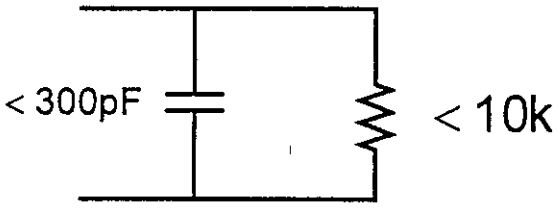


DM:

Z_S:

$1\mu H \leq 1\Omega$

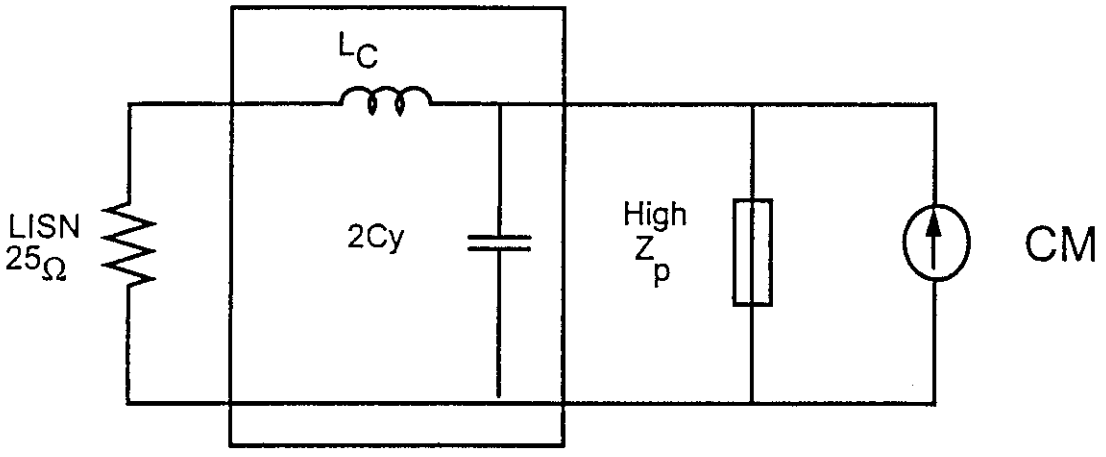
Z_p:

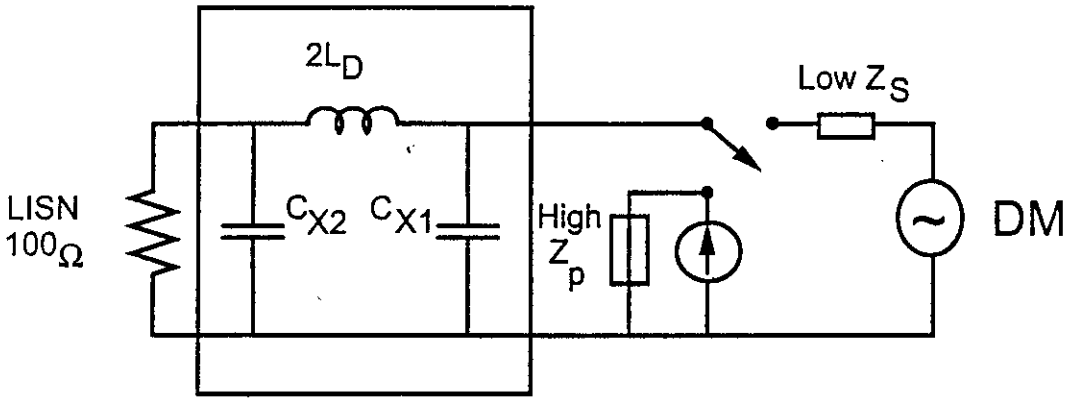


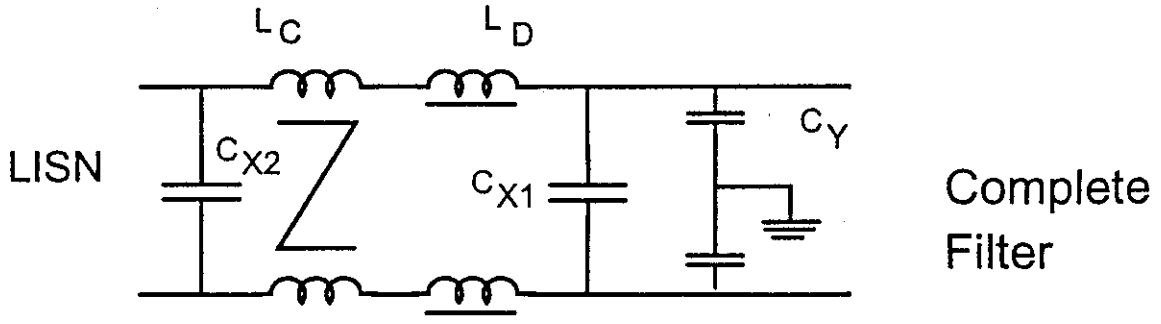
* For Power Supplies 50-500 Watts

*Ref [2], [3]

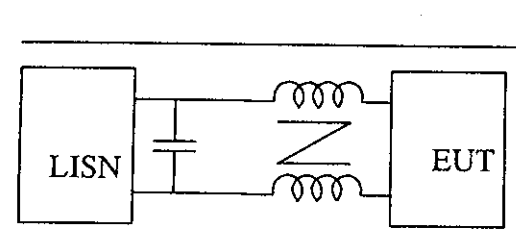
A Commonly-Used Filter Topology







How to Place X Capacitor?



	IDM	NIDM
	More Effective	Less Effective
	Less Effective	More Effective

Asymmetrical Filter Topology: X Cap is always on LISN side

Symmetrical Filter Topology: When IDM is dominant, X cap should be on LISN side; When NIDM is dominant, X cap should be on EUT side.