Know-How of EMI Control

Power Electronics Lab.

www.pwm.pe.kr

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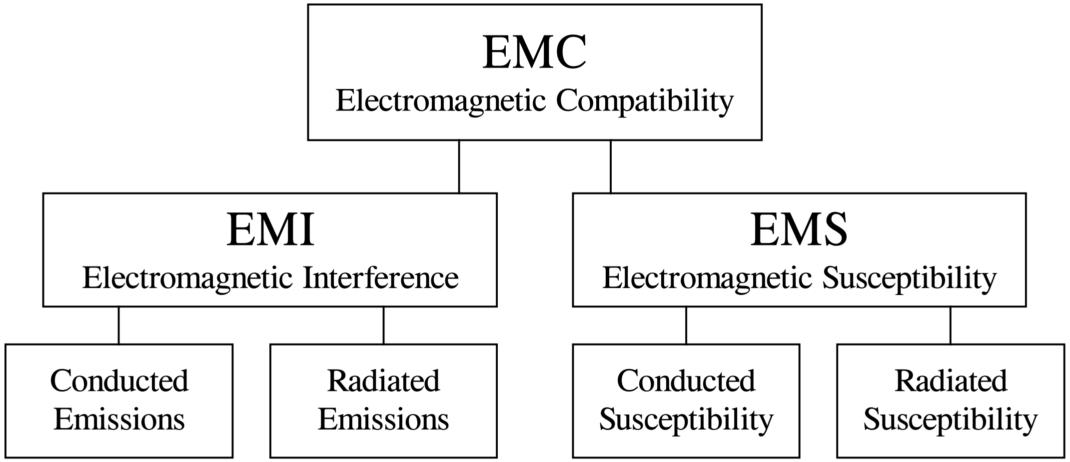
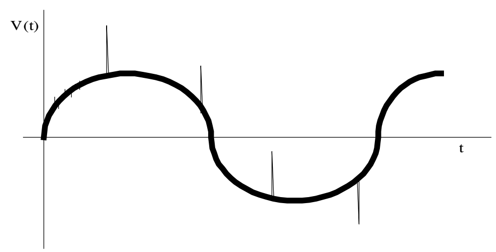
Ref. - Electromagnetic compatibility in power electronics, Laszlo Tihanyi, IEEE press, 1995
- EMI troubleshooting techniques, Michel Mardiguian, McGraw-Hill, 2000
- EMI filter design, Richard Lee Ozenbaugh, Marcel Dekker, 2001
- Controlling the parasitic parameters to improve EMI filter performance, S.Wang, FC Lee and W.G. Odendaal, APEC 2004, pp.503-509



- A device is considered to be **electro magnetically compatible** only if its effects are tolerated by all other devices operating in the same environment.
- EMI levels are increasing significantly from PC, power switching equipment…
- 150KHz~1GHz for EMI
- CISPR(international committee for radio interference) was founded in 1933.

Electromagnetic Disturbances

- Noise:
  Small amplitude and high frequency source
  Welding machine, SMPS..
- Impulses:
  +/- peaks on line voltage
  Short duration, high amplitude, fast rise/fall time
  Switches, Relay, SCR..
- Transients:
  A few periods of the line frequency
  High power switch..



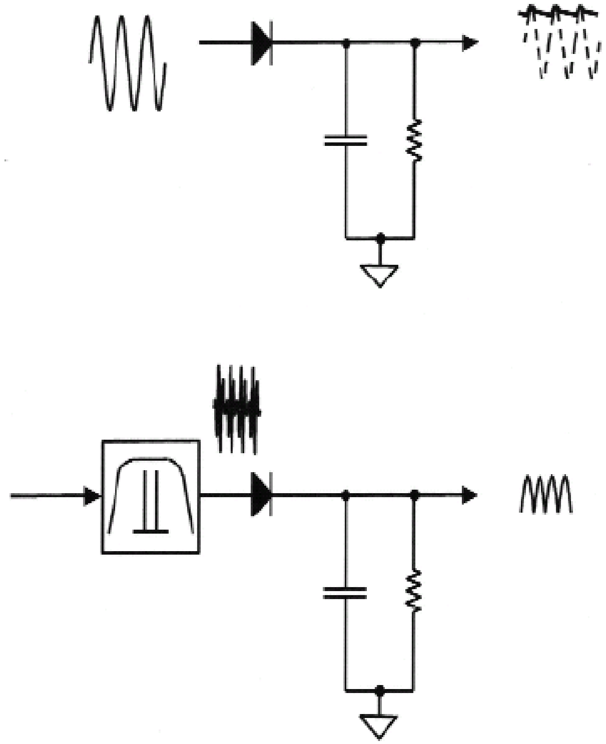
EMI receiver

- CISPR spec. : 9KHz b.w.(-6dB), quasi-peak(QP)
  (charge 1ms/discharge 100ms), accuracy +/- 2dB

- Peak>QP>effective(RMS)>average – A broadband signal
- Peak=QP=effective(RMS)=average – A narrowband signal

For initial measurements, peak detection is used.

The spectrum analyzer must sweep considerably slower when the quasi-peak detector is on.



dBuV ⇔ dBm

- 0dBm=1mW , $P=V^2/R$
- dBW=10 log P =dBm+30
- dBV=20 log V_1/V_2 =20 log V_1 [V_2=1V]
- dBuV=dBV+120 [V_2=1uV]
- dBW=dBV- 10 log R
- dBm=dBuV-120-10logR+30

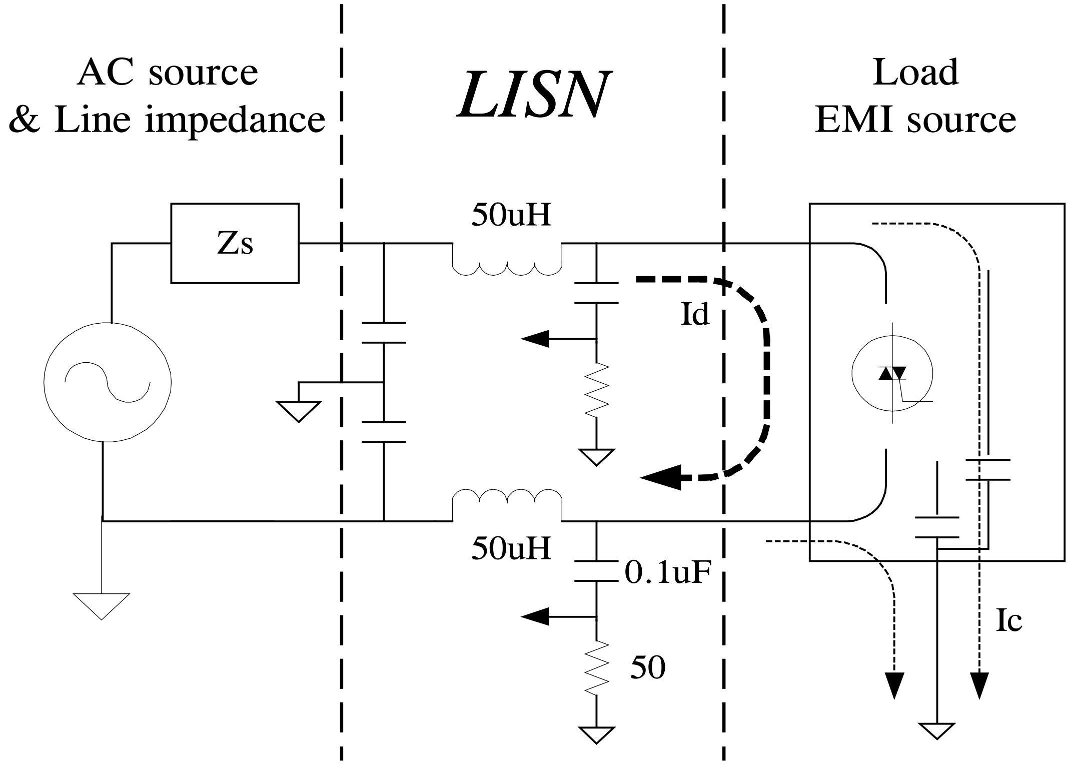
  =dBuV-107 [R=50]

dBuV=dBm+107

Conducted EMI

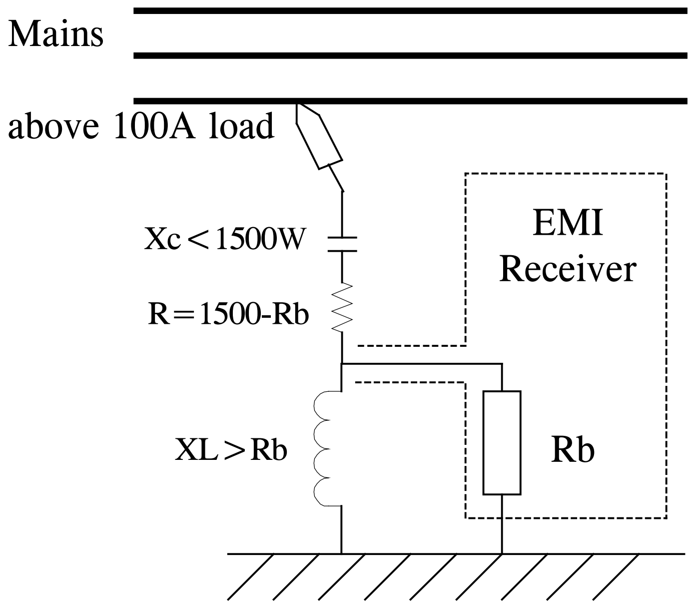
0.15~30 MHz

Common Mode & Differential Mode Voltage



Conducted EMI

- Direct measurement for high power loads
  >100A
- Diff-Mode Voltage :
  150~1600KHz
- Common Mode Voltage :
  >1600KHz
  Coupling paths?



- Measurement at 10KHz B.W.
  -1dB correction factor(20log 10/9=1dB)

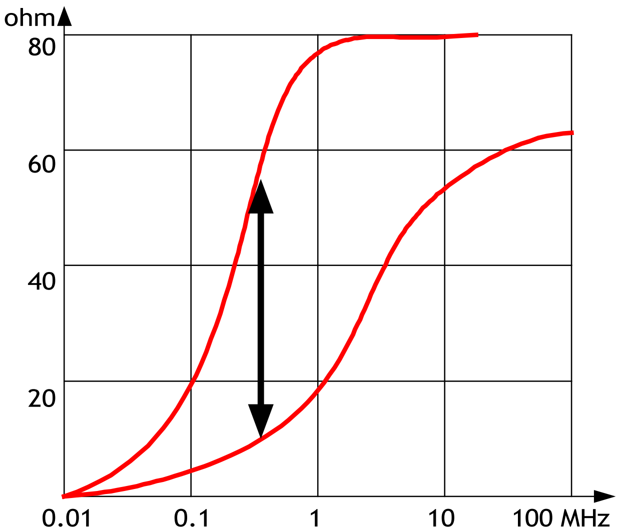
Radiated EMI

- If the conducted emissions are reduced, the radiated emissions are also often reduced.

Conducted EMI	Freq. Range (MHz)	Limits (dBuV)	
		Quasi-peak	Average
Class A	0.15-0.5	79	66
	0.5-30	73	60
Class B	0.15-0.5	66-56	56-46
	0.5-5	56	46
	5-30	60	50

Radiated EMI Freq. Range (MHz)	QP Limits (dBuV/m)	
	Class A (10m)	Class B (10m)
30-230	40	30
230-1000	47	37

AC Line & Load Impedance



- Load Impedance
  = most **L** and **C**
  + a few **R**

- Line impedance :
  a function of line length, conductor spacing, diameter…
- Open wire: 90~180 ohm
- Pair/twisted: 50~90 ohm

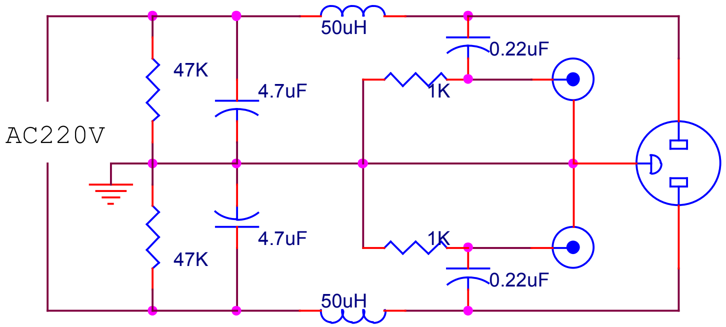
  <10KHz ~0 ohm

  ~100KHz 4 ohm

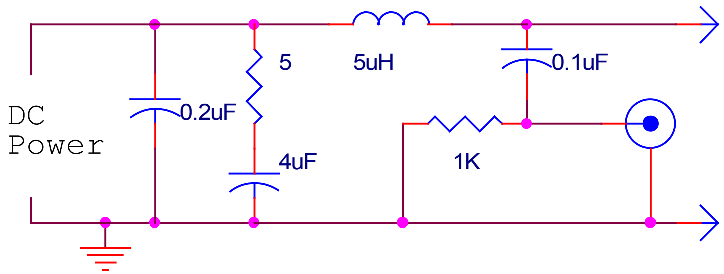
  >100KHz 50 ohm

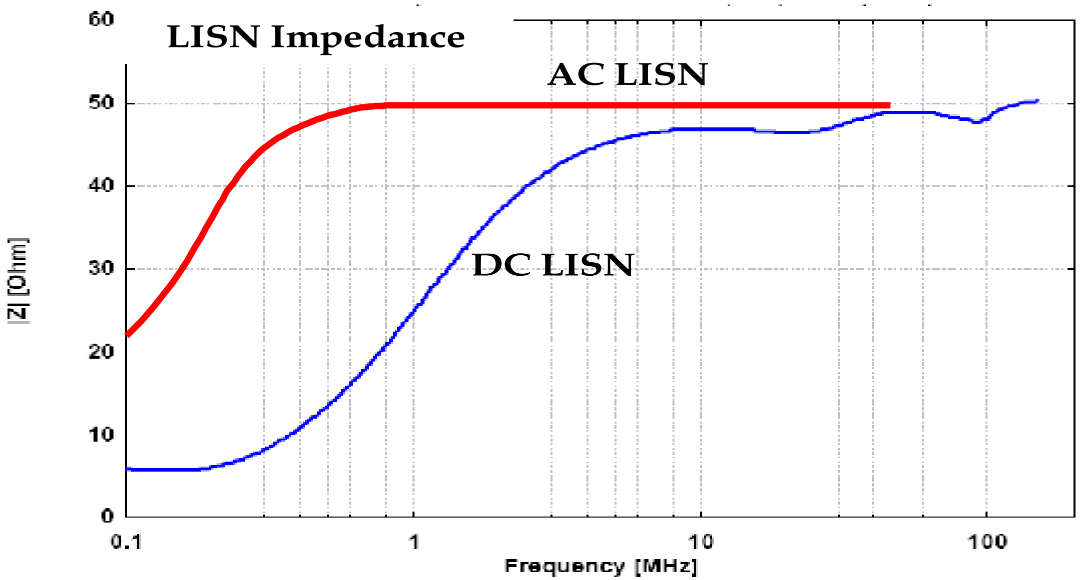
LISN(Line Impedance Stabilization Network)

AC LISN : 0.15~30 MHz



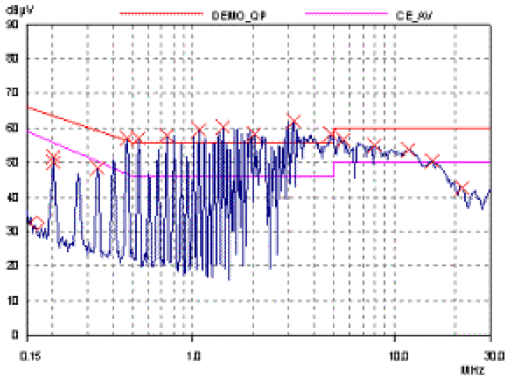
DC LISN : 0.15~108 MHz

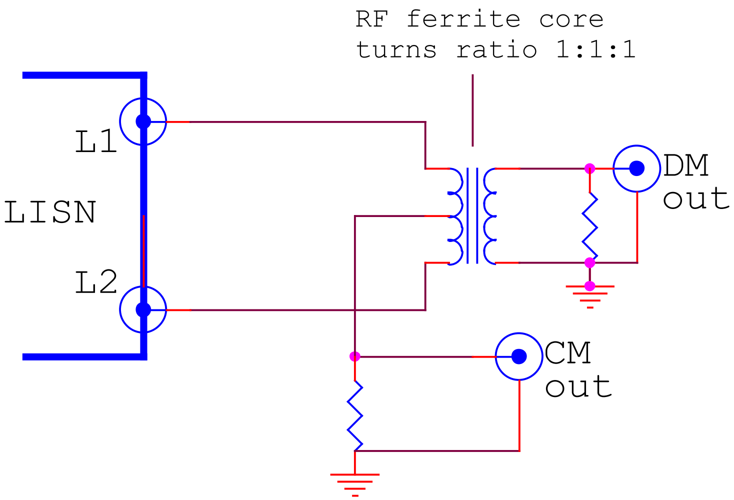




DM-CM Splitter

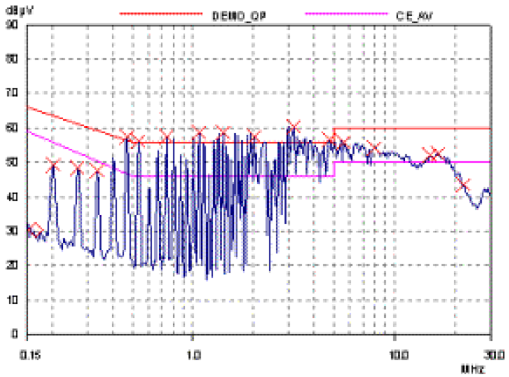
Differential mode - Common mode

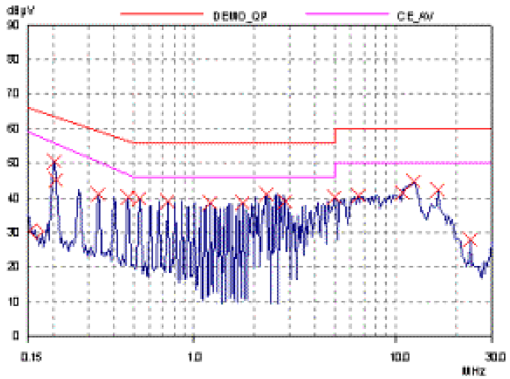




- Total noise =

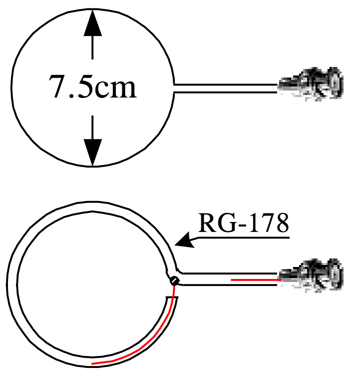
Common mode noise + Diff. Mode noise





Near-Field Probe(1)

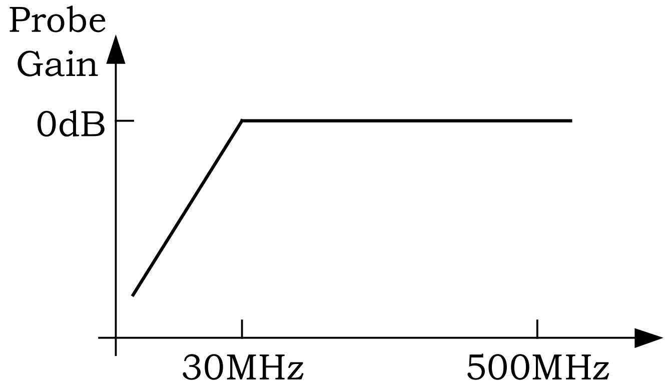
Loop Ant. H-field



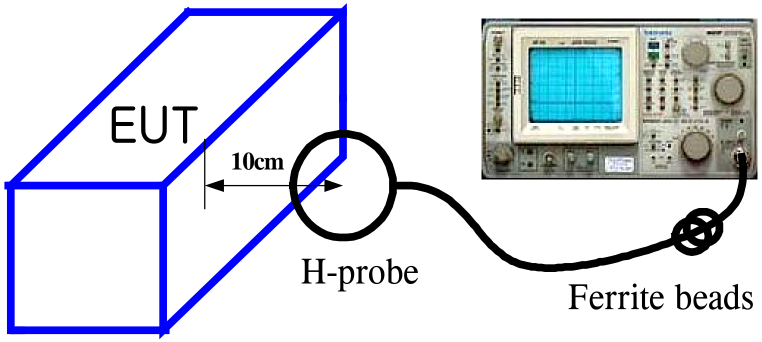
- 1mm coil loop(Dia. 7.5cm): L=250nH
  $f_{cut\text{-}off}$ = 30 MHz (Z_T 50Ω)
- Coaxial cable Loop: removing E-field affection

$$V_o(uV) = 2\pi f \cdot \mu_0 H \cdot A = 2\pi f \cdot 4\pi 10^{-7} \cdot \pi \cdot r^2 \cdot H$$
$$= 0.035\, f_{MHz} H_{uA/m}$$

$$V_{50\Omega}(uV) = H_{uA/m}$$
$$E[dBuV\ /m] = V[dBuV_{50\Omega}] + 51.5$$



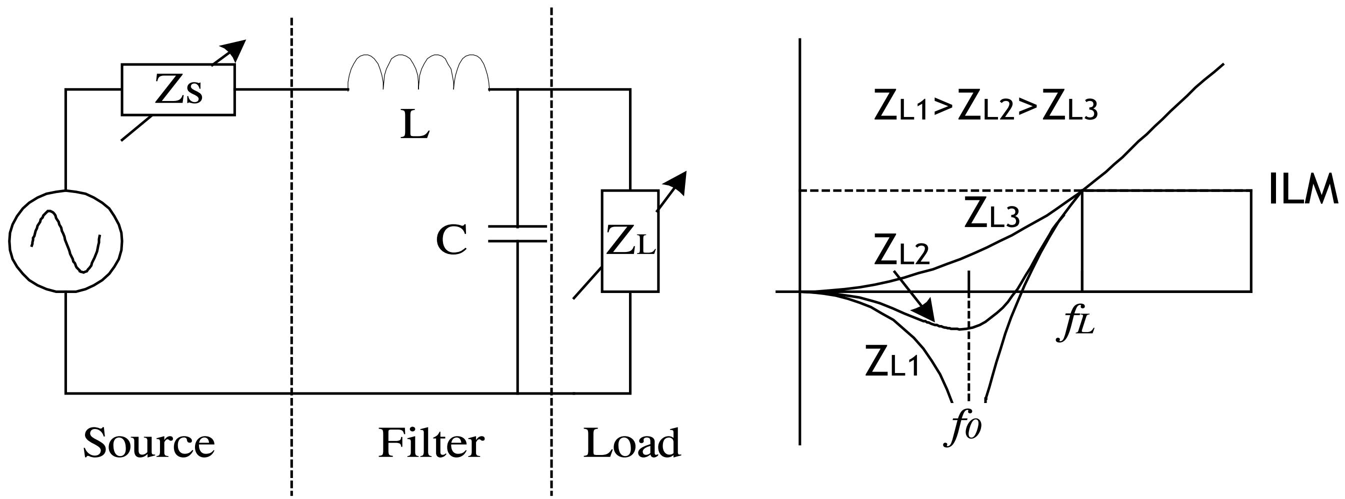
Near-Field Probe(2)



Radiated EMI					
f[MHz]	30	100	200	300	500
Class B Limit @10m	30	30	30	37	37
Correction factor	64	53	47	43	40
Limit @ 0.1m	94	83	77	80	77
H-probe output H[dBuA/m] (Limit)	43	32	26	29	26

EMI Filter Design(1)

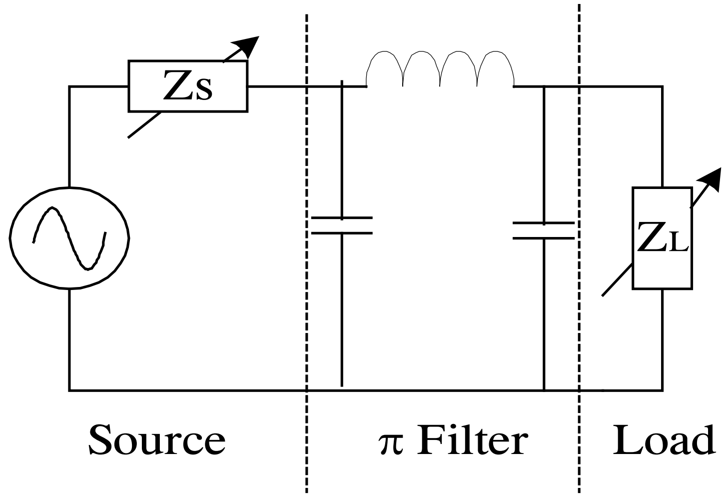
mismatched impedance condition



- Conventional filter design: fixed input and output impedance
- EMI filter: varying impedances – No design rules
- If Zs≈ 0, Insertion loss = Attenuation

EMI Filter Design(2)

mismatched impedance condition

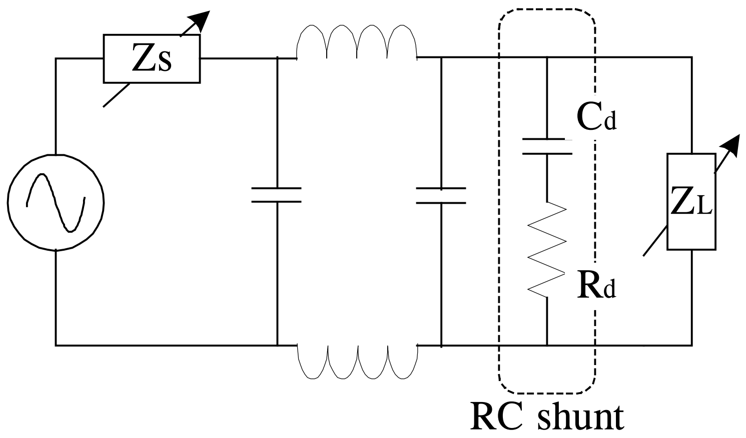


- Conventional filter design (theoratical)

  60 dB/dec insertion loss

- Practical insertion loss : 20 dB/dec

RC Shunt



- It stabilizes the load impedance.

  -> reducing resonant rises above f_d

- Nominal load R_L

  $R_d=R_L$

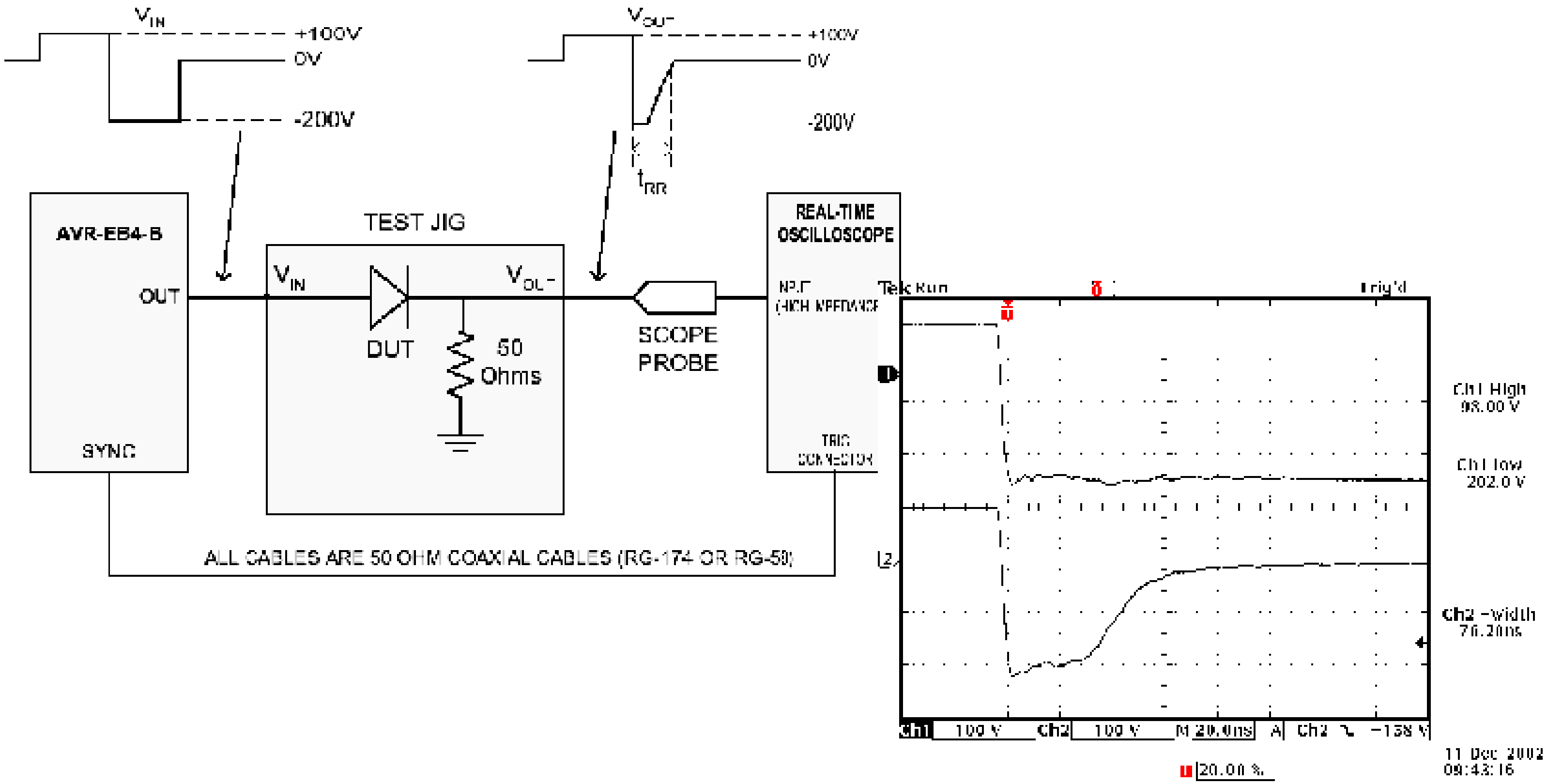
  $C_d=1/(2\pi f_d R_d)$

- Load 300V 3A -> $R_d=100$

  $f_d=1KHz$ $C_d=1.6uF$

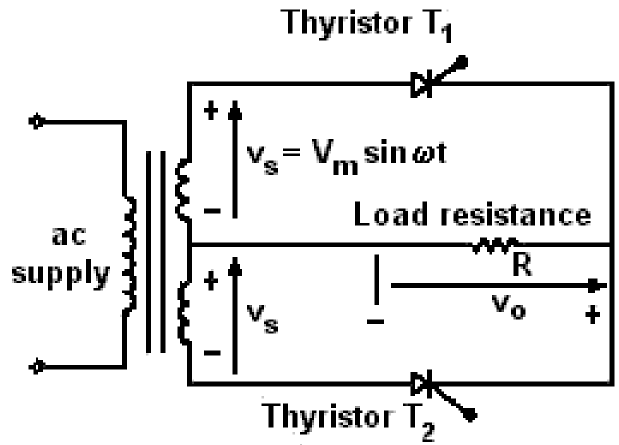
EMI from Power Electronics

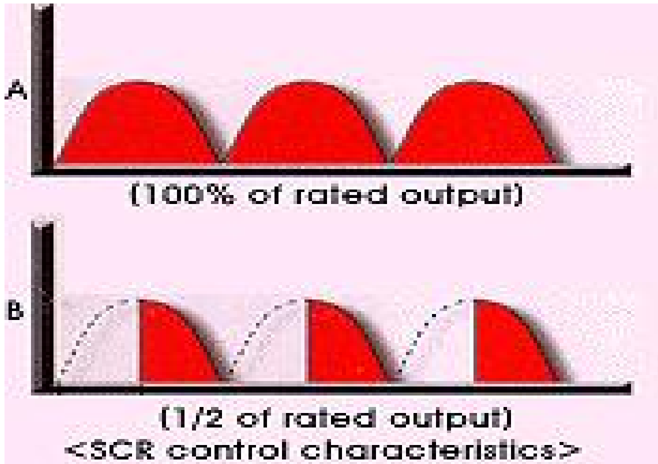
The primary cause of EMI is Switching action.

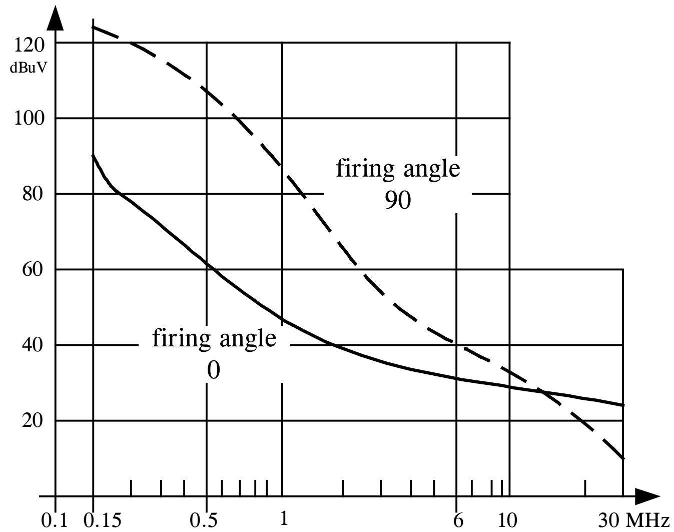


EMI from Power Electronics

SCR Rectifier

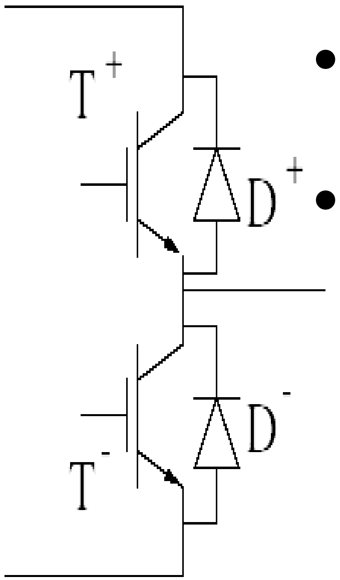




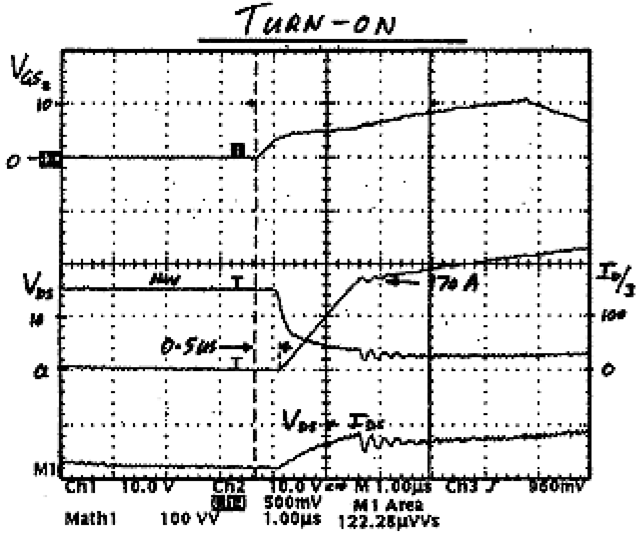


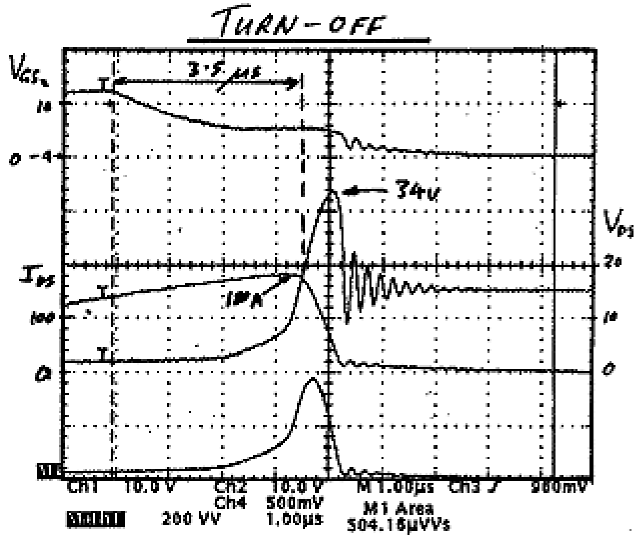
EMI from Power Electronics

IGBT Switching



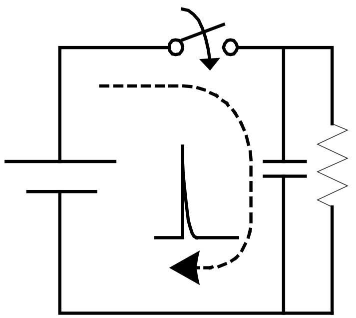
- Diff. Mode EMI : by reverse recovery current of free wheeling diode
- Comm. Mode EMI: by parasitic cap. b/w Heatsink and T- switch
- Switching speed: MOSFET>IGBT>TR>SCR



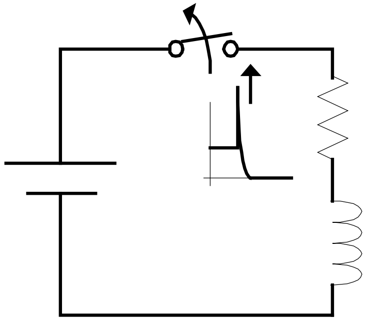


Noise Suppression

Snubber

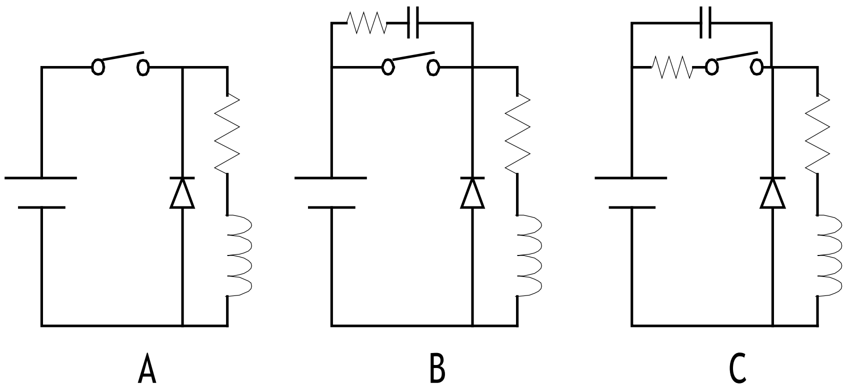


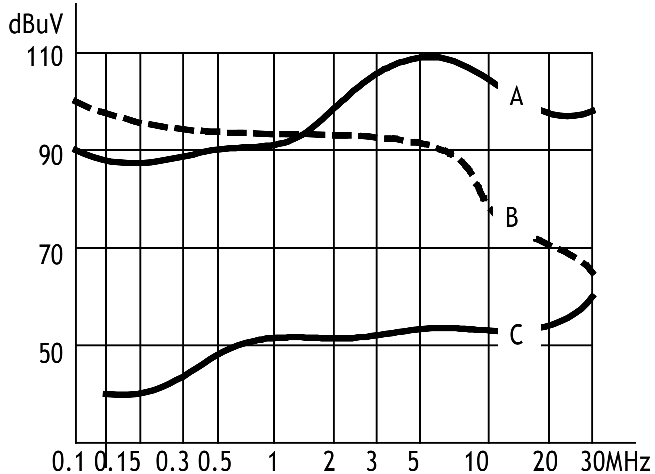
Inrush current at turn-on



Surge voltage at turn-off

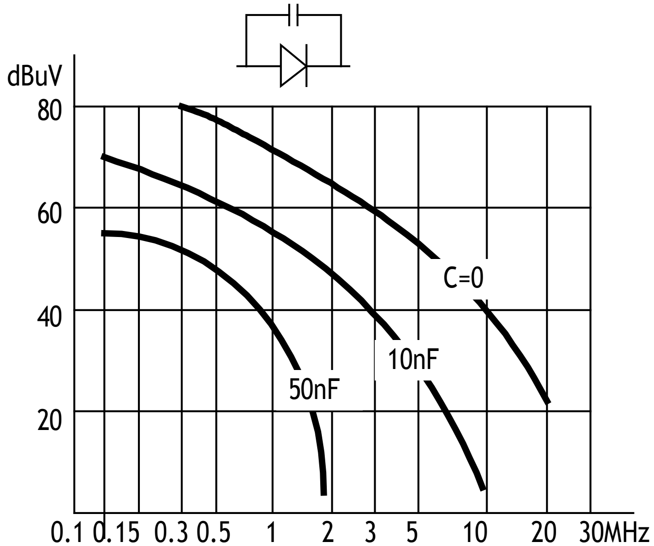
- AC circuit: zero cross switching, RC snubber
- DC circuit: RC snubber
- Diode: C snubber

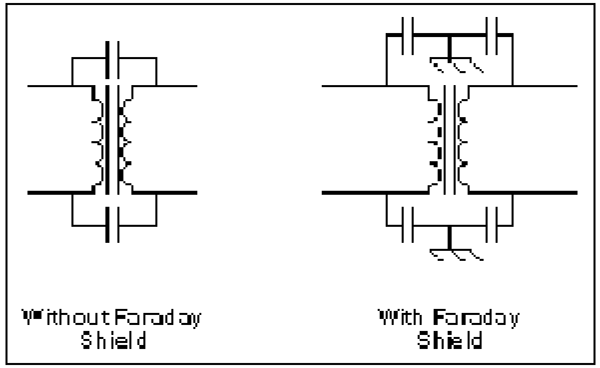


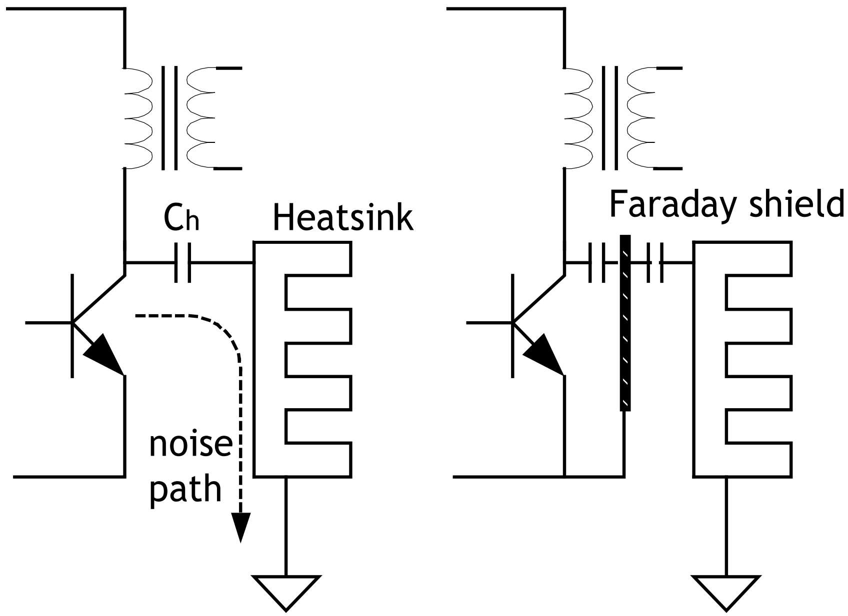


Noise Suppression

Shield



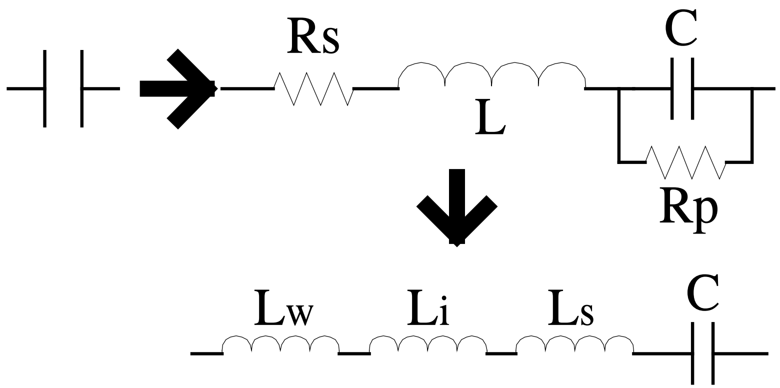




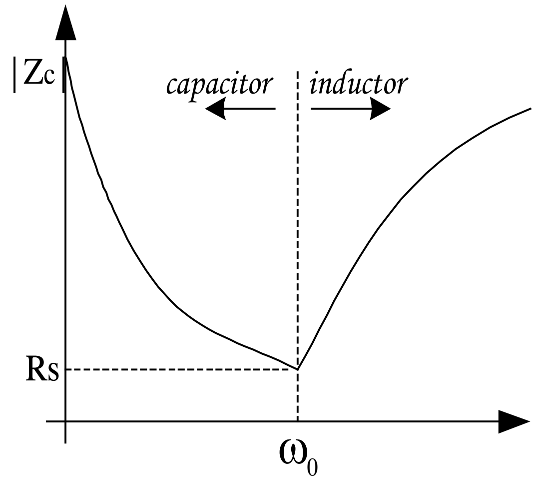
Faraday shield is effective on power switches and HF transformers.

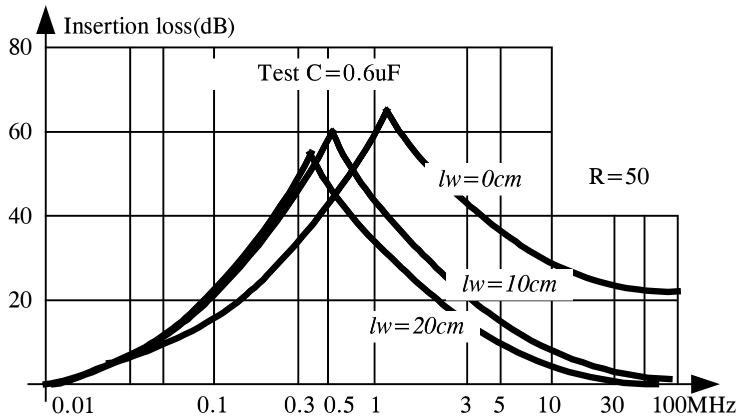
Filter Elements

capacitor-1



Simple model

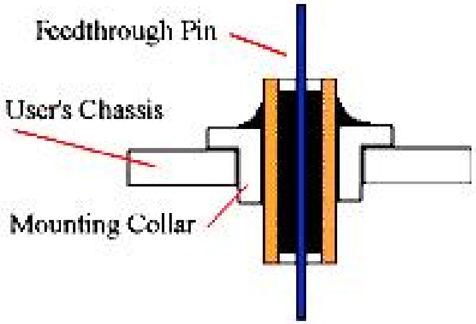


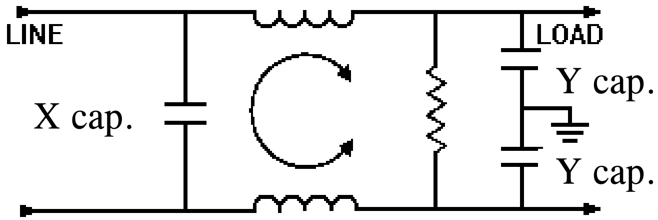


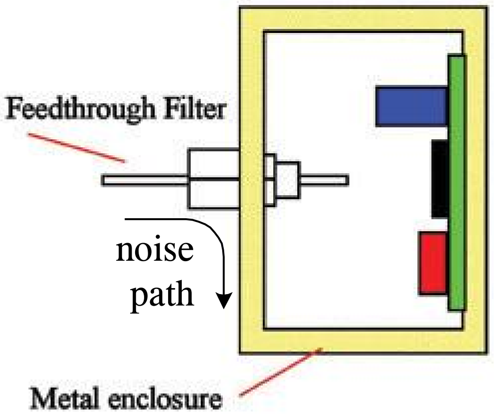
- Lw : Inductance of lead wire
- Li : Inductance of internal wire
- Ls : Inductance of structure

- Electrolytic C: <1KHz
- Tantalum C: <20KHz
- Ceramic C: <1000MHz

Filter Elements
capacitor-2





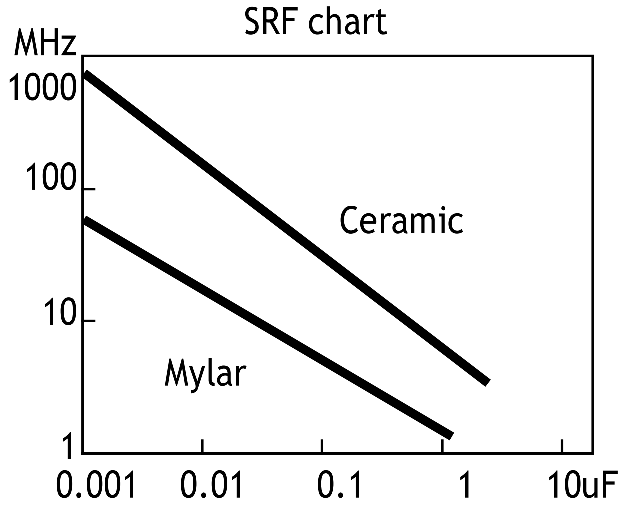


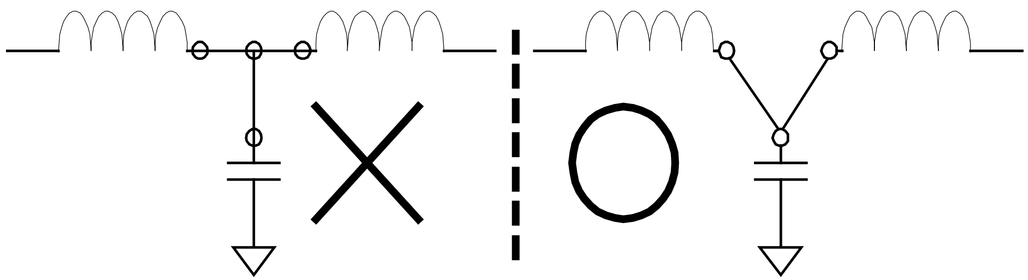
- Feedthrough cap. for radiated EMI
- X cap . for Diff. Mode voltage
- Y cap. for Comm. Mode voltage
  max. leakage current =3.5mA
  300uA for medical equip.

Filter Elements

capacitor-3

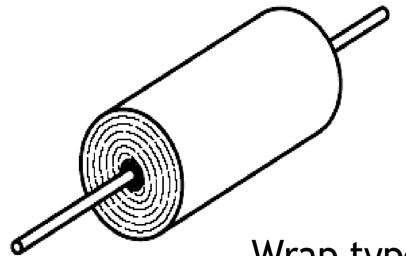
- AC system : WV=4.2xVrms
- DC system: WV=2.5xVdc
- Self Resonant Frequency: ESL+C
  ->paralleling main C // small C
  (low SRF//high SRF)
- Veeing capacitor:Removing inductance of lead





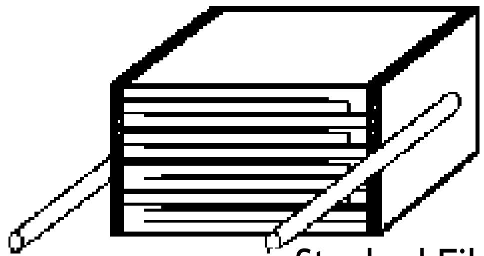
<u>Filter Elements</u>
capacitor-4

- Applied <u>Over-voltage</u>
  -> creepage of the dielectric slowly
  -> carbonizing a path
  -> arc !!! finally


Wrap type

Structure

- Warp type : very high ESR & ESL
  inductive C, not for EMI filter
- Extended foil type : insert-tap winding
  low ESR & ESL


Stacked Film
-Extended foil

Filter Elements
capacitor-5

- Metallized film : coated metallized aluminum on the dielectric film

  -> high loss, much noise
- Film & Foil

  Polycarbonate: -55~125

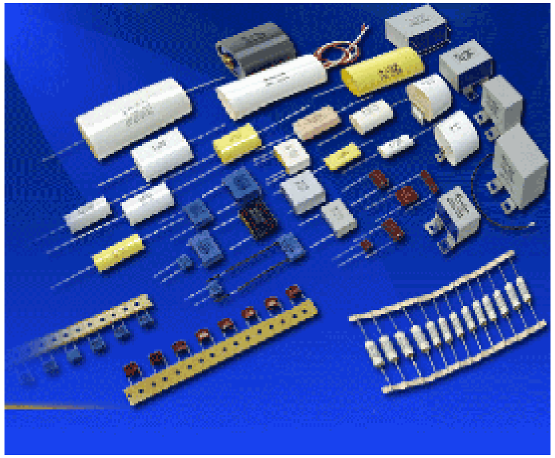
  higher Q, high cost

  Polypropylene: -55~85

  high Q

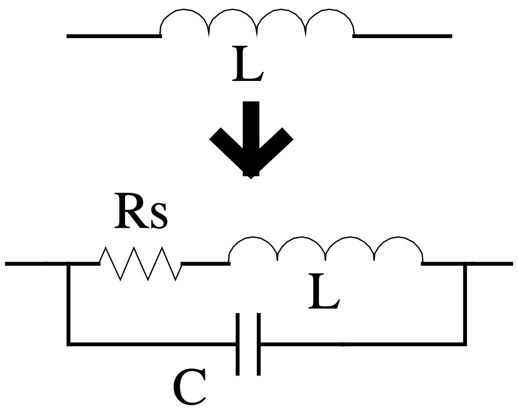
  Polyester(Mylar):-55~85

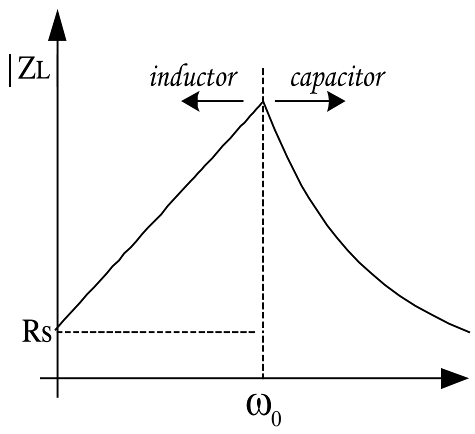
  low Q, low cost

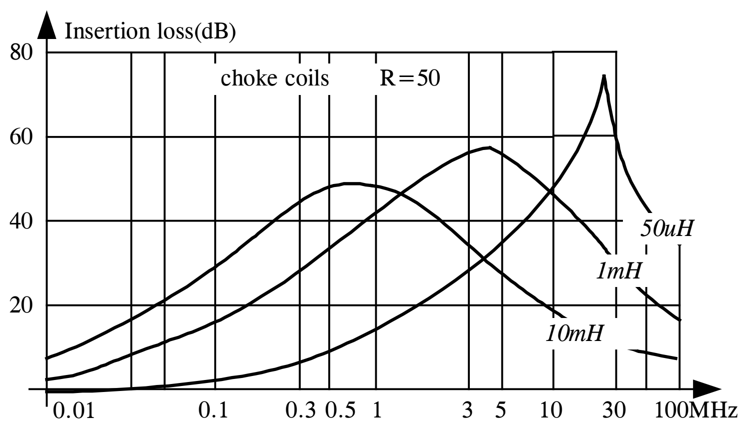


Filter Elements

coil-1

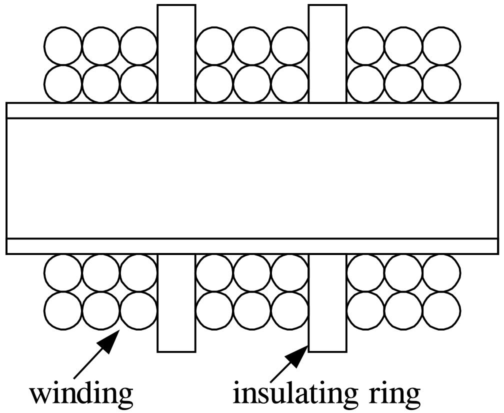


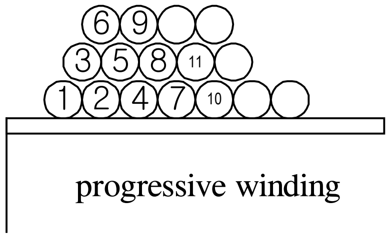




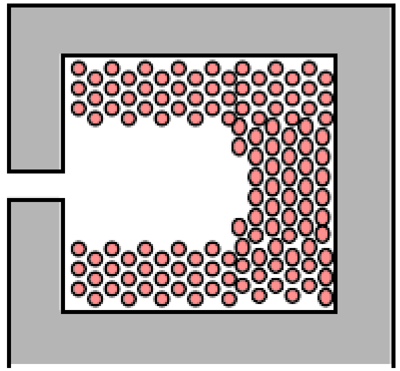
Filter Elements

coil-2

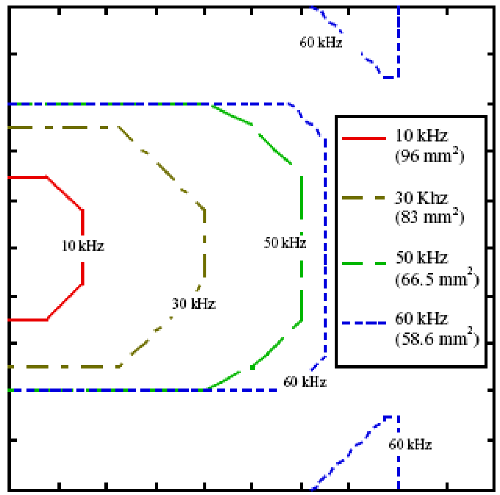




- Reducing parasitic capacitance

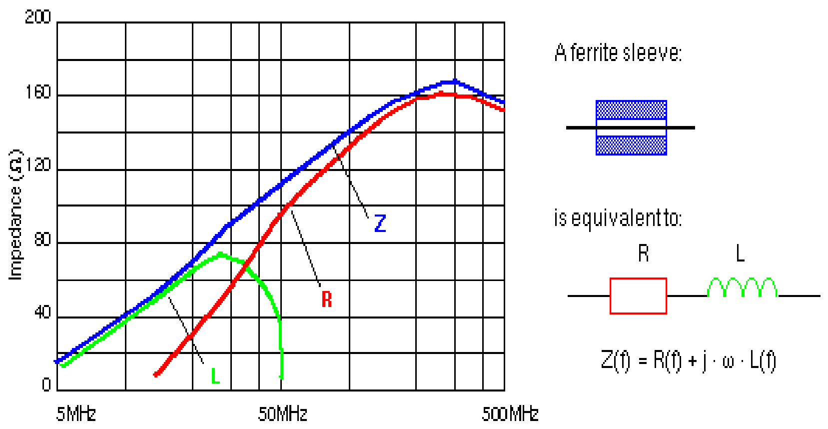


- Optimized winding shape with air-gap



Filter Elements

coil-3



- Common mode choke coil : with ferrite core
- Gyromagnetic frequency limit

  $fg = 5000/\mu i$ [MHz]
- Half of initial inductance at fg
- Manganese-zinc ferrite : < 10MHz

- Bead : one turn coil, no stray C, wideband char.
- Nickel-zinc ferrite: ~1GHz, good temp. stability

Filter Elements

Transformer as EMI filter

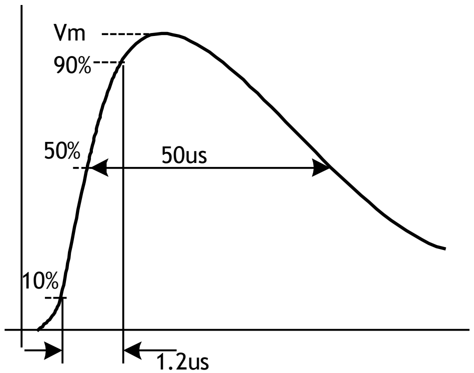
- EMI filtering
- Isolation
- Voltage translation
- Common mode rejection
- Low leakage current(100uA)
- No spike voltage

- Very big
- Heavy

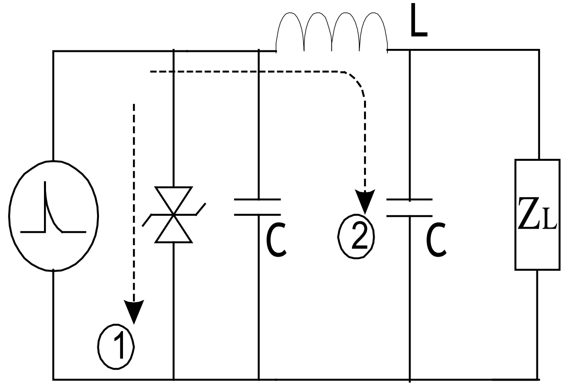
60 Hz Steel iron core Trans.
32dB loss at 14KHz

EMS Test

- Impulse voltage withstand test
  Source Impedance: 500 Energy: 0.5Ws
- Impulse current withstand test
- High-freq disturbance test(1MHz)
- Electrostatic discharge test



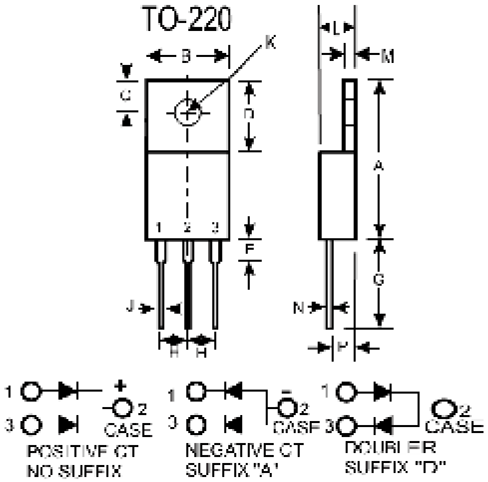
Voltage Test Impulse Waveform

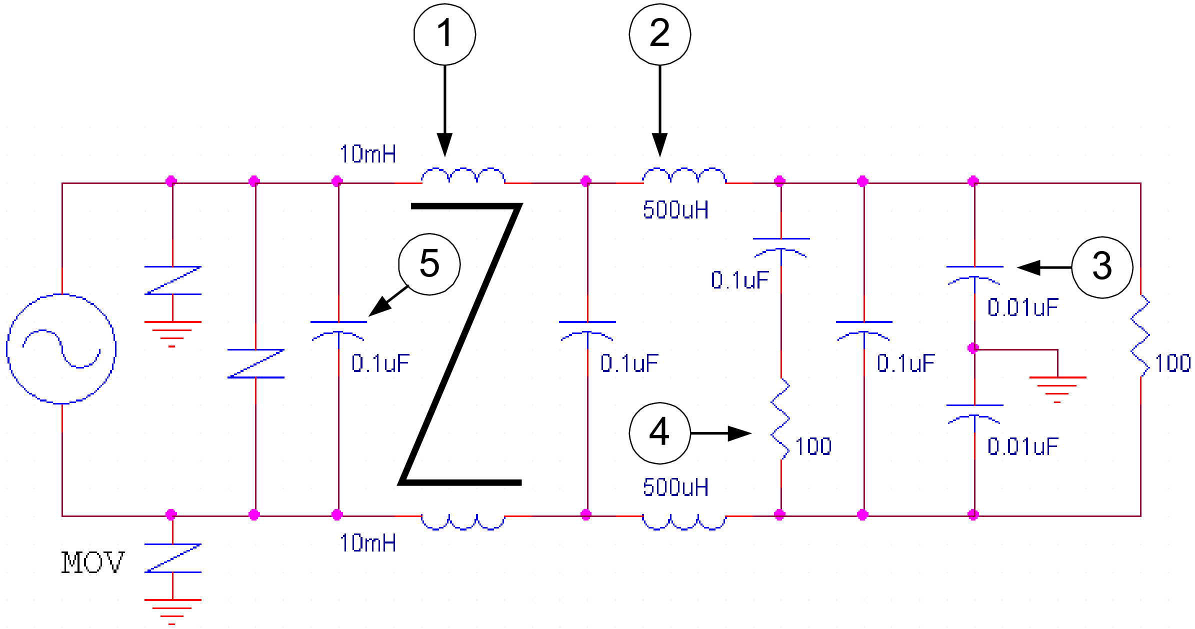


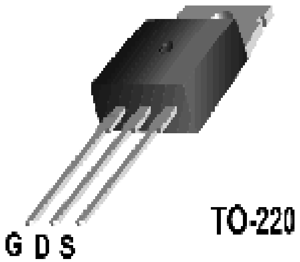
MOV
Metal Oxside Varistor

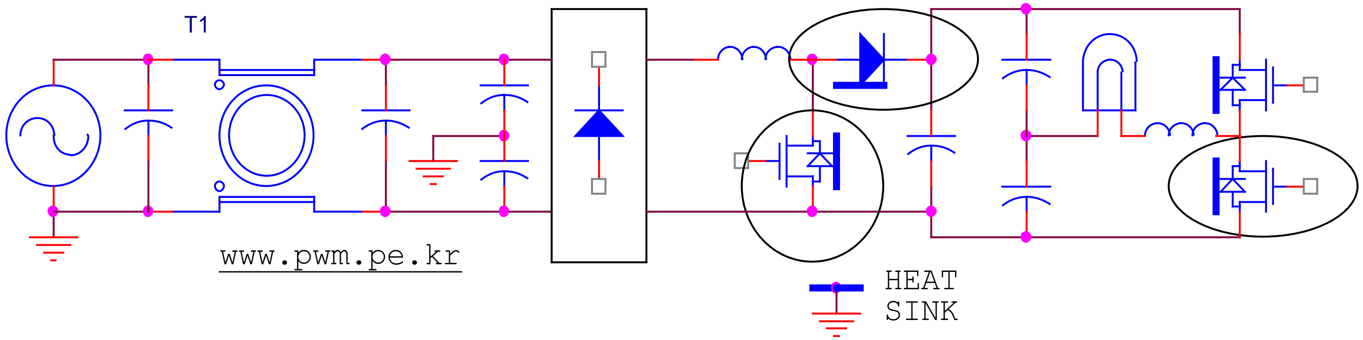
- Paths: 1->2
- Check max.V of L, SFRs of L & C

Example


TO-220
CASE
POSITIVE CT
NO SUFFIX
NEGATIVE CT
SUFFIX "A"
DOUBLER
SUFFIX "D"


1
2
3
4
5
10mH
500uH
0.1uF
0.01uF
100
MOV


G D S
TO-220

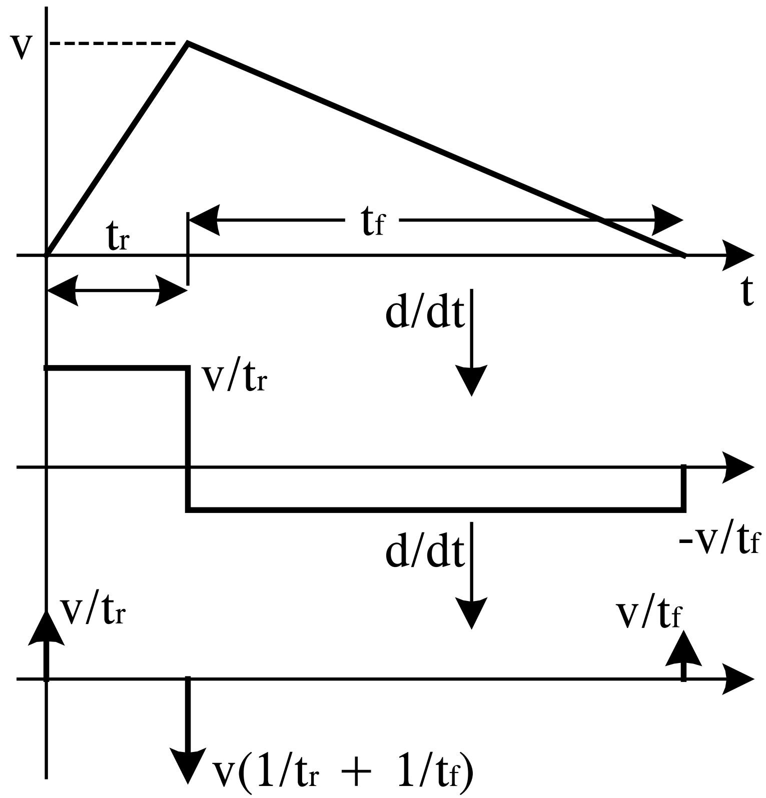

T1
www.pwm.pe.kr
HEAT
SINK

Graphic Harmonic Analysis

Quick spectrum plotting as Bode-plot

$$|F(jw)| \le \int_{-\infty}^{\infty} |f(t)|\,dt$$

$$|F(jw)| \le \frac{\int_{-\infty}^{\infty} |f^{n}(t)|\,dt}{w^{n}}$$



Graphic Harmonic Analysis

Example

- n=0 $F_1(f) = V\frac{(tr+tf)}{2}$
- n=1 $F_2(f) = \frac{V(tr/tr+tf/tf)}{2\pi \bullet f} = \frac{V}{\pi f}$

  Crossover point f_1 of $F_1(f)$ and $F_2(f)$ $f_1 = \frac{2}{\pi(tr+tf)}$
- n=2 $F_3(f) = \frac{V(1/tr+1/tf)2}{4\pi^2 \bullet f^2} = \frac{V(1/tr+1/tf)}{2\pi^2 f^2}$

  Crossover point f_2 of $F_3(f)$ and $F_2(f)$ $f_2 = \frac{1/tr+1/tf}{2\pi}$
- Let [V],[us]

  A1=114+20log[V(tr+tf)] [dBuV/MHz]

  A2=110+20logV-20log(f)

  A3=94+20log(V(1/tr+1/tf))-40log(f)