Recent Developments in EMI Filters

By Prof. Dan Chen

-Introduction

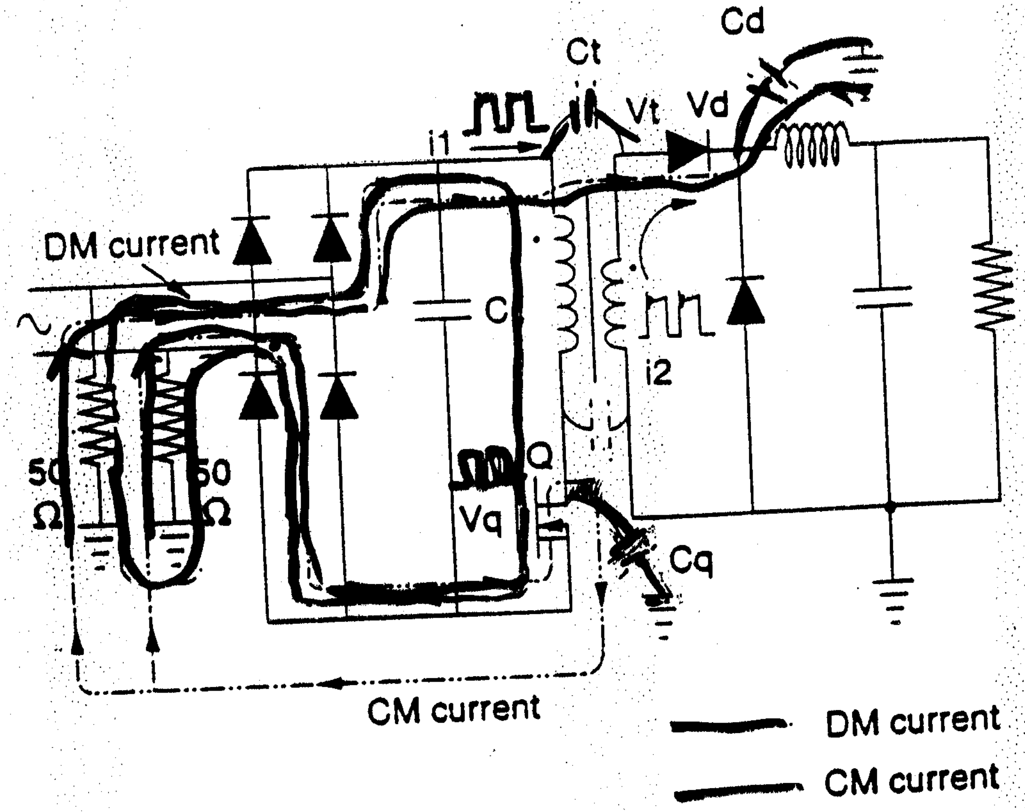
-Several Recent Techniques for EMI reduction

-Prediction/Simulation of Conducted EMI

-Effects of Parasitic Coupling

-Integration of Filters

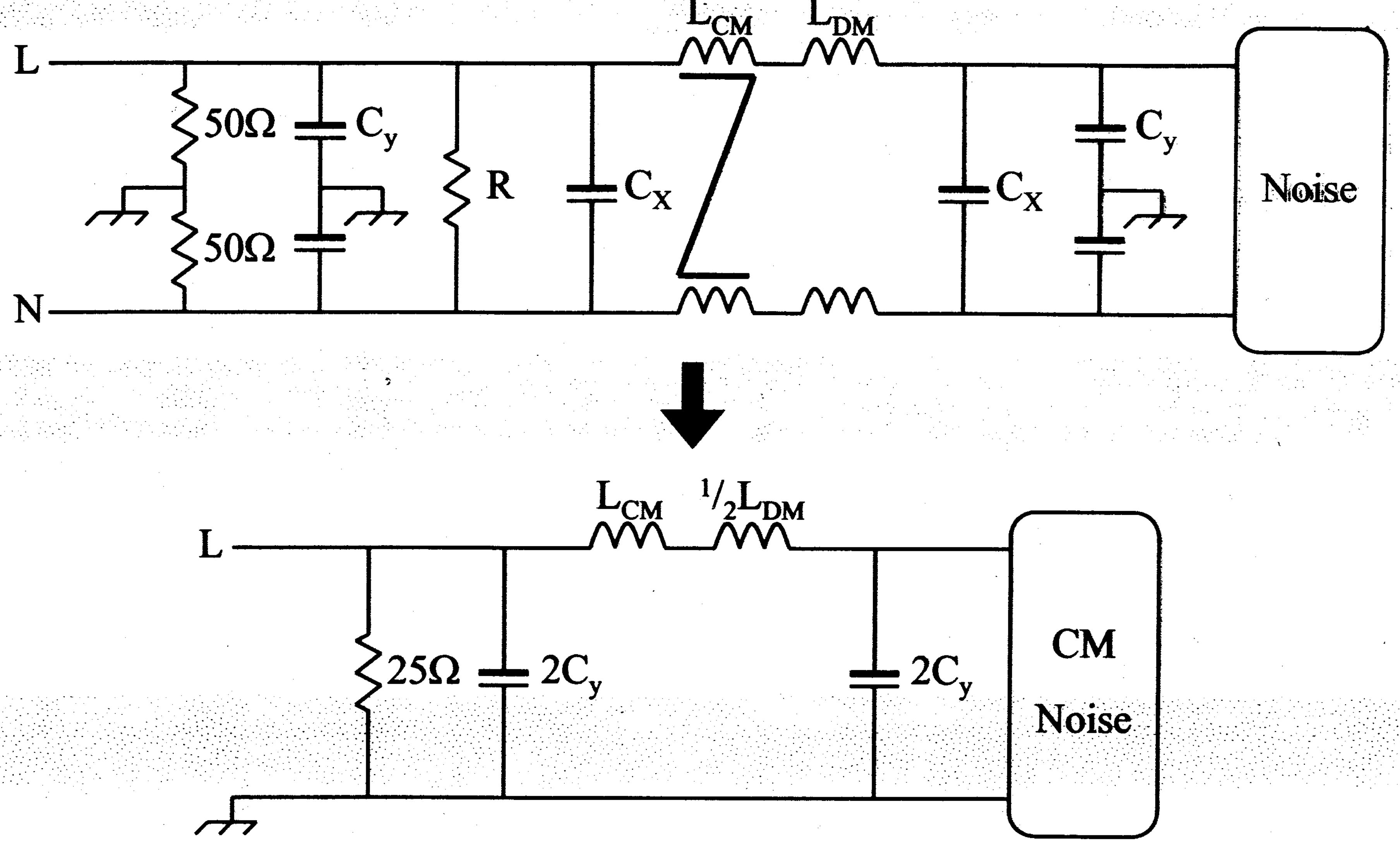
Noise Sources and Coupling Path



D.M. Noise - Caused by i_1

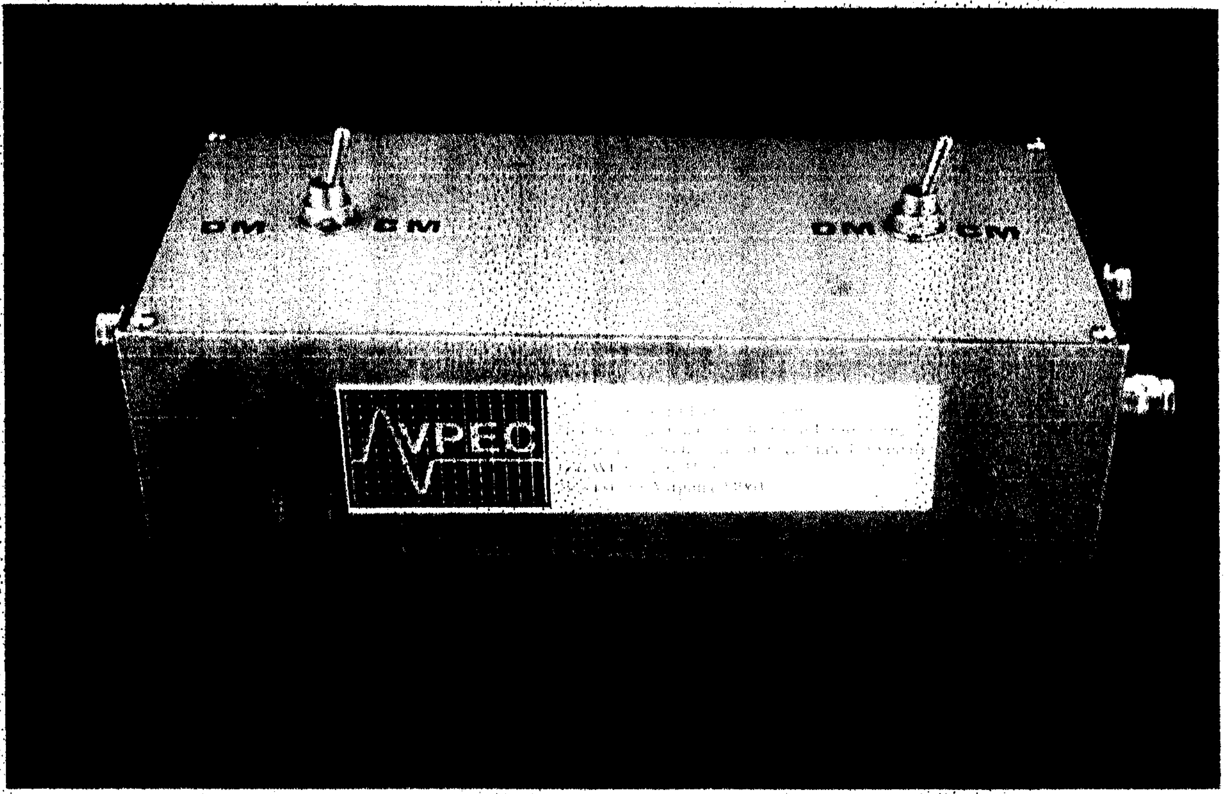
C.M. Noise - Caused by Parasitic Capacitances

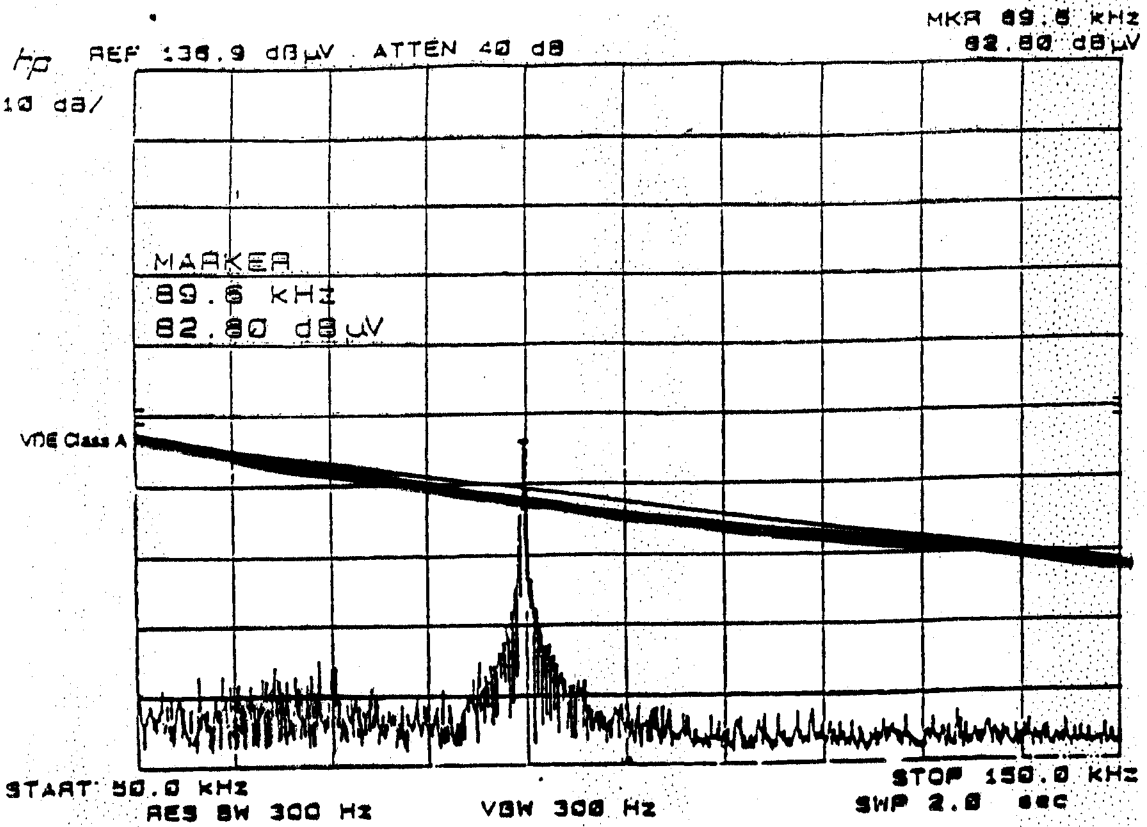
Filtering

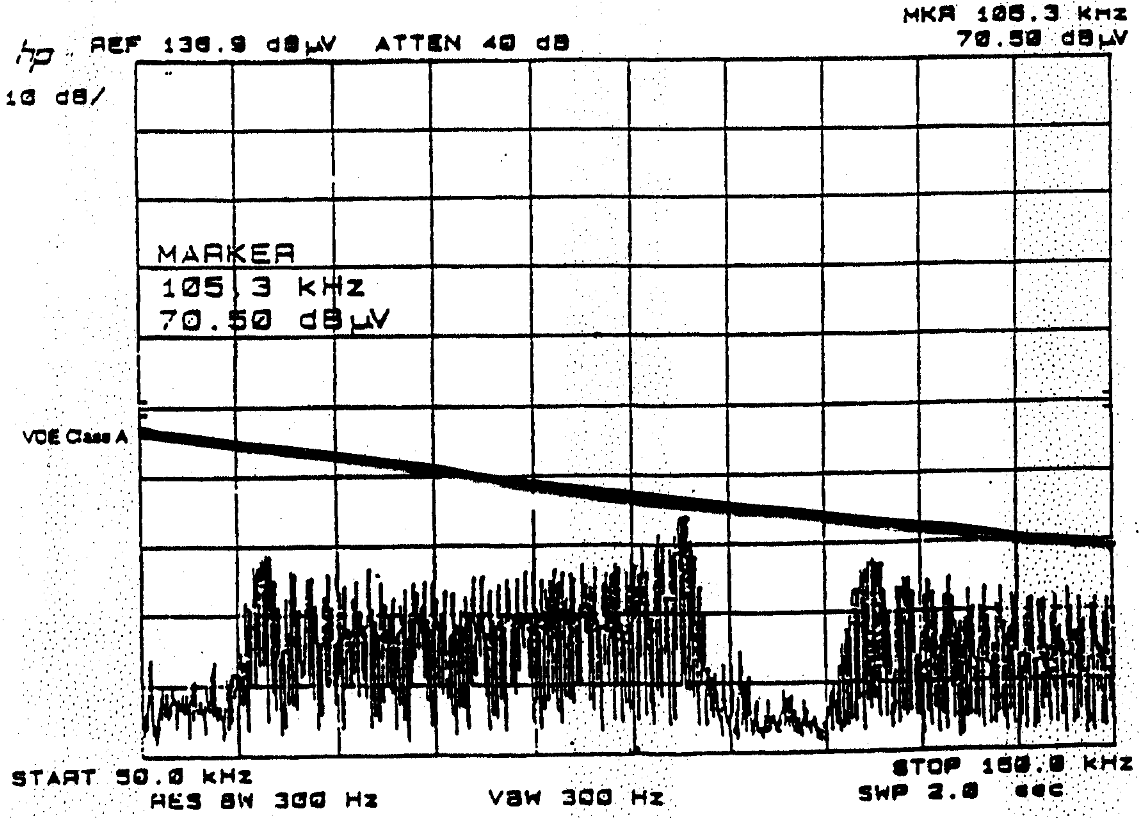

L
N
50Ω
50Ω
C_y
R
C_X
L_{CM}
L_{DM}
C_X
C_y
Noise
L
25Ω
$2C_y$
L_{CM}
$^1/_2L_{DM}$
$2C_y$
CM
Noise

Conducted EMI Reduction by Frequency Modulation

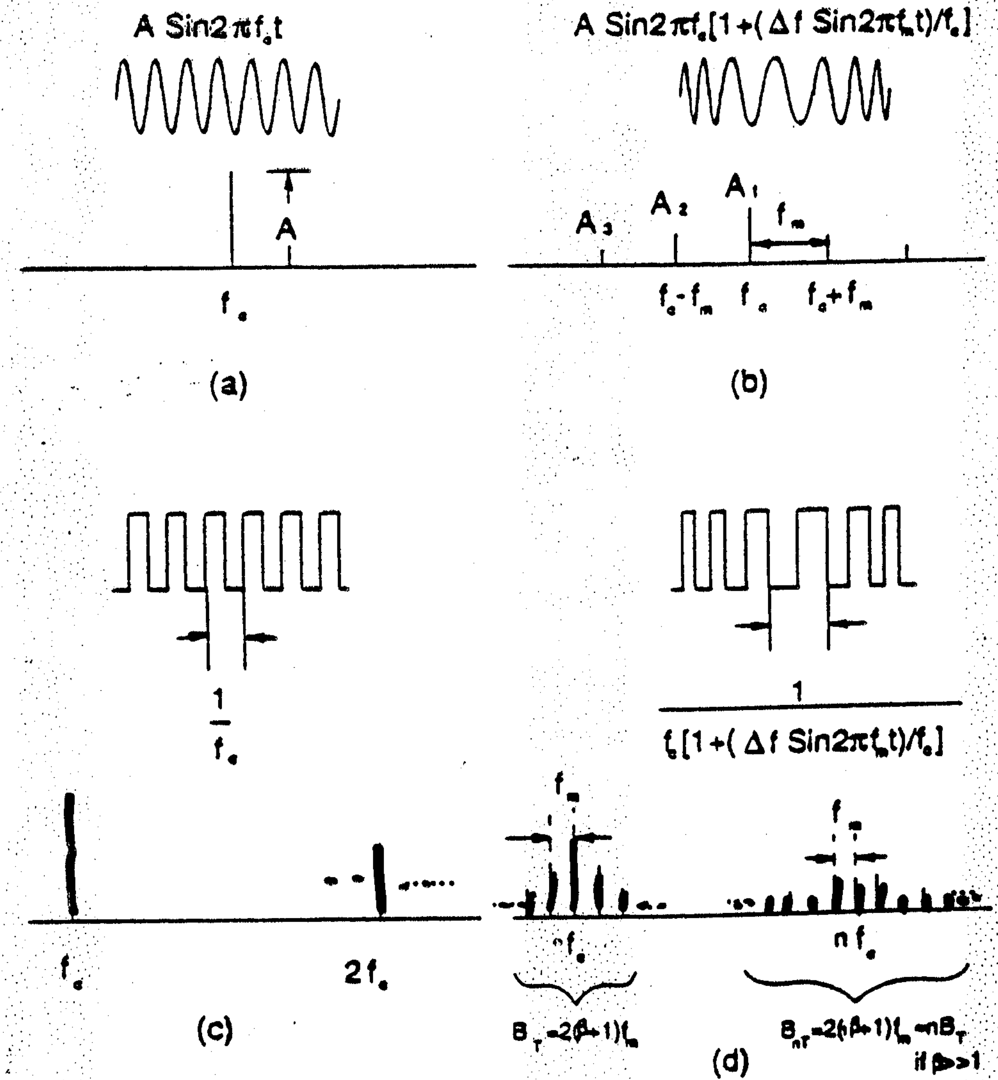
- Suppression
- Decoupling
- Filtering / Shielding
- Frequency Modulation


DM
CM
DM
CM
VPEC

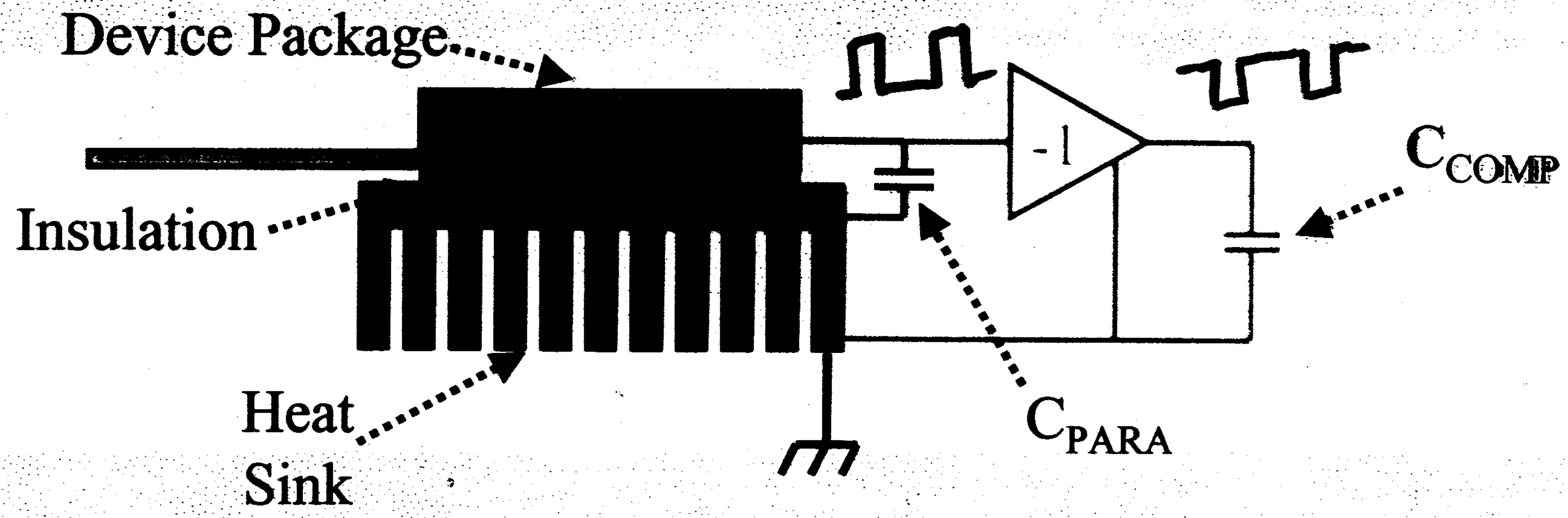

hp
REF 136.9 dBµV ATTEN 40 dB
10 dB/
MKR 89.6 kHz
82.80 dBµV
MARKER
89.6 kHz
82.80 dBµV
VDE Class A
START 50.0 kHz
RES BW 300 Hz
VBW 300 Hz
STOP 150.0 kHz
SWP 2.0 sec


hp
REF 136.9 dBµV ATTEN 40 dB
10 dB/
MKR 105.3 kHz
70.50 dBµV
MARKER
105.3 kHz
70.50 dBµV
VDE Class A
START 50.0 kHz
RES BW 300 Hz
VBW 300 Hz
STOP 150.0 kHz
SWP 2.0 sec

Frequency Spectrum of FM Signals

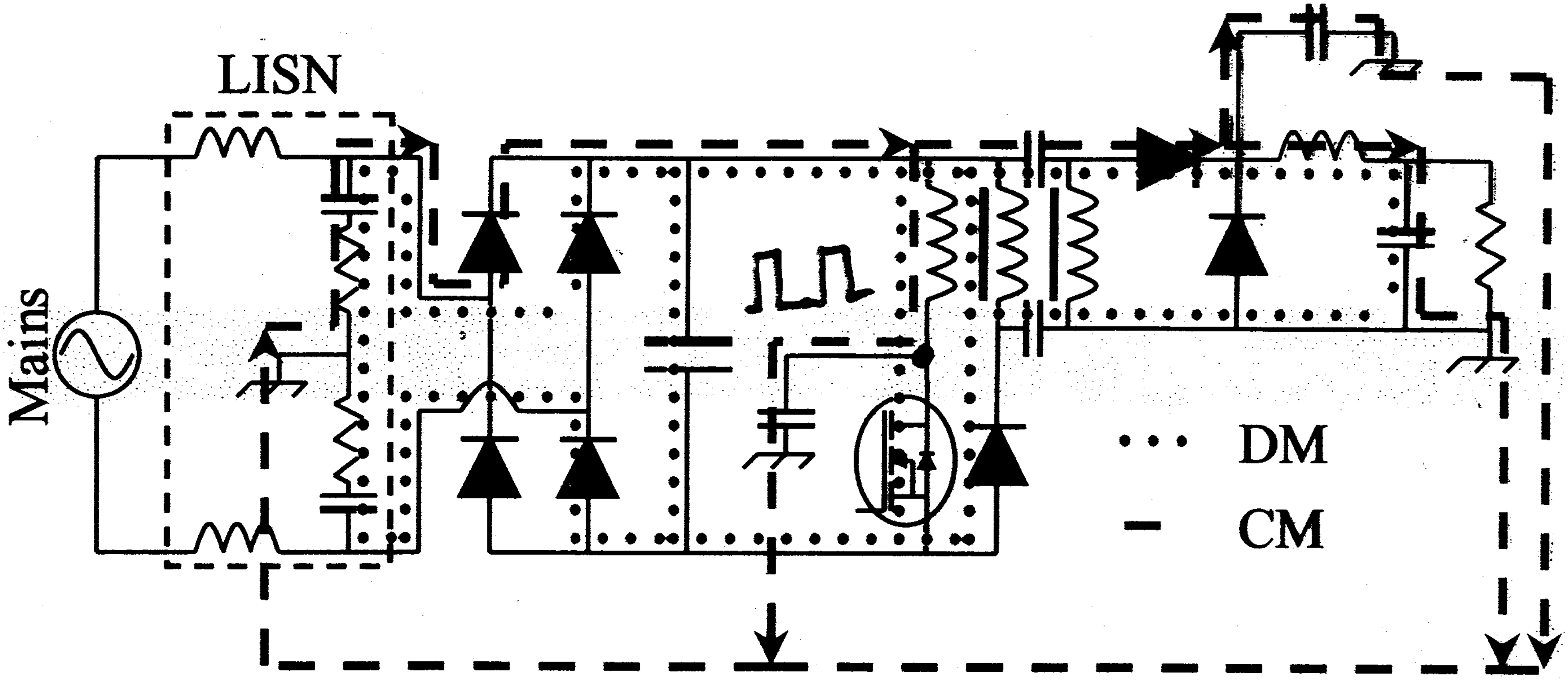


Passive Cancellation Concept

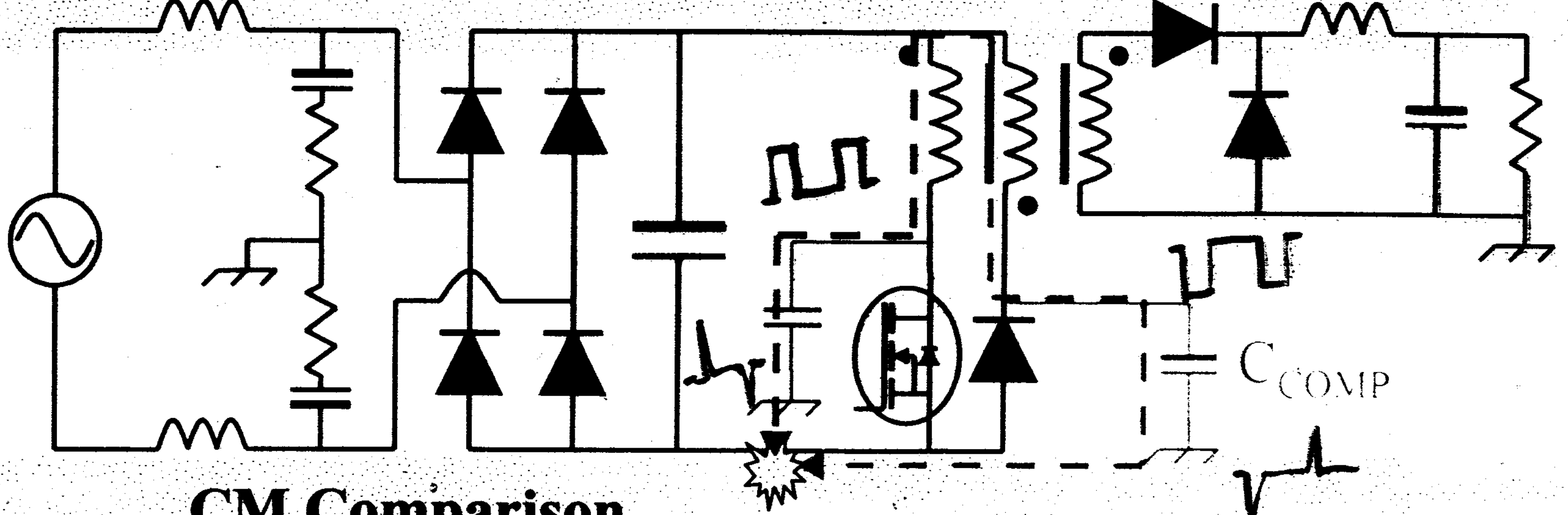


- Use transformer winding to capture switch $^{dv}/_{dt}$ and reverse polarity
- Generate equal and opposite noise current with C_{COMP}

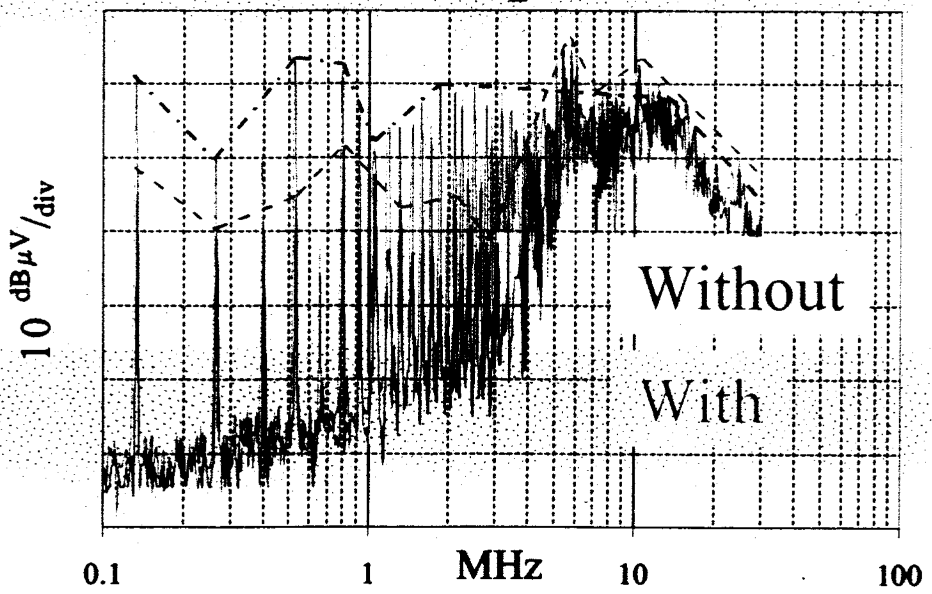
Noise Paths in a Converter



Forward Converter



CM Comparison



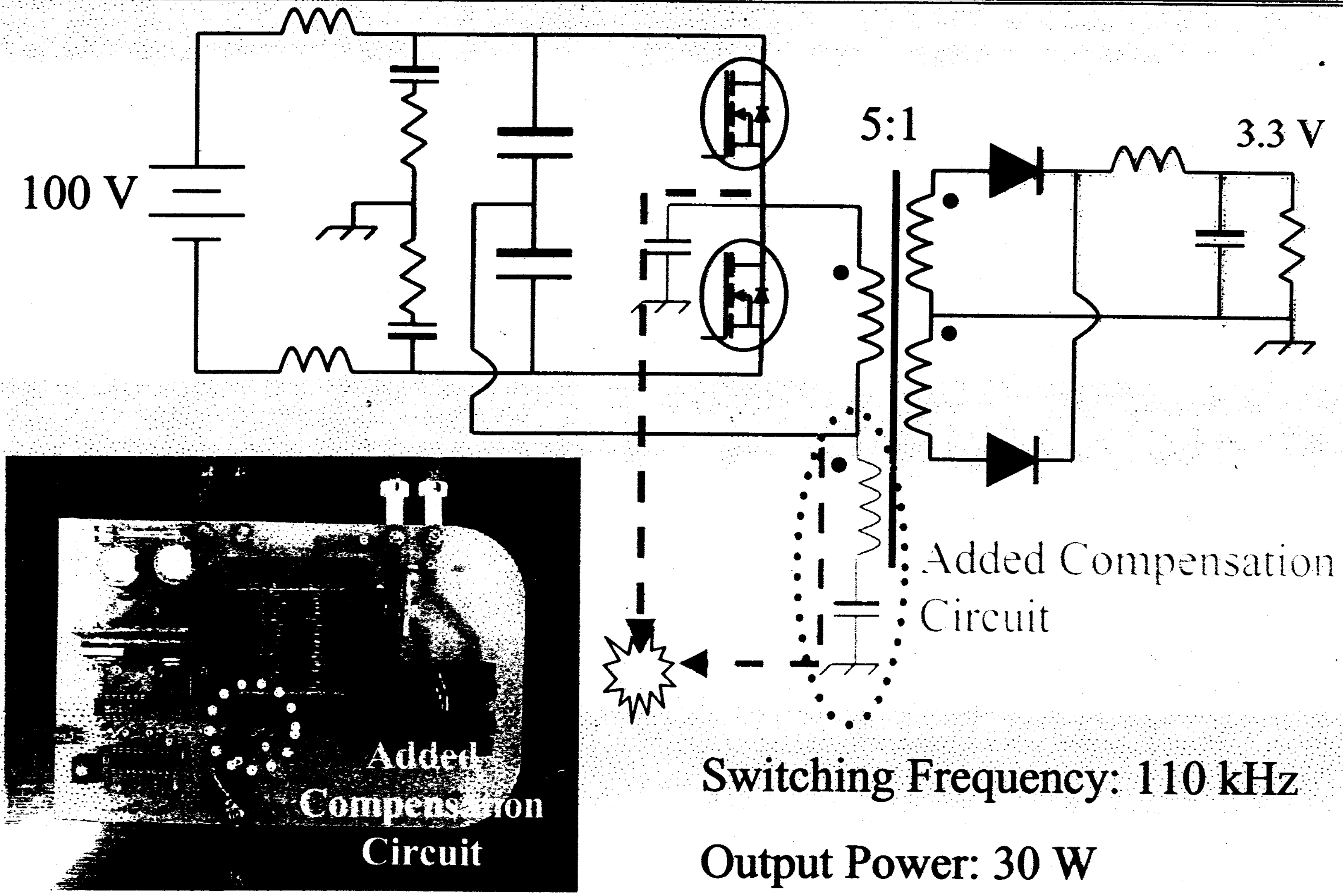
Input Voltage: 120 VAC

Output Voltage: 12 V

Output Power: 100 W

Switching Frequency: 110 kHz

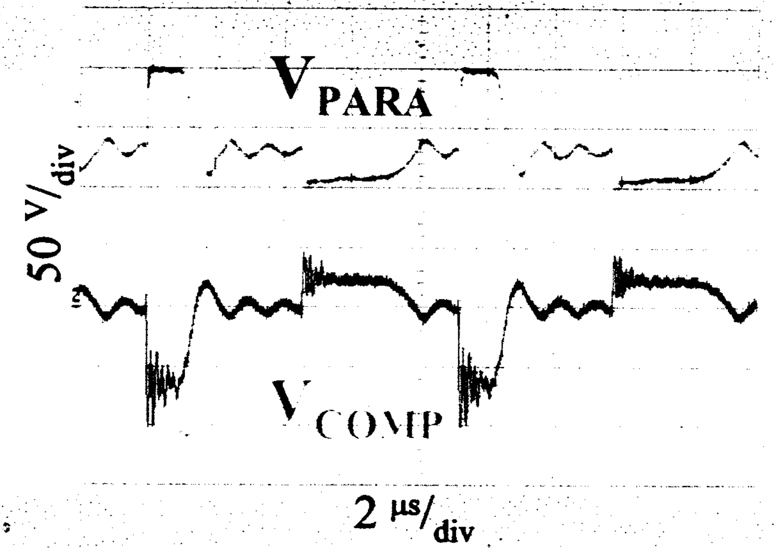
Half-Bridge DC/DC



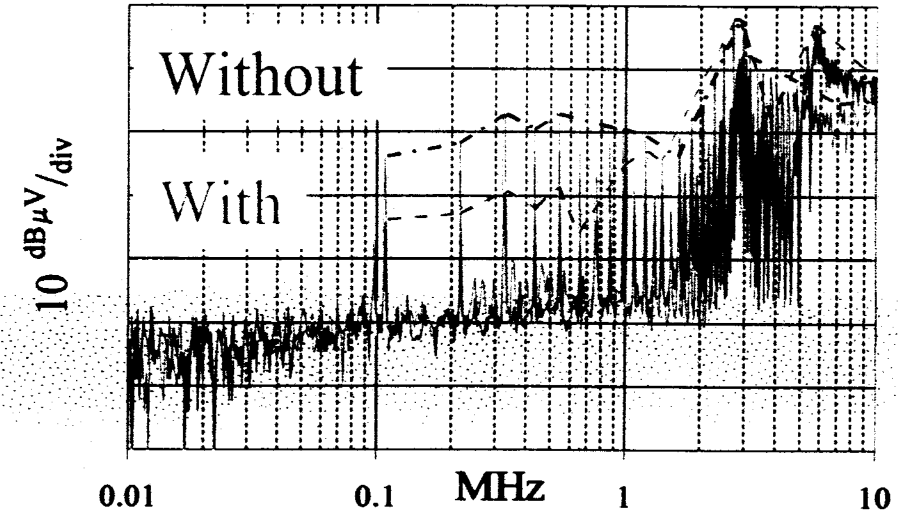
Switching Frequency: 110 kHz

Output Power: 30 W

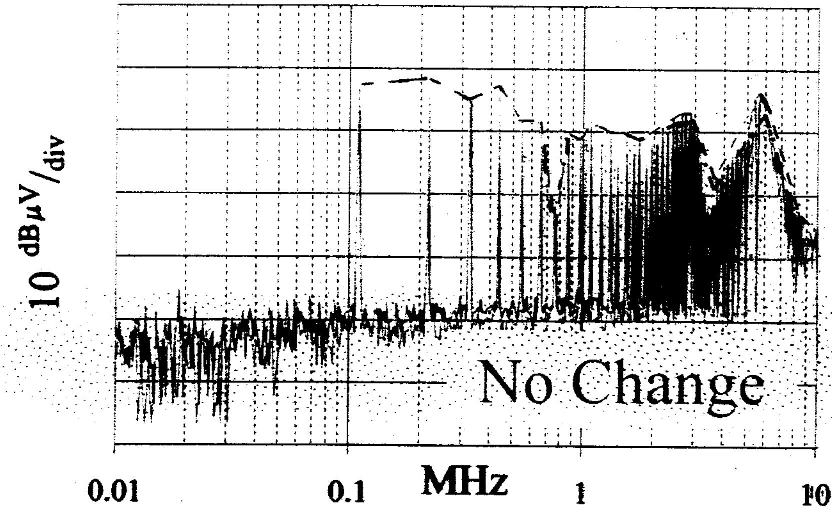
Half-Bridge Results



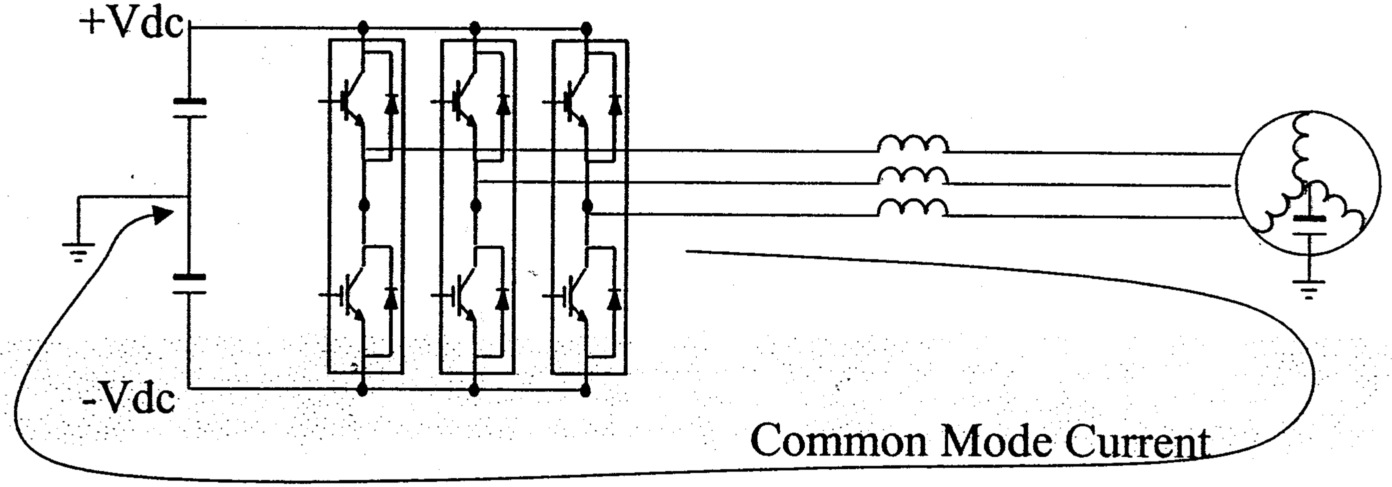
CM Comparison



DM Comparison

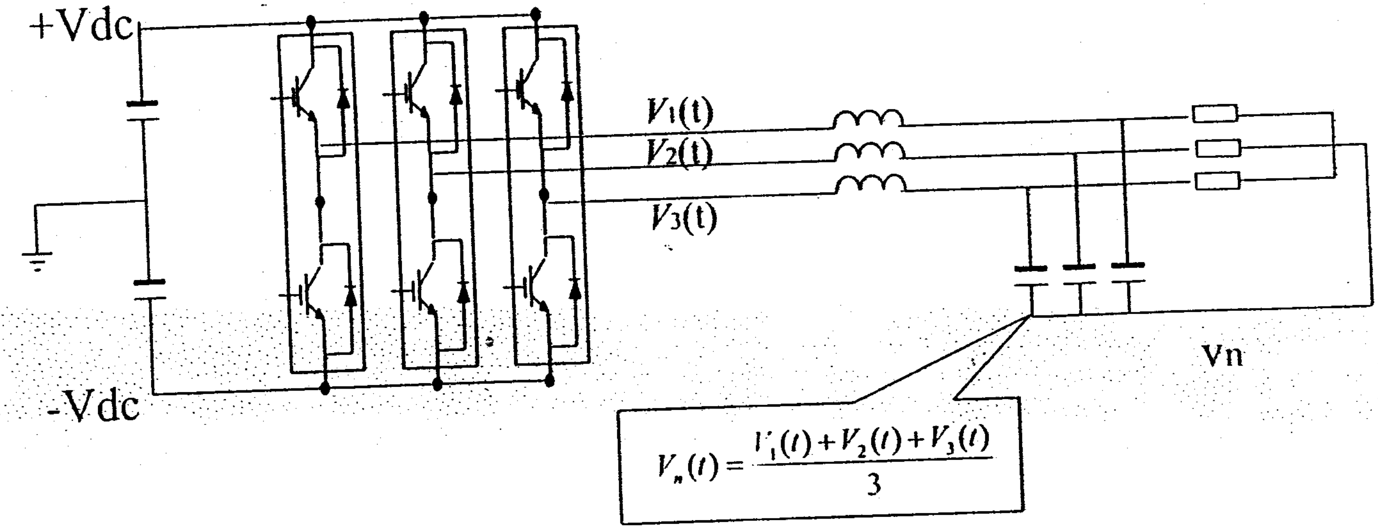


Problems Caused by Common Mode Current

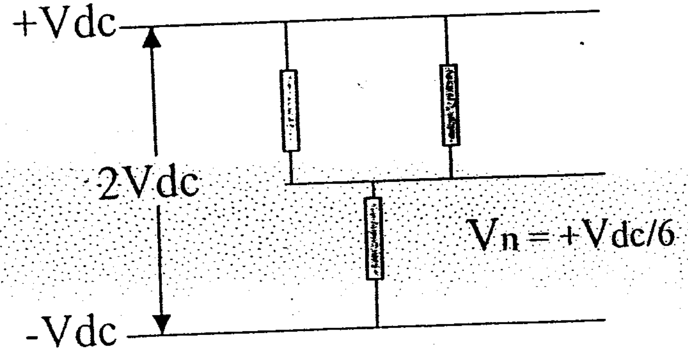


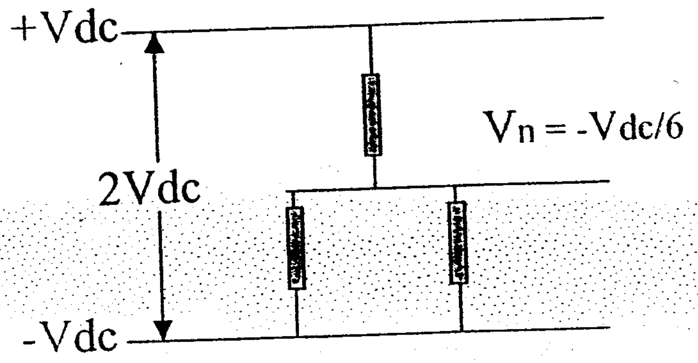
- Conducted EMI
- Damage to motor bearings
- Shortening of insulation life of motors and transformers
- Activation of ground fault detection circuit

3-leg inverter with floating load neutral point

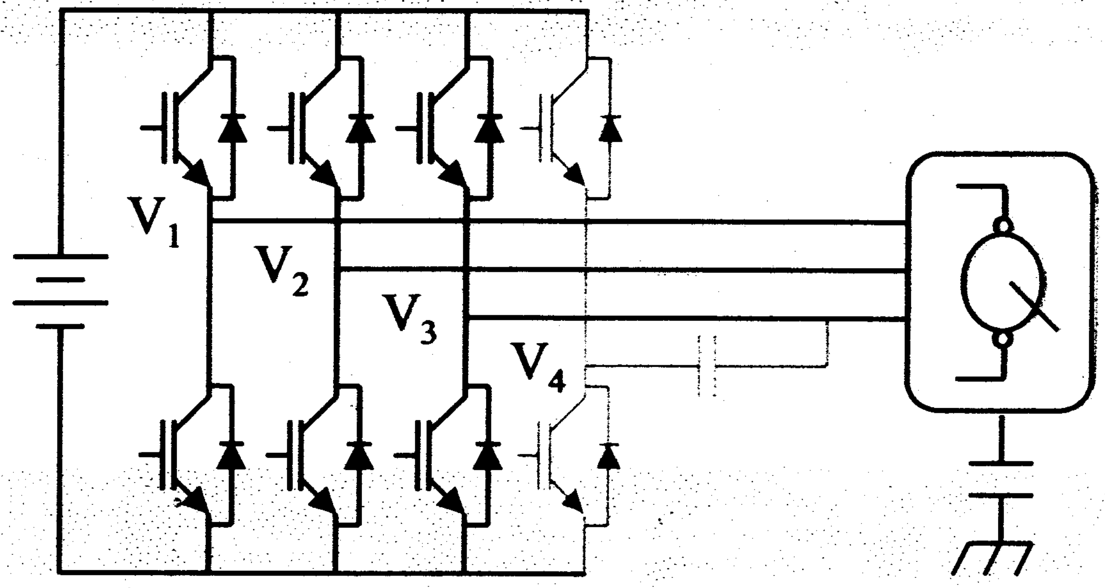


$$V_n(t) = \frac{V_1(t) + V_2(t) + V_3(t)}{3}$$





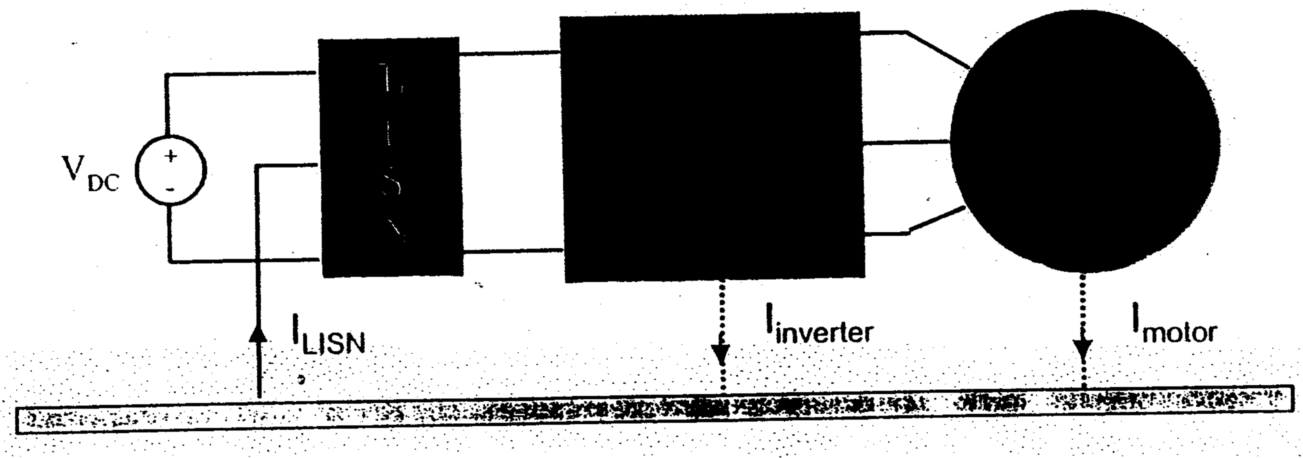
Active Cancellation



Modulate such that $V_1 + V_2 + V_3 + V_4 = 0$

Oriti, Julian, Lipo, “A New Space Vector Modulation
Strategy for Common Mode Voltage Reduction”, PESC ‘97

3-Phase PWM inverter-fed AC motor drive system

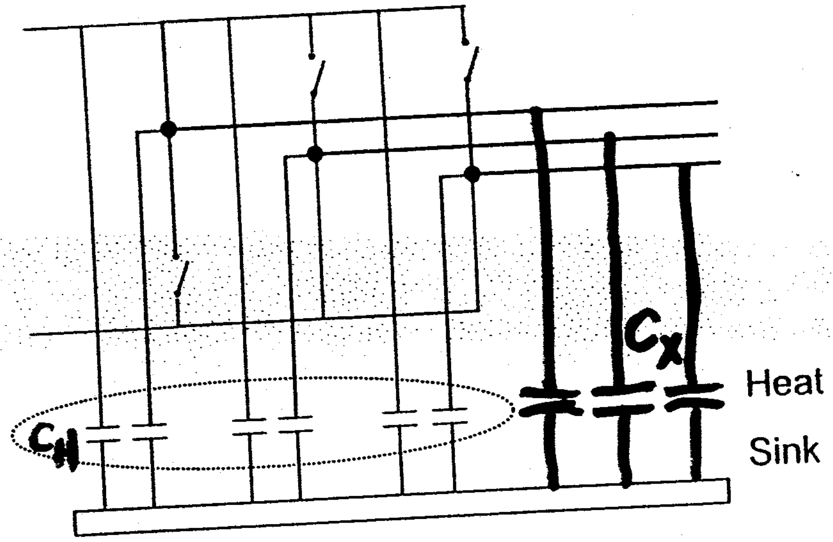


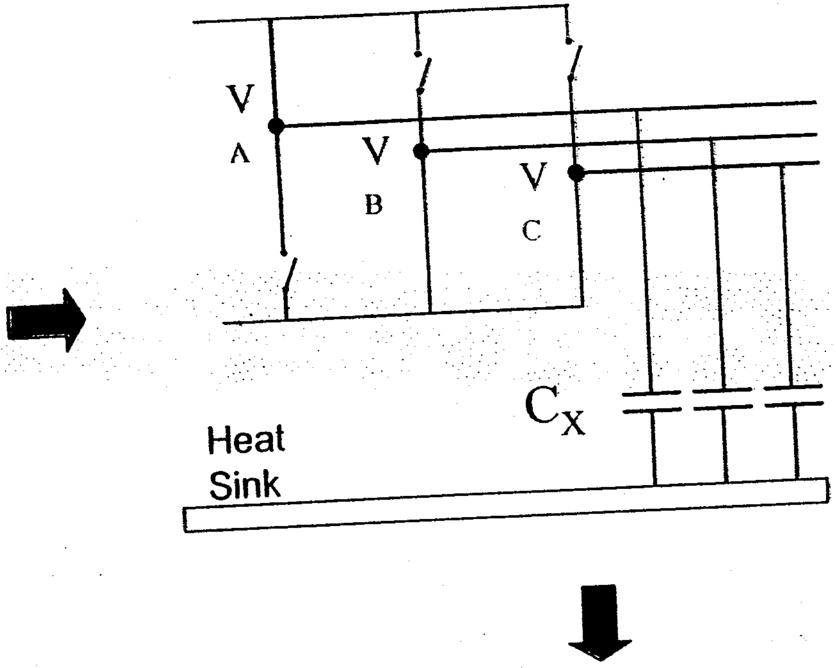
$$I_{CM}=I_{LISN}=I_{inverter}+I_{motor}$$

- **Undesirable influence on the motor current control**
- **Incorrect operation of current-operated circuit breakers**
- **Cause electromagnetic interference**

Make V_{N1} equal to V_{N2}

Method C: Add compensation capacitors to heat sink



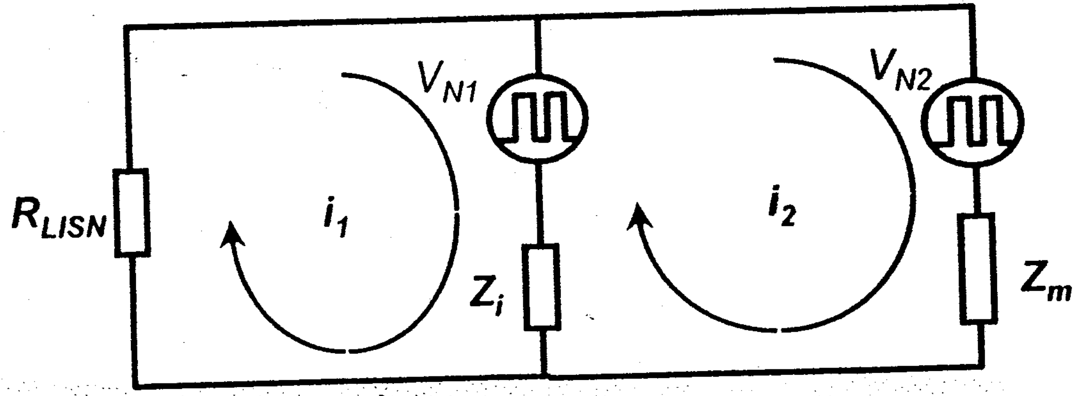


V_{N1}= Noise voltage on heat sink

$V_{N1}=(V_A+V_B+V_C)/3=V_{N2}$

$C_X >> C_H$ → C_H can be neglected

Equivalent Circuit of CM Current Loop



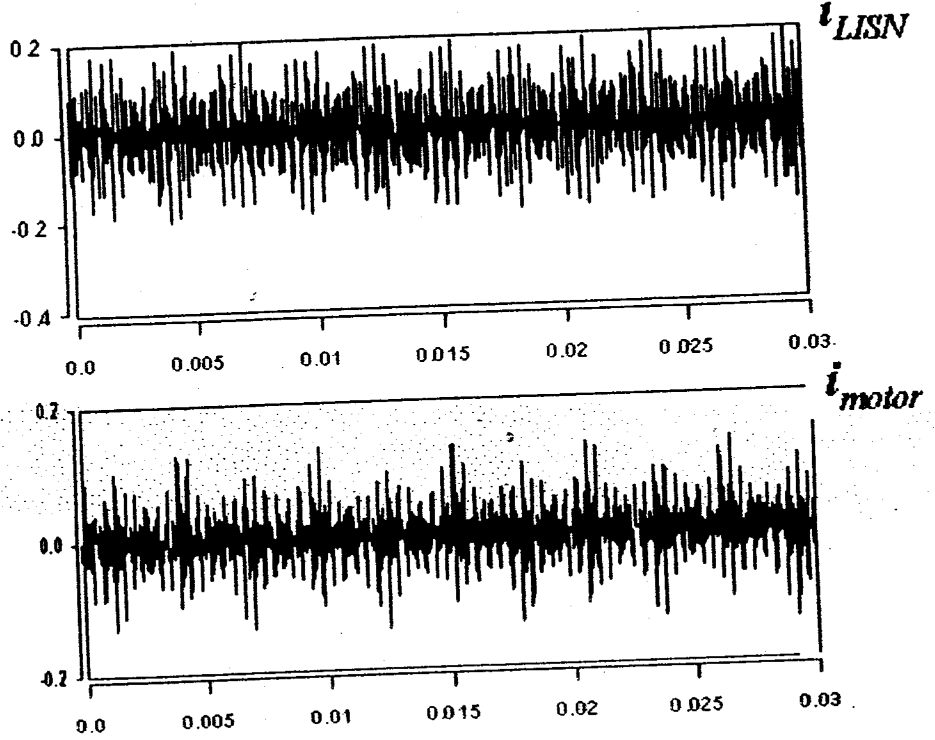
$$Z_i = \frac{1}{6C_H s} + L_H s + R_H$$

$$Z_m = \frac{1}{3} L_{cable} s + \frac{1}{3C_s s} + R_G$$

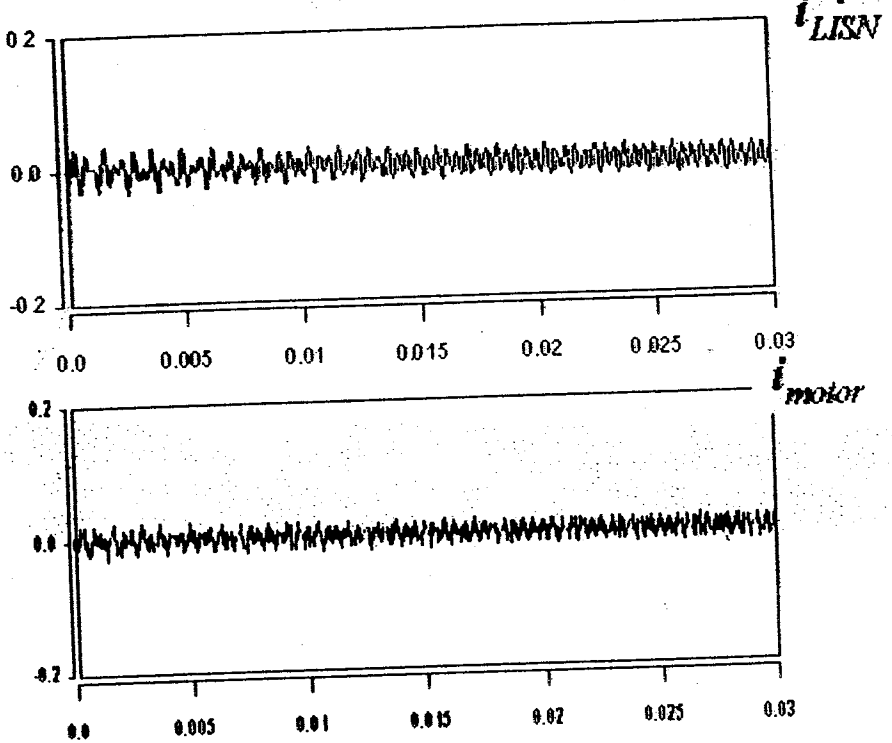
$$i_{LISN} = i_1 = \frac{v_{n1}}{\frac{Z_i}{Z_m} R_{LISN} + Z_i + R_{LISN}} + \frac{v_{n2}}{\frac{Z_m}{Z_i} R_{LISN} + Z_m + R_{LISN}}$$

$$i_{motor} = i_2 = -\frac{v_{n1}}{\frac{Z_i Z_m}{R_{LISN}} + Z_i + Z_m} + \frac{v_{n2}}{\frac{Z_i R_{LISN}}{Z_i + R_{LISN}} + Z_m}$$

Compare simulation results of Method A and C



method A



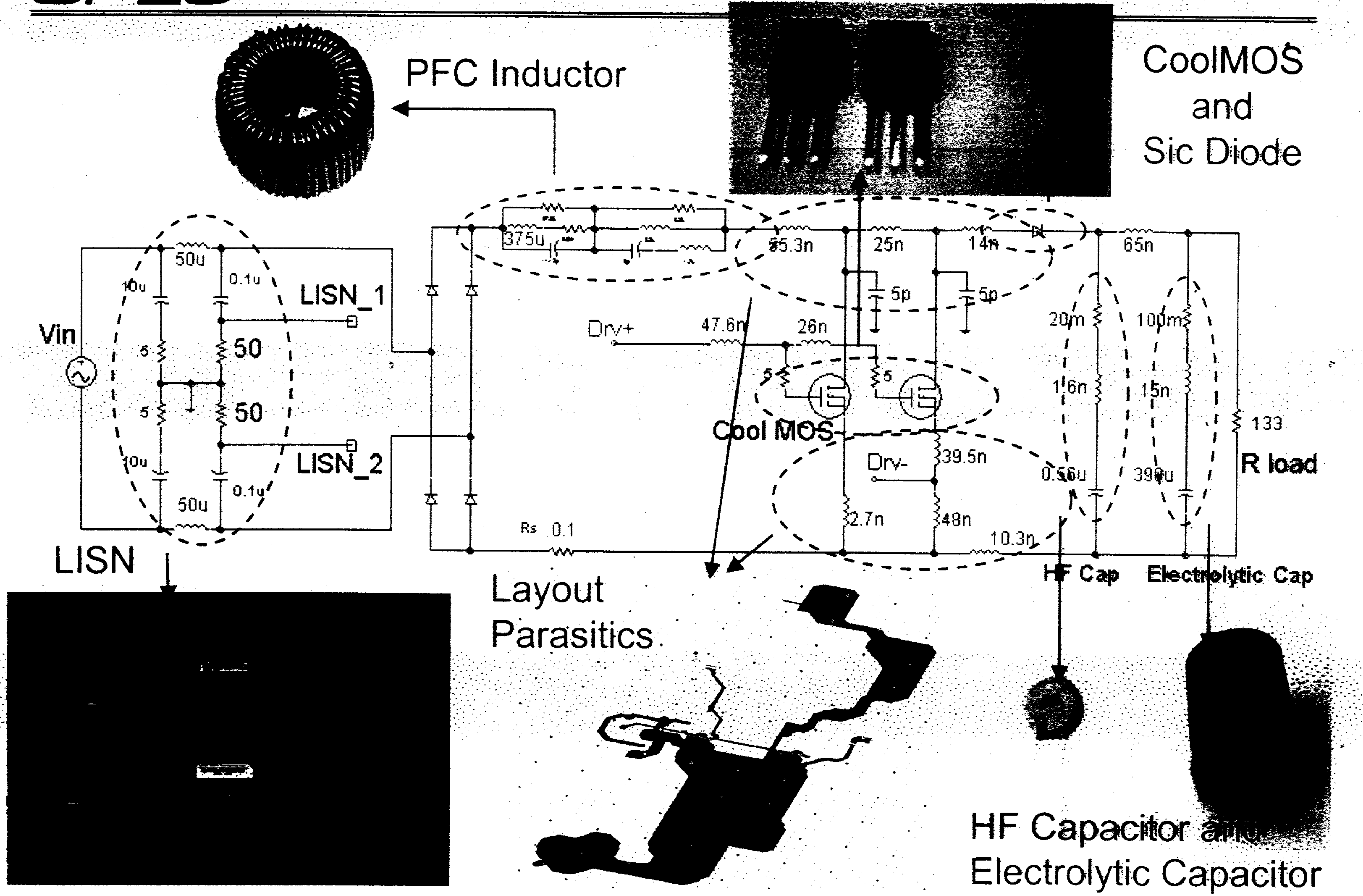
method C

Compared with method A and C, method C significantly attenuate CM currents

Power Circuit EMI Simulation Steps

- Component modeling (impedance analyzer)
- Layout Modeling (Ansoft “Maxwell”)
- Time –Domain simulation (SPICE ect)
- Conversion to Freq. Domain info. (Fast-Fourier Transform)

System Simulation Circuit for Conducted EMI



PFC Inductor

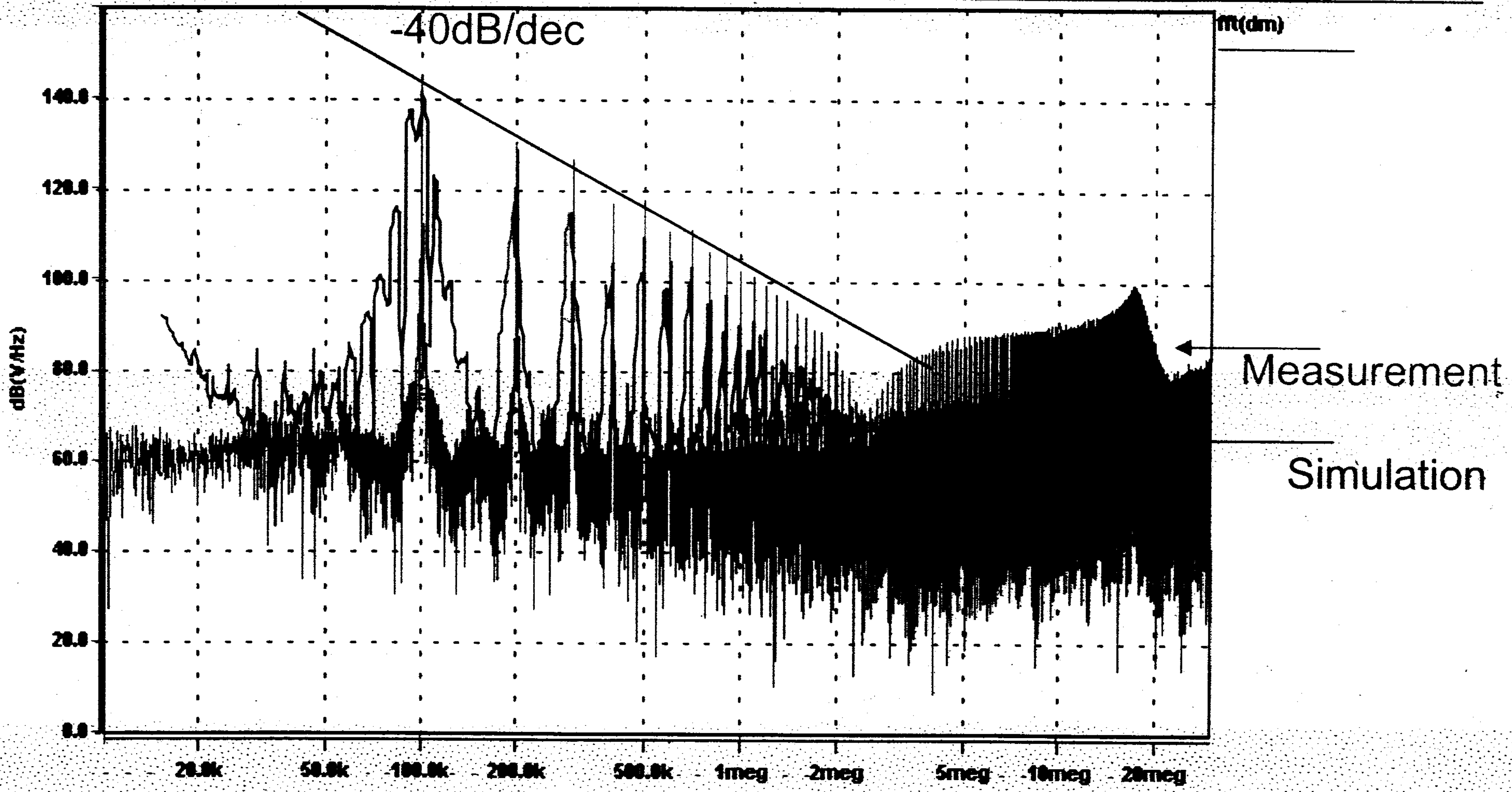
CoolMOS
and
Sic Diode

LISN

Layout
Parasitics

HF Capacitor and
Electrolytic Capacitor

Problems in DM noise measurement



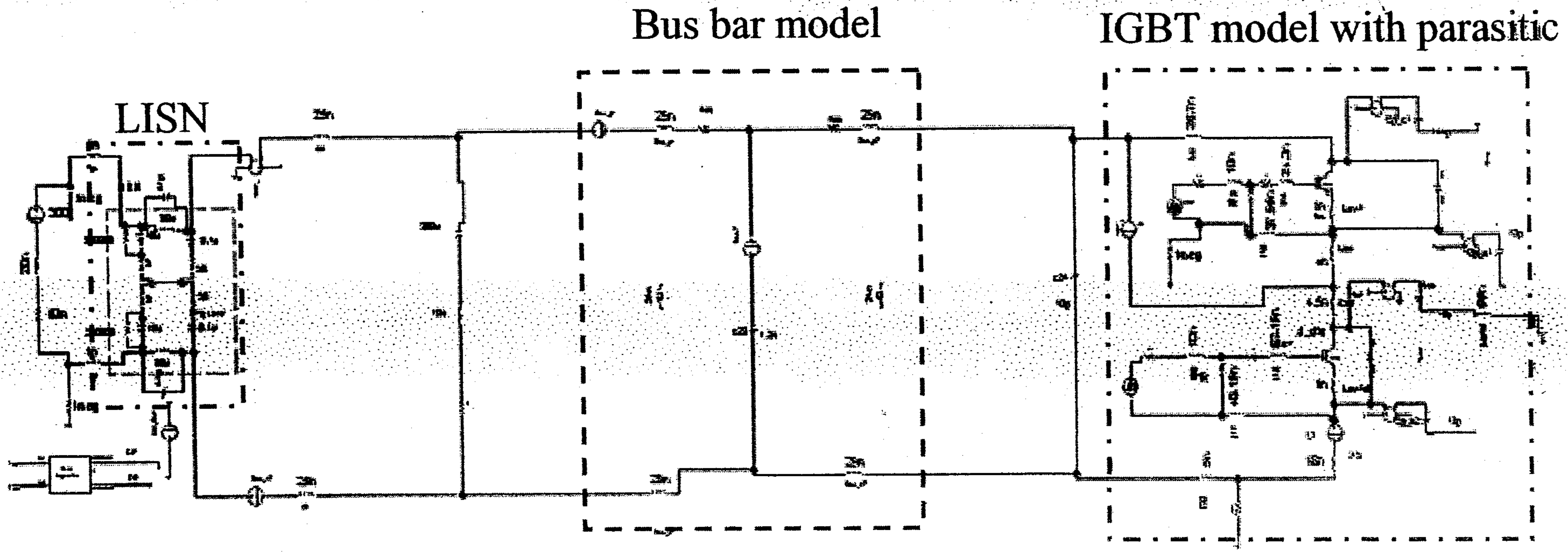
Problems:

- ☐ **Noise level in low frequency cannot match the simulated level.**
- ☐ **The slope in low frequency is not –40dB/dec.**

Verification of Model in Single-Leg Testing

Single-leg Testing

Single-leg Simulatio



Comparison of LISN Measurement Noise

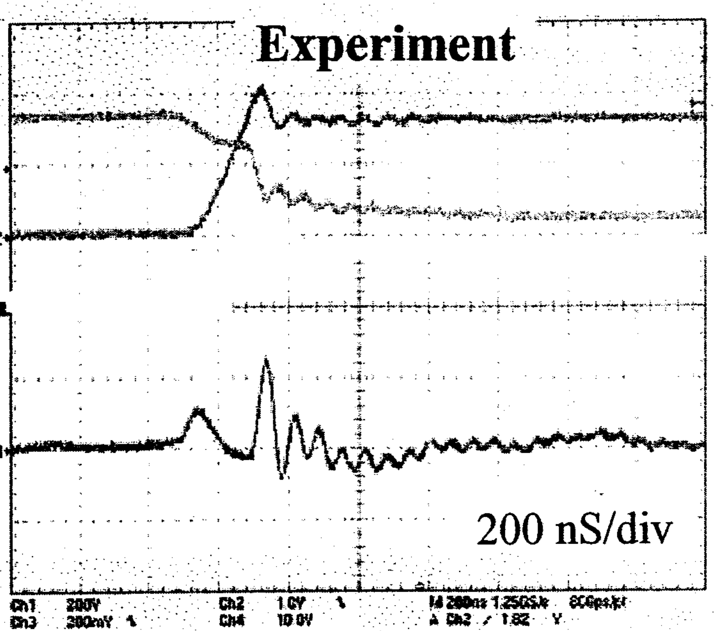
Experiment

200V/div

100A/div

CM

10 V/div



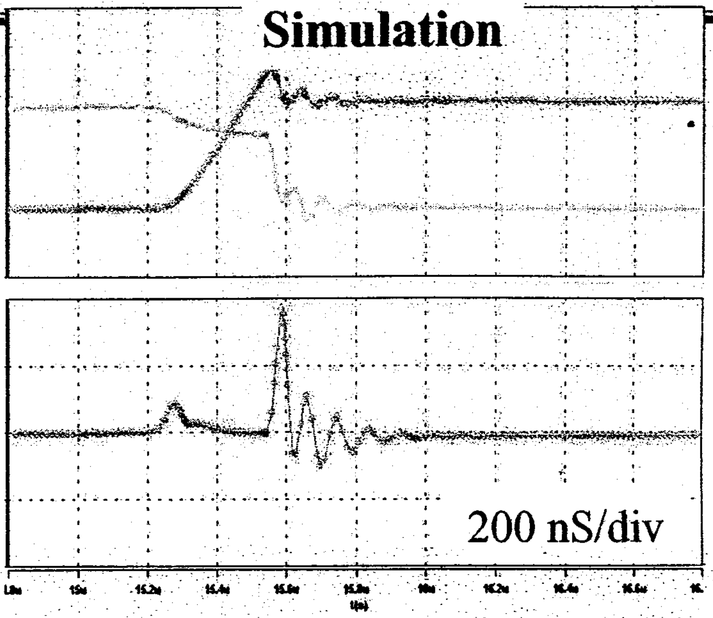
Simulation

200V/div

100A/div

CM

10 V/div



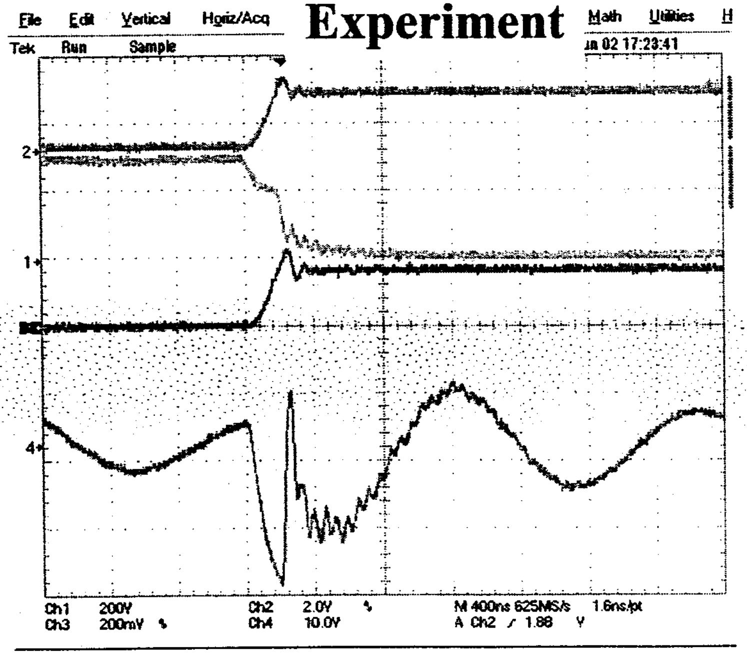
Experiment

200V/div

200A/div

10 V/div

DM



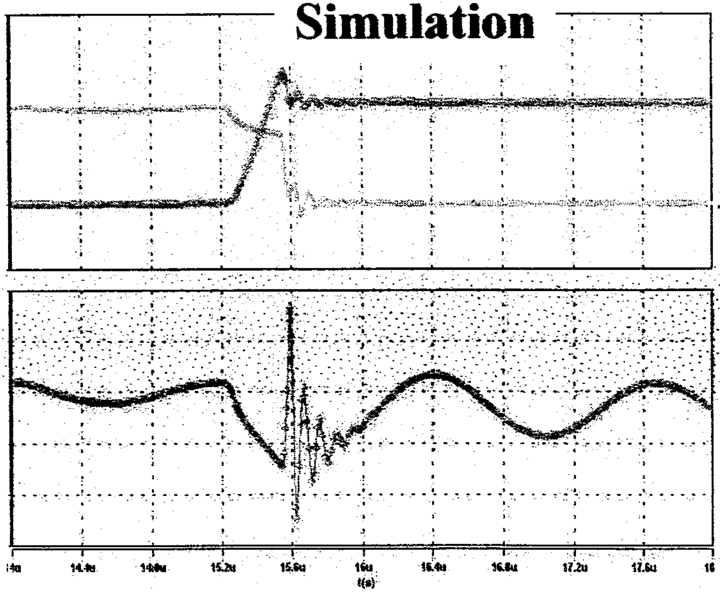
Simulation

200V/div

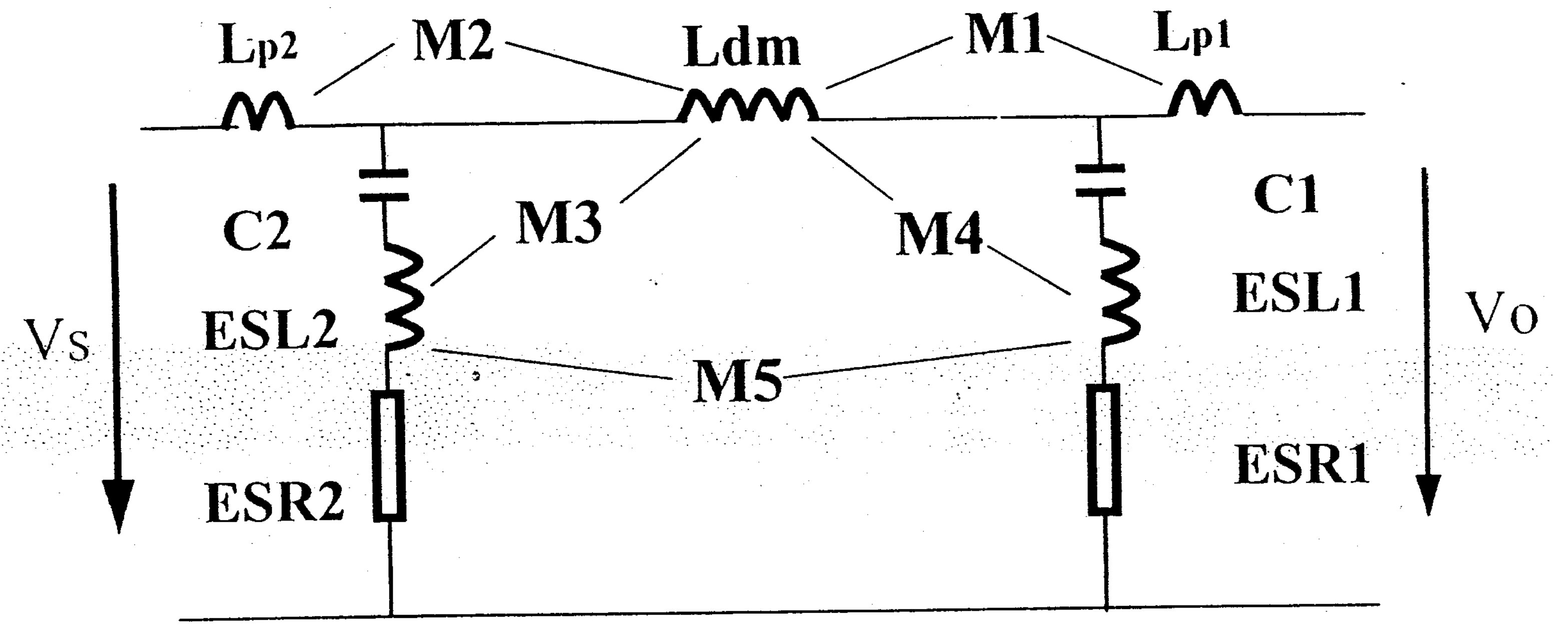
100A/div

10 V/div

DM

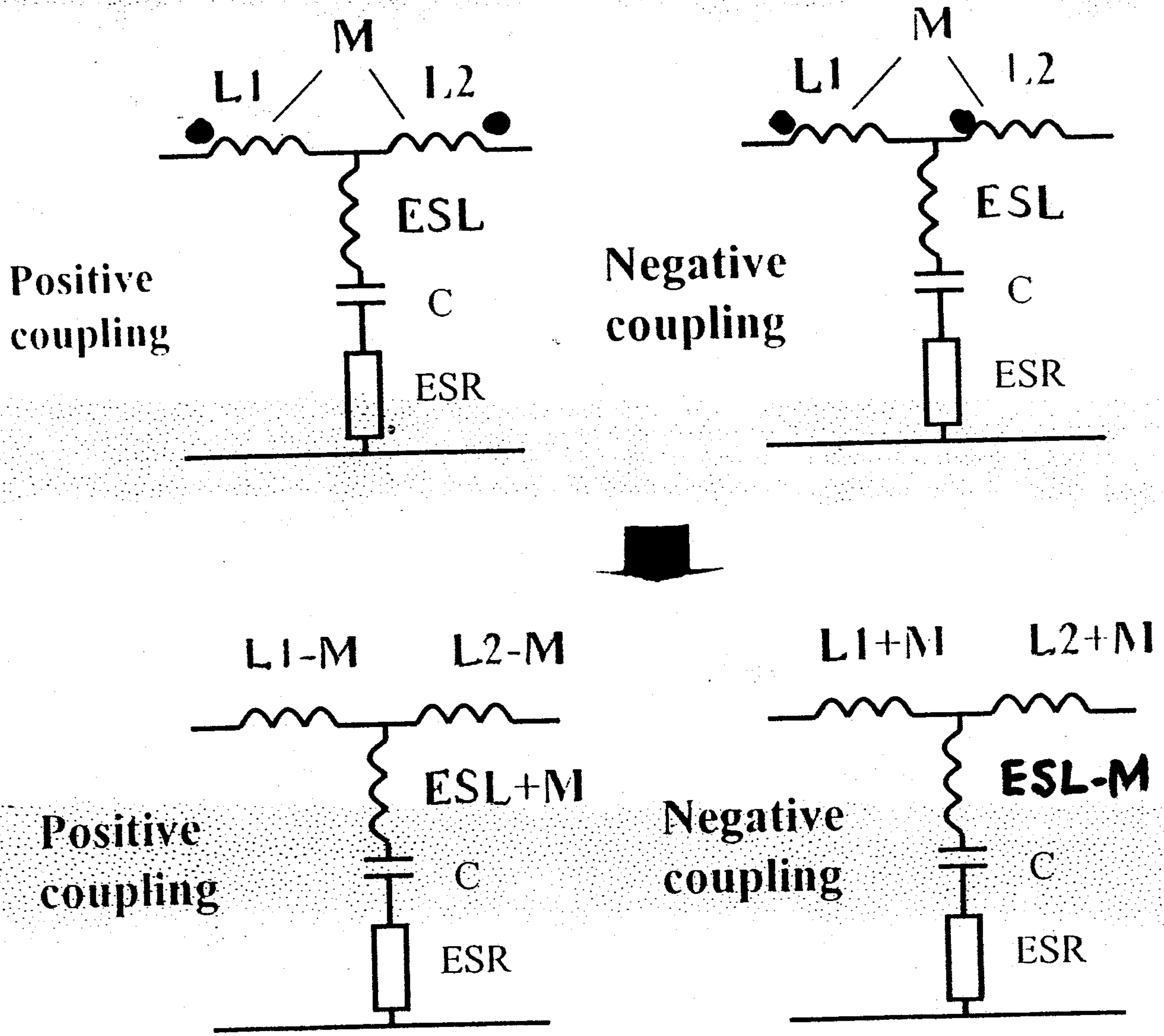


The Inductive couplings existing in DM filters

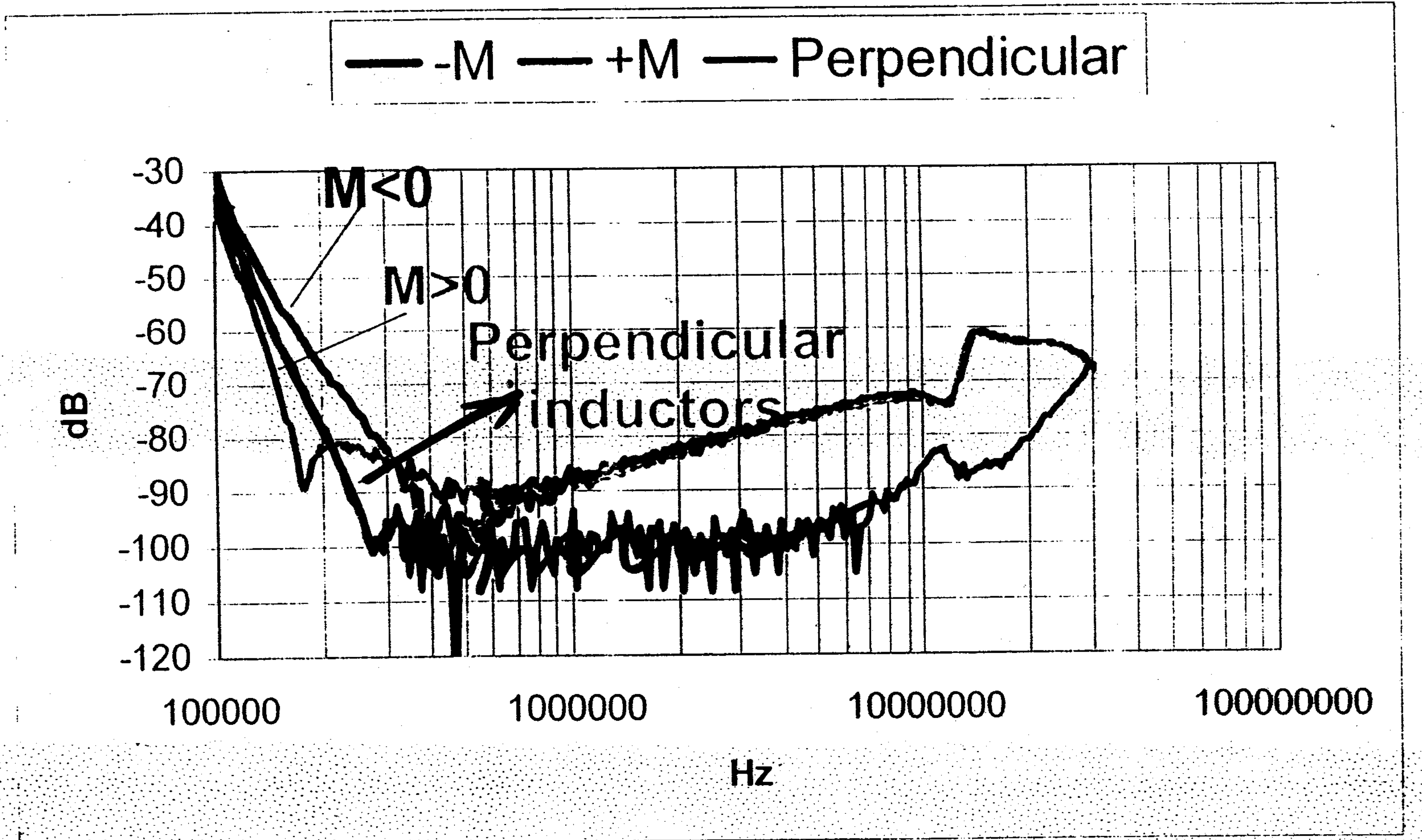


All couplings would affect the capacitor branches;
The filter performance is affected by these couplings.

The coupling effects in the T filter network

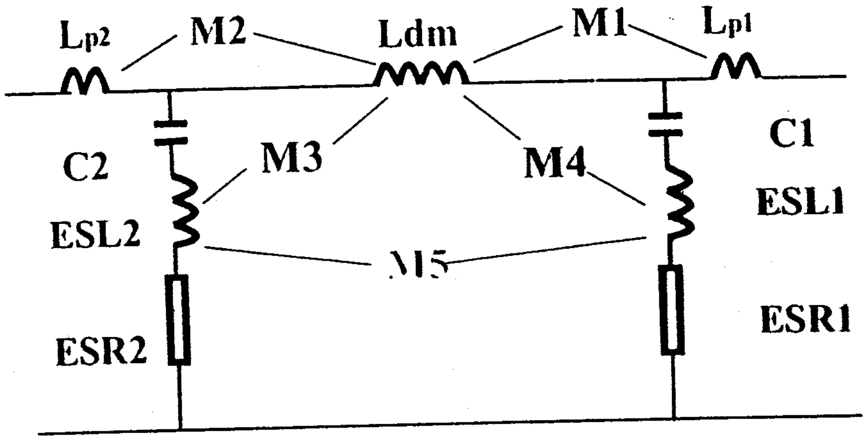


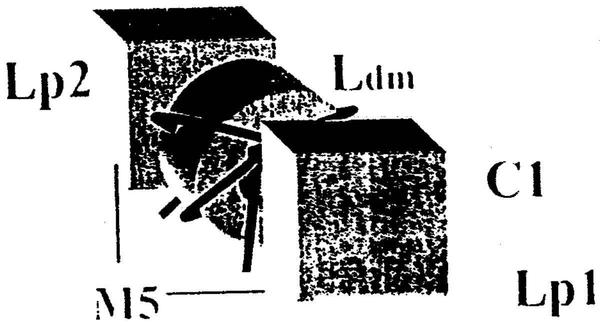
The transfer gain comparison



Perpendicular inductors offer the best performance at the expense of larger space

The coupling between capacitor branches

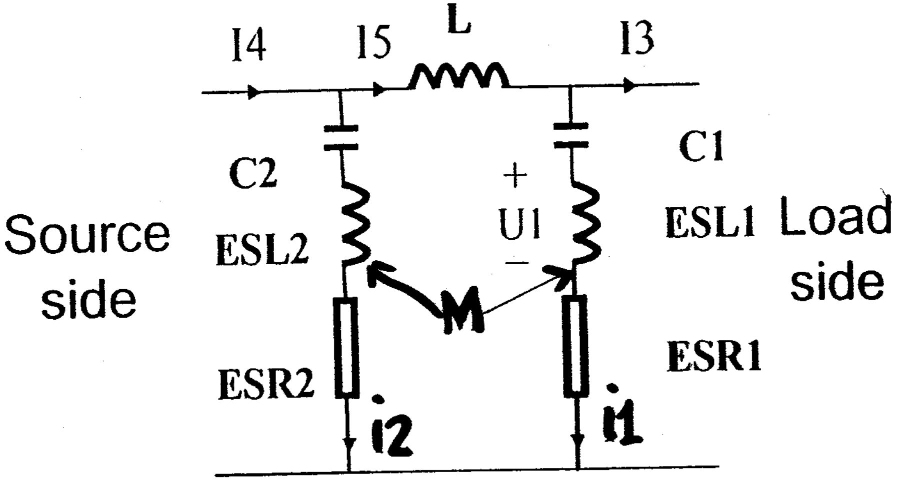




M5 caused by:

a. Capacitor structure

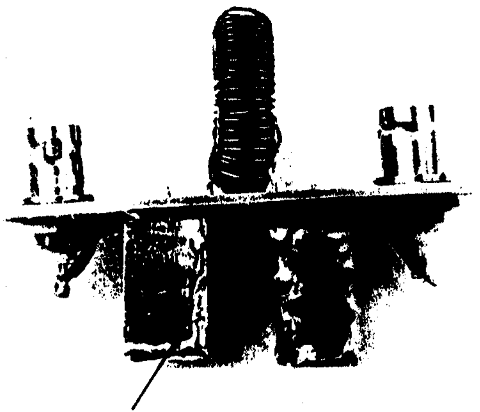
b. Pin and layout



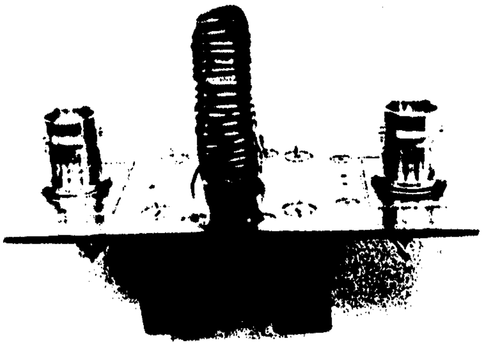
$$\dot{U}_1 = j\omega\dot{I}_1 \bullet ESL1 + j\omega\dot{I}_2 \bullet M = j\omega\dot{I}_1(ESL1 + \frac{\dot{I}_2}{\dot{I}_1}M)$$

I2 >> I1, M is amplified by I2/I1 times

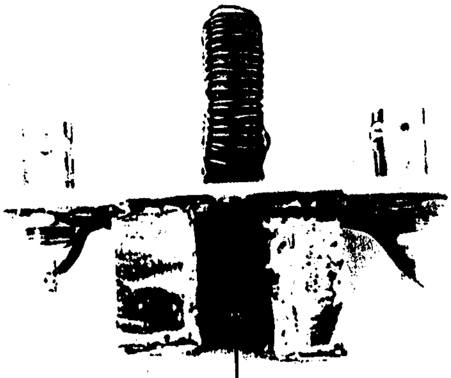
The coupling between capacitor branches



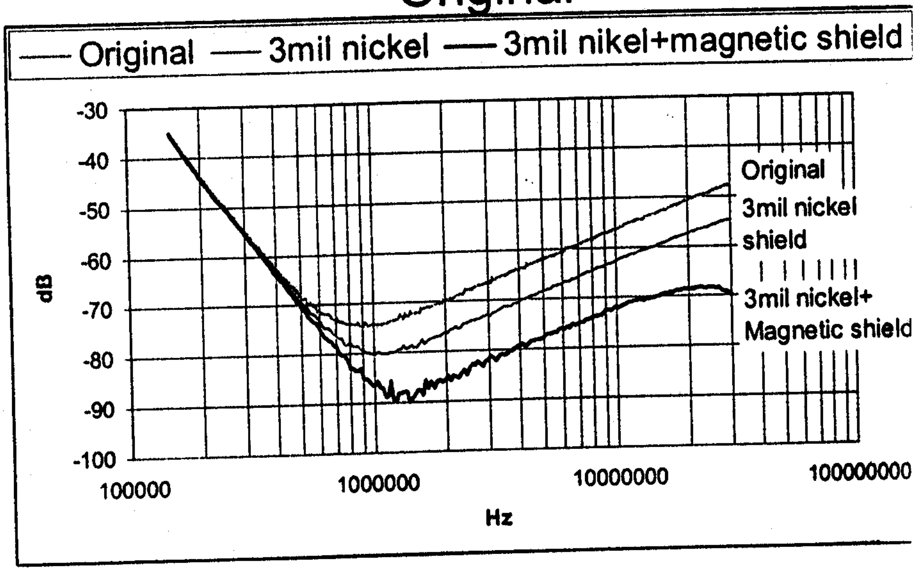
3mil nickel



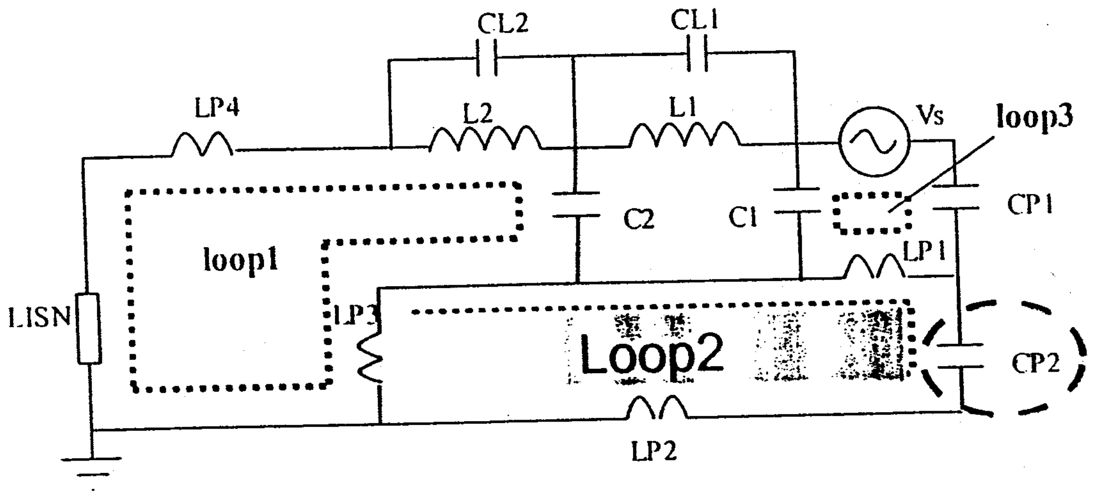
Original



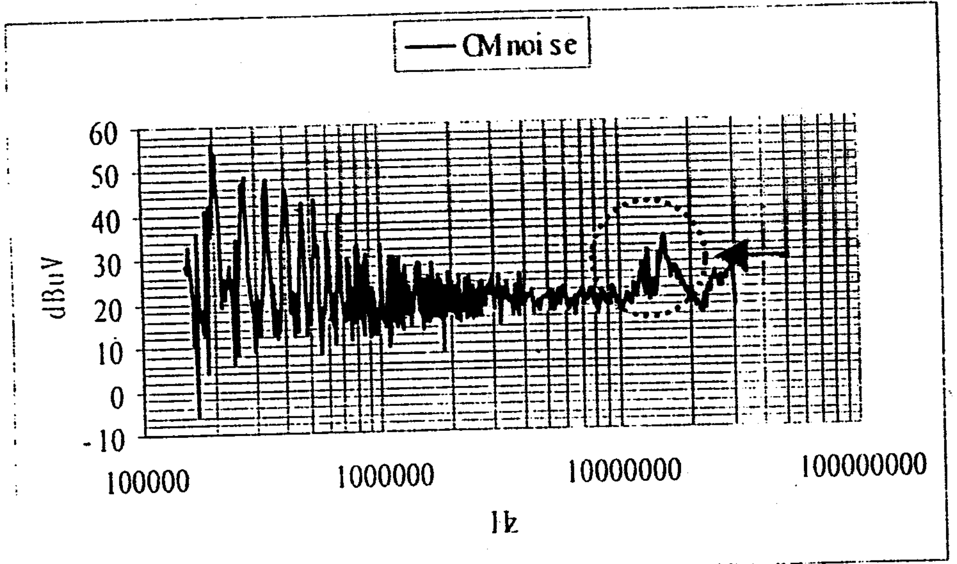
3mil nickel+Magnetic shield



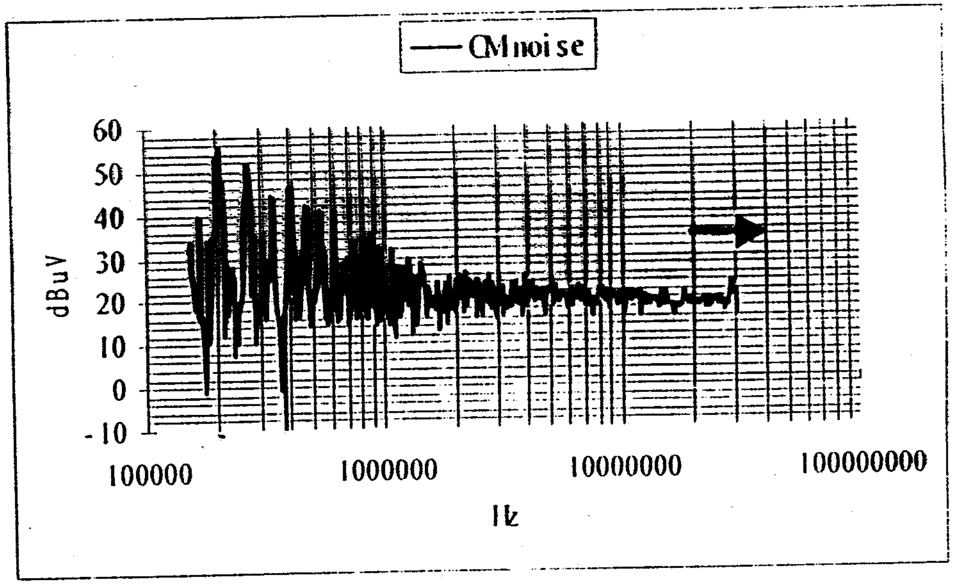
CM coupling through the ground-loop resonance



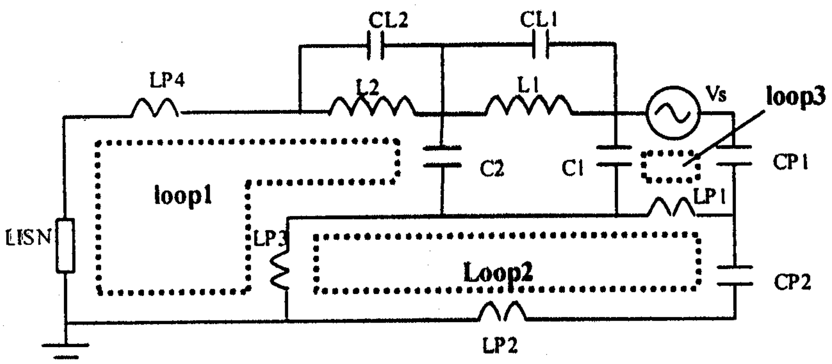
With smaller distance: Larger Cp2



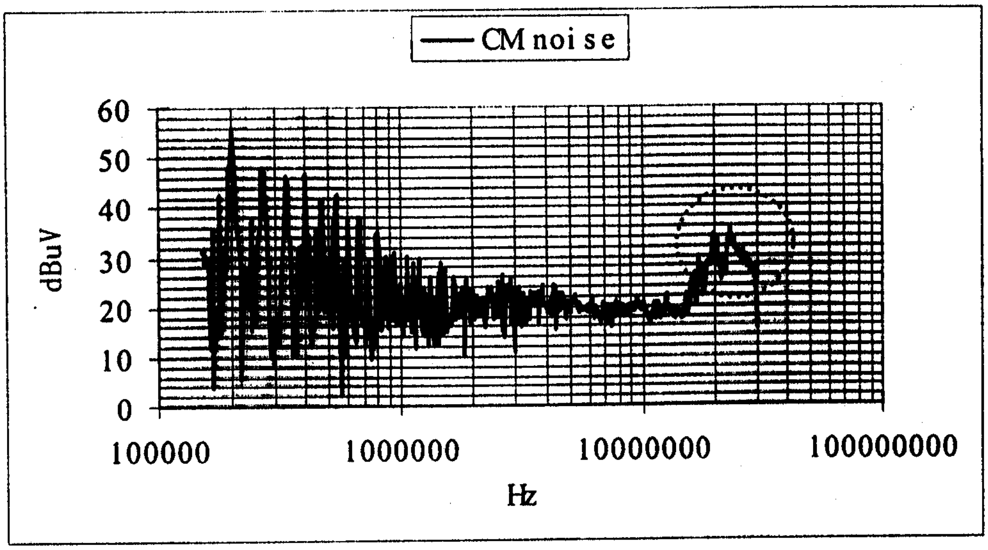
With smaller loop2 area: smaller inductance



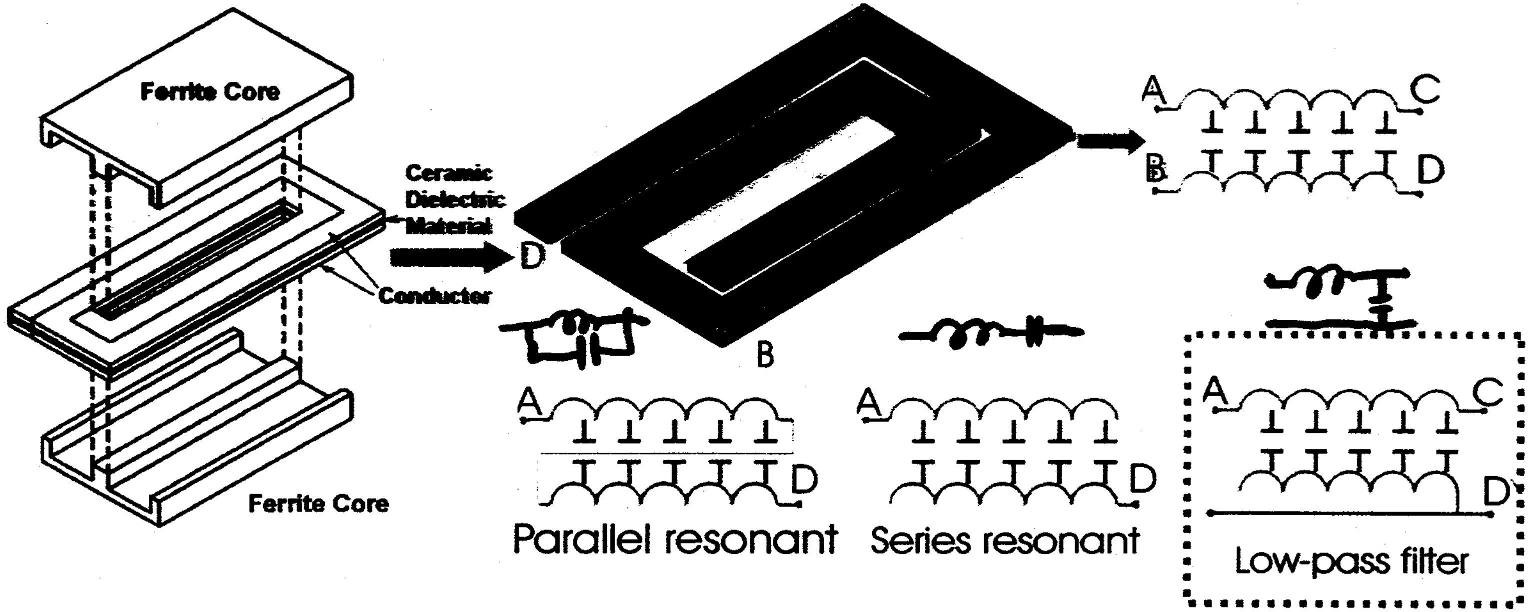
CM coupling through the ground-loop resonance



$$f = \frac{1}{2\pi\sqrt{(L_{p1} + L_{p2} + L_{p3})C_{p2}}}$$



Passive Integration Technology:
Spiral Winding Planar Integrated L-C

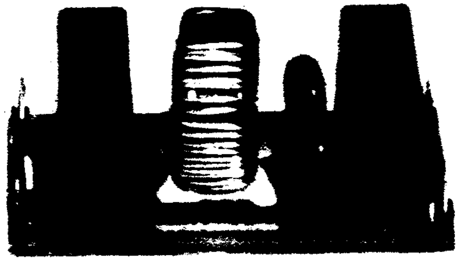


- High permittivity dielectric material **between** two planar conductive windings
- **Distributed structure - multiple resonance points**
- **Terminal characteristics changeable**
- **Internal current distribution dependent on termination**

Compared with Discrete EMI Filter: Initial Results

Integrated

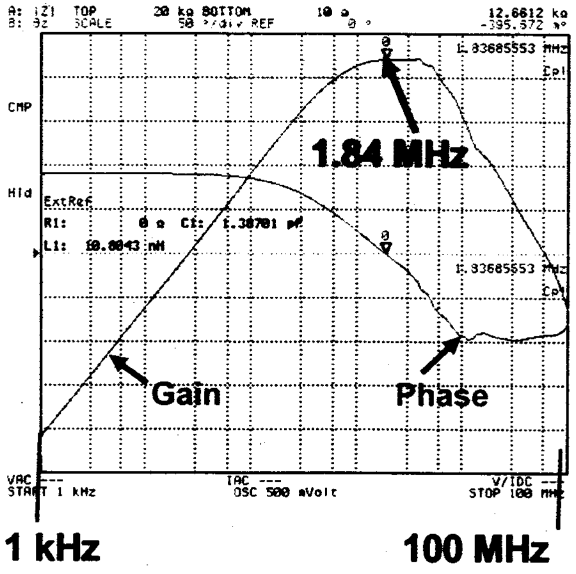
Discrete



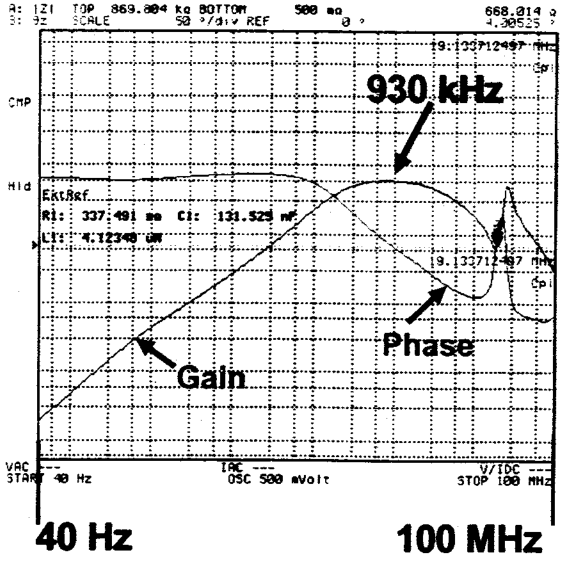
Parameter Comparison

Parameters	Integrated	Discrete
EPC (pF)	3	12
No. of Components	1	5
Profile (cm)	1.6	2.6
Volume (cm3)	27.4	39.8

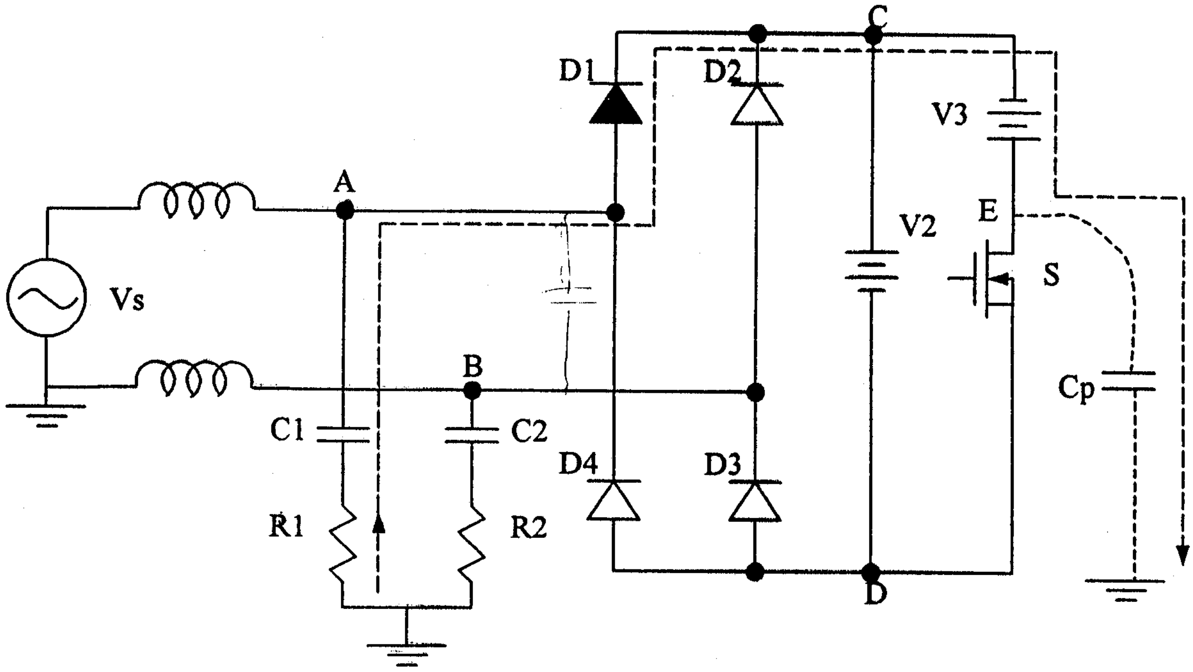
Impedance of Integrated CM Choke (EPC = 3 pF)



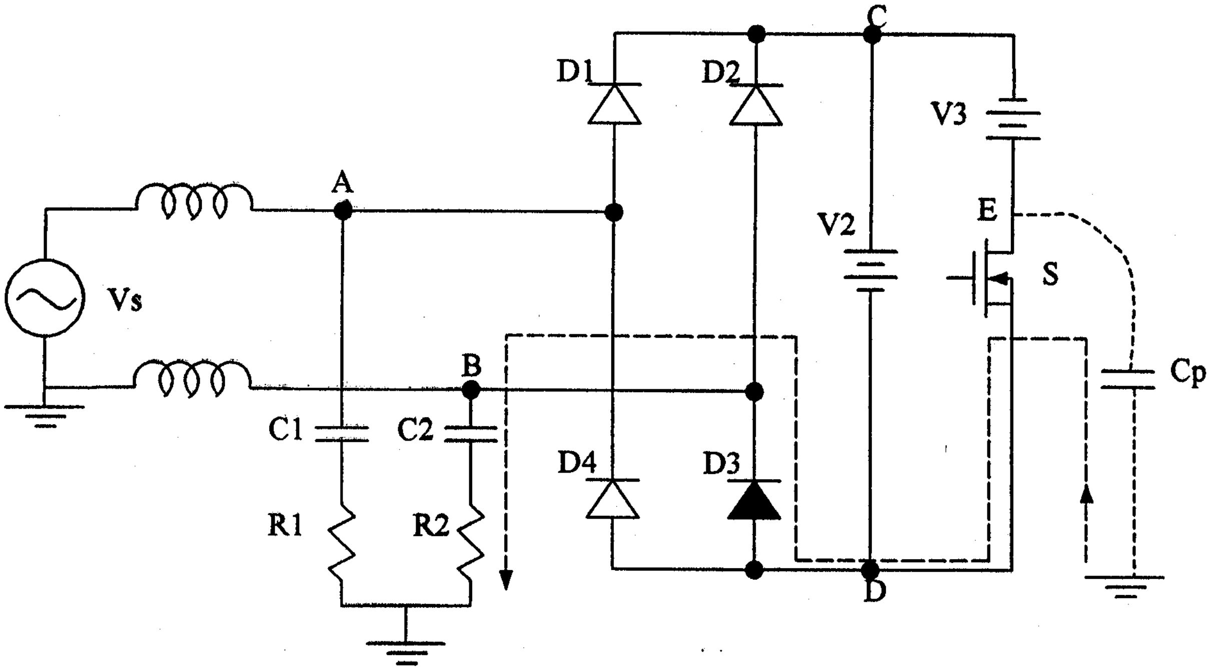
Impedance of Discrete CM Choke (EPC = 12 pF)



Mechanism of Mix-Mode Noise Coupling

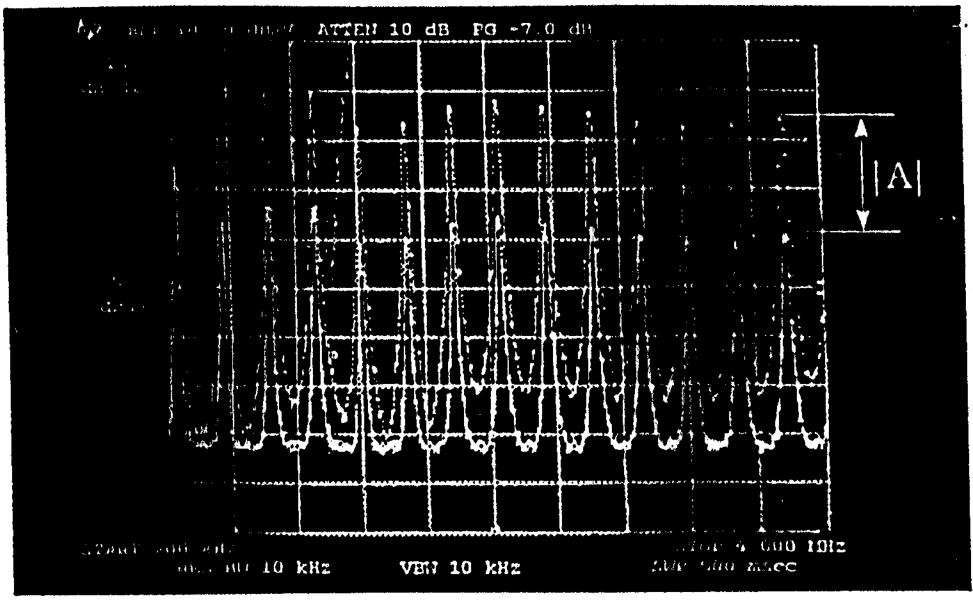


Diodes off, MOSFET turned off, Cp charged

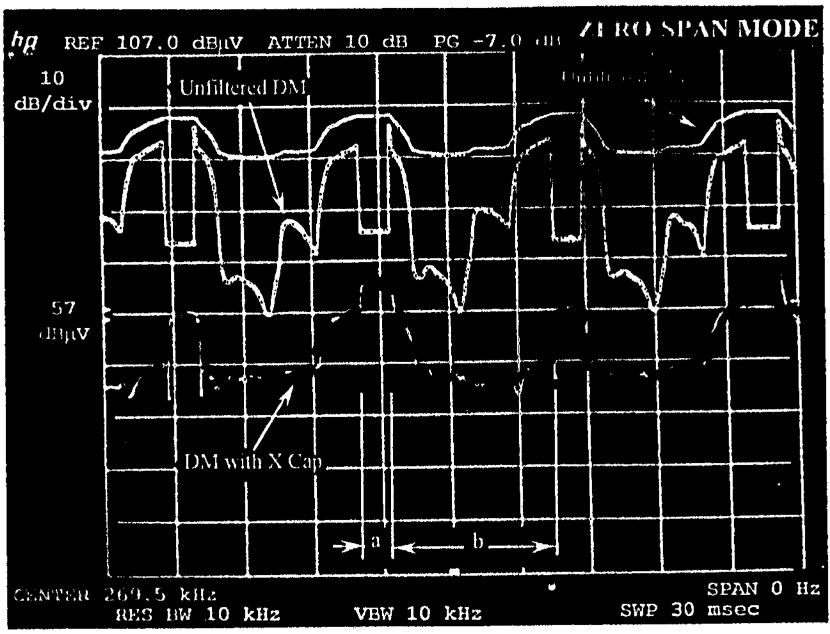


Diodes off, MOSFET turned on, Cp discharged

EMI Measurement of an Off-line Power Supply

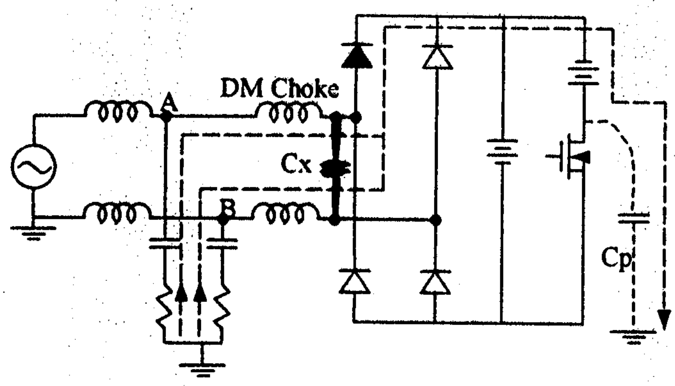


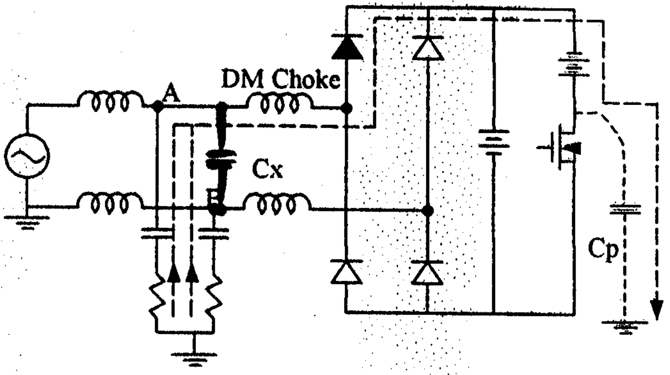
- Sweep in the time-domain reserves only maximum values.

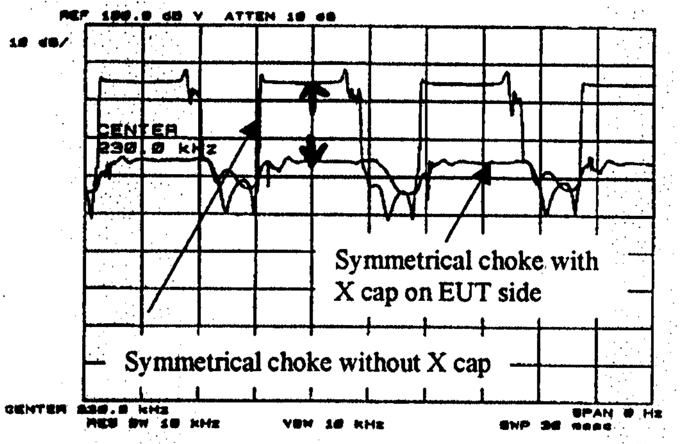


Which Side Should the X Cap Be Placed?

Symmetrical Choke

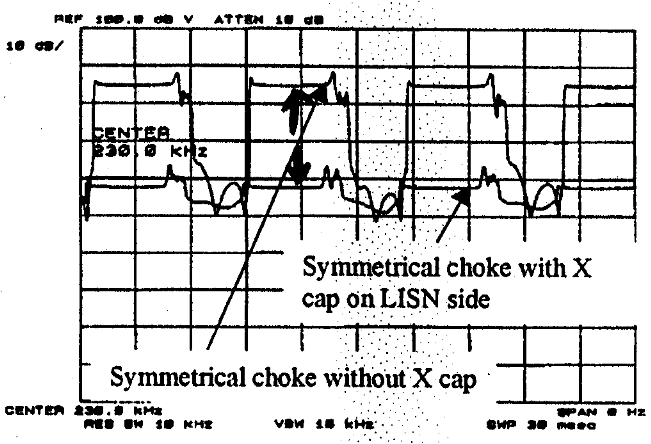






Symmetrical choke with X cap on EUT side

Symmetrical choke without X cap



Symmetrical choke with X cap on LISN side

Symmetrical choke without X cap