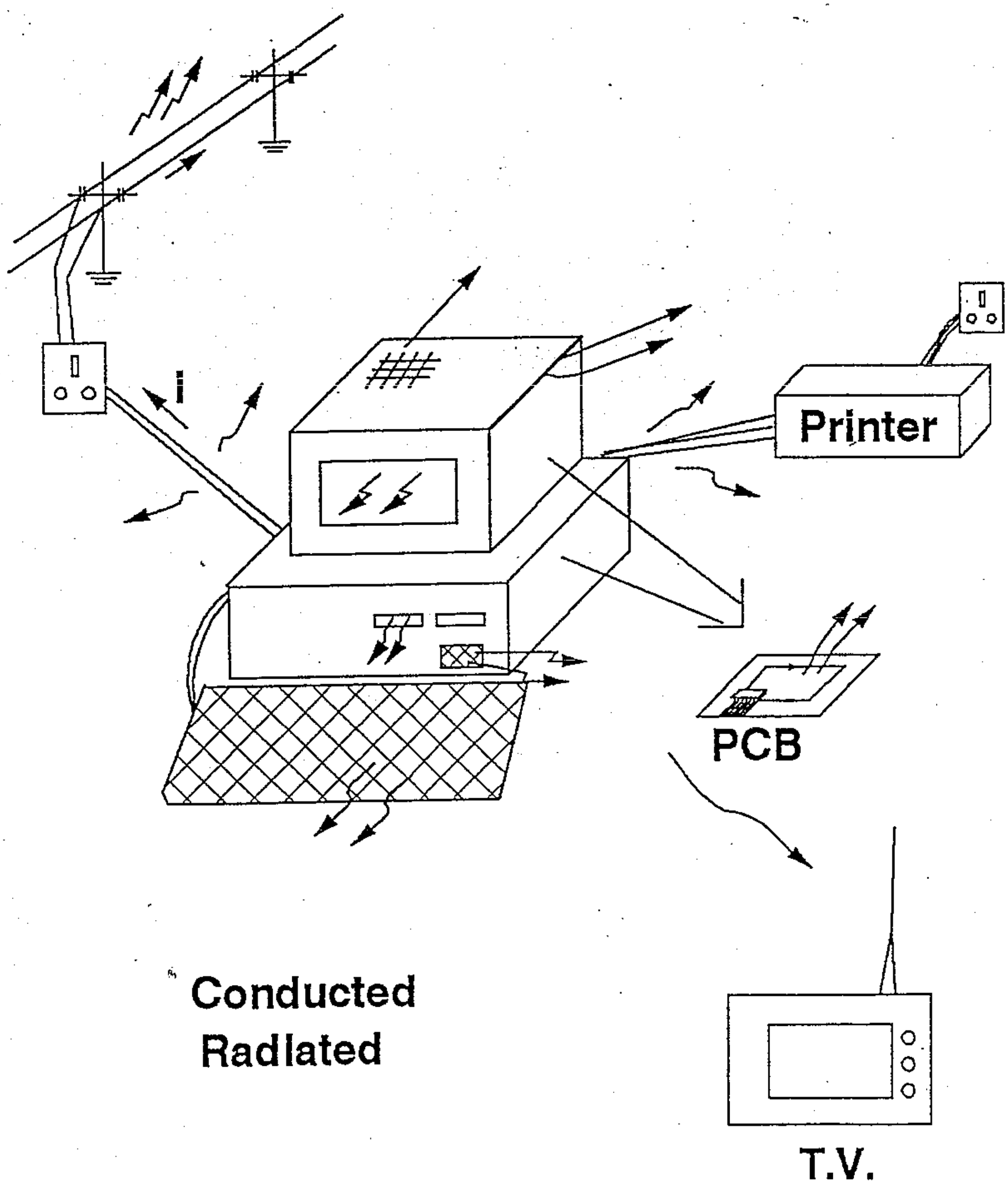
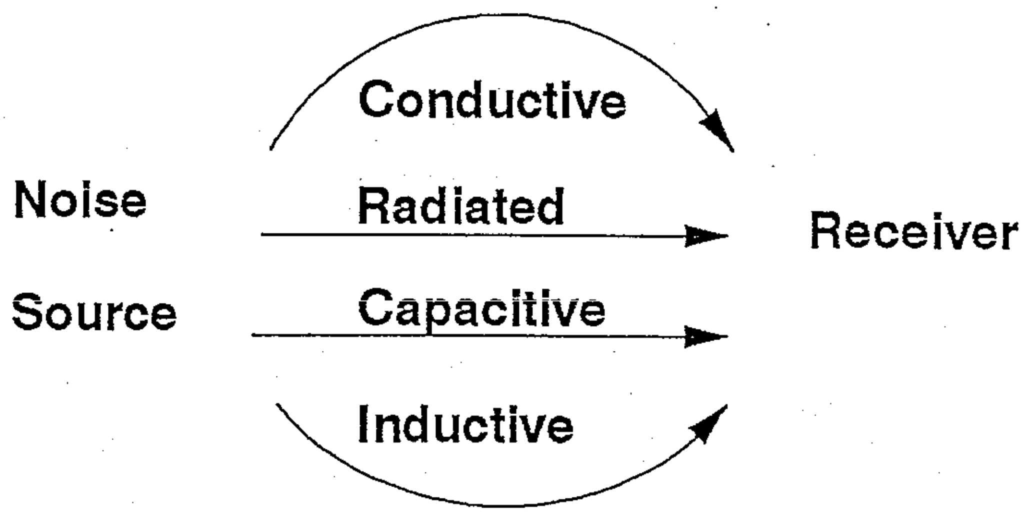
一、簡介
(Introduction)

EMI Problem in PC



Conducted
Radiated

EMI , EMC
干擾 相容



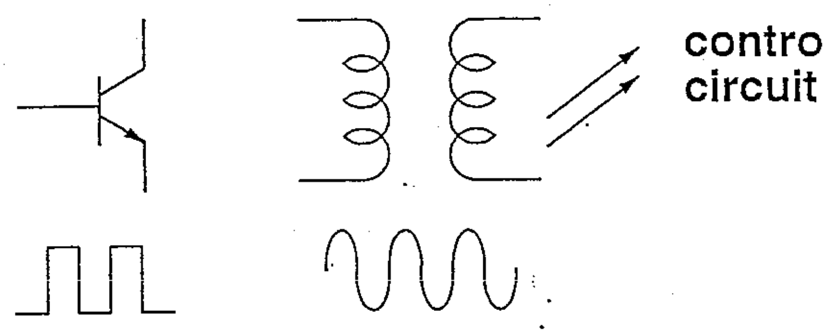
Cure

filtering , shielding , grounding

isolation , seperation , orientation

Purposes of EMI Control
(目的)

Minimize Noise in a Circuit 減少干擾



Meet Government Regulation 符合標準

FCC A, B
VDE A, B
MIL SPEC
- - -

二、導體耦和之雜訊

(Noise Coupled Through Conductors)

(I * Z coupling)

II — Noise Coupled through Conductors

導線傳導之雜因

Capacitive Coupling

(E field coupling)

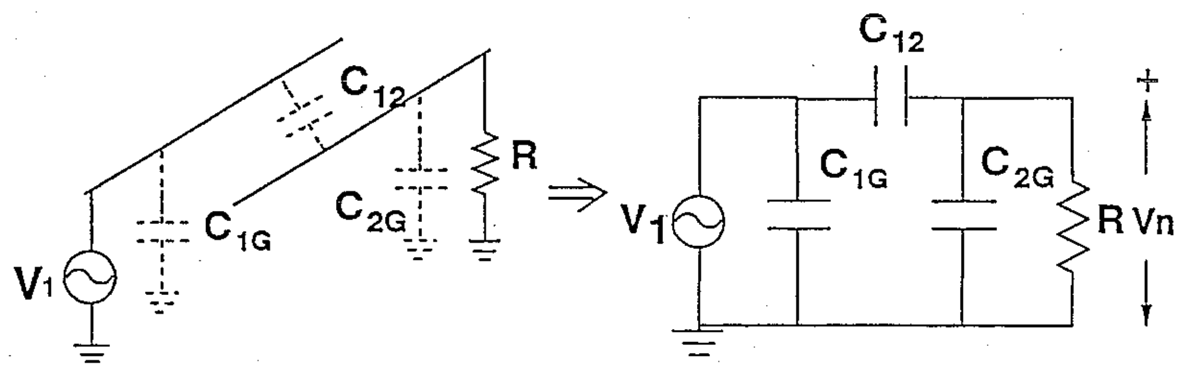
Inductive Coupling

(B field coupling)

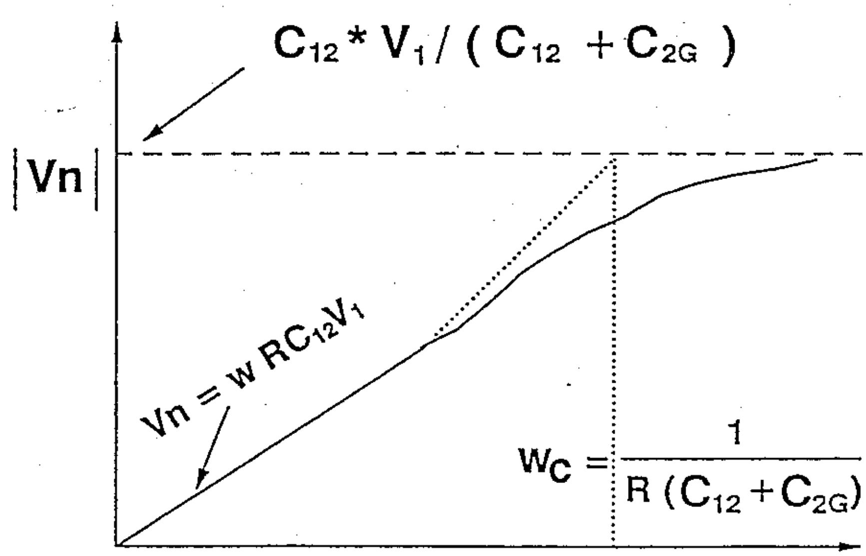
Common Impedance Coupling

(I * Z coupling)

Capacitive Coupling



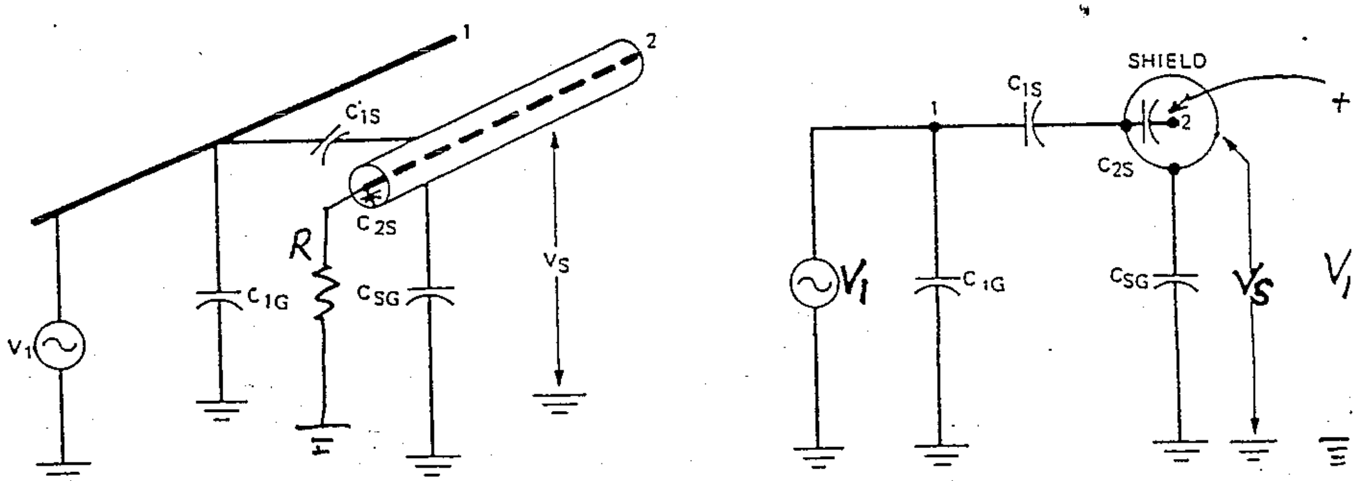
$$Vn = \frac{jw\,[C_{12}/(C_{12}+C_{2G})]}{jw + 1/R * (C_{12}+C_{2G})}\, V_1$$



Vn ↑ if C_{12} ↑ , w ↑ , R ↑

Effect of a Shield

隱蔽效應



- $$Vs = \frac{C_{1S}}{C_{1S} + C_{GS}} V_1$$
- $Vn = Vs$ if $R \longrightarrow \infty$
- If the shield is grounded, $Vn = Vs = 0$
  If the shield is connected to a d.c. voltage, $Vn = ?$
- Ground wire must be low impedance to be effective.
  (Use wide conductor, soldered well)

- Ungrounded Shield

  —— ineffective (無 效)

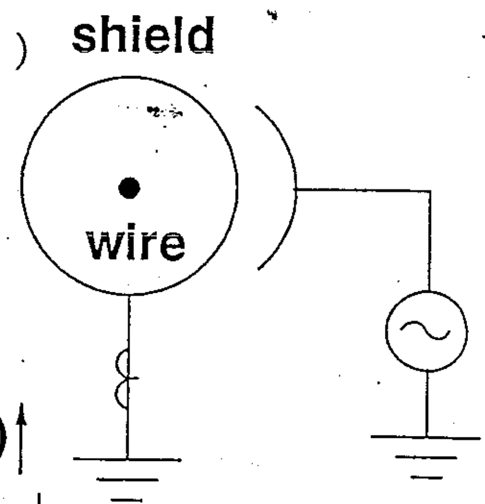
- Poor Grounding

  —— poor shielding

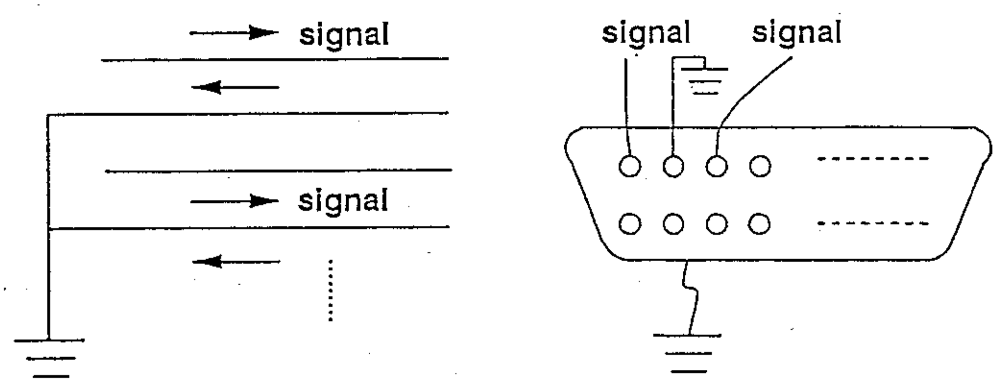
  (不 太 有 效)

- Frequency (of noise)↑

  shielding effectiveness ↓

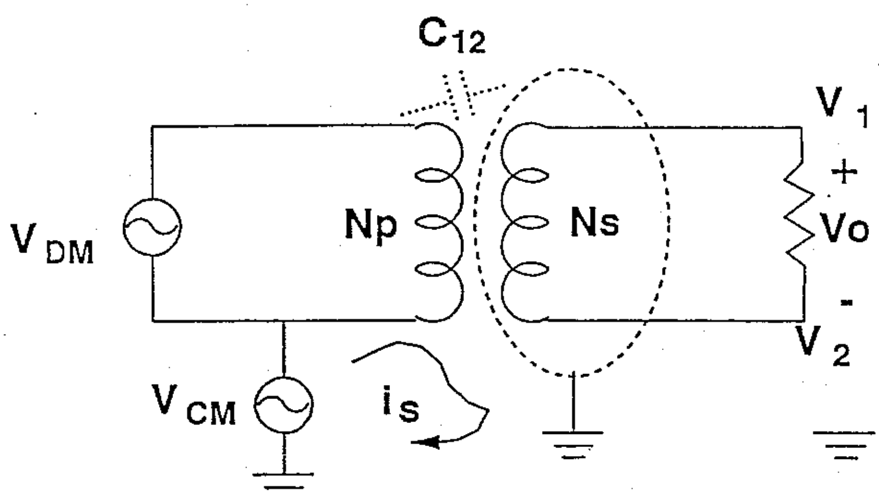


Shielding of Ribbon Cables and Connectors



- Grounded wire provides shielding between signal lines
- Separate return avoid common impedance coupling
- $C_{12} \approx 2P.F / in$

Transformer Shielding



- $Vo = V_{DM} * \frac{Ns}{Np} + V_{CM} / CMRR$

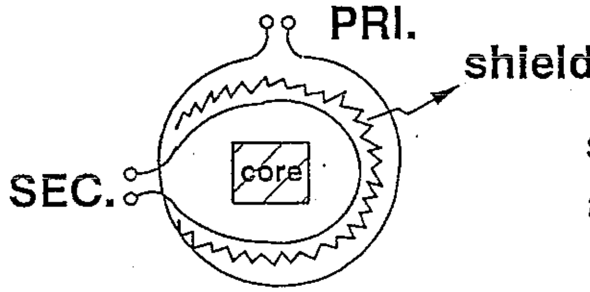
  CMRR (Common Mode Rejection Ratio)
  CMRR ↑ with shield

- Shield diverts current i to ground
  導向
- Improper shield construction afects magnetic coupling

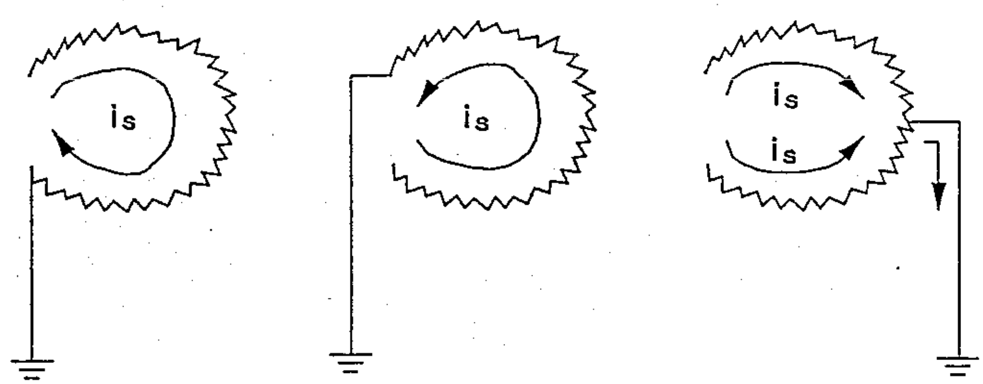
- Typical Reduction : 100 db at 60 HZ
  20 db at 1 MHZ

Transformer Shield Construction

如 何 用　shield ?



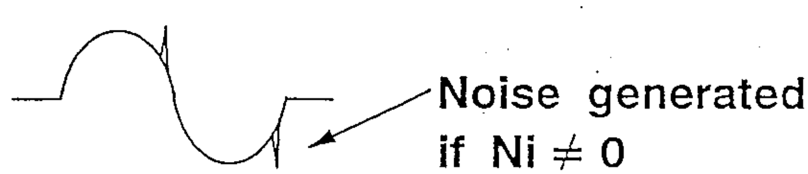
shield must not form a closed loop !!



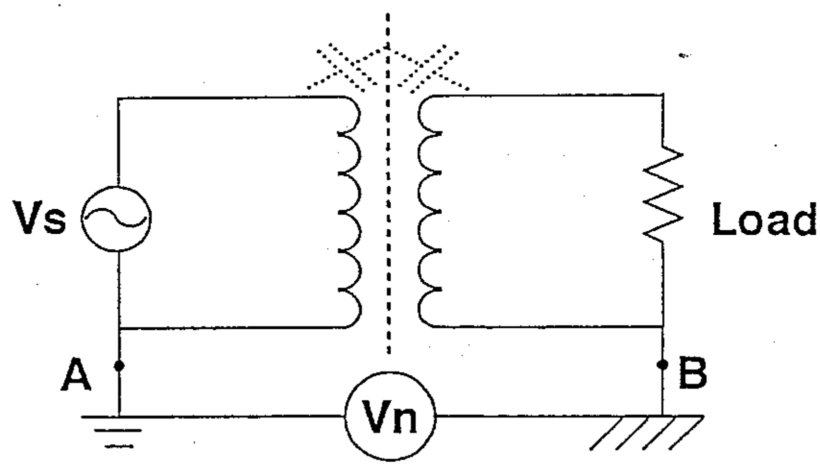
(A)　　　(B)　　　(C)

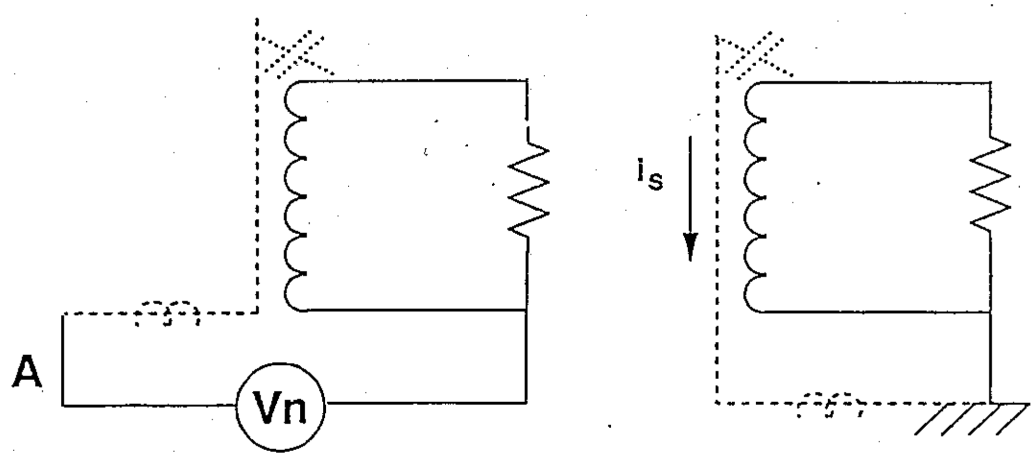
Case (C) is best because $\Sigma Ni = 0$

$\Longrightarrow$ does not affect magnetic coupling



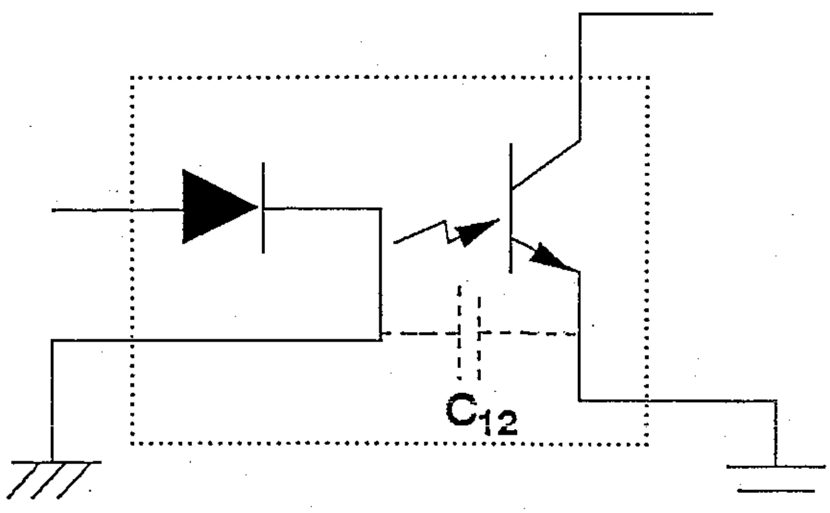
Which Side Shield Tied to ?





Tie it to the side that you want to protect.

Photo - Coupler

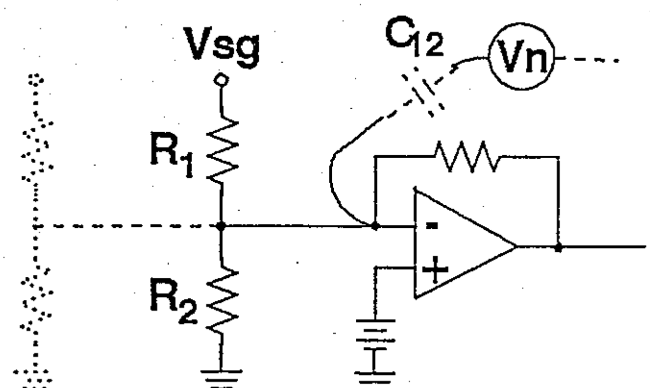


- **Shielded photo-coupler improves noise immunity.**

Reducing Capacitively - Coupled Noise

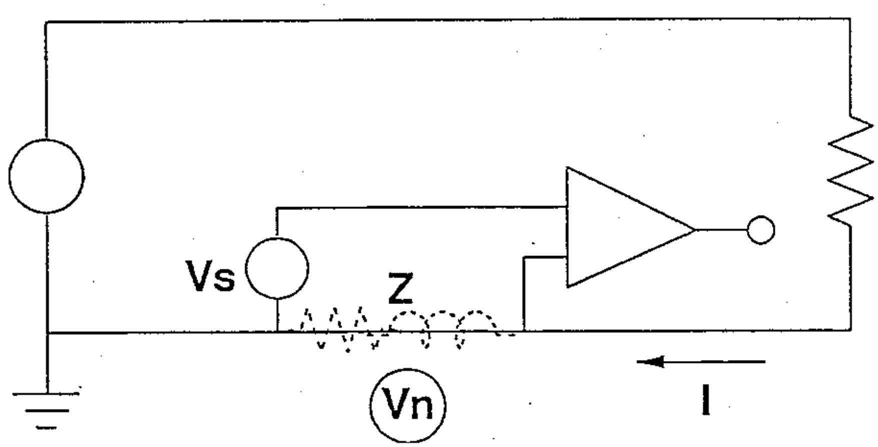
減少 C－耦合之雜訊

- Sensitive line should stay away from high dv / dt line
- Sensitive line should be as low impedance (to ground) as possible
- Sensitive point should stay as close to the amplifier as possible



- Ground unused pins in a I.C. or a connector.

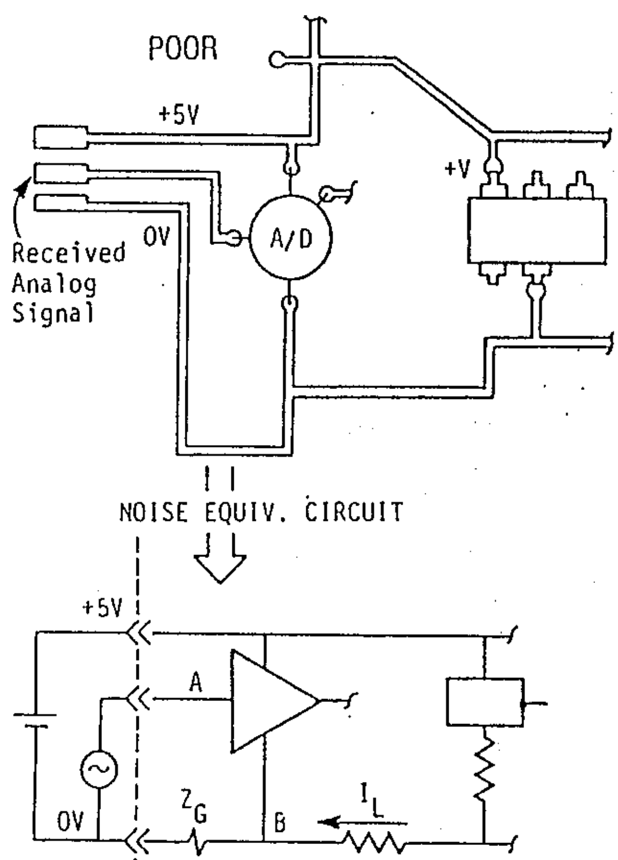
Common Impedance Coupling



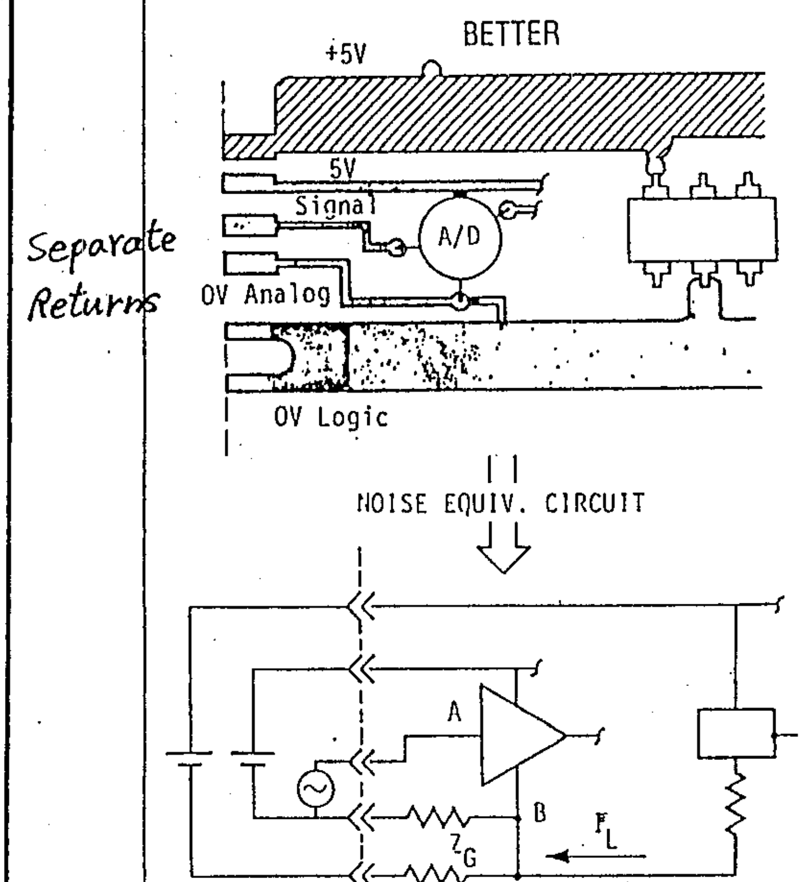
- I Z couples noise into circuit
- Z = R + jwL ; R effect small
  L effect can be large
- L ≅ 20 nH for 2.5 cm long #20 wire

$$Vn = L\,di/dt = 20\text{ nH} * \frac{100\text{mA}}{20\text{ns}} = 100\text{mv}$$

Noise Coupled Through Common Impedance



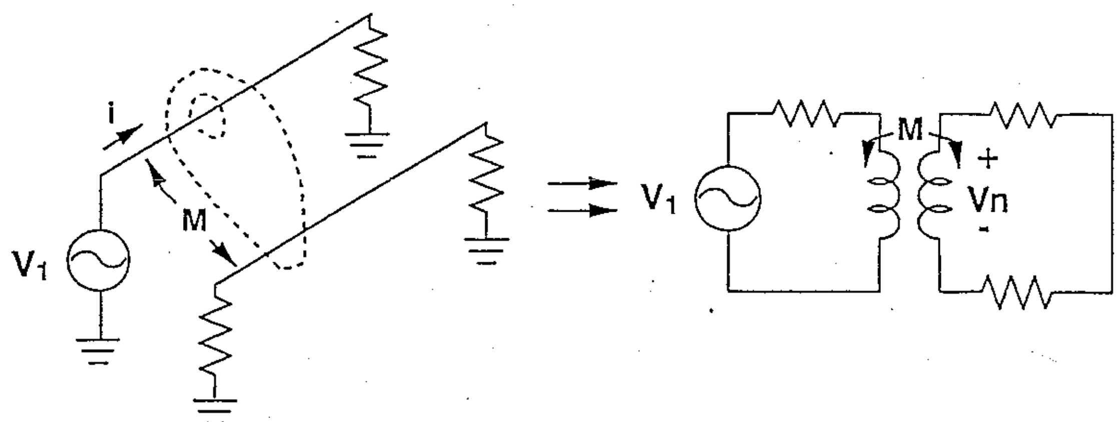
Voltage Drop Of Pulsed $I_L \times G_Z$
Appears At Analog Ampl. Input AB



Voltage Drop $I_L \times Z_G$ No Longer
Offends Input AB.

Inductive Coupling

磁性耦合



$$Vn = M\frac{di}{dt} = jwMi_1$$

M (mutual inductance)

$$= \frac{A\cos\theta\, u}{lm}$$

A : Area

u : permeability

im : maganetic mean length

θ : angle of two planes

Ground-Plane Impedance
of 1-Oz. Copper Foil (t=.03mm)

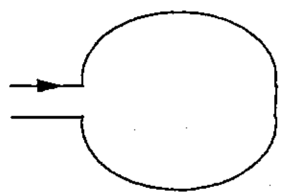
Frequency	Impedance mΩ/sq.	Frequency	Impedance mΩ/sq.
100 Hz	0.574	20 MHz	1.61
1 kHz	0.574	30 MHz	2.03
10 kHz	0.574	50 MHz	2.62
100 kHz	0.574	70 MHz	3.09
1 MHz	0.582	100 MHz	3.69
2 MHz	0.604	200 MHz	5.22
3 MHz	0.638	300 MHz	6.39
5 MHz	0.736	500 MHz	8.26
7 MHz	0.855	700 MHz	9.77
10 MHz	1.04	1 GHz	11.6

- **Beyond 5 MHZ, $Z \propto \sqrt{f}$ due to skin effect**
- **Inductive effect is slightly evident above 500 MHZ**
- **Wire : length >> width**
  ground plane : length ≈ width

Reciprocal Theorem

對等原理（易收者亦能放）

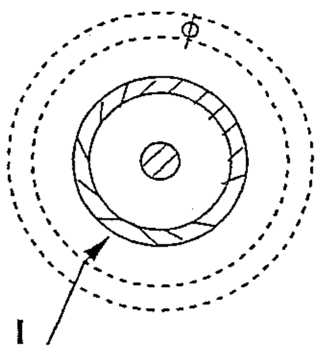
Geometry good for receiving is also good for radiating

-  

Better for radiation control and also less susceptible to radiation

- Case (C) better than (B) better than (A)

Coaxial Cables

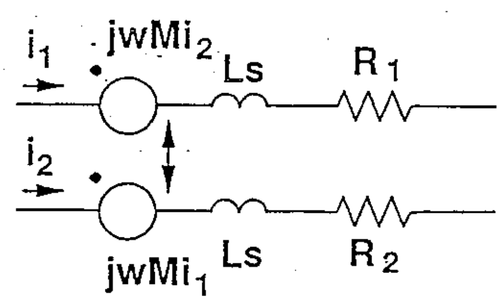


Ls (self inductance)
$= \phi / I$
M (mutual inductance)
$= \frac{\phi_s}{I}$ (Generated by I that encircles the shield)

- Because of close coupling , $\phi_s = \phi$

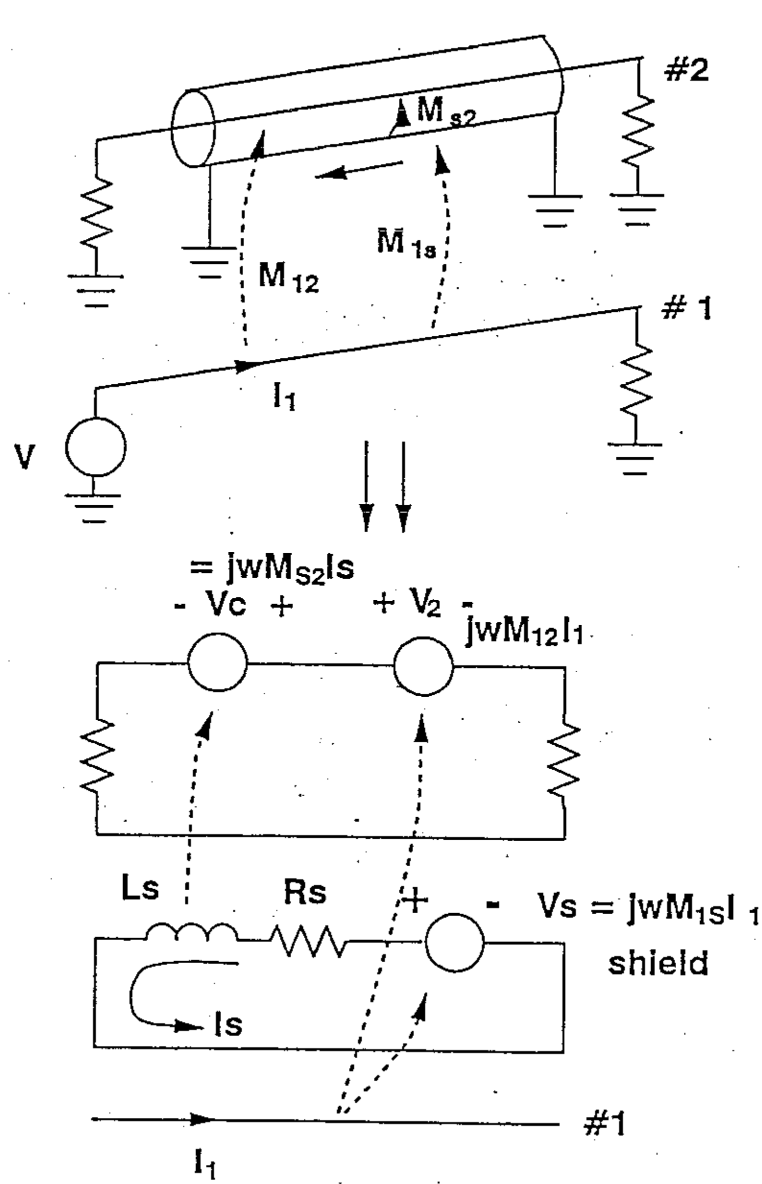
  $\therefore$ $\boxed{Ls = M}$

- Coaxial Cable =



- Twisted wire , M smaller , but still close to Ls

Inductive Decoupling



$$Vn\ (\text{in \#2 wire}) = V_2 - V_C = jw\,(M_{12} \cdot I_1 - M_{S2} I_S)$$

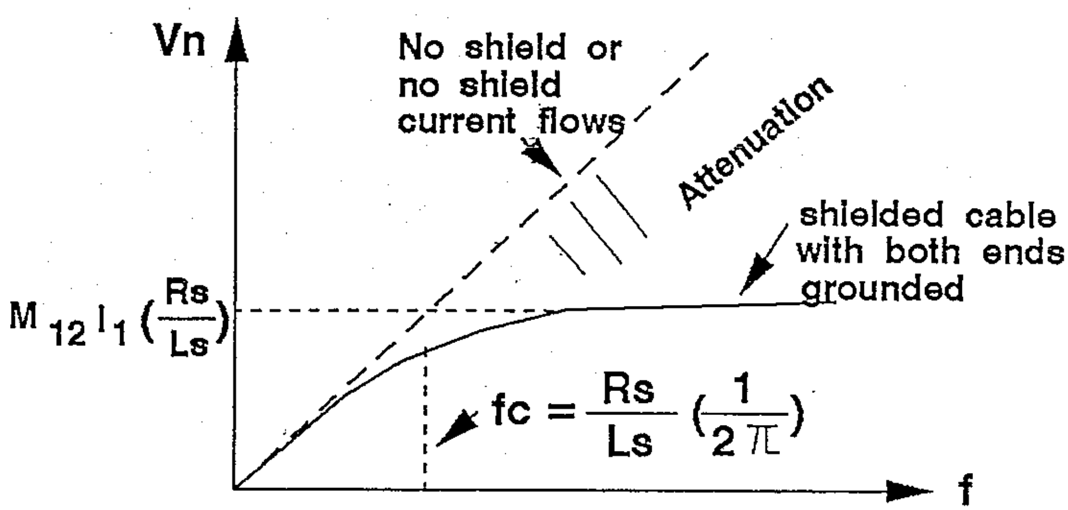
Shielding Effectiveness

$$V_n = jw\,(M_{12} I_1 - M_{s2} I_s)$$

$$= jw\left(M_{12} I_1 - M_{s2}\frac{jwM_{1s} I_1}{jwL_s + R_s}\right)$$

$$\begin{pmatrix} \because M_{1s} \\ = M_{12} \end{pmatrix} \blacktriangleright = jw\,M_{12} I_1 \left(1 - \frac{jwM_{s2}}{jwL_s + R_s}\right)$$

$$\begin{pmatrix} \because M_{s2} \\ = L_s \end{pmatrix} \blacktriangleright = jw\,M_{12} I_1 \left(\frac{R_s / L_s}{jw + R_s / L_s}\right)$$



Comments on Shielding Effectiveness

- Shield grounded at one end $\Longrightarrow$
  no magnetic shielding effect

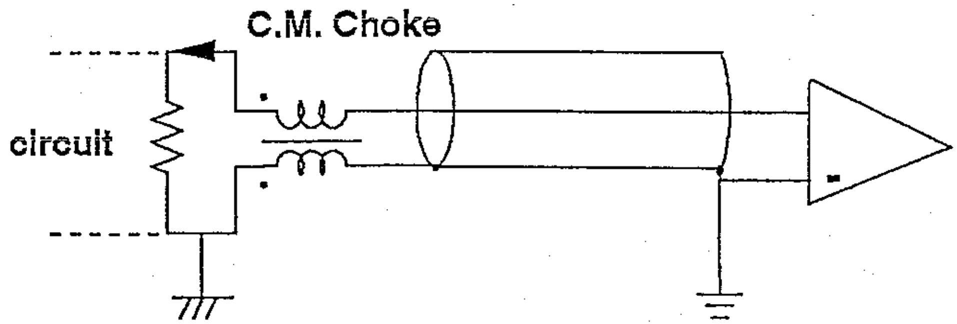
- Low frequency magnetic field ($f < f_c$ $= \dfrac{R_s}{2\pi L_s}$) is difficuilt to shield

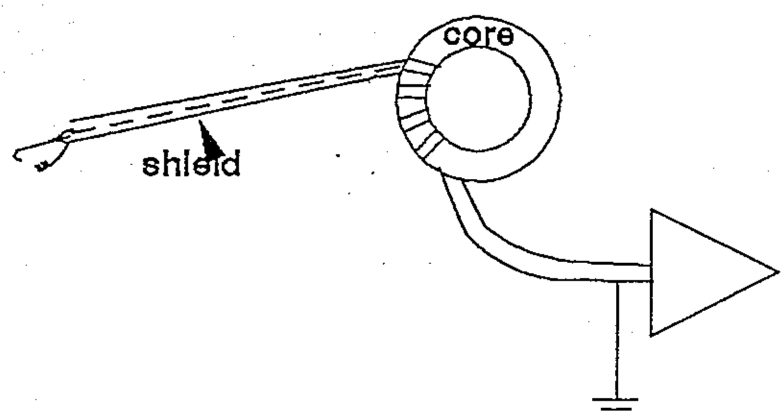
fc : coaxial cable RG - 213 0.7 KHZ

RG'- 59C 1.6 KHZ

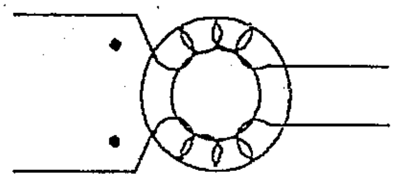
Shielded twisted pair 22 Ga " 7 KHZ

Insertion of C.M. Choke



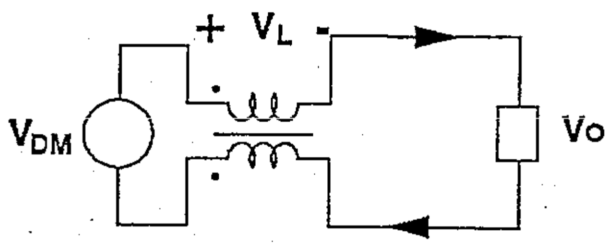


Common -- Mode Chokes



$\Rightarrow$ large inductance coaxial cable

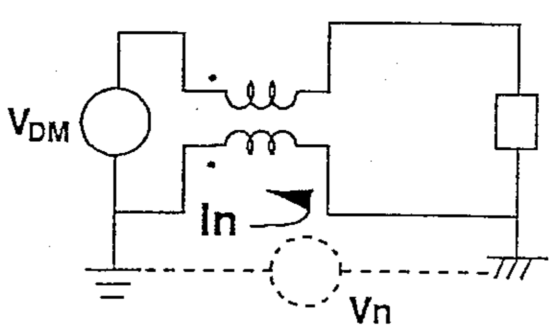
- **Differential - Mode signal Unaffected**



$Vo = V_{DM}$; $V_L = 0$ because $\sum Ni = 0$

$H = 0 \Rightarrow B = \text{constant} \Rightarrow V_L = 0$

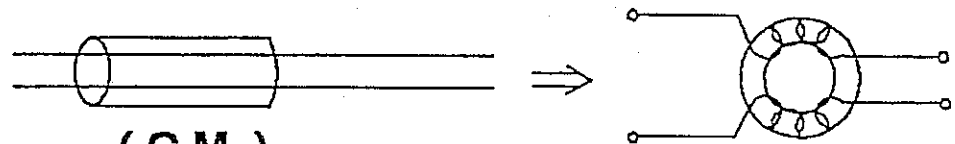
- **Increase Loop Impedance**



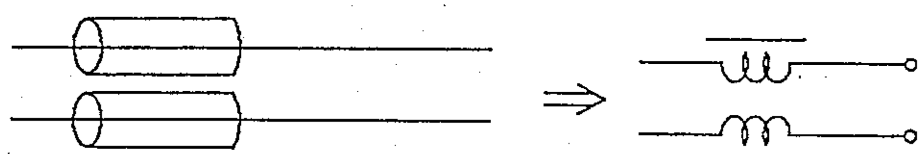
$$I_N = \frac{Vn}{jwLs + Rs}$$

Ls large

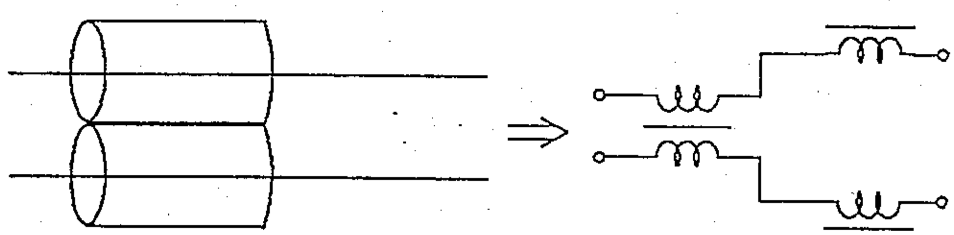
Ferrite Beads as Chokes



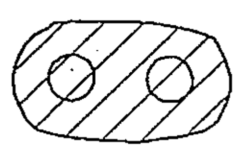
(C.M.)



(D.M.)

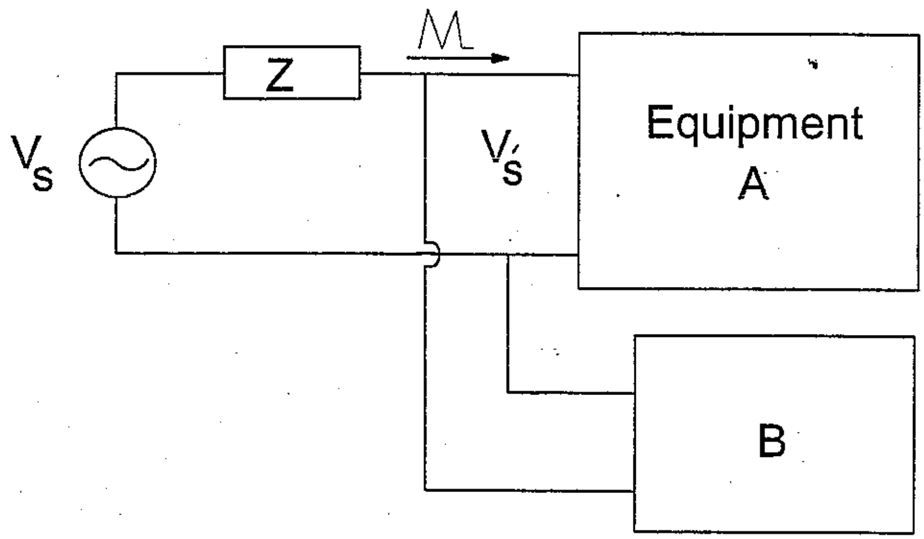


(C.M. + D.M.)



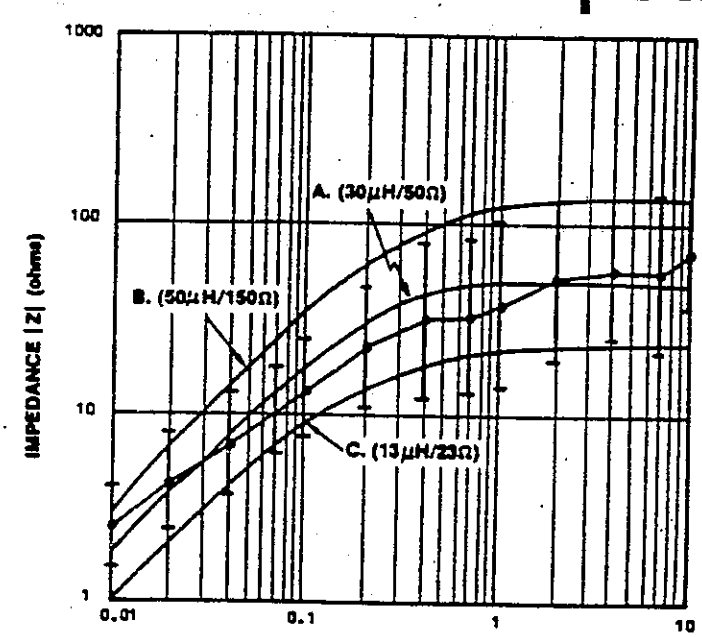
五、傳導性 EMI
(Conducted EMI)

Conducted EMI



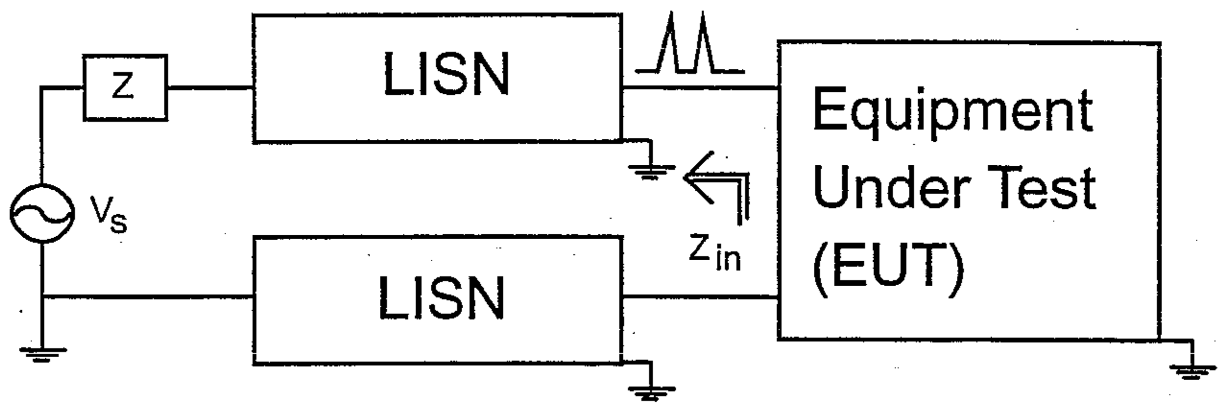
- EMI Depends on Line Impedance Z

Typical Power Line Impedance



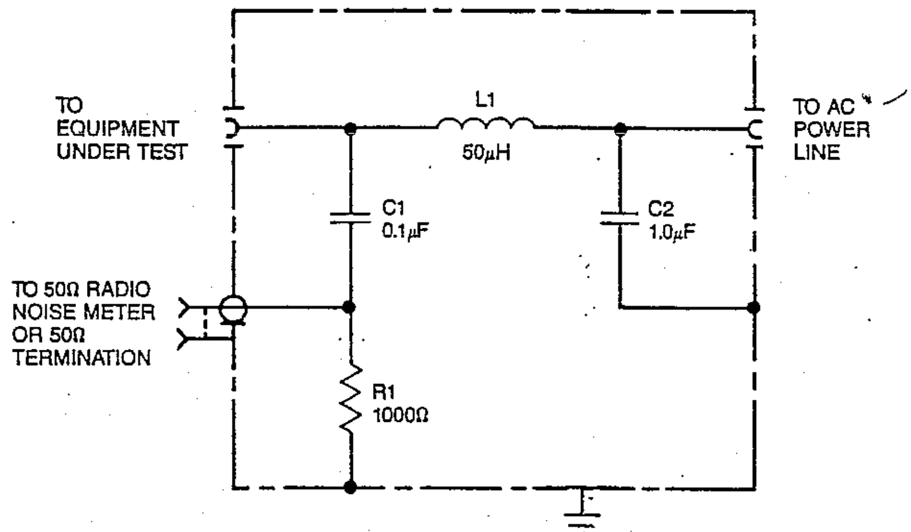
Ref [1]

Line Impedance Stabilizing Network (LISN)



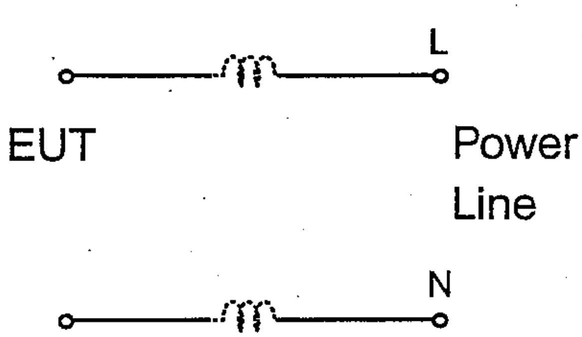
- A LISN is used to ensure repeatable EMI measurement
- Power frequency signal passes through LISN unaffected.
- For noise frequency, $Z_{in} \approx 50\Omega$

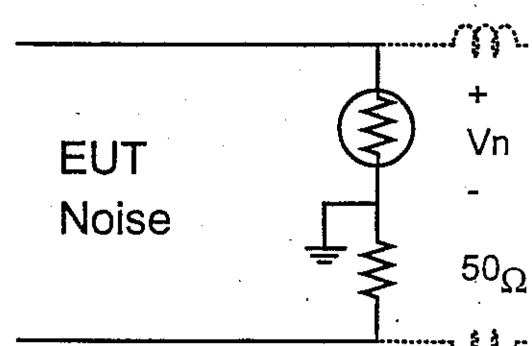
LISN



Power Frequency

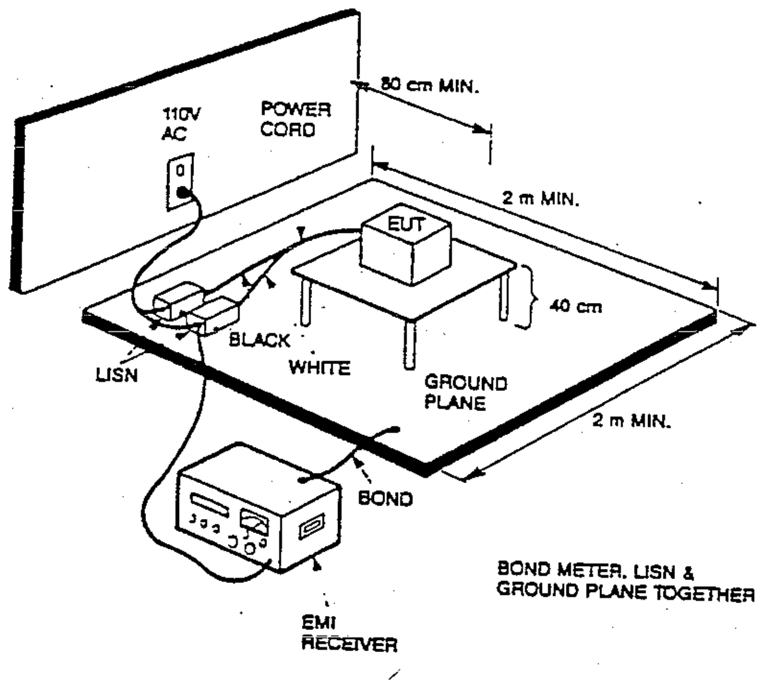
Noise (EMI) Frequency



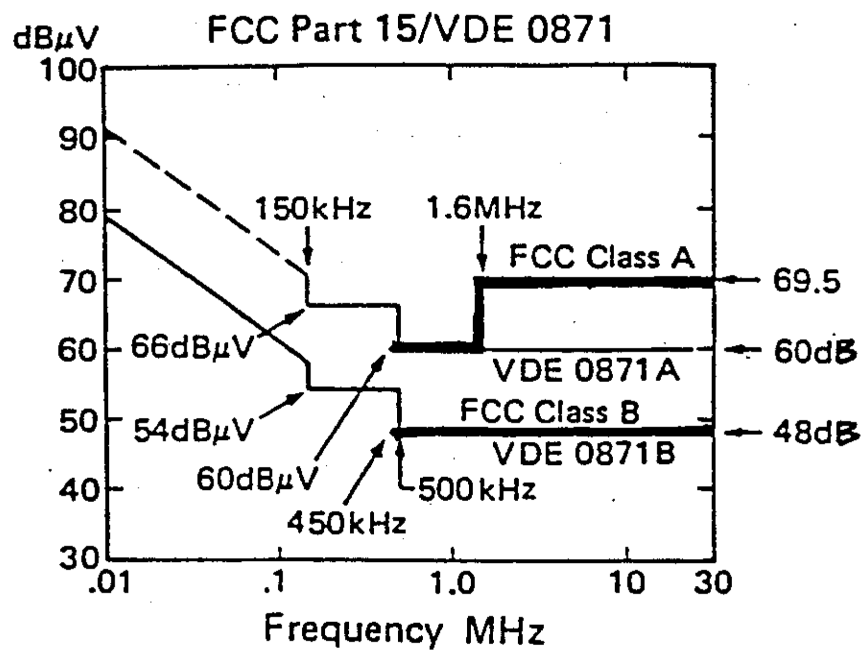


Vn: EMI voltage (conducted)

FCC Conducting Emission Test

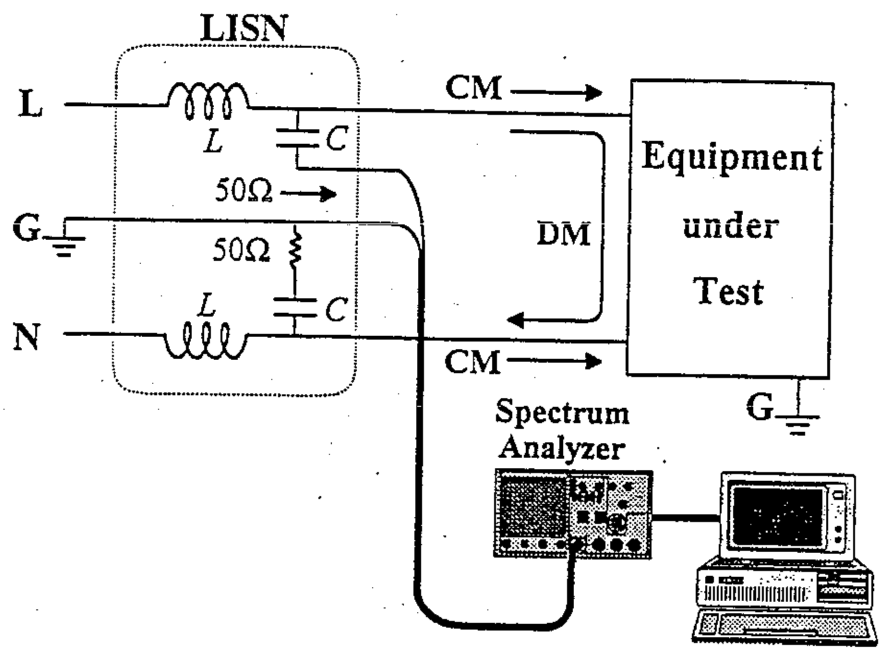


Conduction Emission Limits

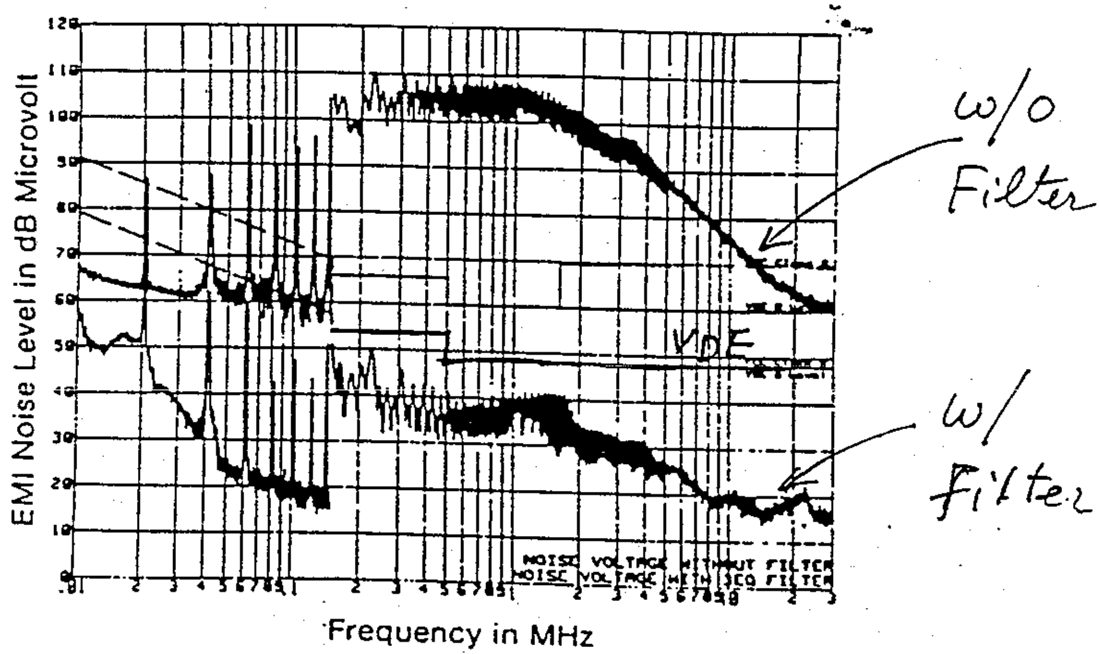


Ref [2]

Conducted EMI Measurement



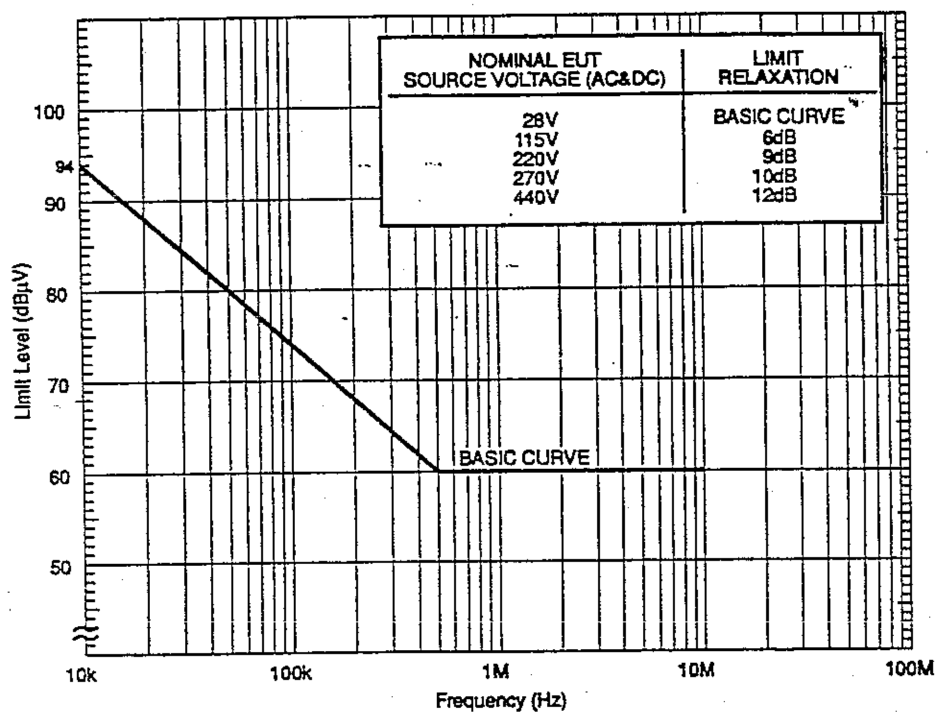
Conducted EMI Test



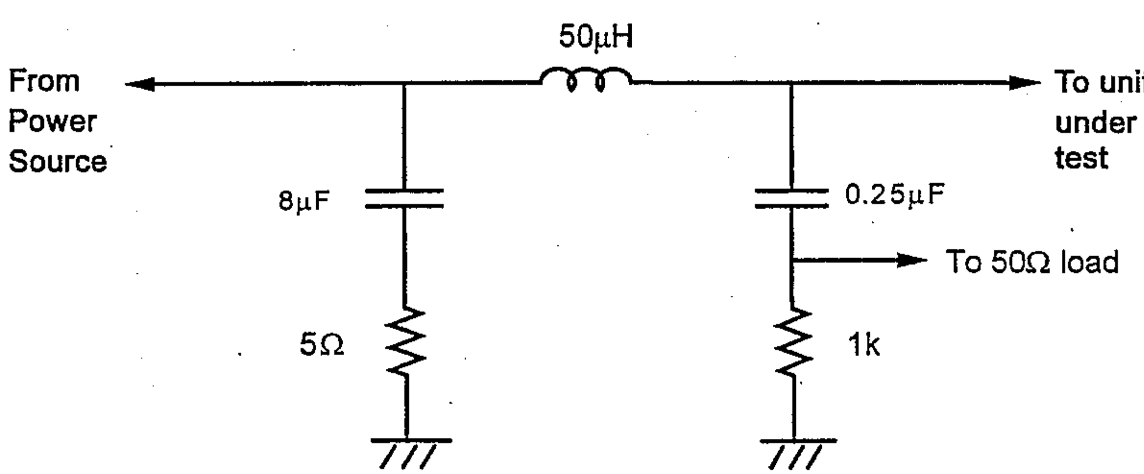
- Measurement bandwidth changes (RBW) at 150 KHz

10K Hz - 150 KHz, RBW = 200 Hz
150 KHz - 30 MHz, RBW = 9 KHz

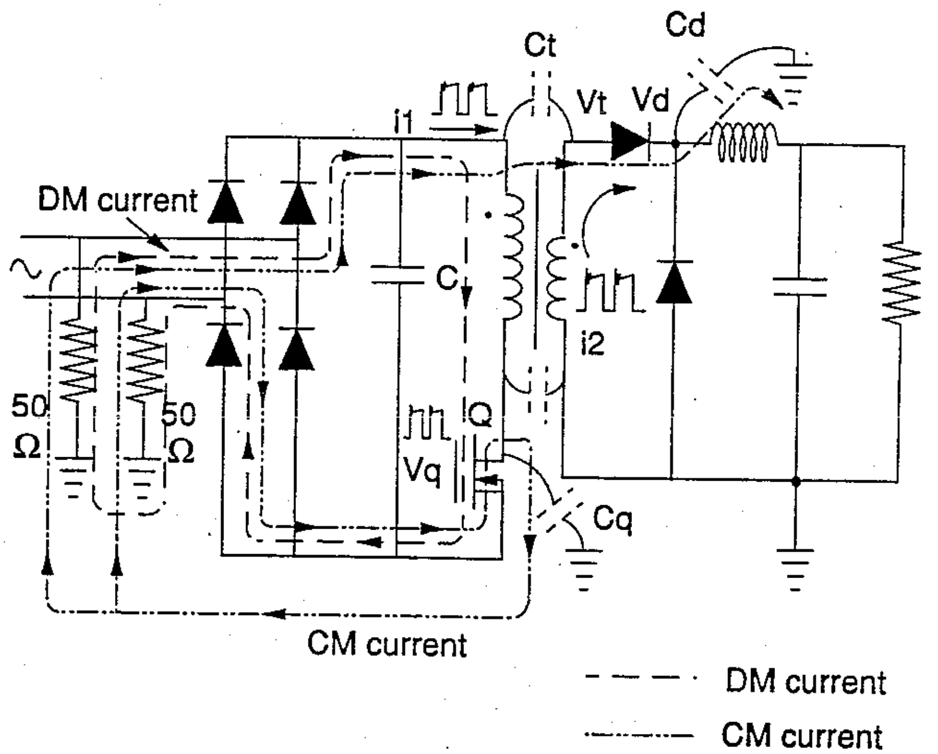
MIL-STD 461 D-CE102 Limit



LISN



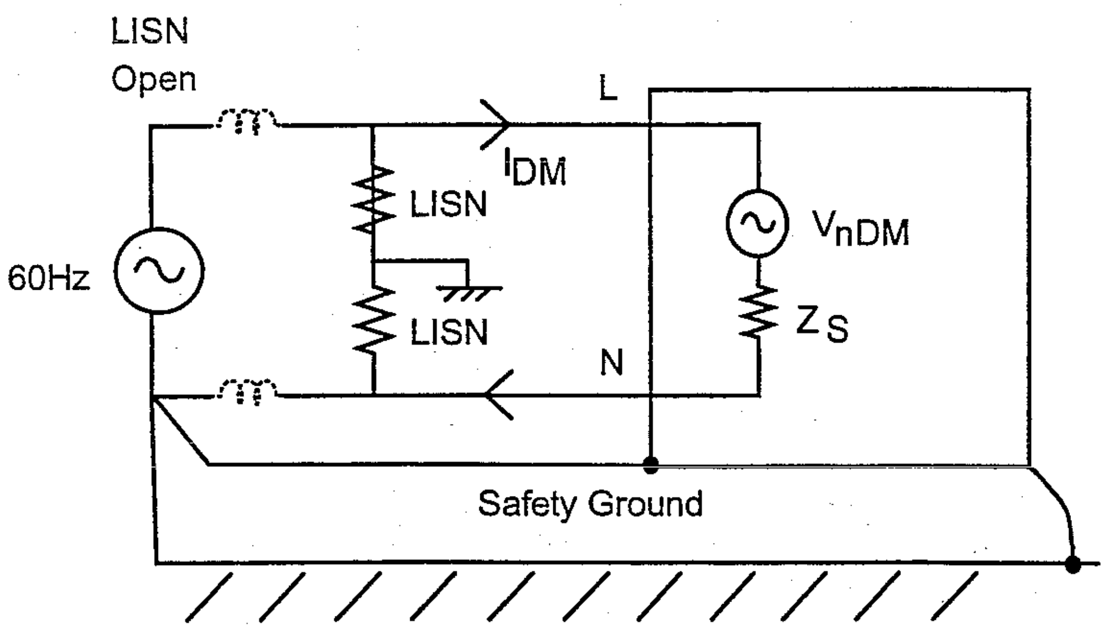
Noise Sources and Coupling Pathes



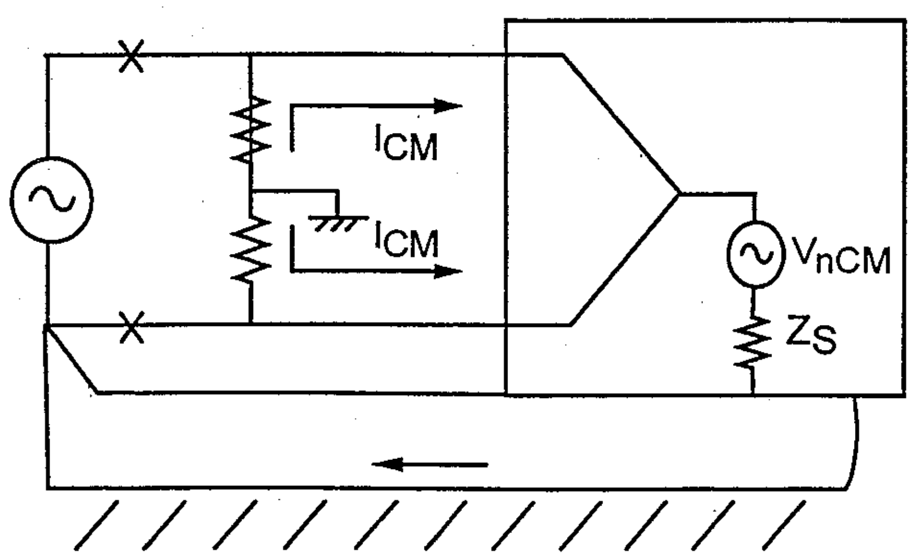
D.M. Noise - Caused by i_1

C.M. Noise - Caused by Parasitic Capacitances

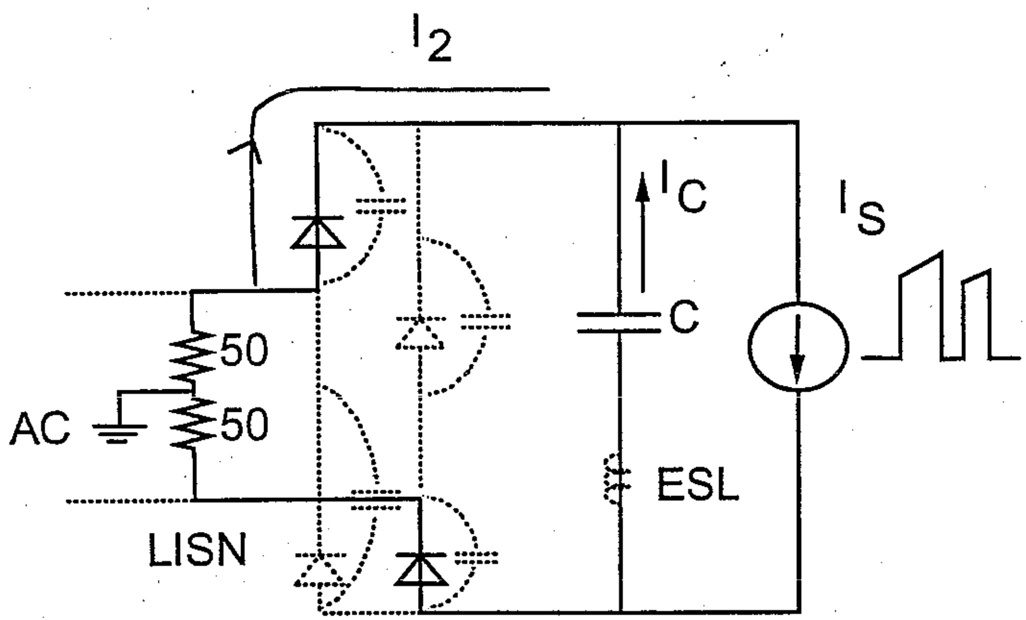
Differential Mode vs. Common Mode



Reference Ground Plane



Reducing D.M. EMI

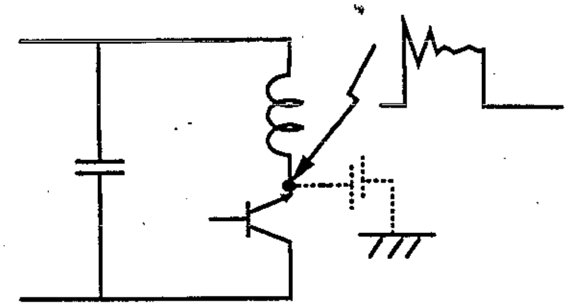


- Is Dependent
- ESL Critical at High Frequency
  For C=20 uf, ESL = 30 n.H., Zc = 8mr, Z*l* = 200 mr at 1MHz.
- Use small ceramic cap. in parallel with large C, across rectifiers

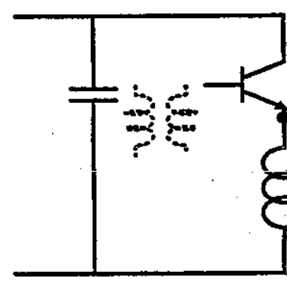
Reducing CM EMI

Transistor Effects

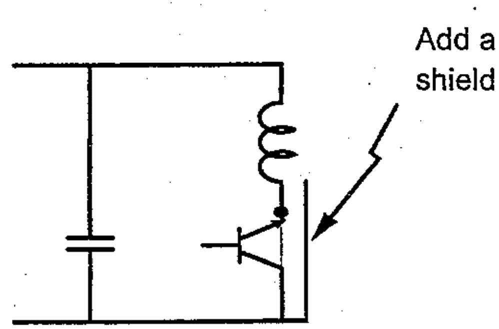
- Reducing ringing

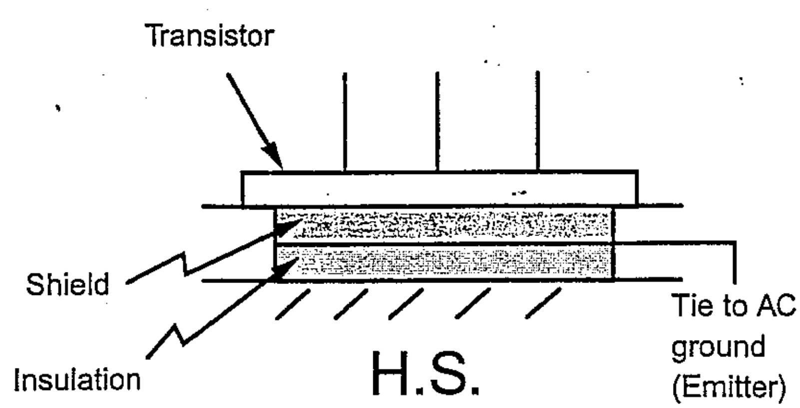


- Tie package (Collector/Drain) to AC ground but this needs an isolated drive

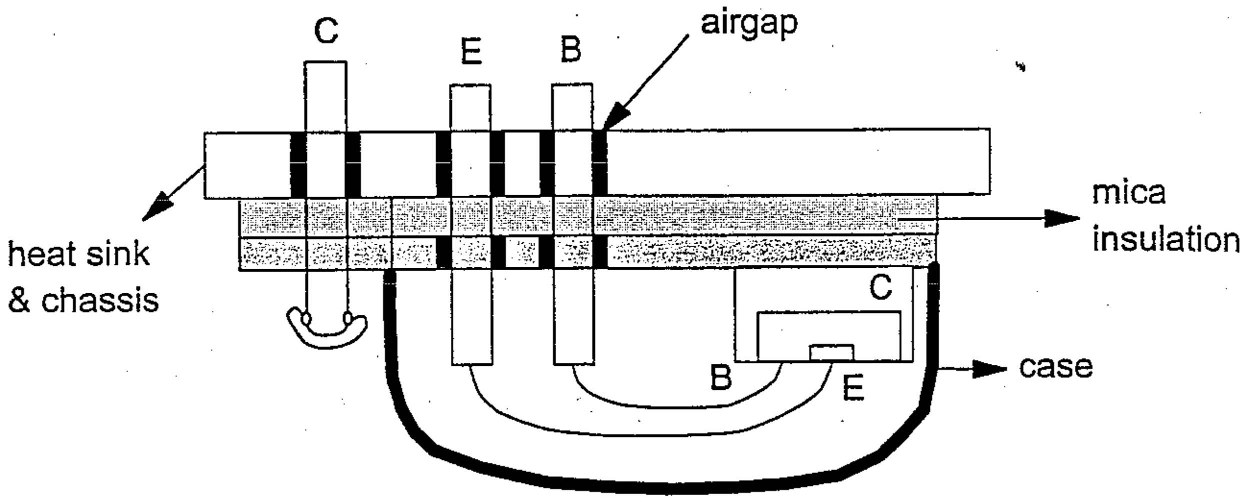


- Add a shield and tie the shield to AC ground (Emitter)





Parasitic Capacitances in Transistor Package



$C_{\text{collector - heat sink}}$ >> $C_{\text{emitter - heat sink}}$

(100 p.f. for TO-3 and mica layer) (< 5 p.f.)

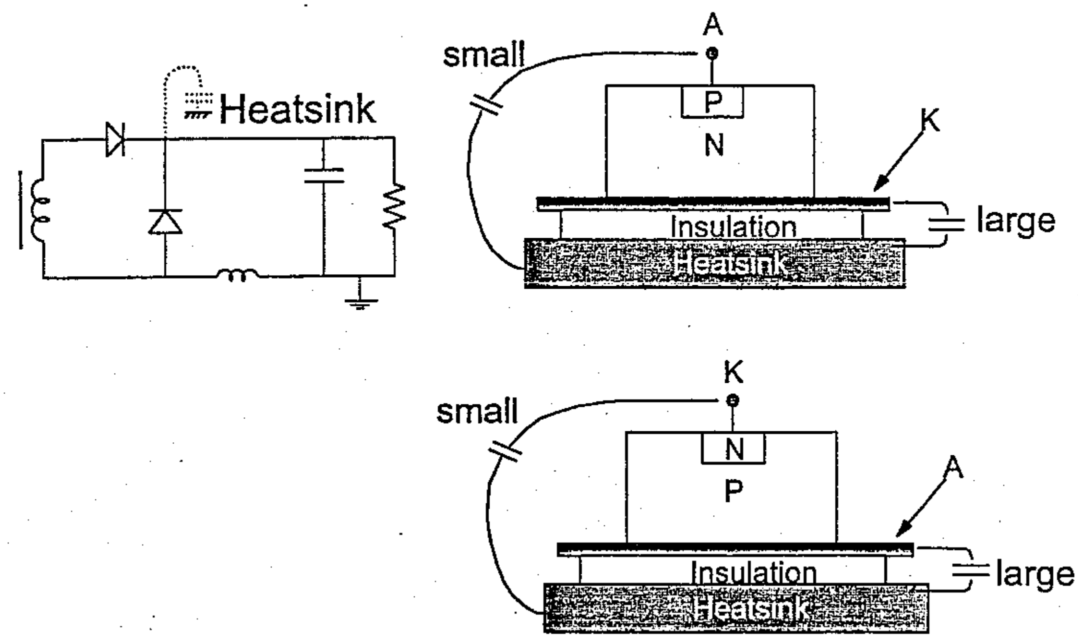
- $C_{parasitic}$ ≈ 100 p.f. for TO - 3
  ≈ 80 p.f. for TO - 5
  ≈ 30 p.f. for TO - 220

  for normal thickness mica insulation

- For isolate package, $C_{parasitic}$ depends very much on chip area. For a 600-V, 75-A IGBT, C ≈ 25 pf

Reducing CM EMI

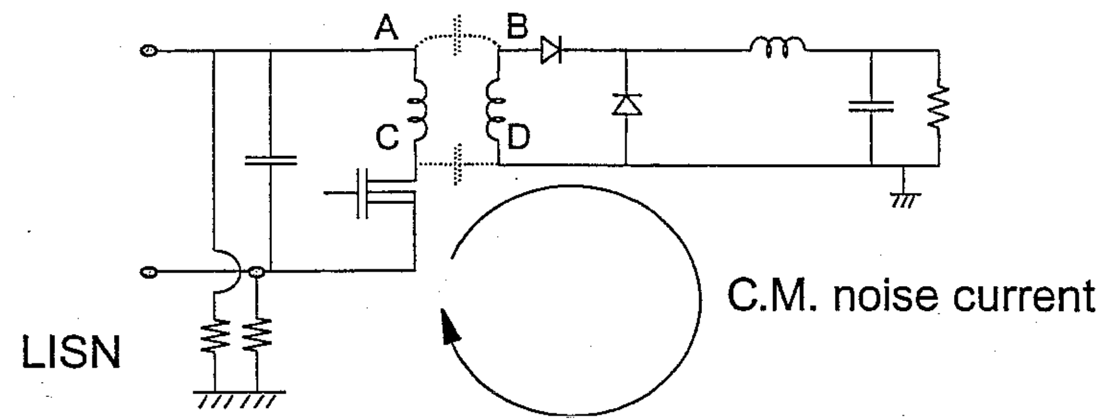
Diode Effects

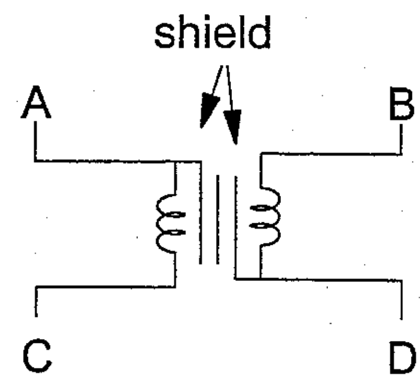


- Tie diode pakcage to AC ground
- Use snubber to reduce ringing
- Use soft diodes

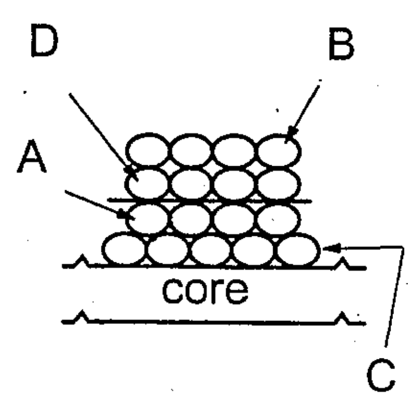
Reducing CM EMI

Transformer Effects



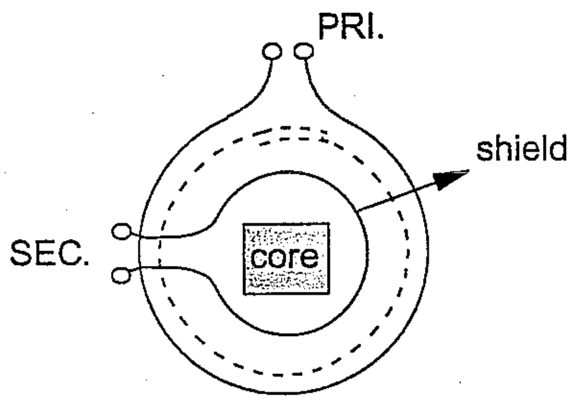


- Use shield (expensive)
- Tie sheilds to AC ground

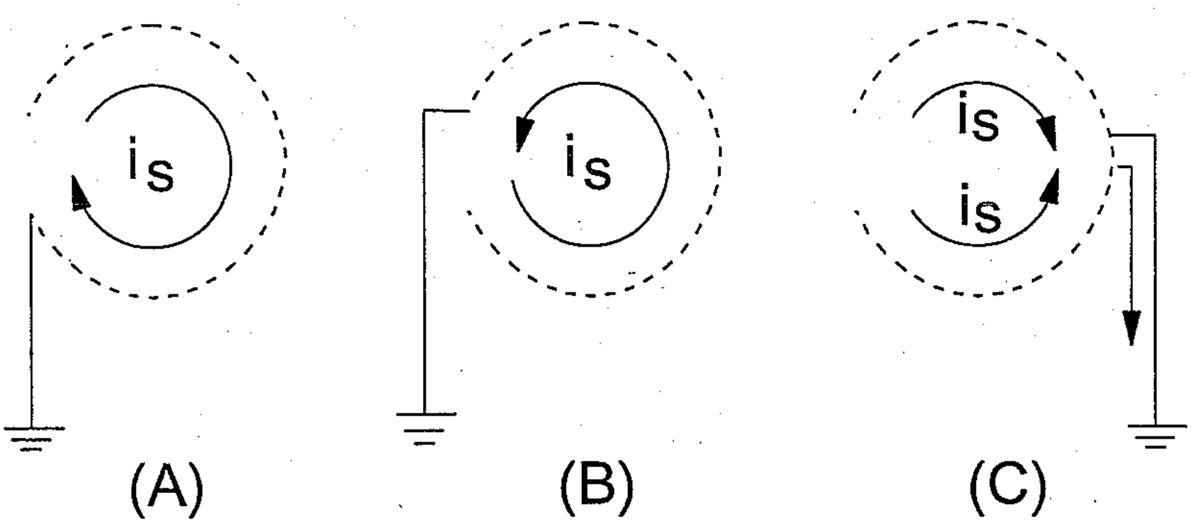


- If shields are not used, wind the turns such that A and D are close to each other

Transformer Shield Construction



shield must not form a closed loop !!



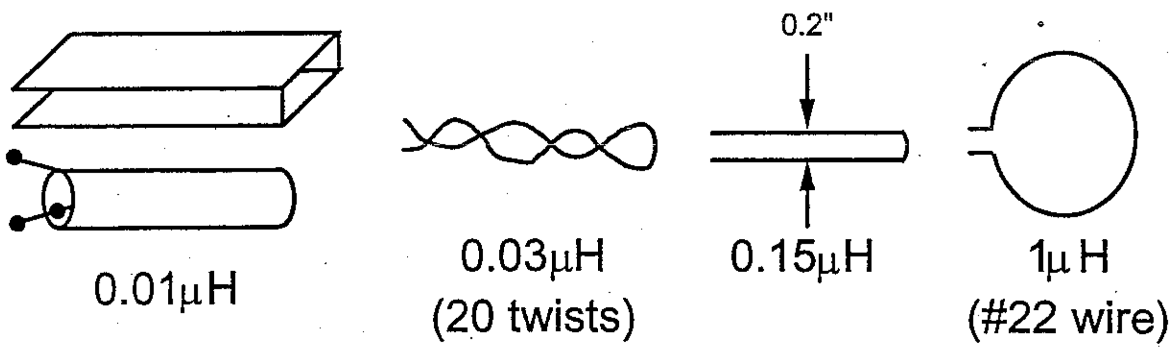
- Case (c) is best because $\sum Ni = 0$

$\Rightarrow$ does not affect magnetic coupling

- Keep ground wire impedance small

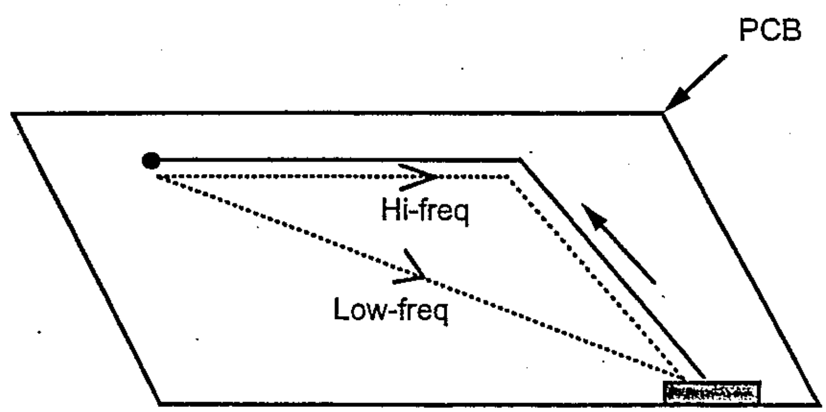
Inductance of Conductors

$$L = \frac{\Phi}{I}$$



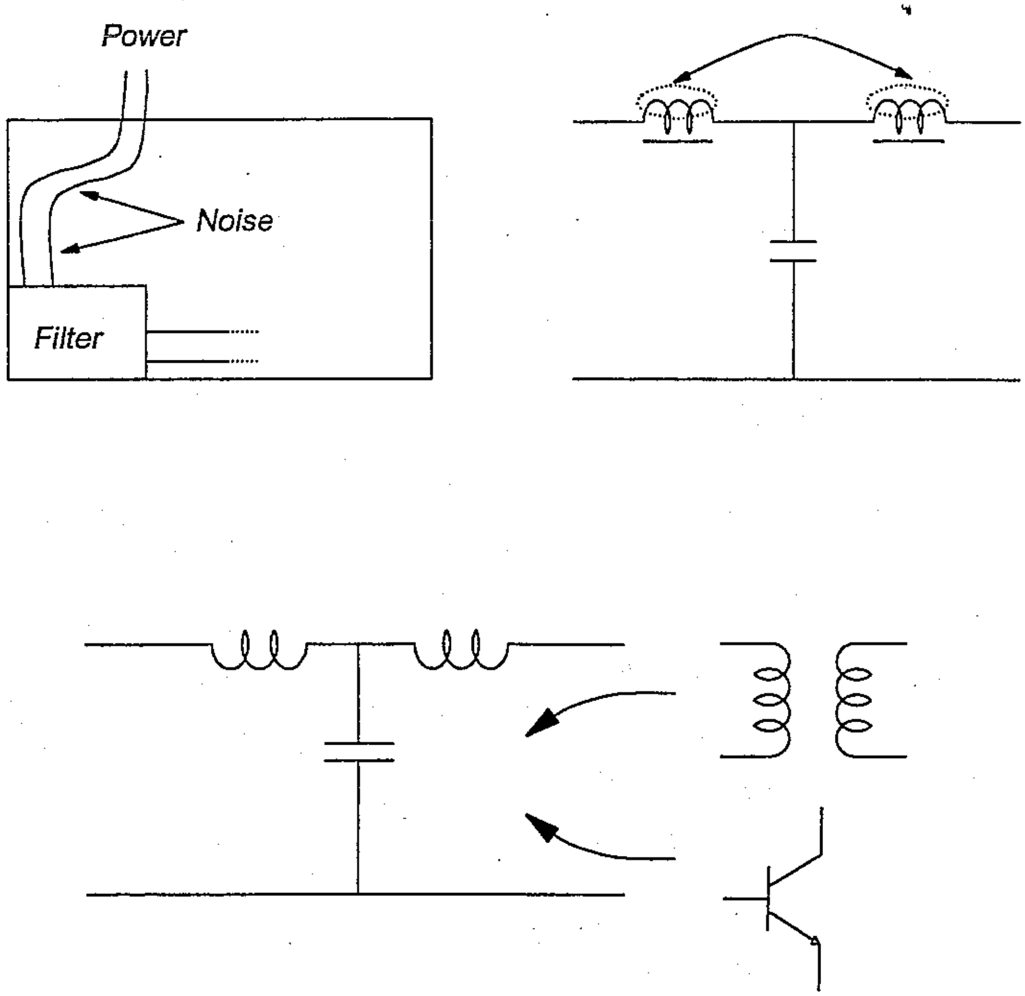
* All for 6" long

High-Frequency Current Path in a Conducting Plane



conducting plane on reverse side

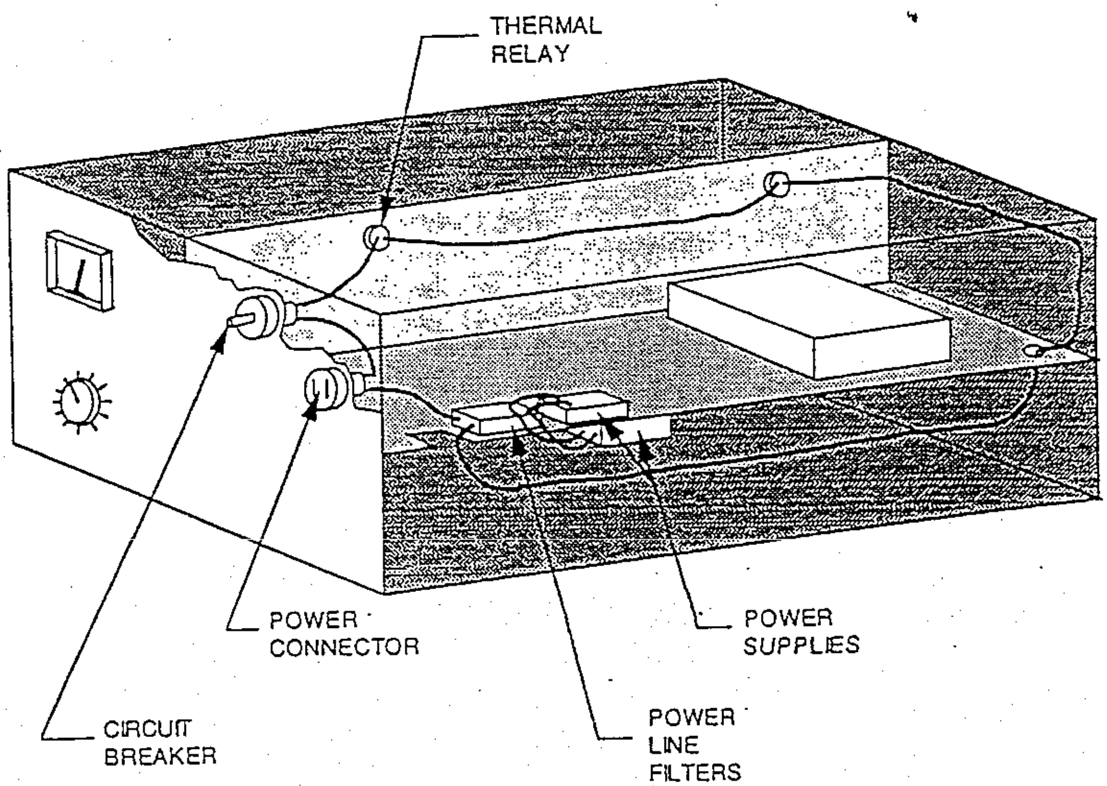
Radiation Coupling

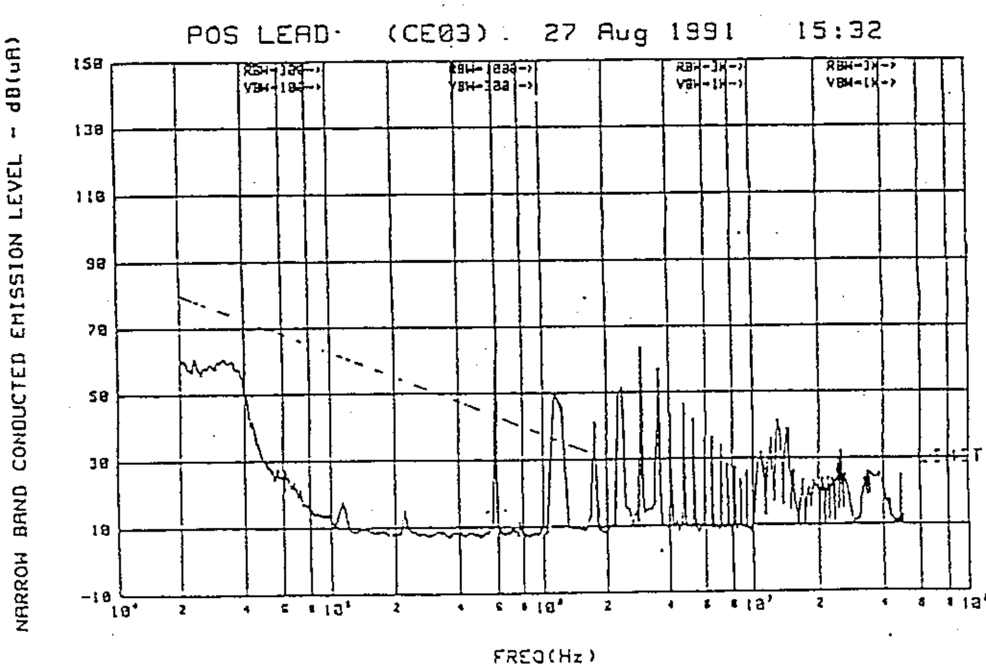


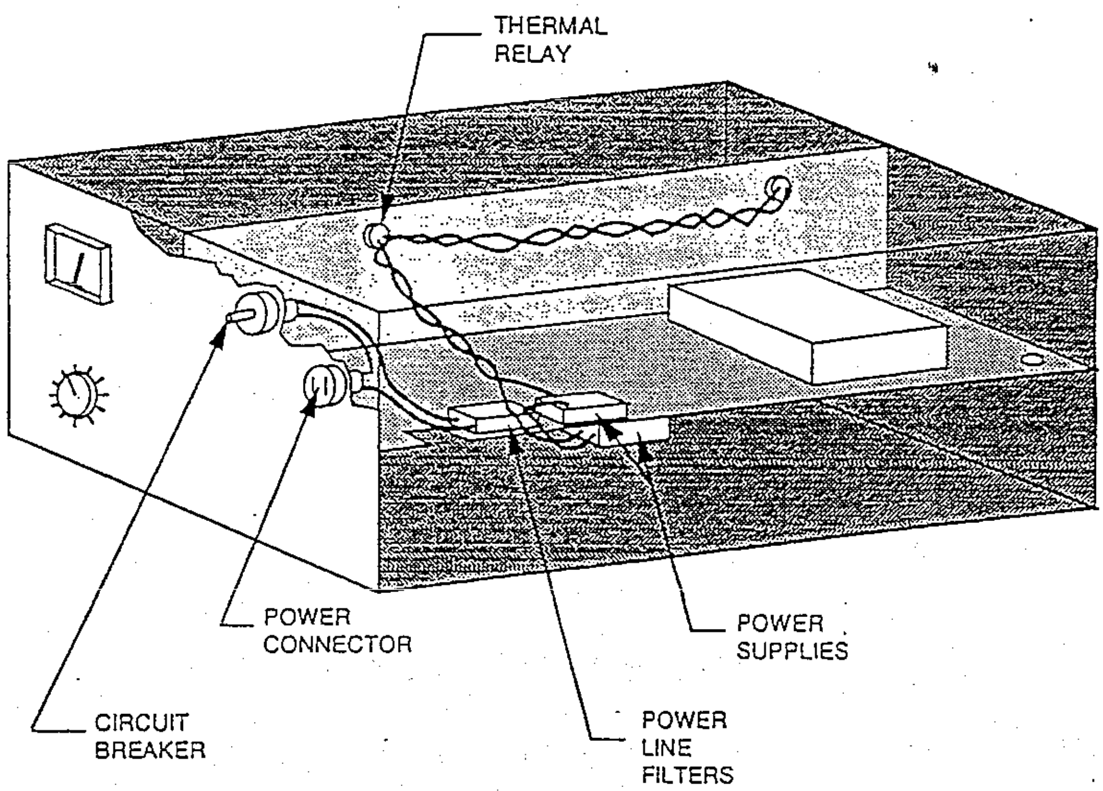
Symptons: Measured EMI not affected by changing filter component

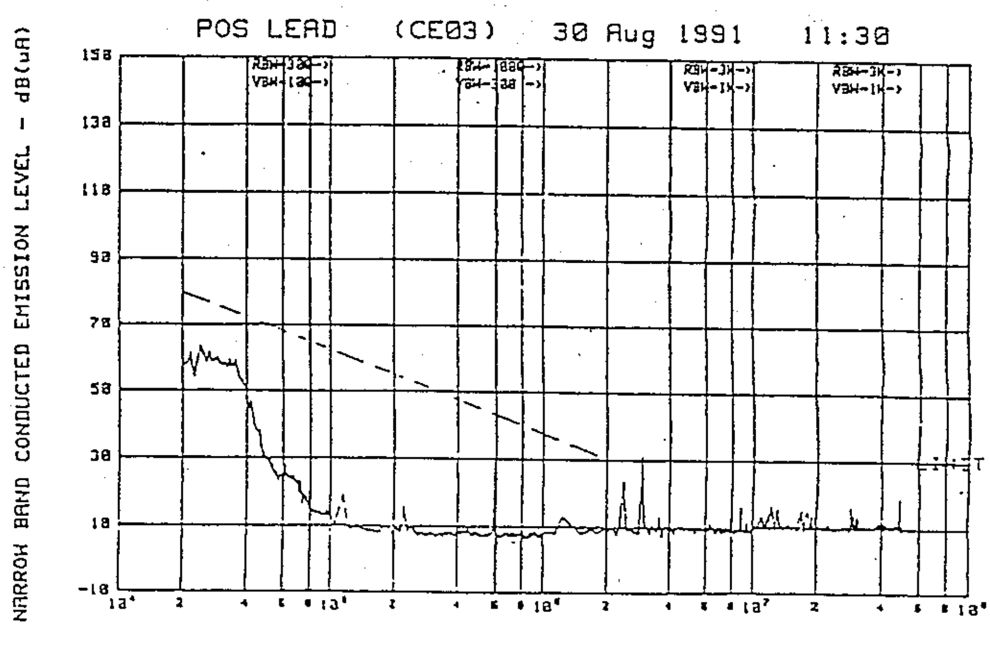
Possible Cures: Rearranging layout, shielding
Reducing wire loop

Radiation Coupling to Conducted EMI





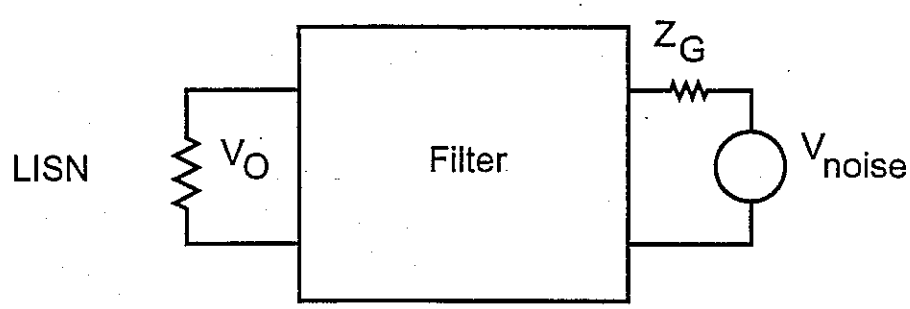

THERMAL
RELAY
POWER
CONNECTOR
POWER
SUPPLIES
CIRCUIT
BREAKER
POWER
LINE
FILTERS


POS LEAD (CE03) 30 Aug 1991 11:30
NARROW BAND CONDUCTED EMISSION LEVEL - dB(uA)
150
130
110
90
70
50
30
10
-10
RBW-30→
VBW-10→
RBW-300→
VBW-30→
RBW-3K→
VBW-1K→
RBW-3K→
VBW-1K→
FREQ(Hz)

六、 EMI 濾波器

(EMI Filters)

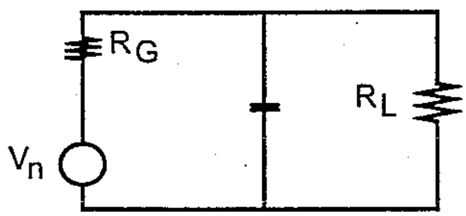
Filter Attenuation



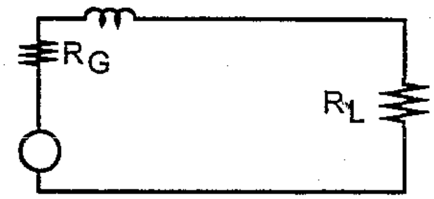
$$Ad_B = 20 \log \frac{(V_O) \text{ w/o filter}}{(V_O) \text{ with filter}}$$

- Ad_B depends not only on the filter used but also on noise-source impedance and LISN impendance.
- Ad_B ↑ as impedance mismatch ↑
- Commercial filter attenuation obtained in a 50_Ω - 50_Ω system.

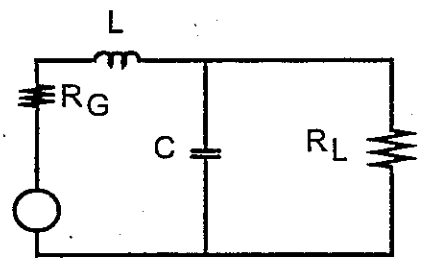
Effectiveness of a Filter



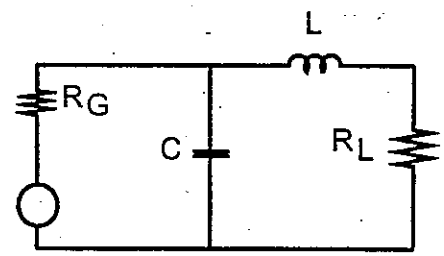
effective if $\frac{1}{wc} << R_L, R_G$



if $wL << R_L, R_G$

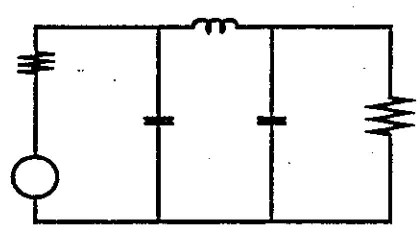


if $wL >> R_G$ & $\frac{1}{wc} << R_L$

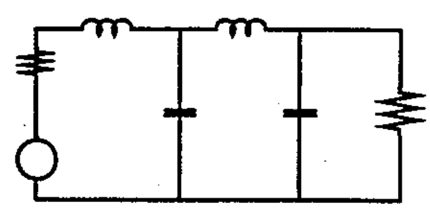


if $wL >> R_L$ & $\frac{1}{wc} << R_G$

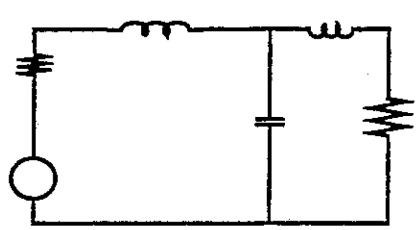
Higher-Order Filters



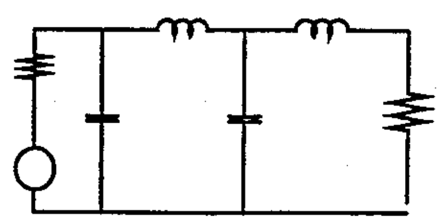
(π)



(LCLC)

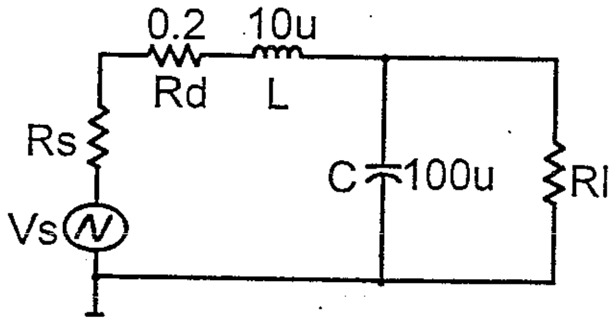


(T)

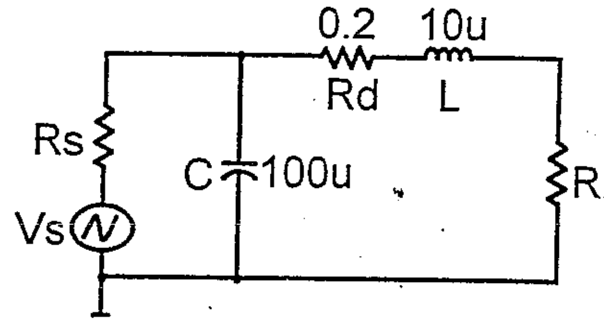


(CLCL)

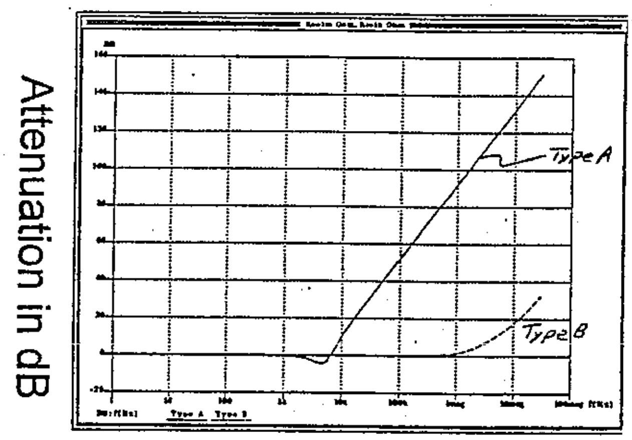
Impedance Effects on Filter Attenuation



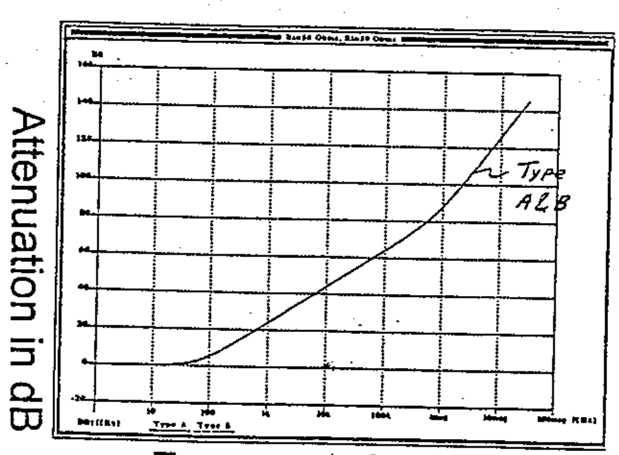
Filter Type A



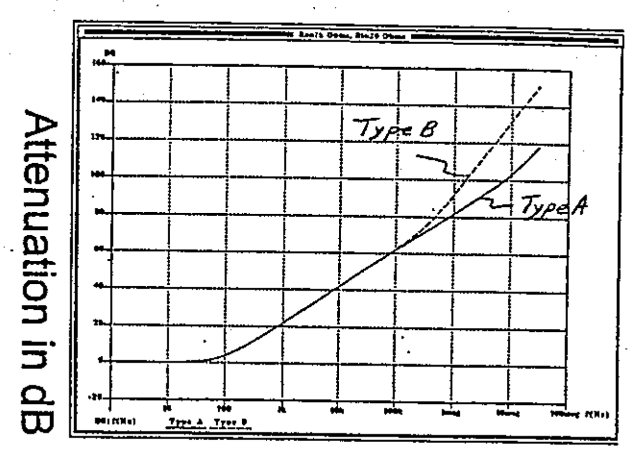
Filter Type B



Frequency in Hz
Rs=1m Ohm, Rl=1K Ohm

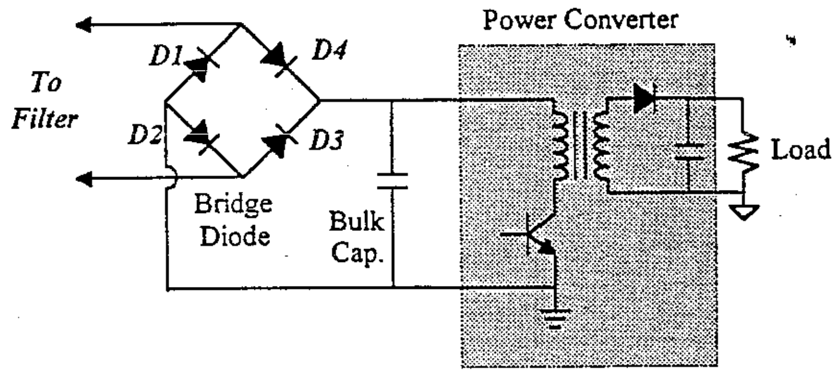


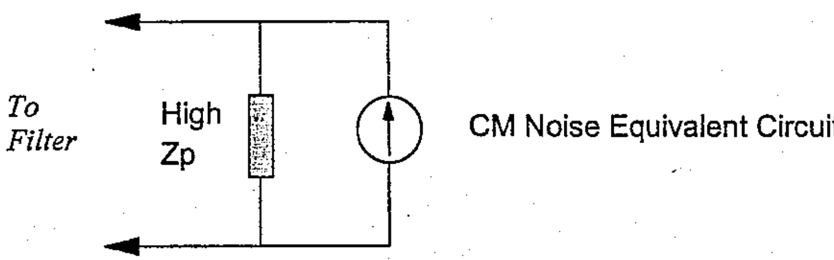
Frequency in Hz
Rs=Rl=50 Ohm

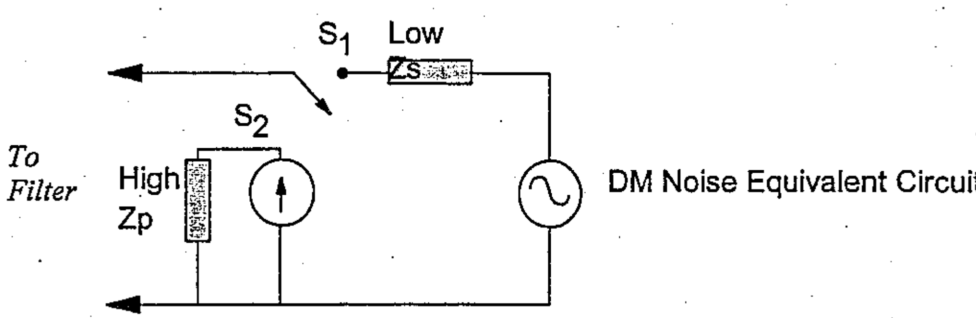


Frequency in Hz
Rs=1K Ohm, Rl=20 Ohm

Noise Source Impedance







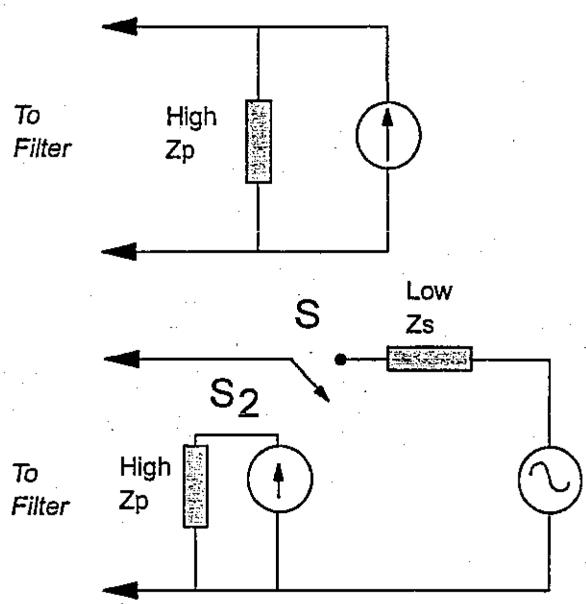
When rectifier diodes "on" ⟶ S_1 "on", S_2 "off"

When rectifier diodes "on" ⟹ S_1 "off", S_2 "on"

- Practically difficult to measure*

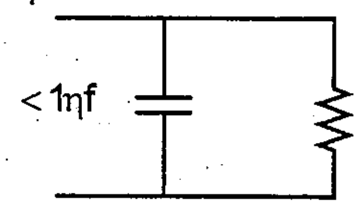
* Ref [2]

Experimental Source Impedance



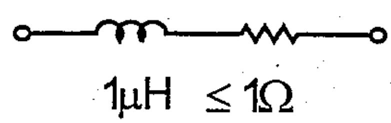
CM:

Z_p:

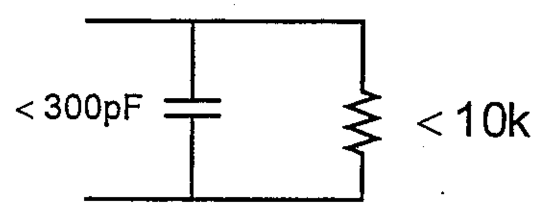


DM:

Z_S:



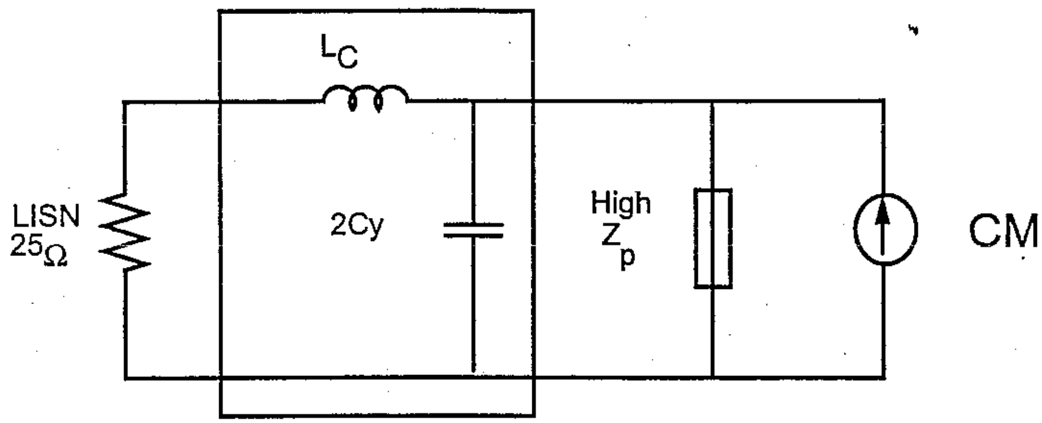
Z_p:

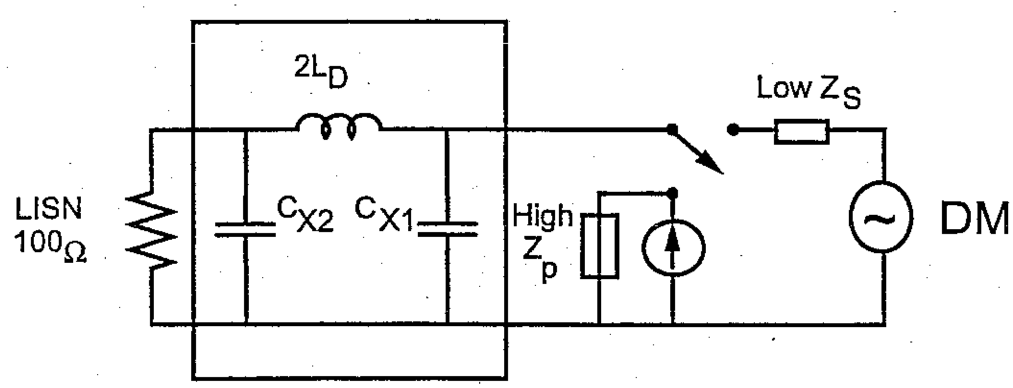


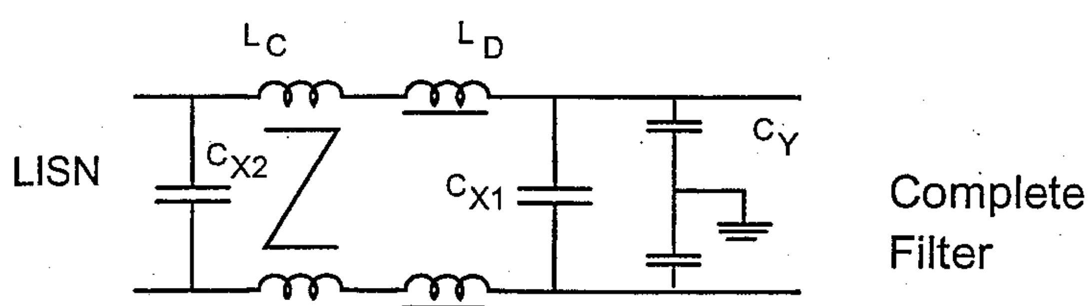
* For Power Supplies 50-500 Watts

*Ref [2], [3]

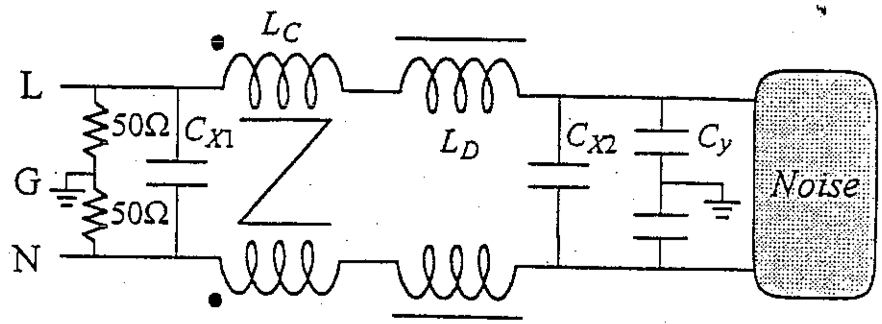
A Commonly-Used Filter Topology

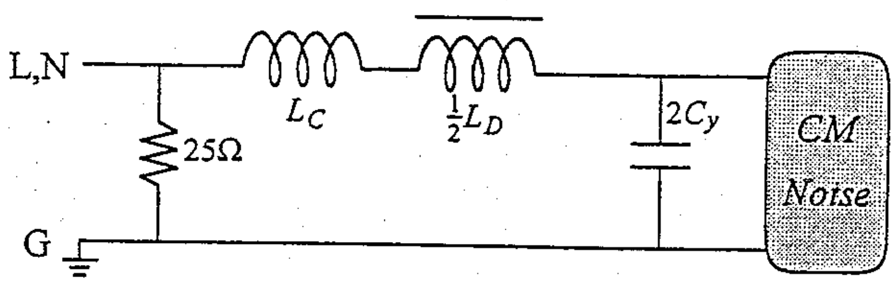


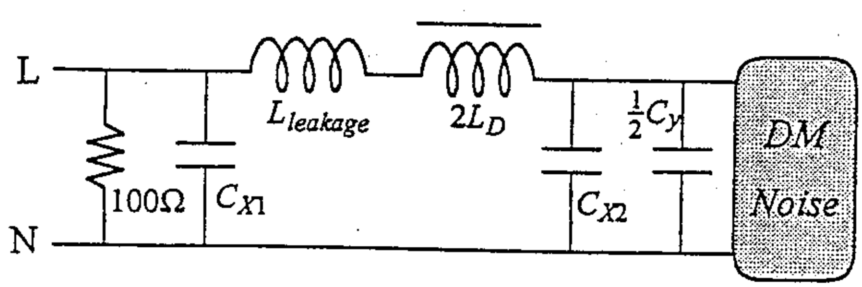




Filter Equivalent Circiuts

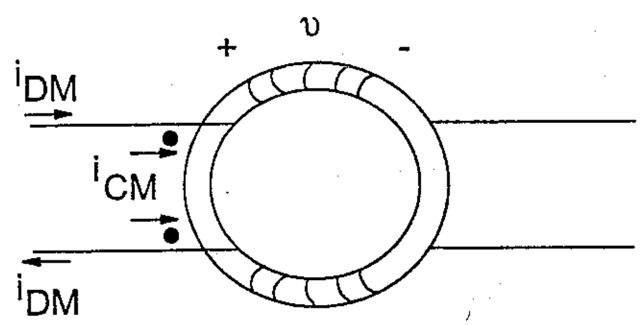


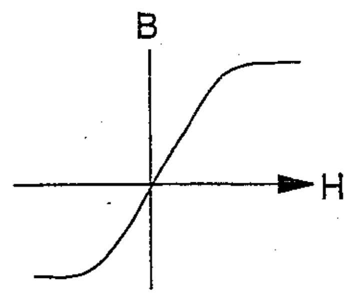




FILTER COMPONENTS

CM Choke (LC)



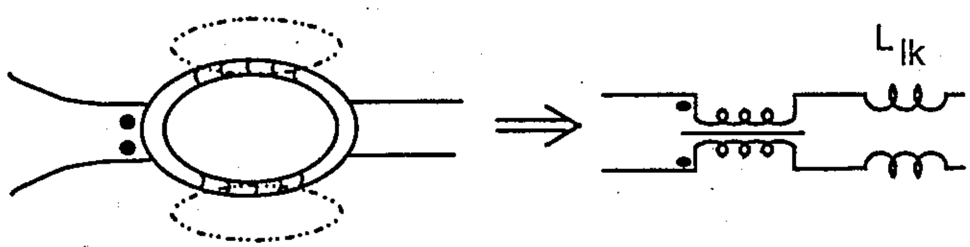


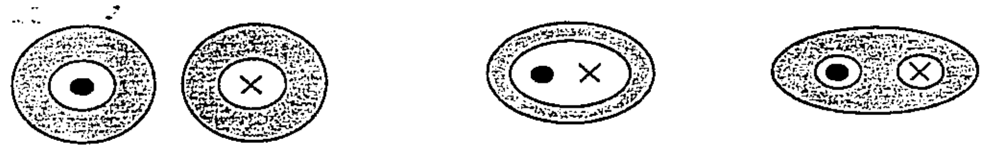
- DM current sees no CM ckoke

$$\text{Total MMF} = \sum_j N_j i_j = 0 \Rightarrow H = 0$$

$$\upsilon = N \frac{d\phi}{dt} = 0$$

- Power (DM) current doesn't saturate the core $\Longrightarrow$ Normally, high-μ cores are used
- Leakage inductance becomes DM choke

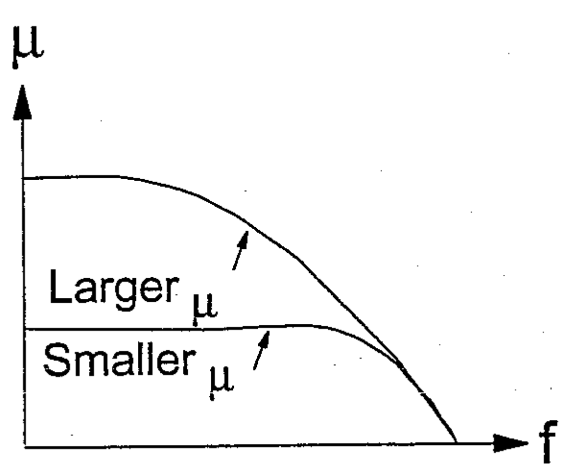


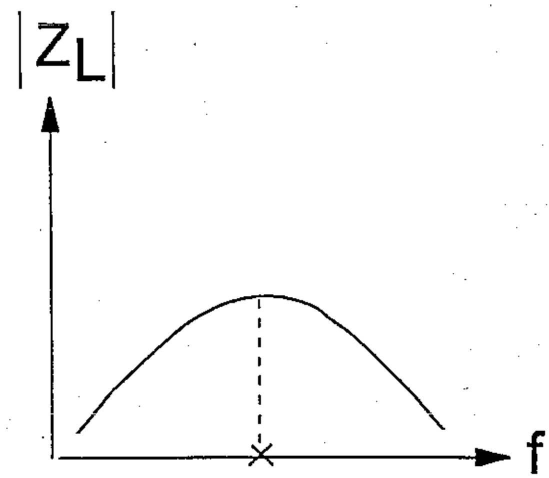
- 

DM Choke　　CM　　DM + CM

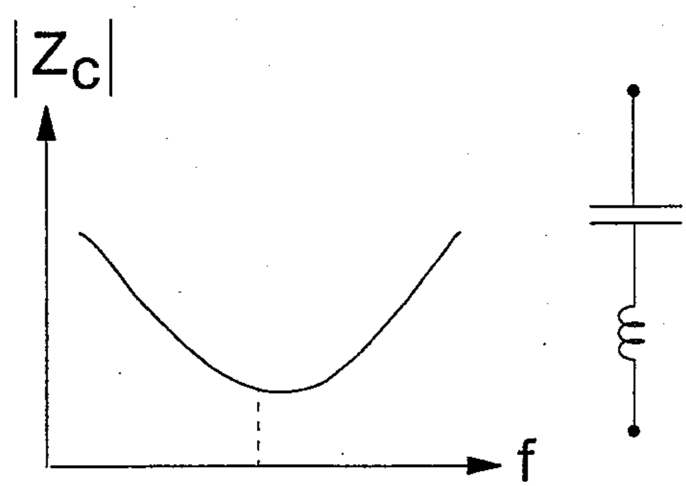
High-Frequency Effects on Filter Components

- Reduction of inductor impedance due to core permeability reduction and self resonance





- Increase of capacitor impedance due to resonance



七、分離 DM 與 CM 雜訊
(Separation of DM and CM)

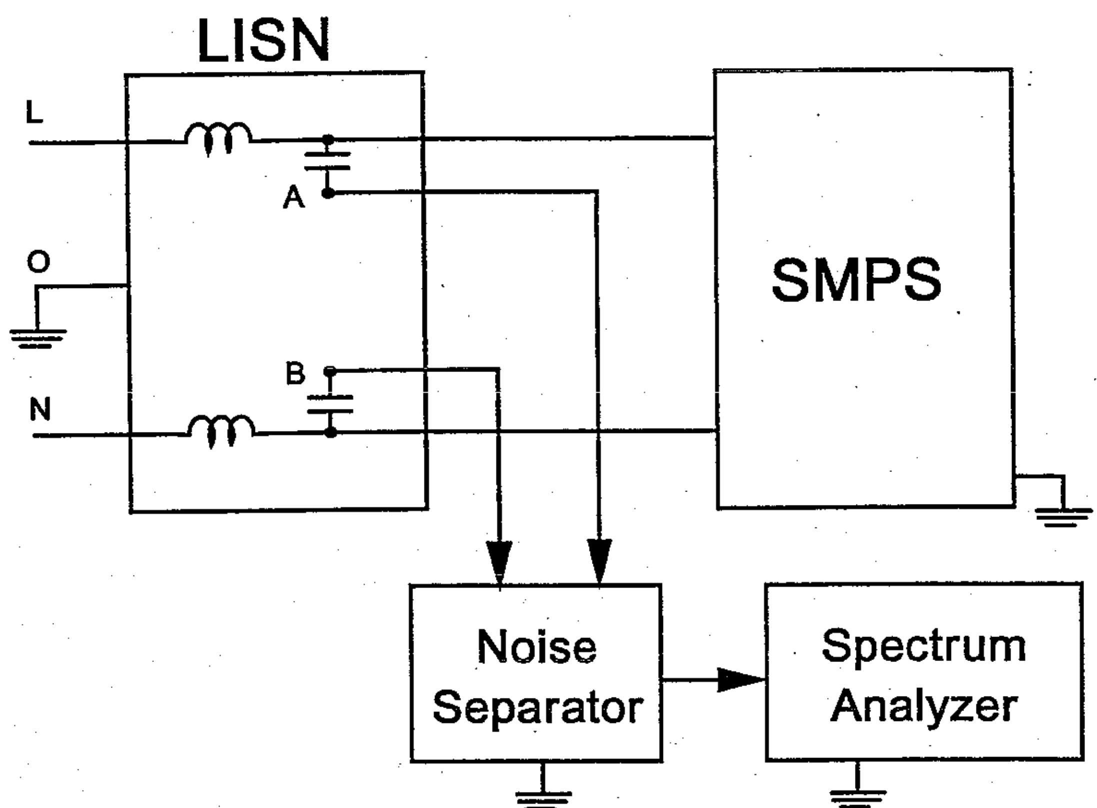
Why Separating DM and CM?

1. Identify the noise sources.
2. Treat DM and CM individually.

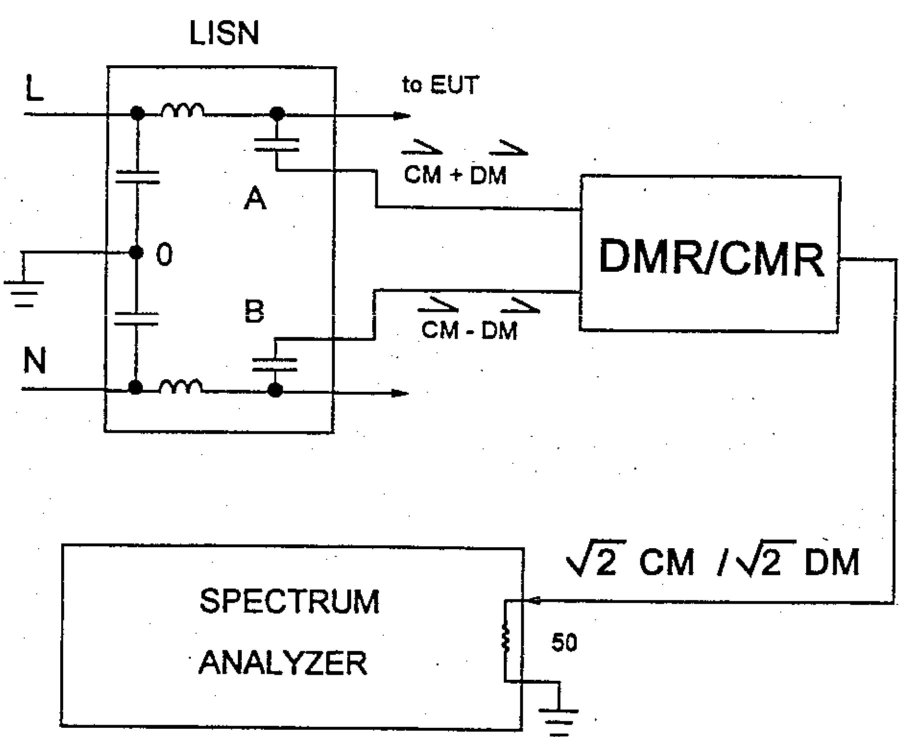
Conventional Approaches

1. Differential Mode Rejection Network (DMRN).
2. Current probe.
3. High Performance Differential Amplifier.

Using Noise Separator

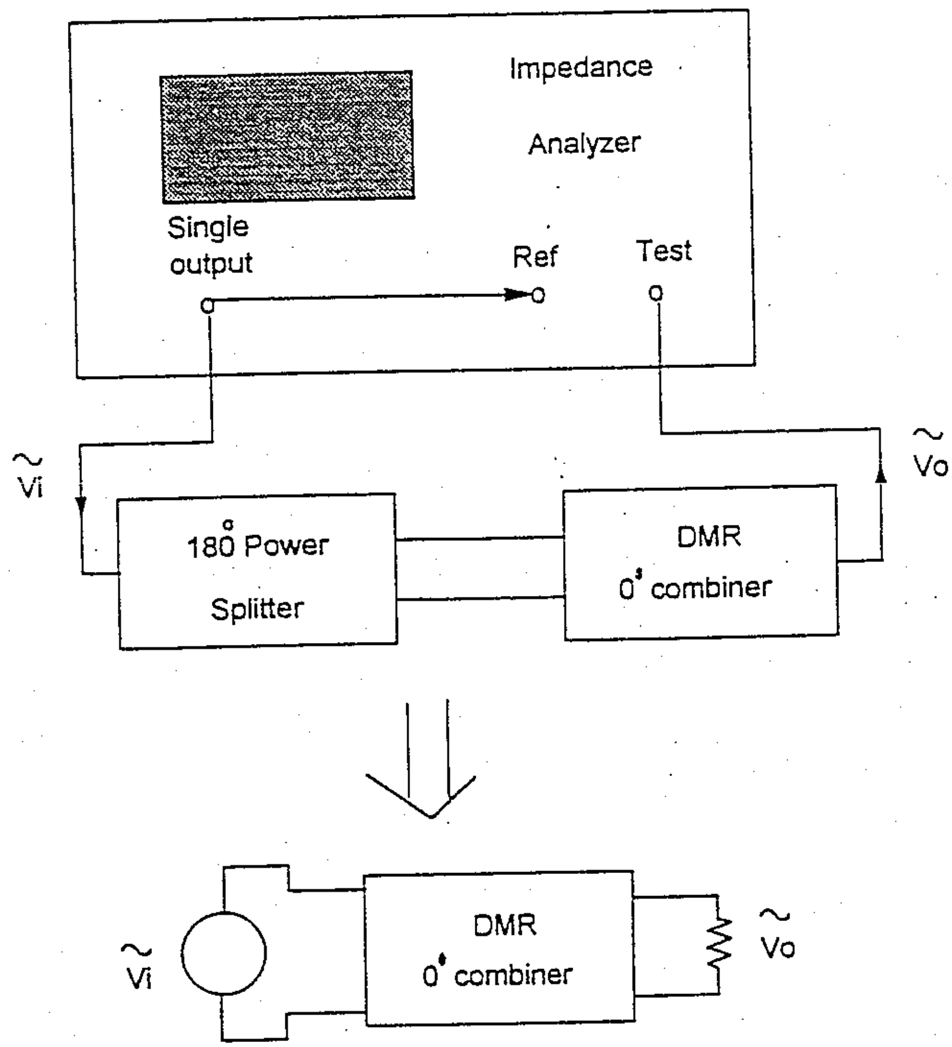


Basic Principle of Noise Separation

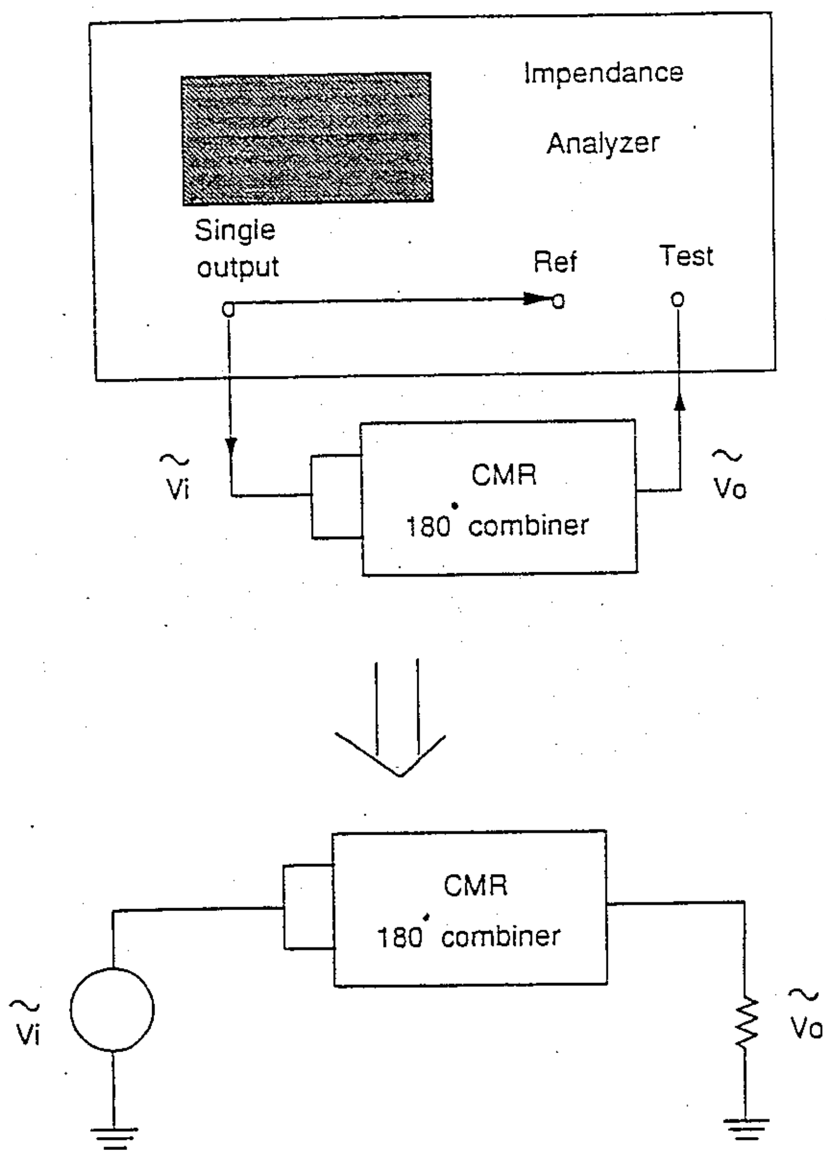


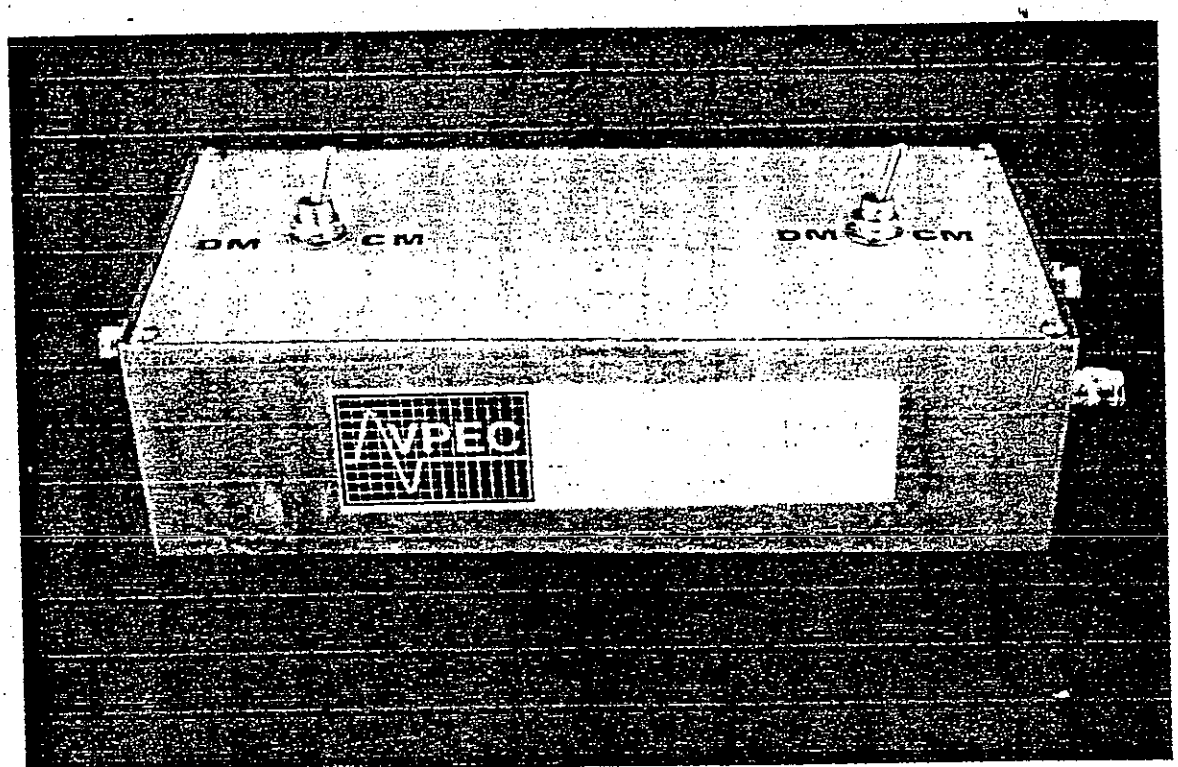
- DMR: 0° power combiner
  CMR: 180° power combiner

Measurement of Rejection of DMR

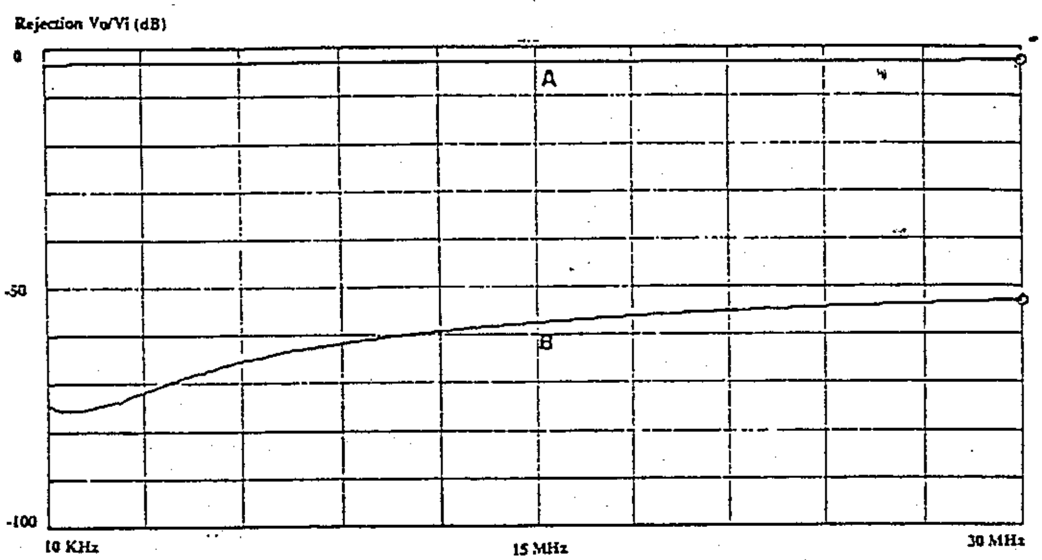


Measurement of Rejection of CMR




DM
CM
DM
CM
VPEC

Test Result of CMR Rejection



A: Vi

B: Vo

Test Result of DMR Rejection