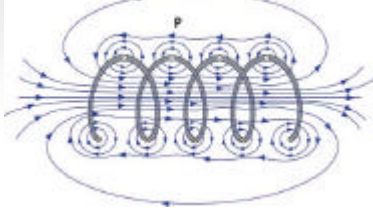

Basics of Electromagnetic Compatibility (EMC)

GungFu Chen
RD Center
Chilisin Electronic Co.

Outline

1. What is ElectroMagnetic Compatibility?
2. Causes of EMI and Signal Integrity
3. Grounding, Isolation and Separation
4. Power System
5. Impedance Control
6. Cabling & I/O Interconnect
7. Interference Couplings
8. Shielding Material (reflection)
9. Shielding Material (absorption)
10. Filtering (RLC Components) & Decoupling
11. EMI Radiation

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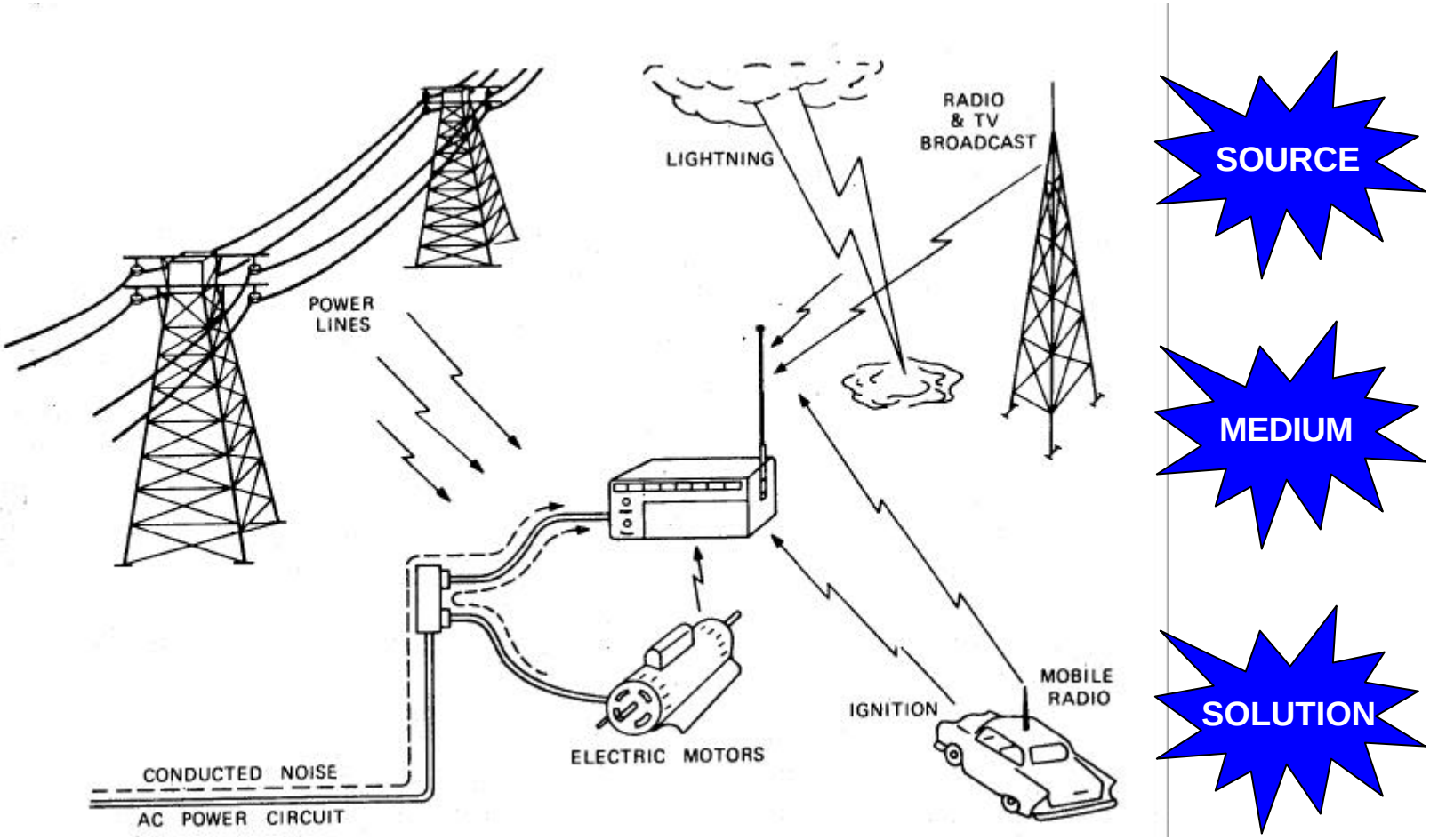
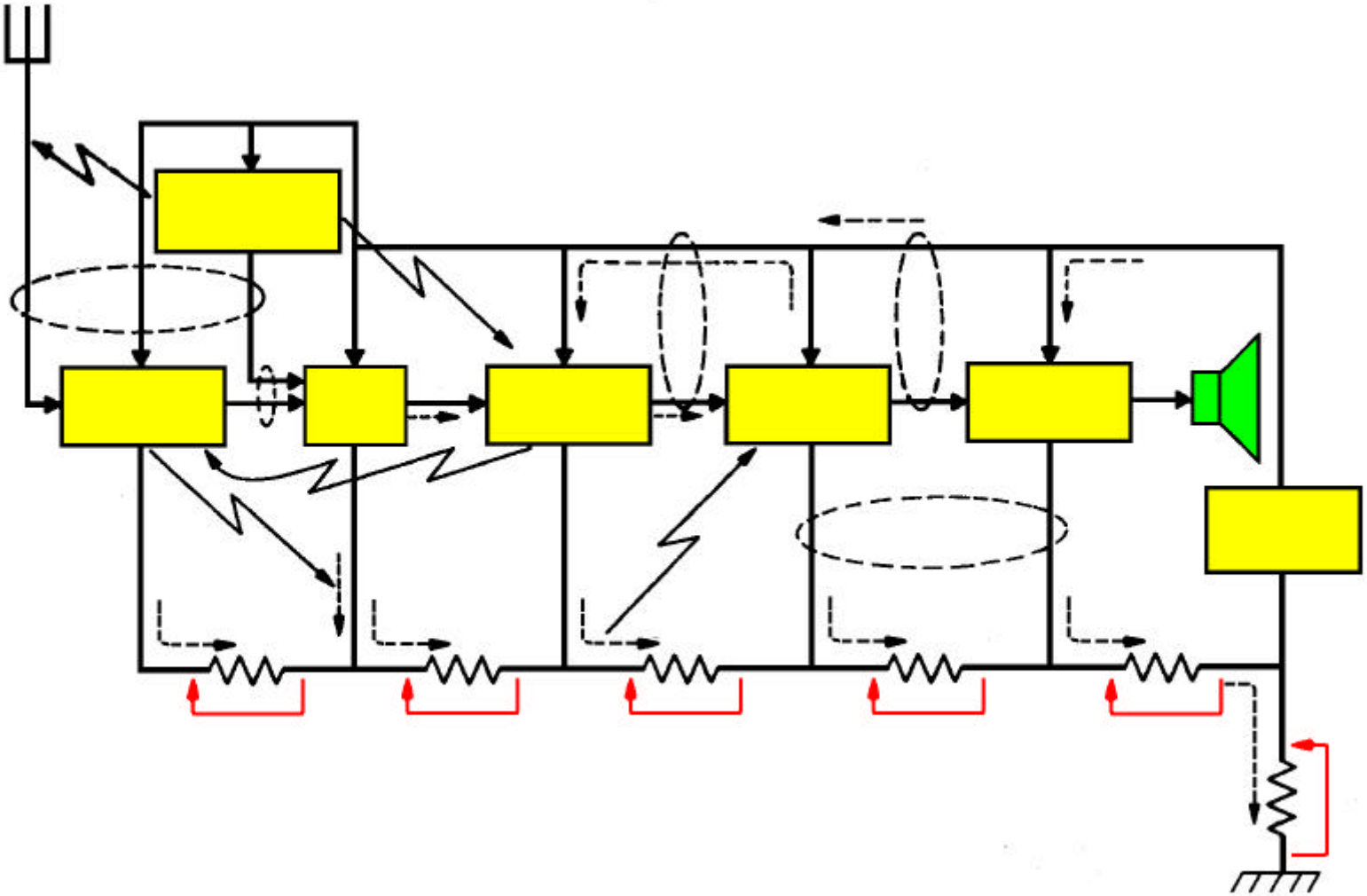
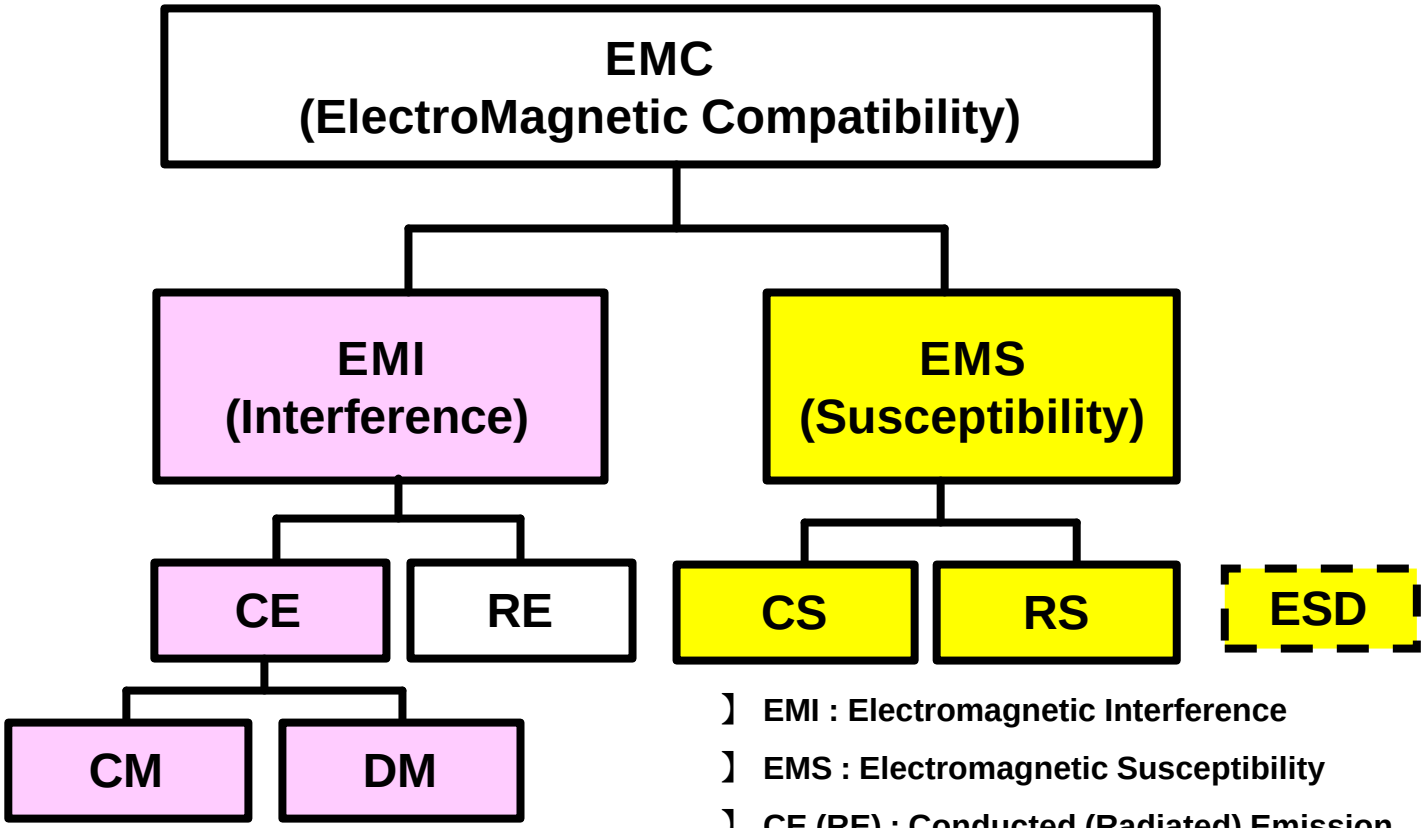
What is ElectroMagnetic Compatibility?



Interference Mechanism



What is ElectroMagnetic Compatibility?



- EMI : Electromagnetic Interference
- EMS : Electromagnetic Susceptibility
- CE (RE) : Conducted (Radiated) Emission
- CS (RS) : Conducted (Radiated) Susceptibility

- CM : Common-Mode component
- DM : Differential-Mode component

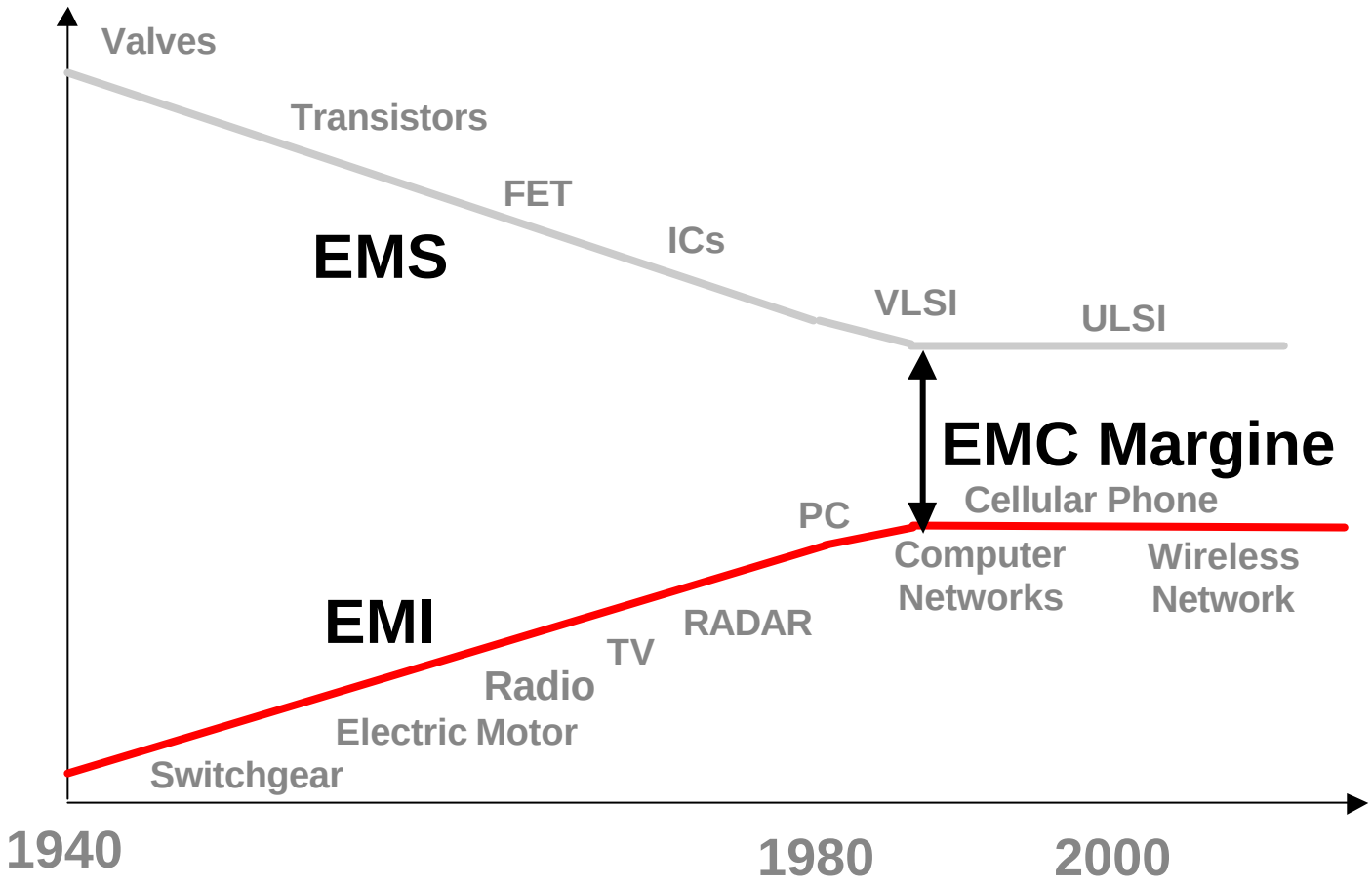
EMI Regulation

- FCC Class A, Class B
- CISPR
- VDE 871
- MIL – STD - 461

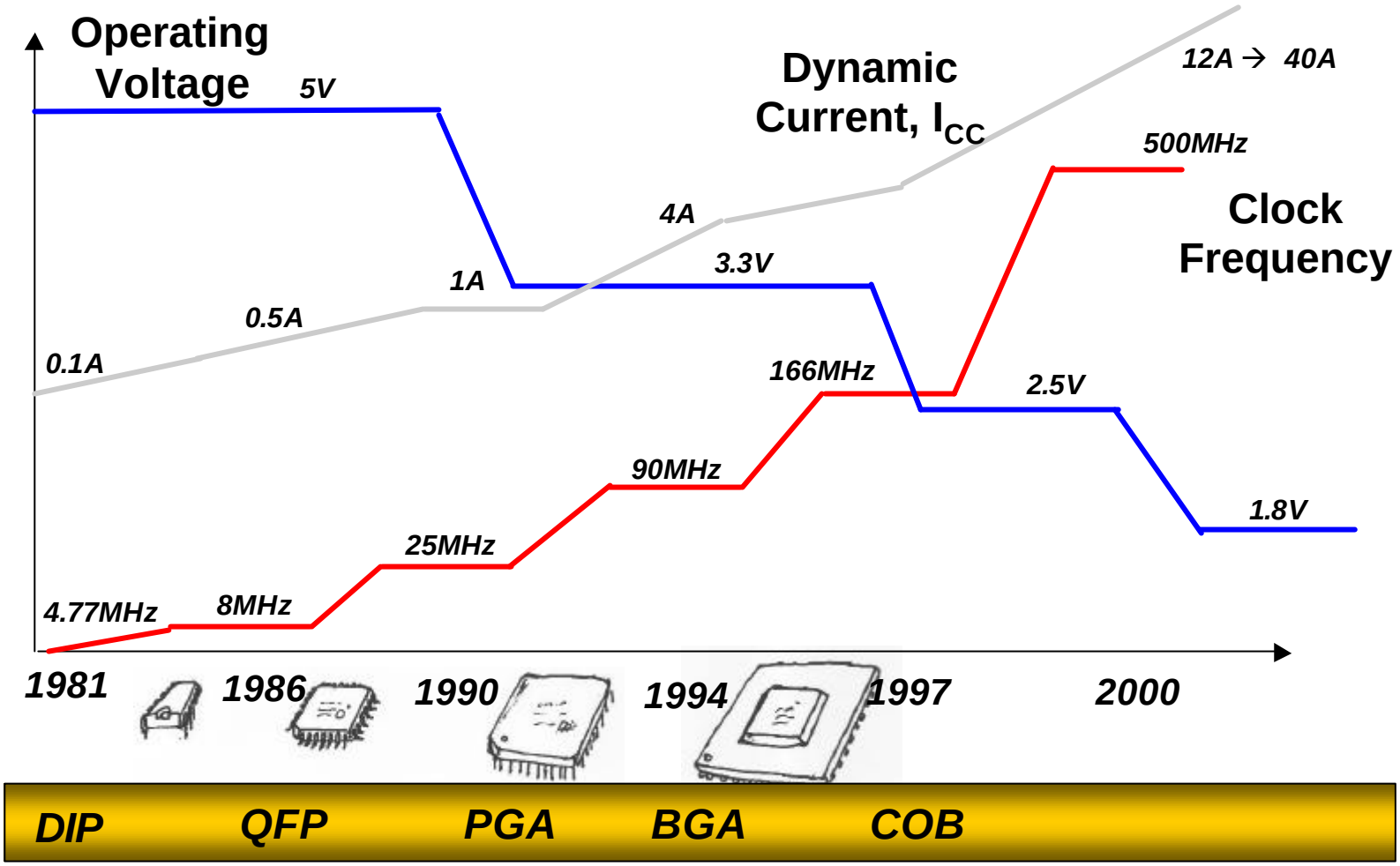
FCC Limits

Frequency (MHz)	A limit	B Limit
0.45-1.705	60 dBμV	48 dBμV
1.705-30	70 dBμV	48 dBμV
30-88	39 dBμV @10m	40 dBμV @3m
88-216	43.5 dBμV @10m	43.5 dBμV @3m
216-960	46.5 dBμV @10m	46 dBμV @3m
> 960	49.5 dBμV @10m	54 dBμV @3m

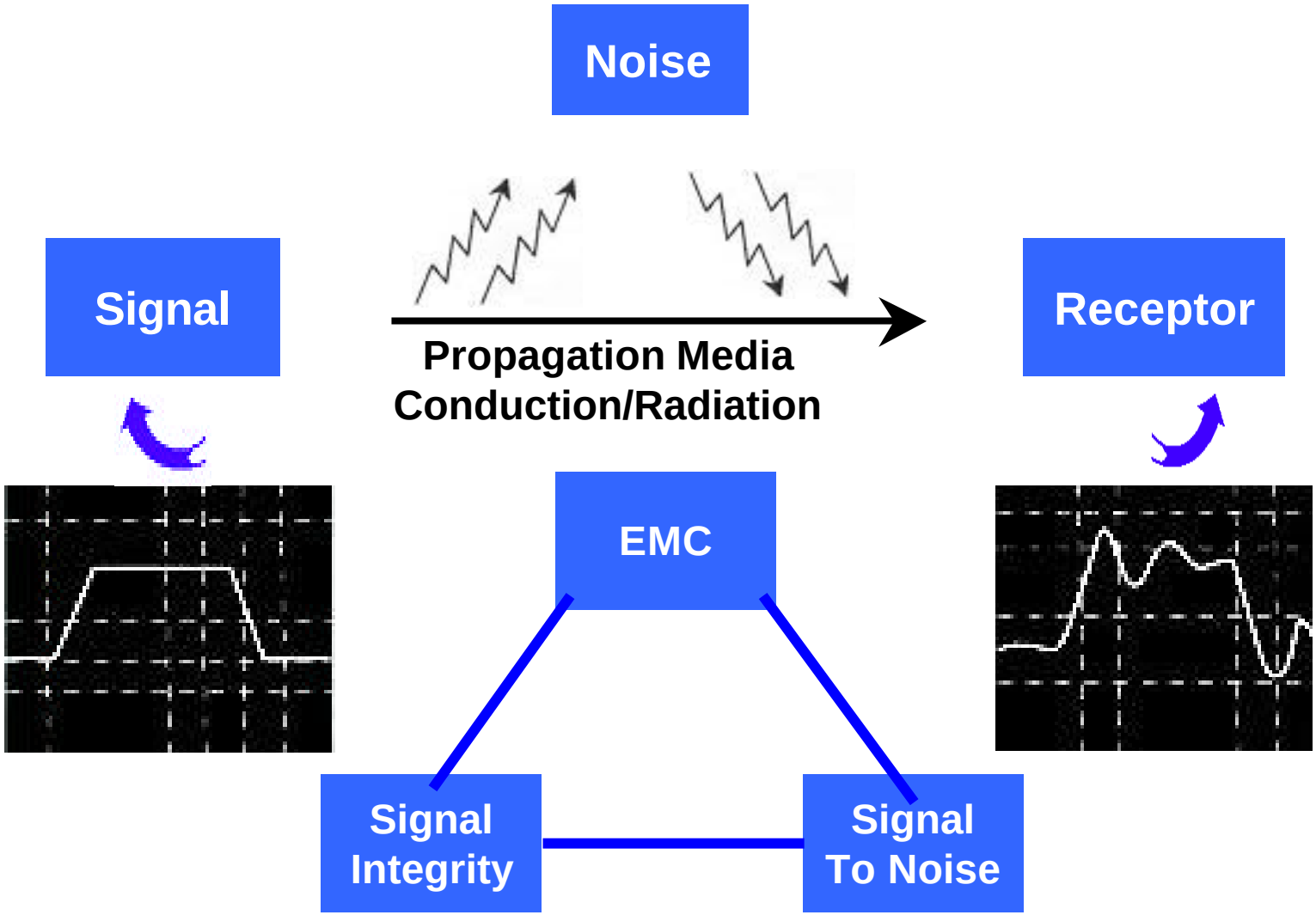
Trends on the needs of EMC



Trends of Reduced Immunity Margin



Elements of EMC



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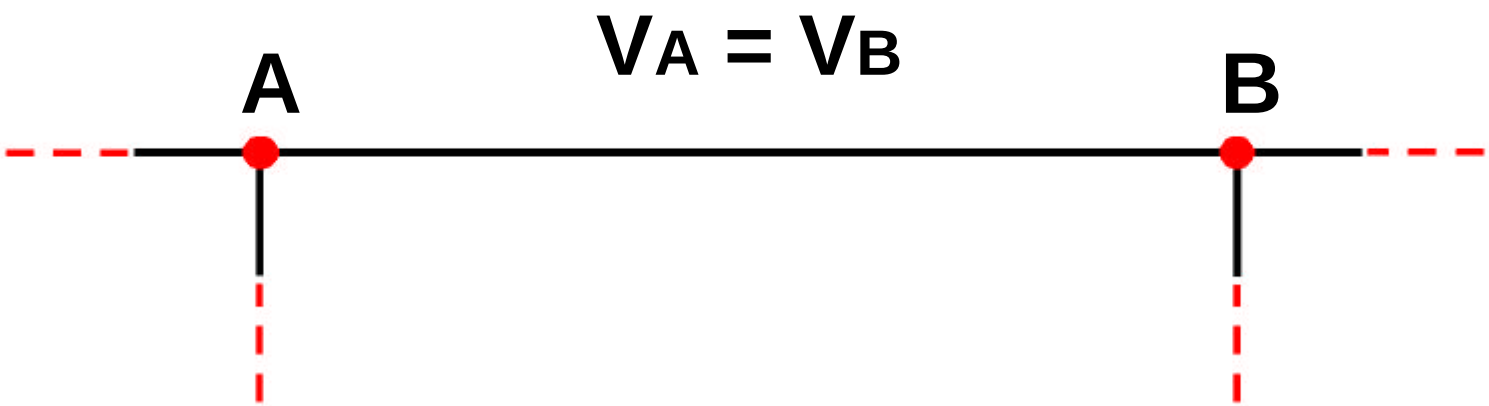
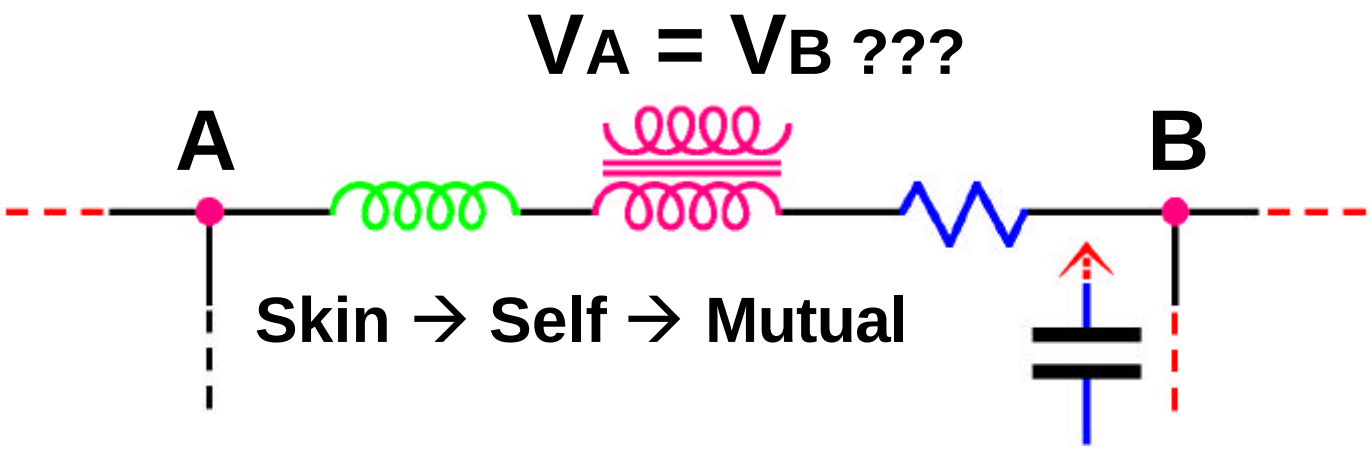
Causes of EMI and Signal Integrity

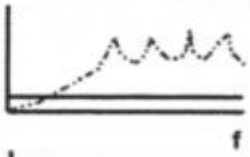
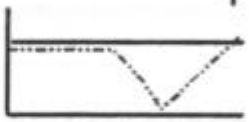
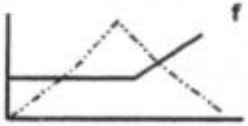
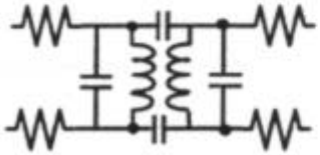
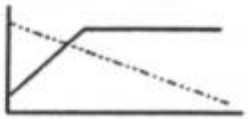
1. **Conducted EMI:**
   - **Parasitic Impedance**
   - **Power Ground Connection**
   - **Ground Connection**
2. **Radiated EMI:**
   - **Poor Ckt Layout**
   - **Unmodeled Parasitic Impedance**

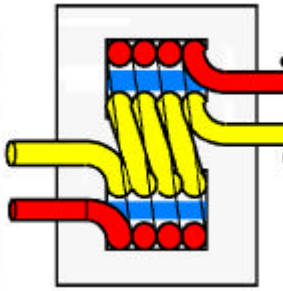
Wire High Frequency Model



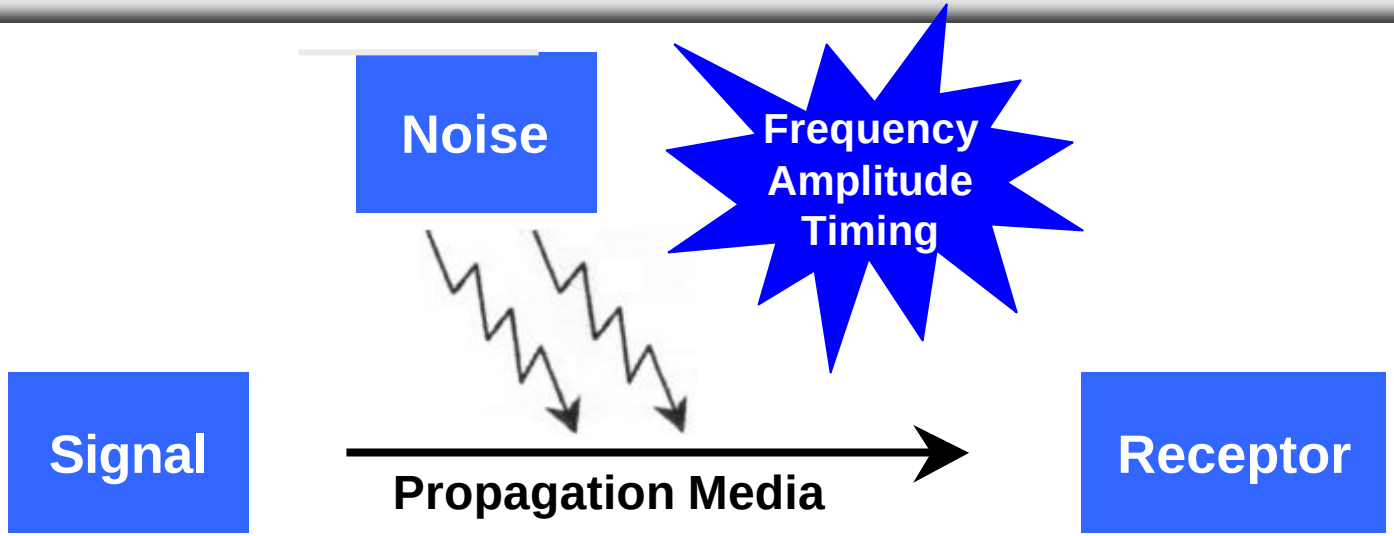


RLC components

Component	Low Frequency Behavior	High Frequency Behavior	Frequency response
Wire			
Resistor			
Capacitor			
Inductor			
Transformer			

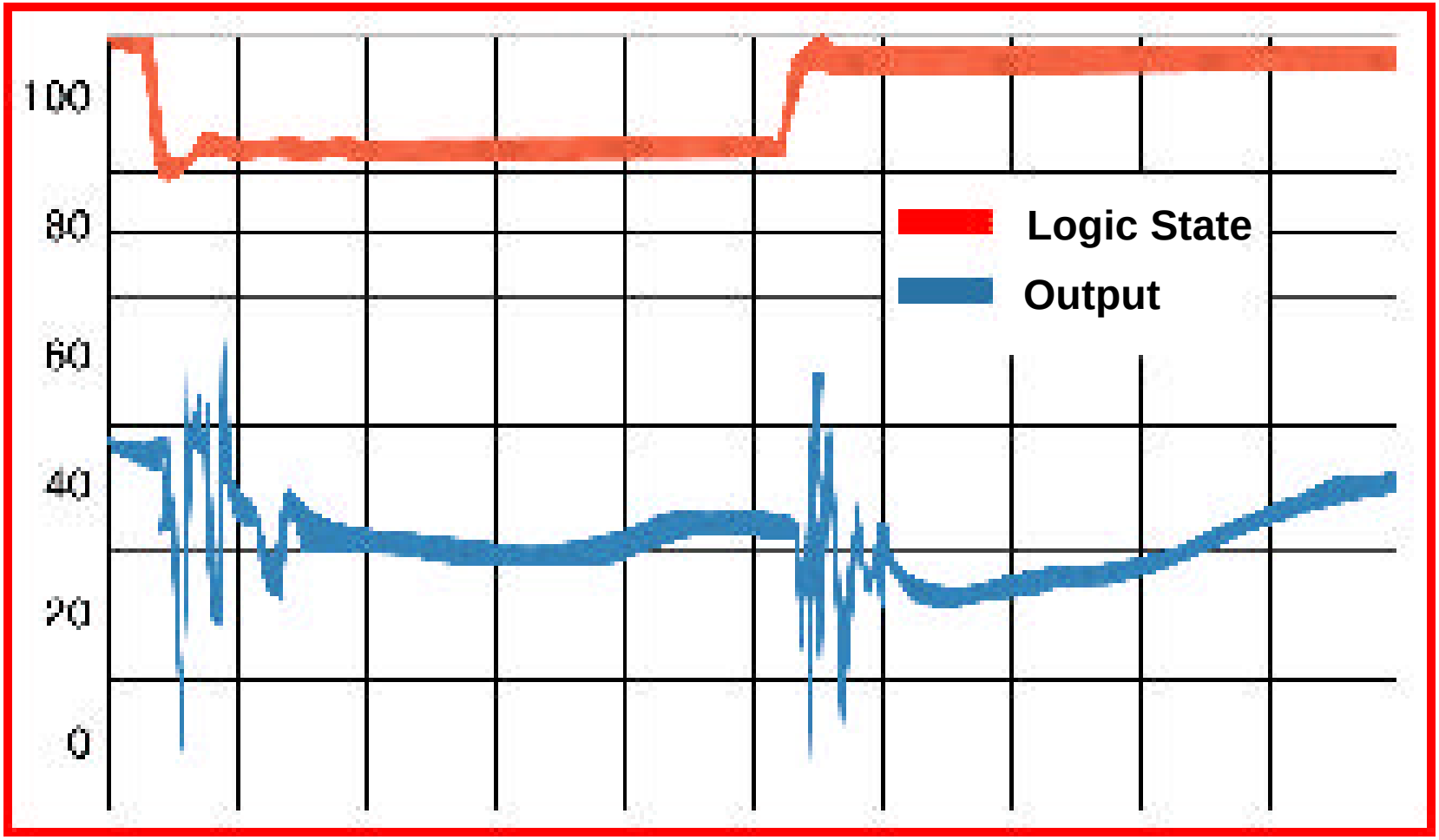


Elements of EMC

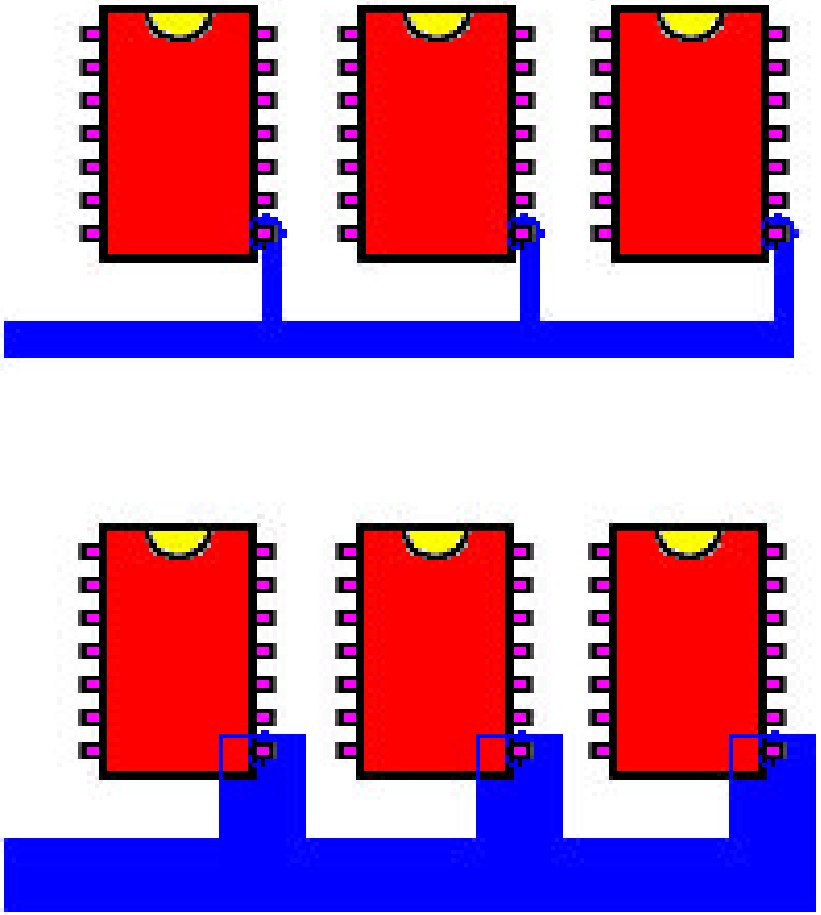


- Interference Couplings
- Shielding Material (reflection)
- Shielding Material (absorption)
- Filtering (RLC Components)
- Decoupling
- Grounding
- Isolation and Separation
- Power System
- Impedance Control
- Cabling & I/O Interconnect

Switching Noise



GND TechnologyND Plan)



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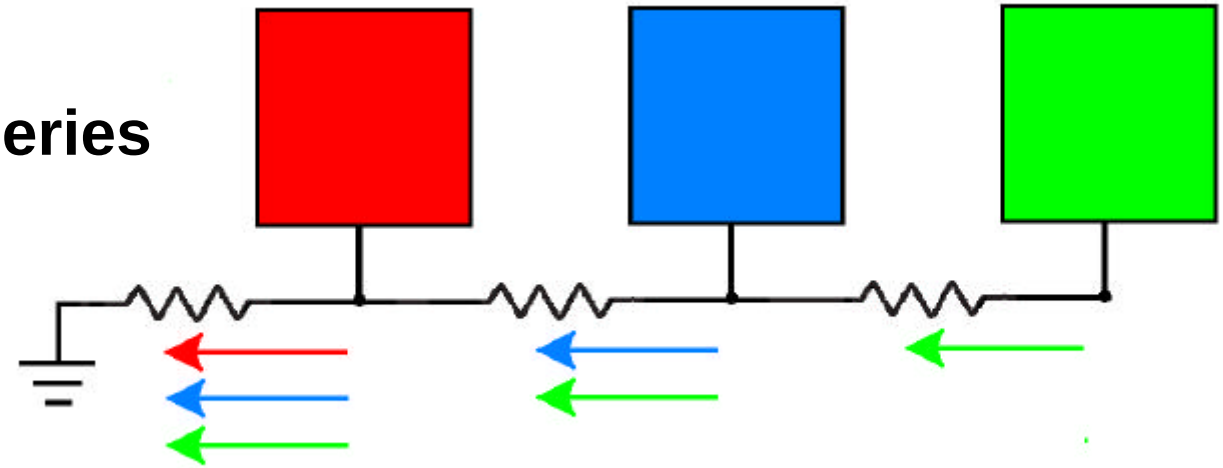
Grounding

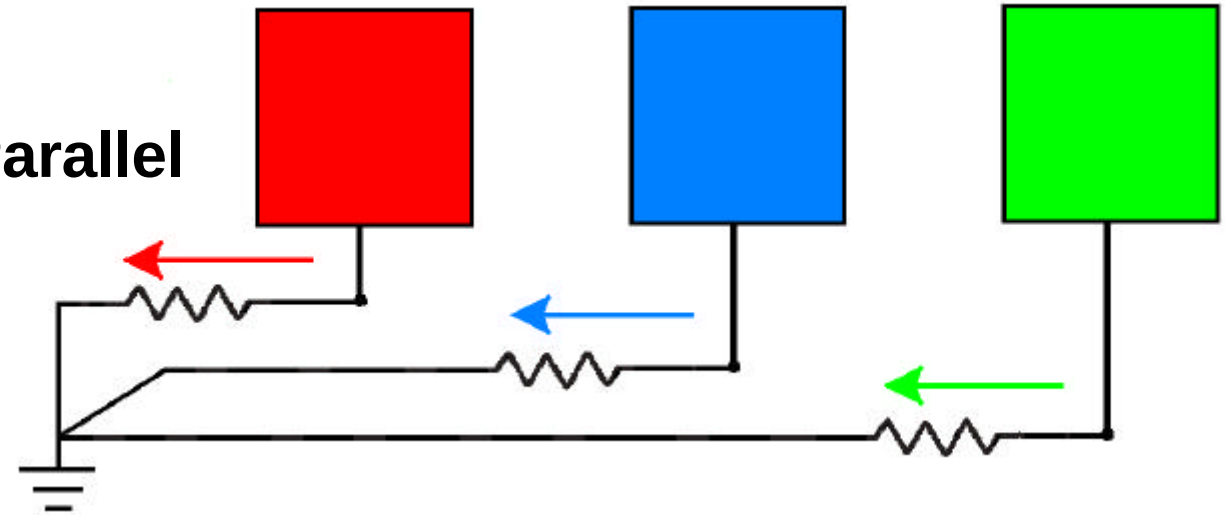
- Single Grounding
  - Series ground connection
  - Parallel ground connection
- Multipoint Grounding
- Ground Seperation

Single Grounding

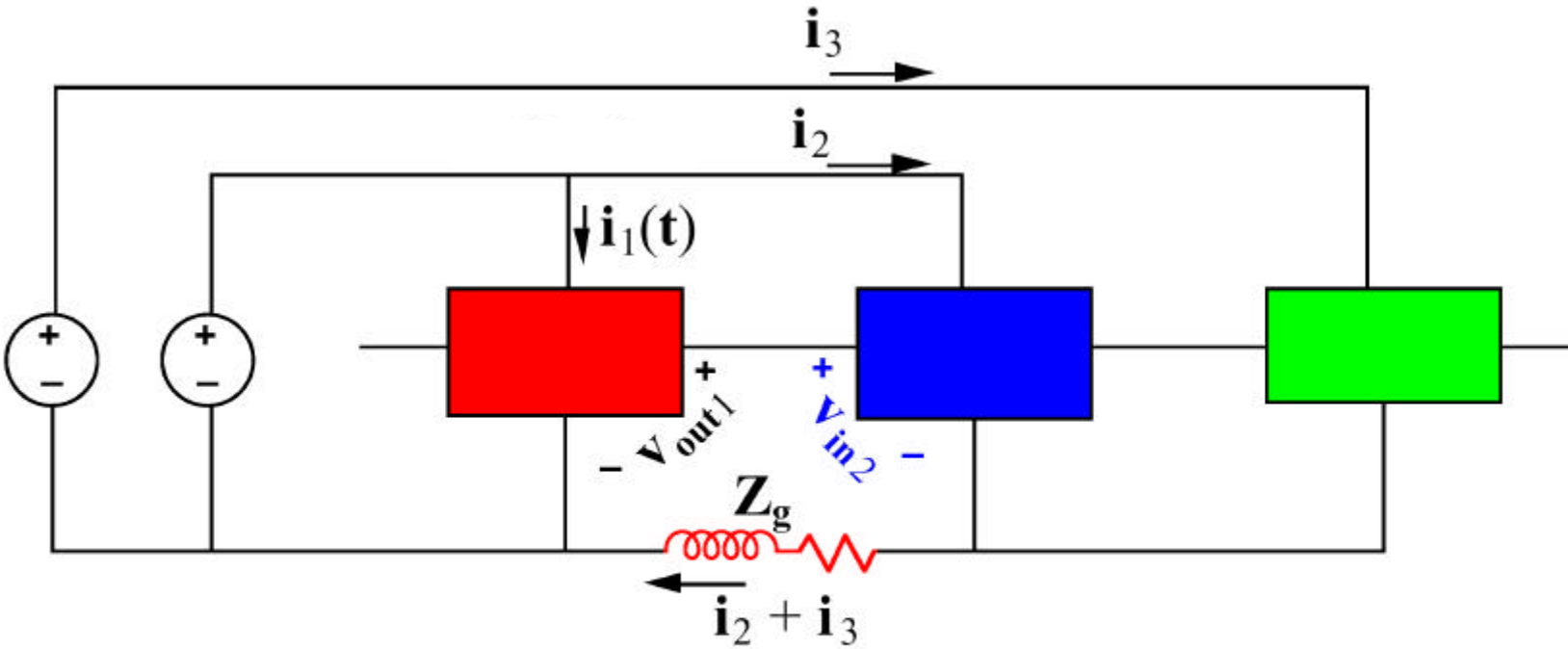
In Series



In Parallel

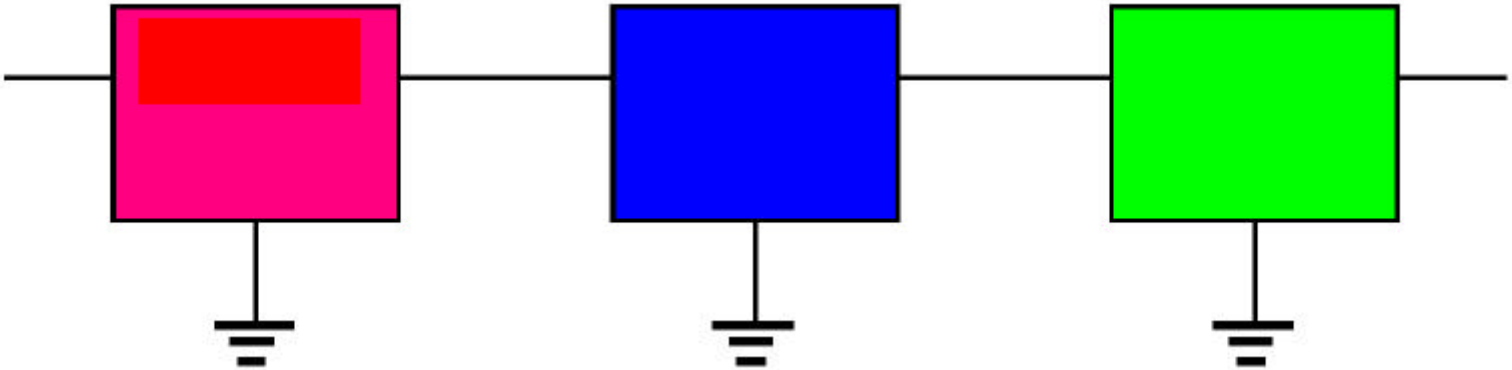


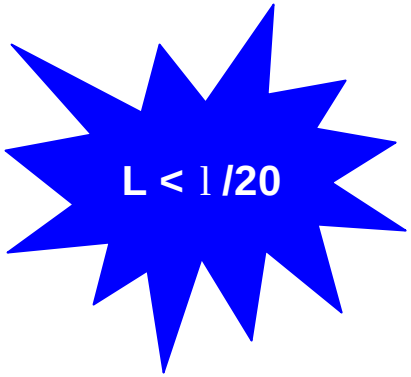
Grounding Impedance Coupling



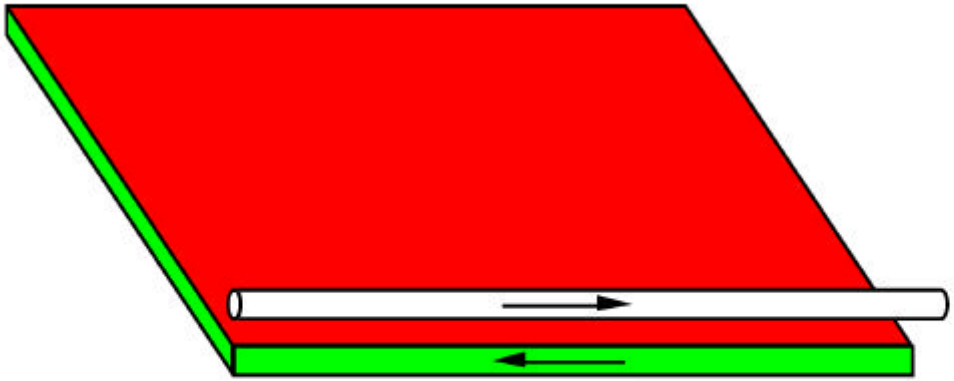
$$v_{in2} = v_{out1} - Z_g\,(i_2 + i_3)$$

Multi-Grounding (f > 10MHz)



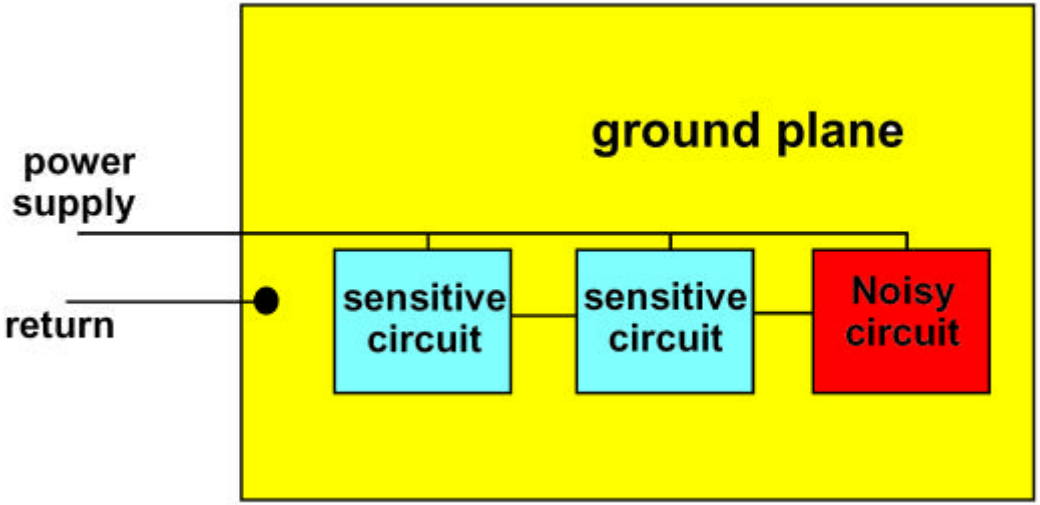


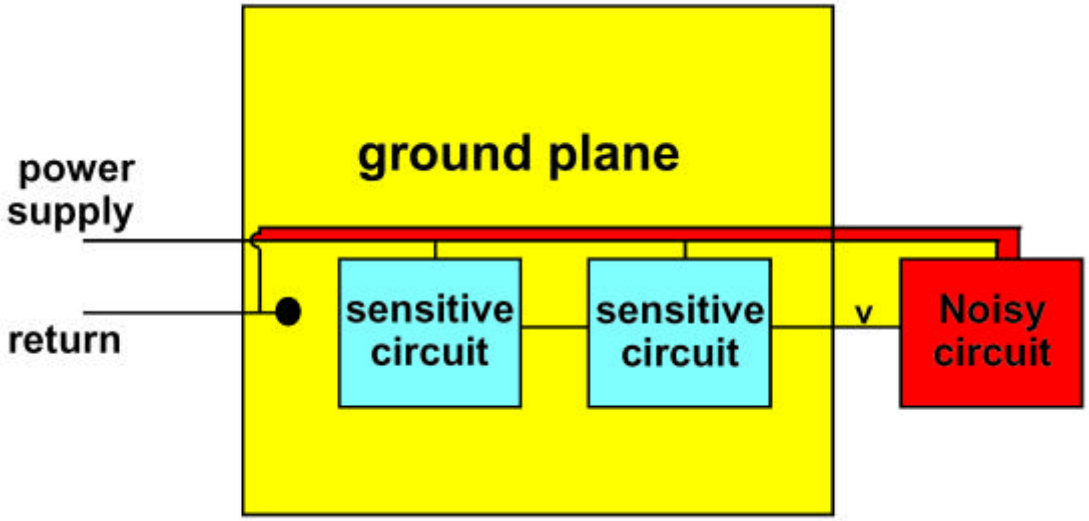
Effectiveness of GND Plane



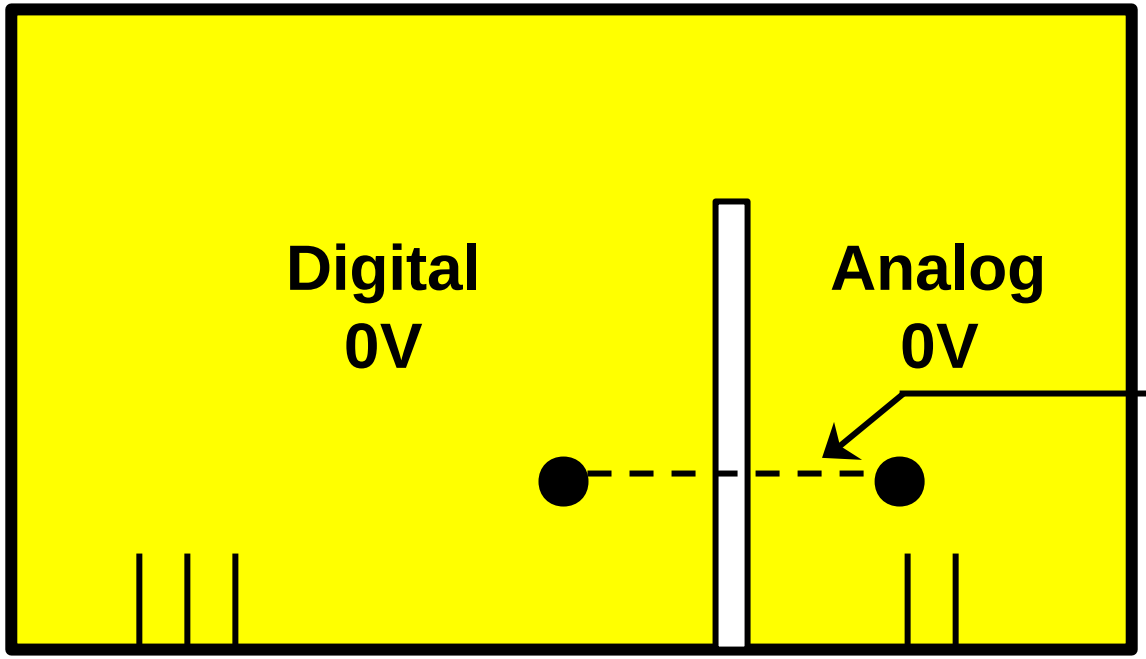
Resistance & Layout of GND plane

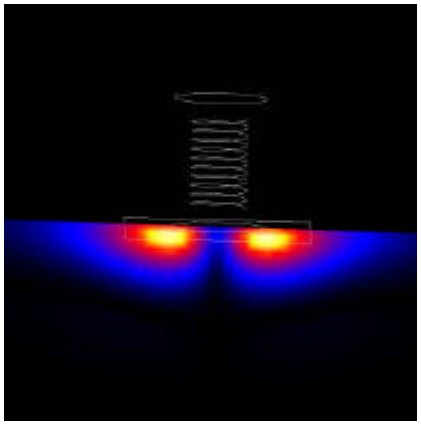
Grounding Separation





Grounding Separation





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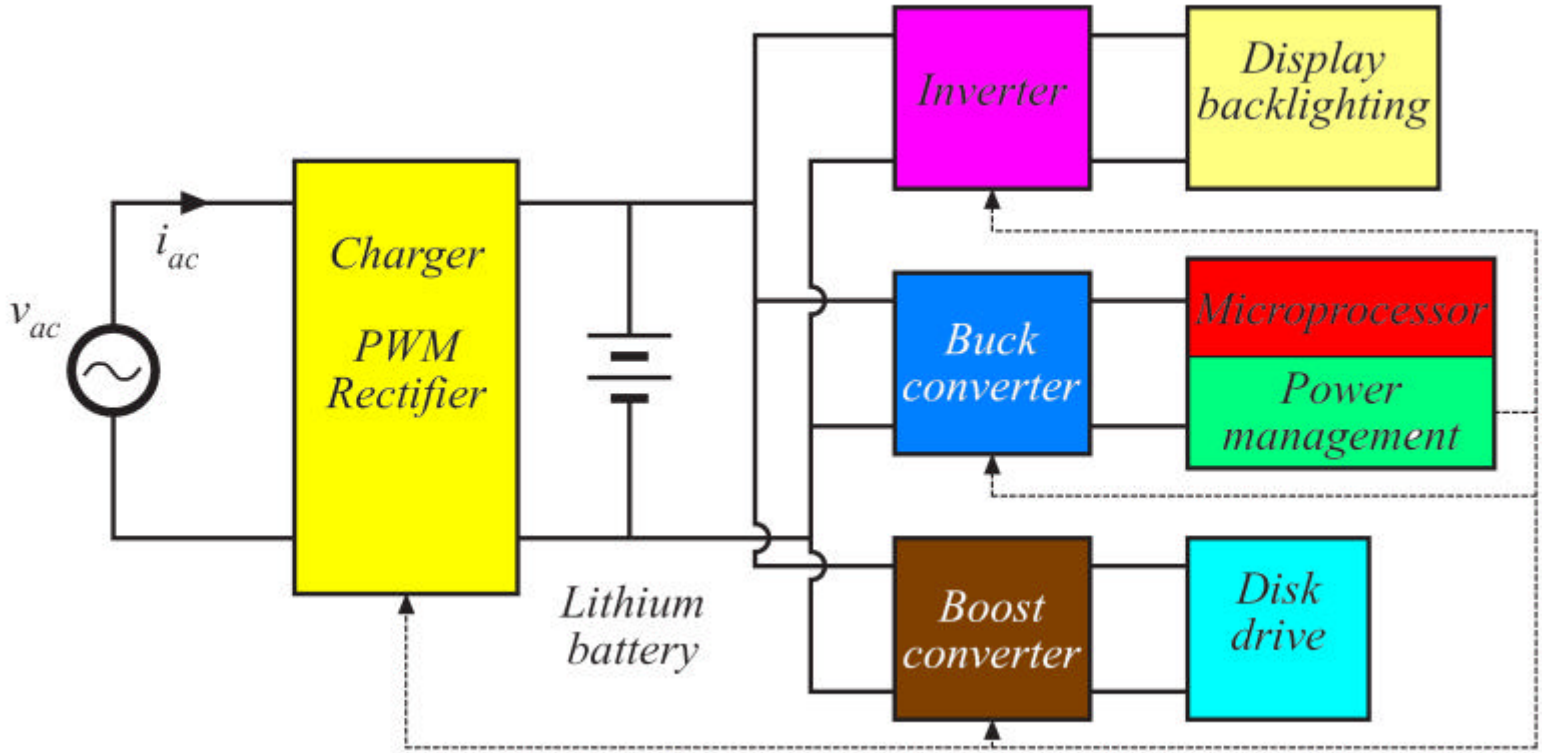
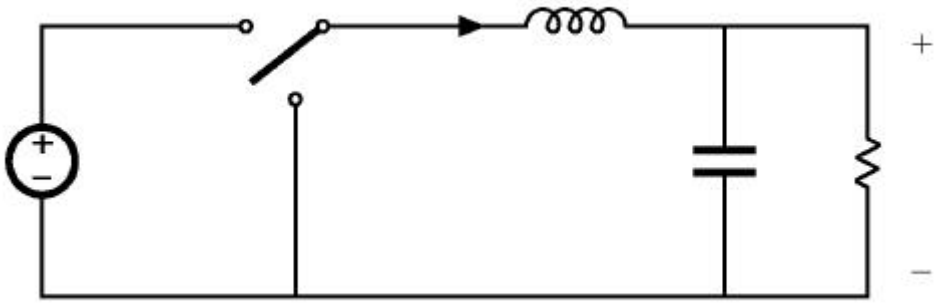
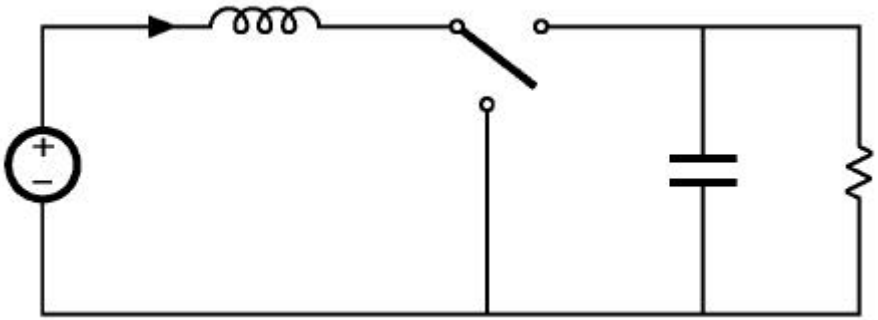
Power for Lap-top Computer



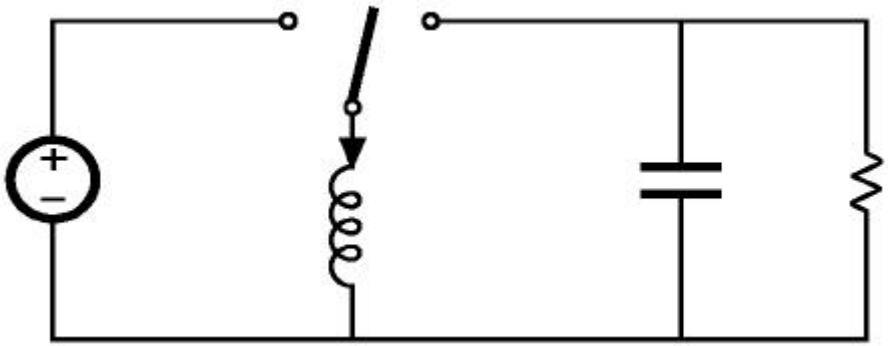
Types of D-D converter



Bulk

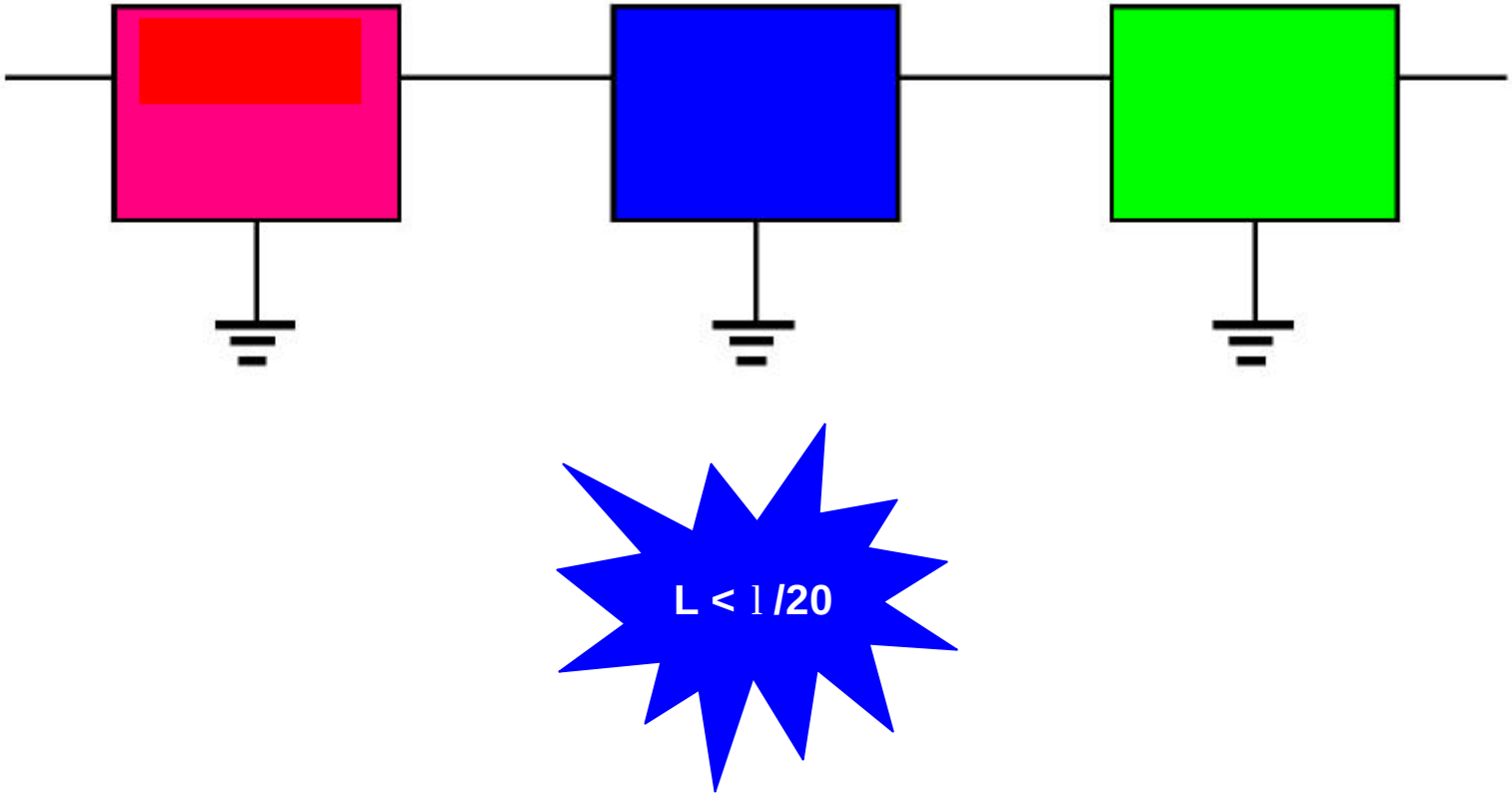


Boost

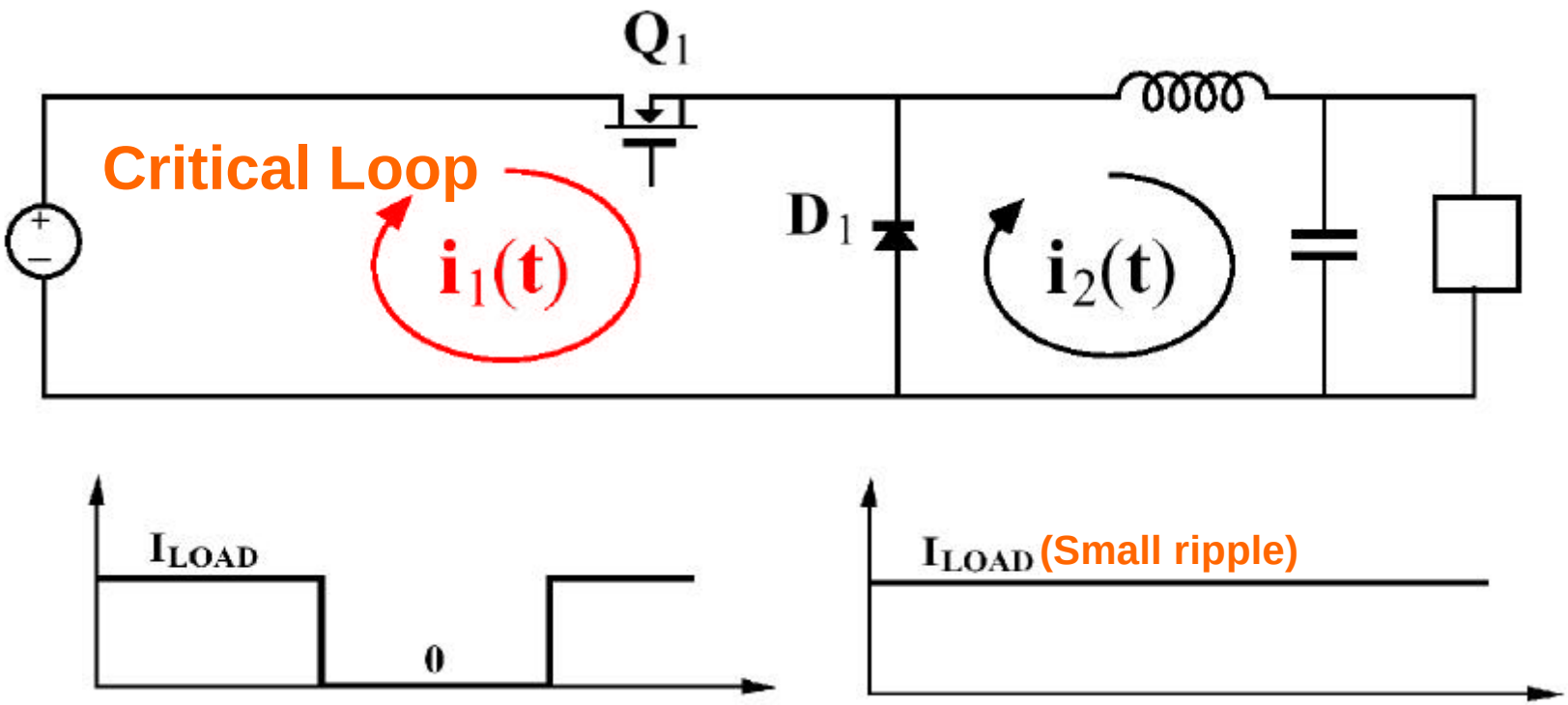


Bulk-Boost

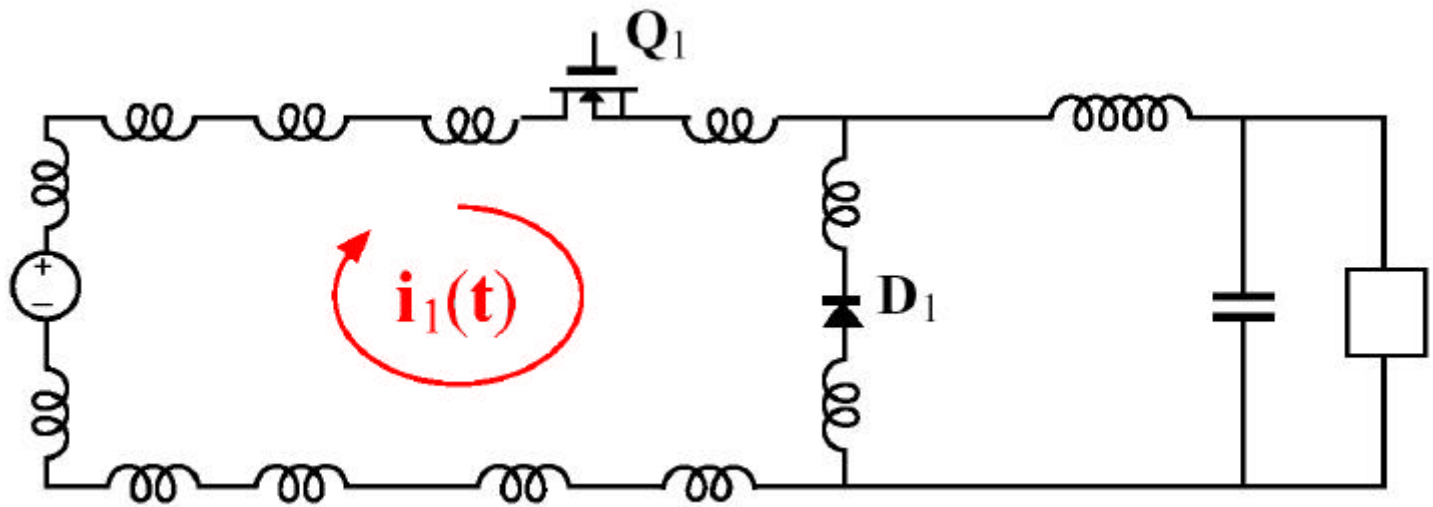
Multi-Grounding (f > 10MHz)

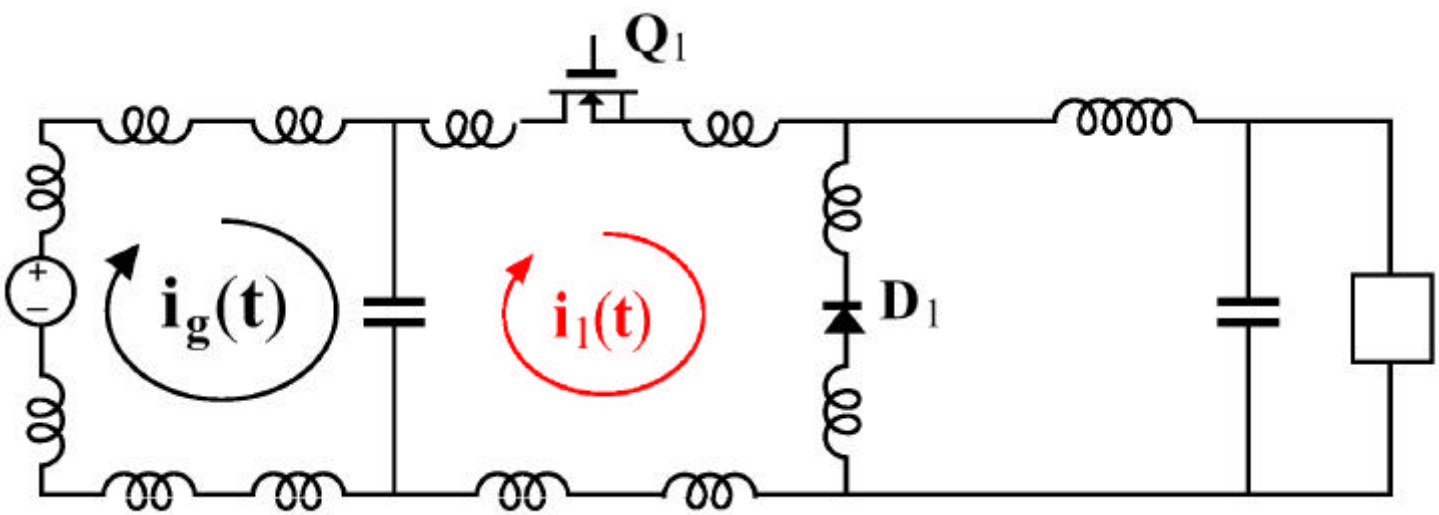


Critical Loop in Buck Converter



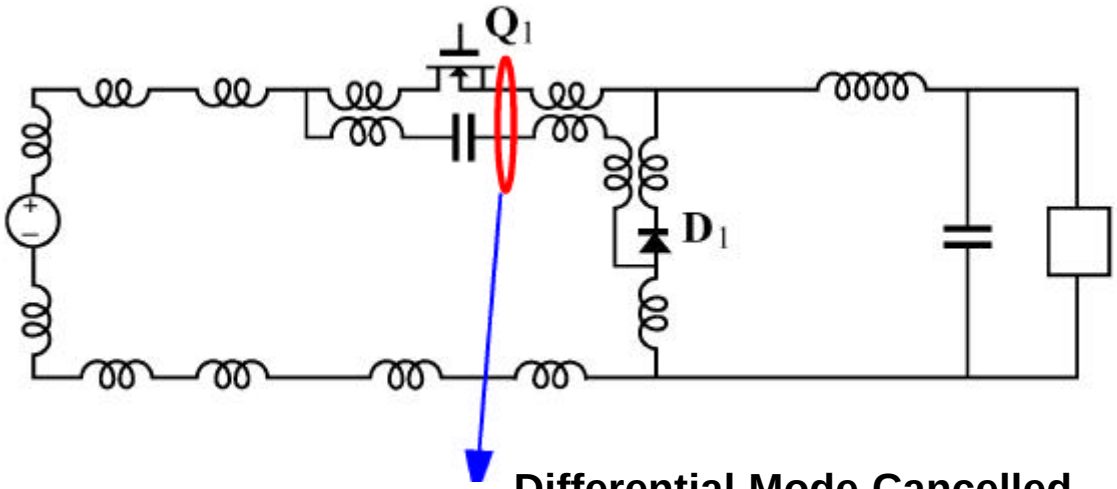
Reducing the Effects of Critical Loop

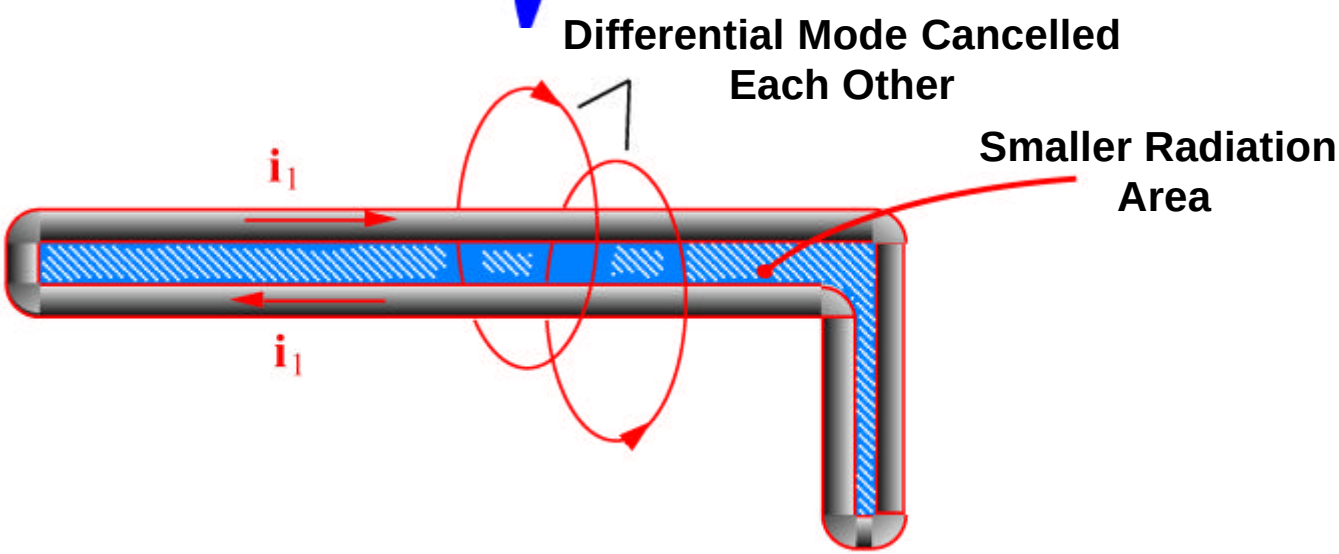




(Bypass capacitor)

Reducing the Effects of Critical Loop





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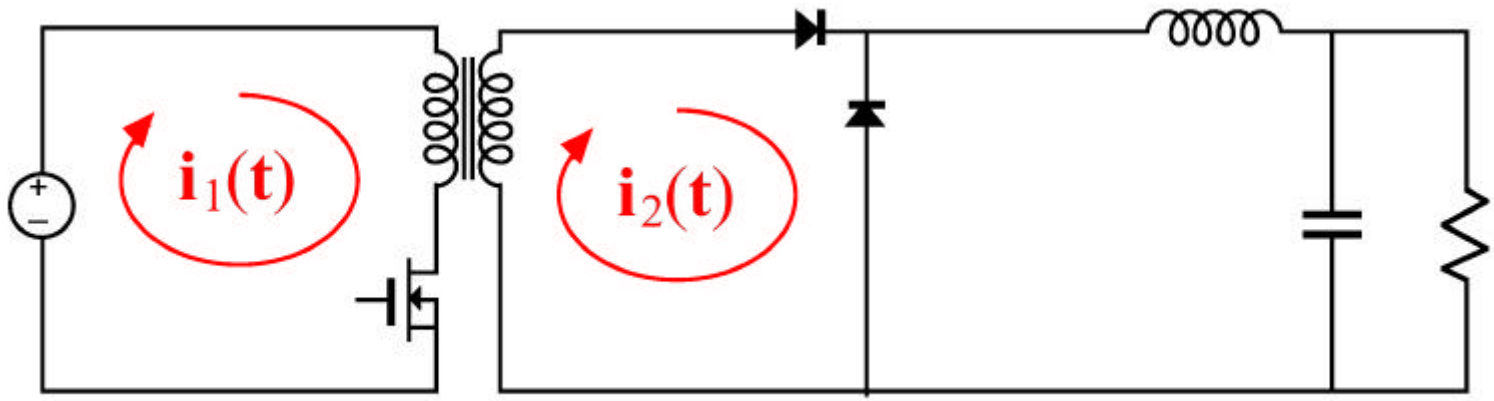
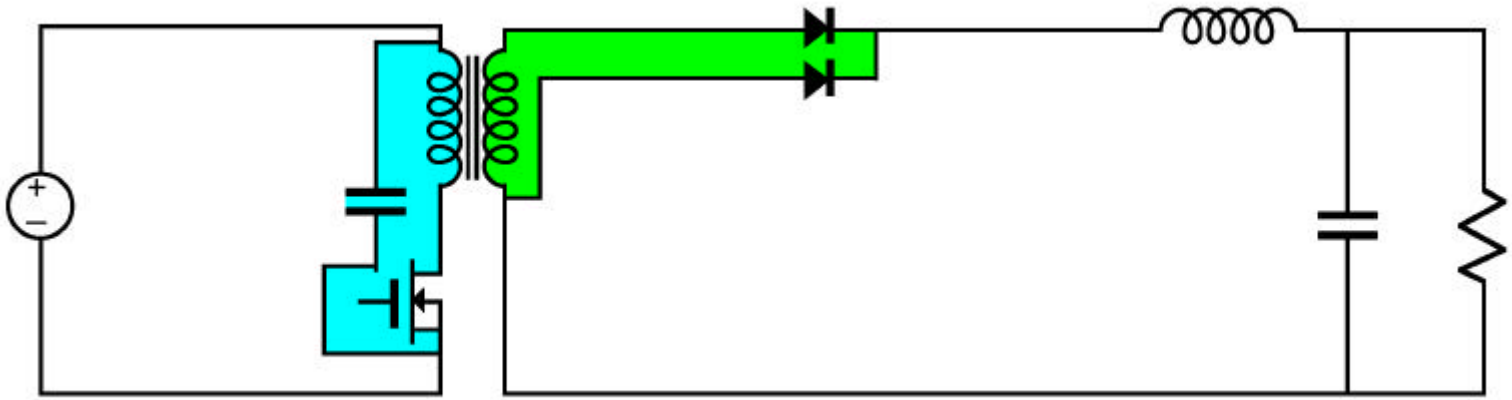
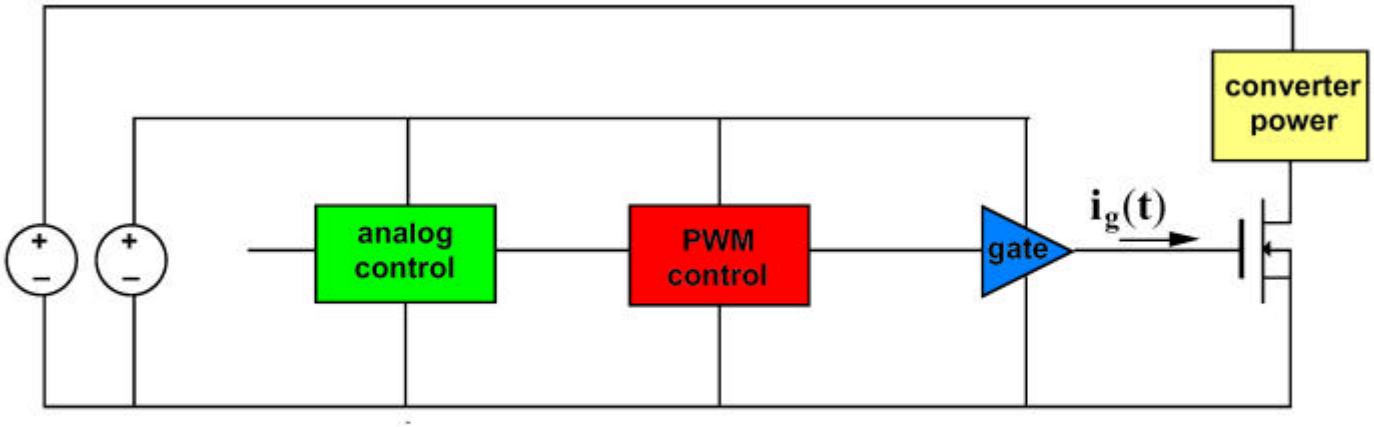
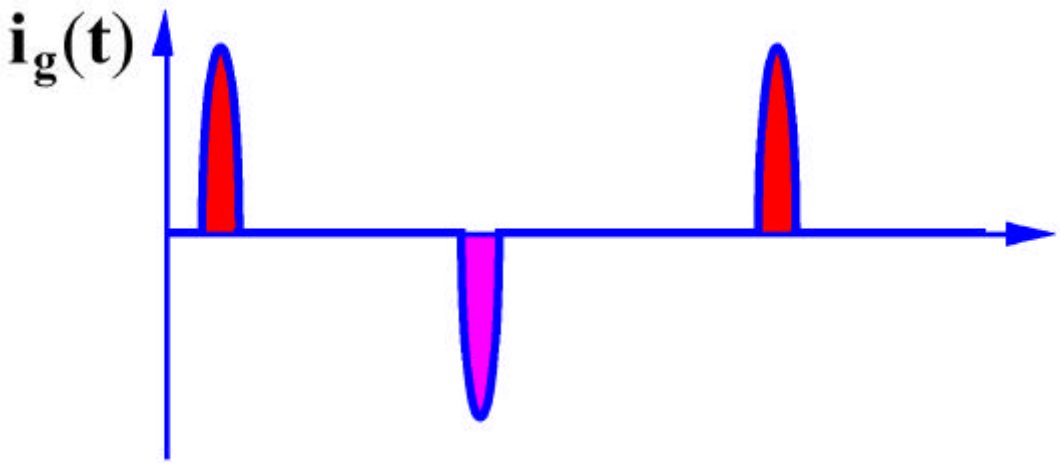


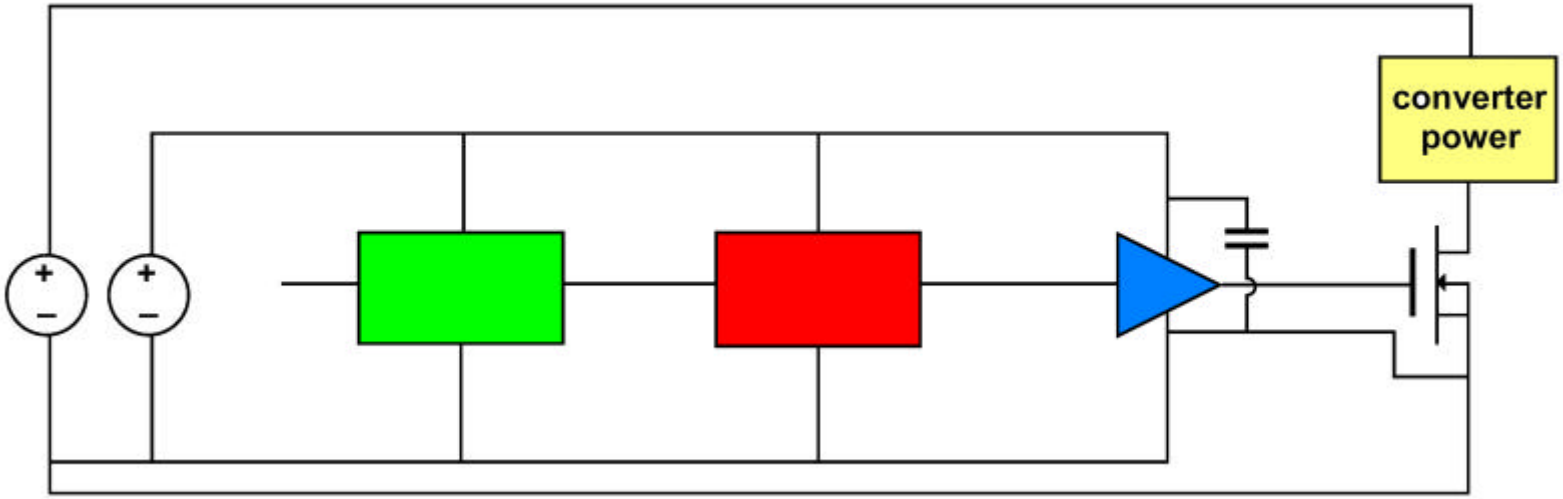


Gate Switching Current

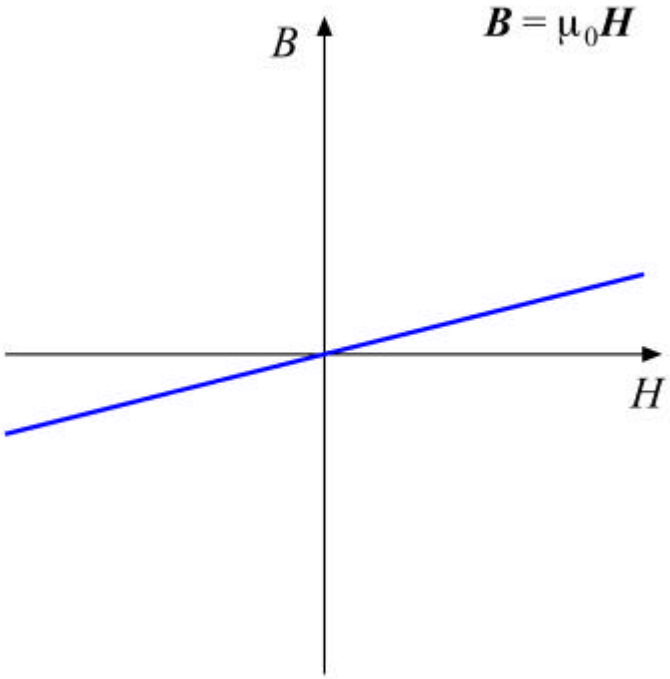


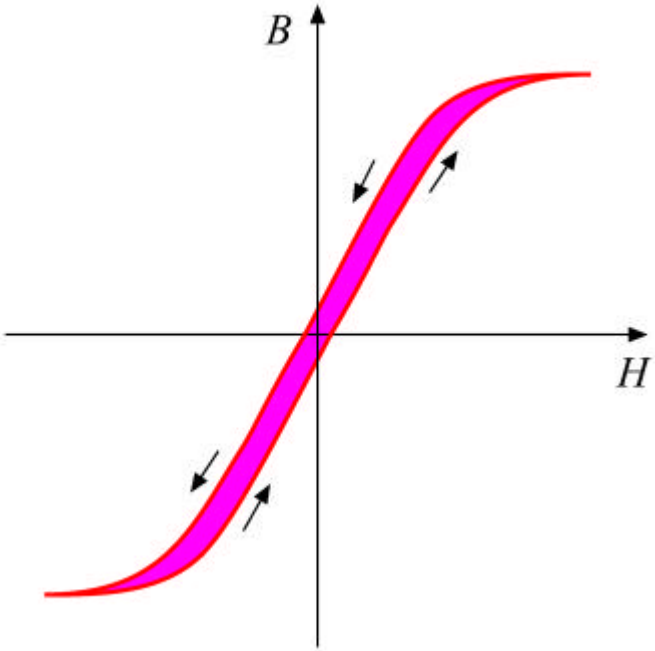


Bypass Switching Current

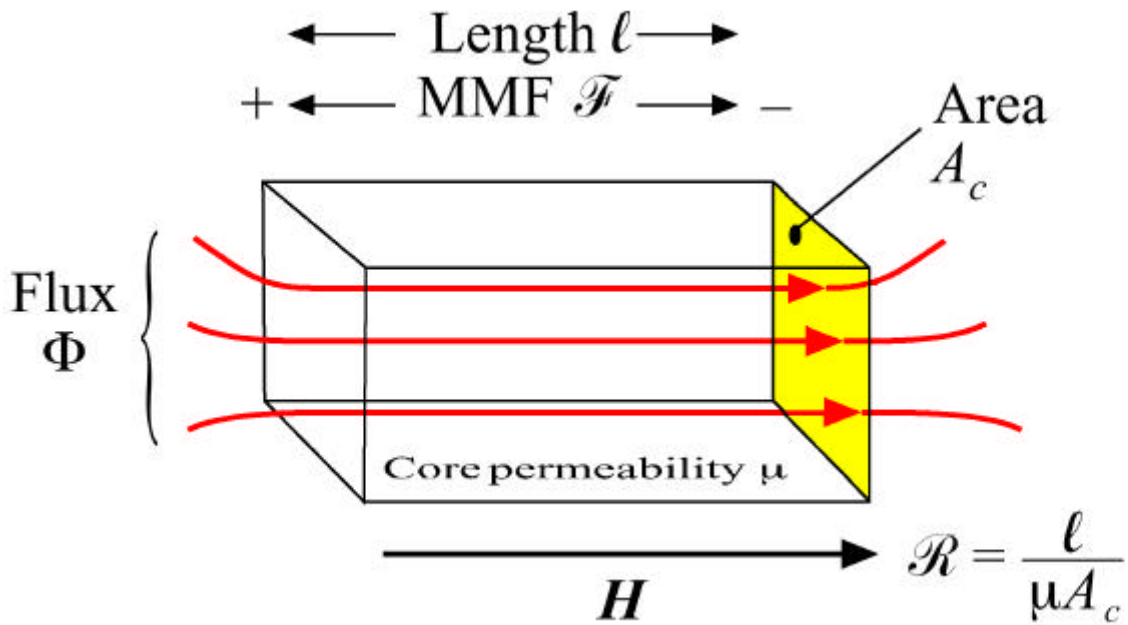


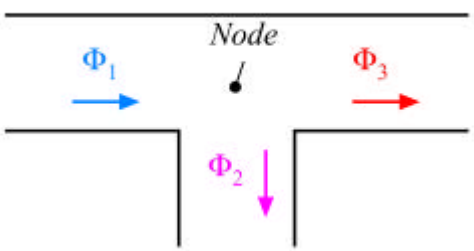
Hysteresis of Magnetic Cores



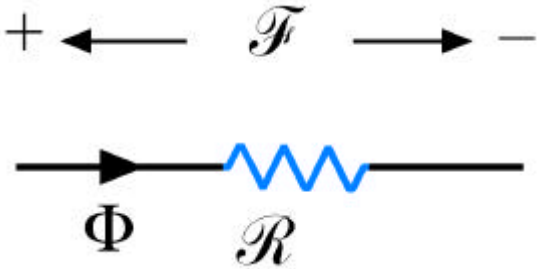


Magnetic Circuits

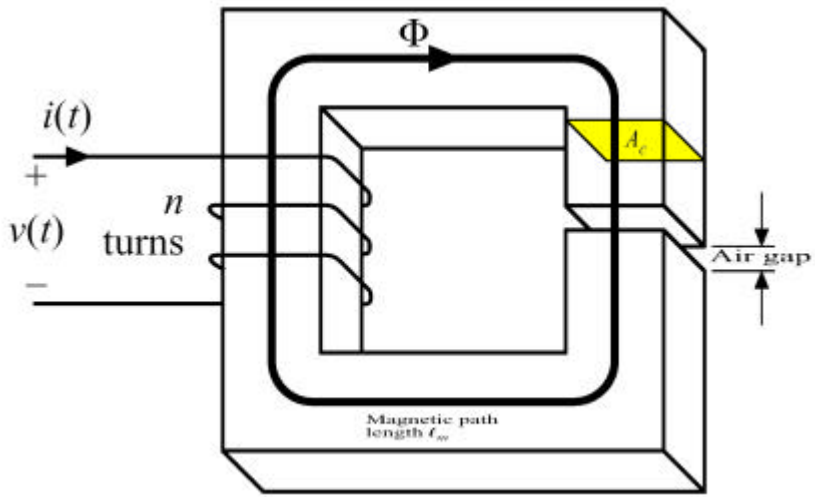


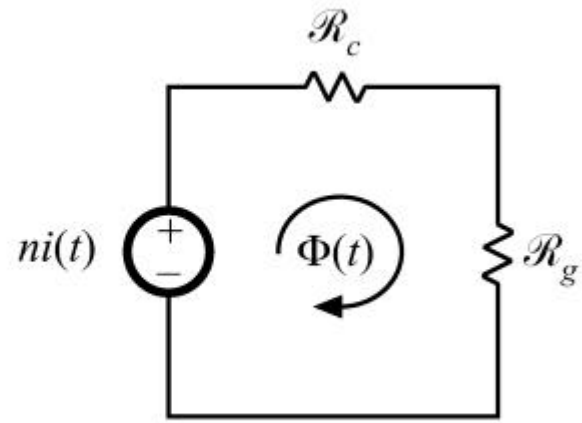


$$\mathscr{F} = H\ell$$
$$= \Phi\mathscr{R}$$



Modeling on Air Gap





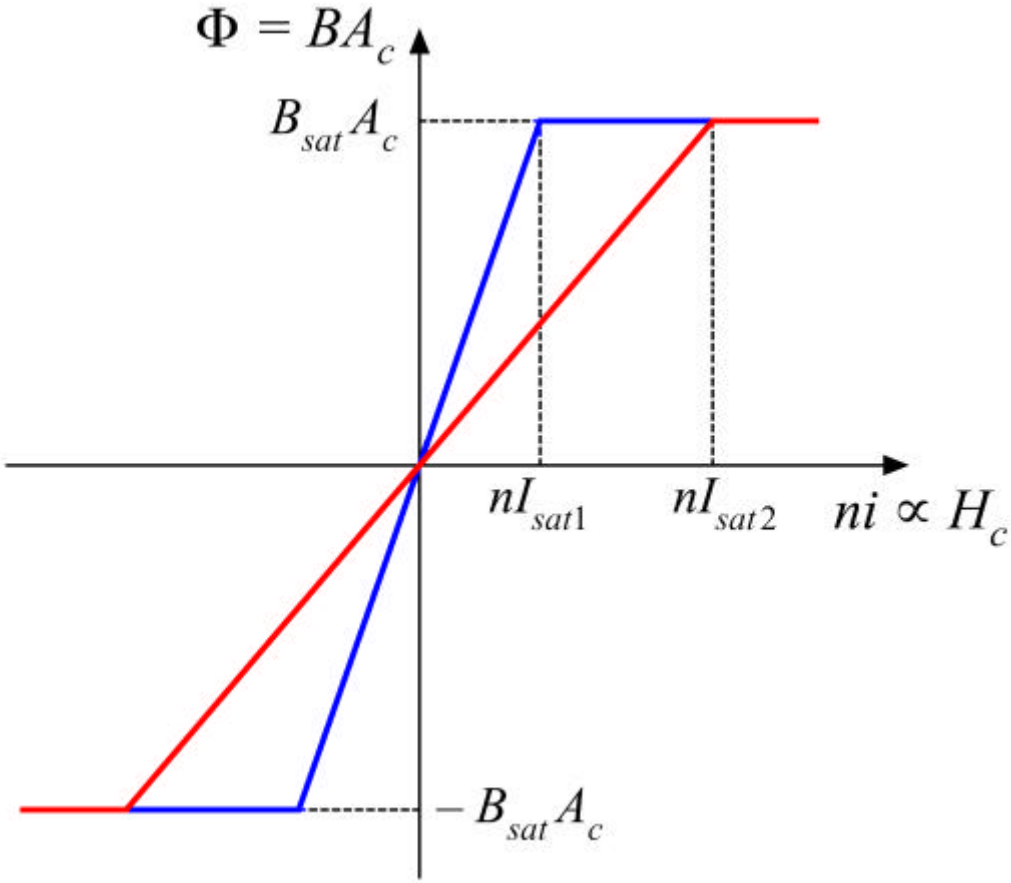
$$\mathcal{F}_c + \mathcal{F}_g = ni$$

$$ni = \Phi\left(\mathcal{R}_c + \mathcal{R}_g\right)$$

$$\mathcal{R}_c = \frac{\ell_c}{\mu A_c}$$

$$\mathcal{R}_g = \frac{\ell_g}{\mu_0 A_c}$$

Effects of Air Gap on Saturation



Outline

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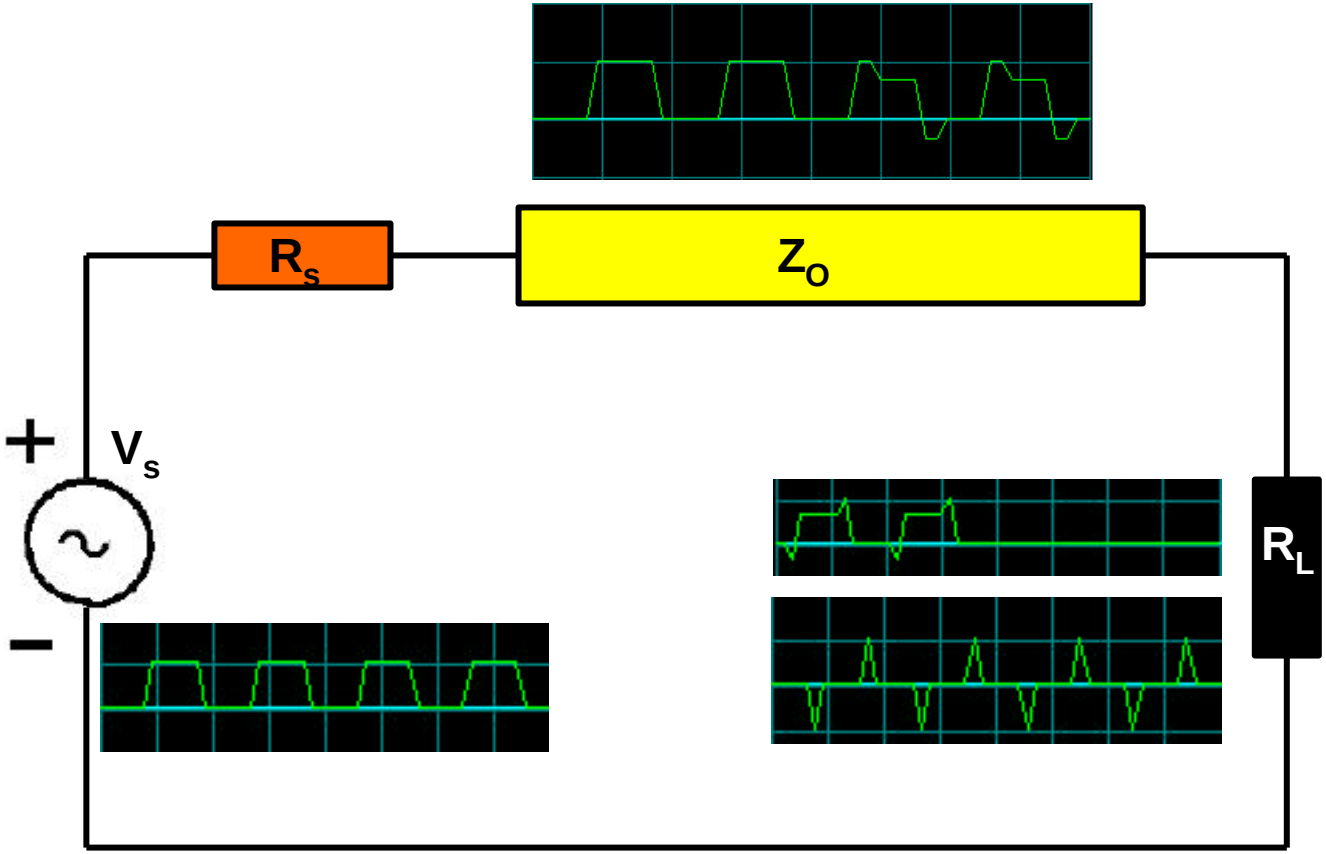
2. Causes of EMI and Signal Integrity
3. Grounding, Isolation and Separation
4. Power System
5. **Impedance Control**
6. Cabling & I/O Interconnect
7. Interference Couplings
8. Shielding Material (reflection)
9. Shielding Material (absorption)
10. Filtering (RLC Components) & Decoupling
11. EMI Radiation

Mismatch and Reflection



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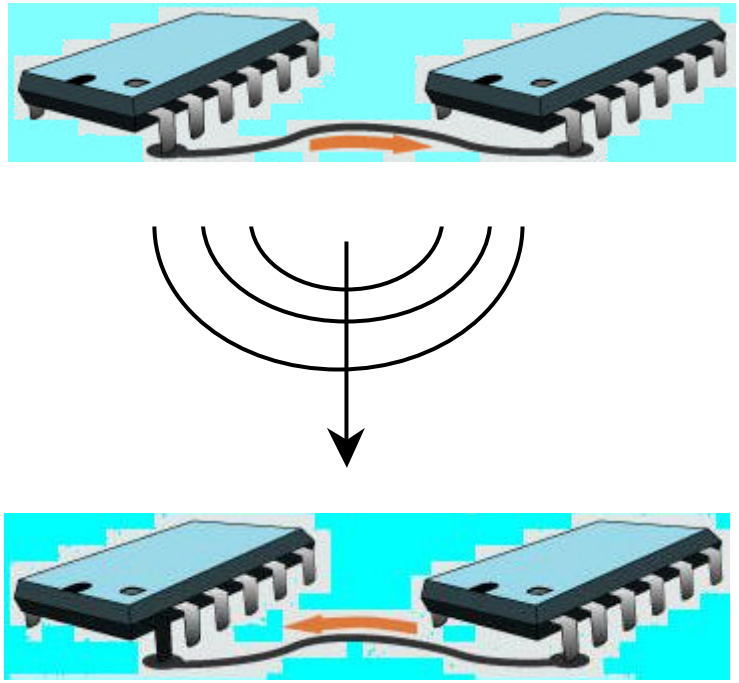
Interference Couplings Mechanism

- **Coupling Path**
- **Cross Talk**
  - **Capacitive coupling**
  - **Inductive Coupling**
- **Coupling Mechanism**
  - **Conducted Mode : DM & CM Conduction**
  - **Radiated Mode : DM & CM Radiation**

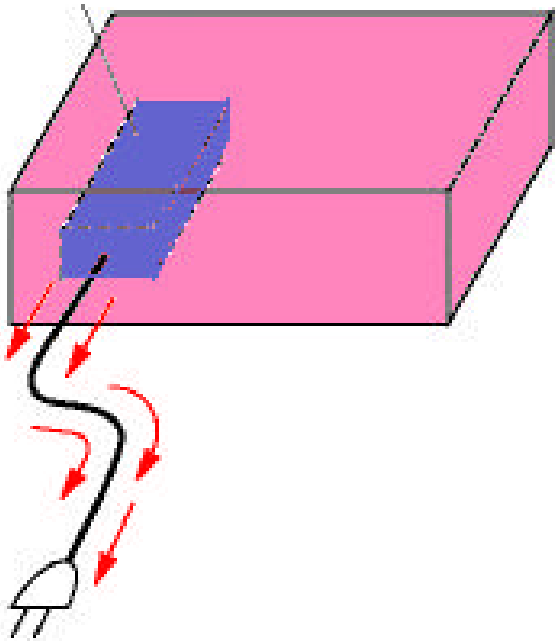
Interference Couplings Mechanism

Radiation Vs. Conduction

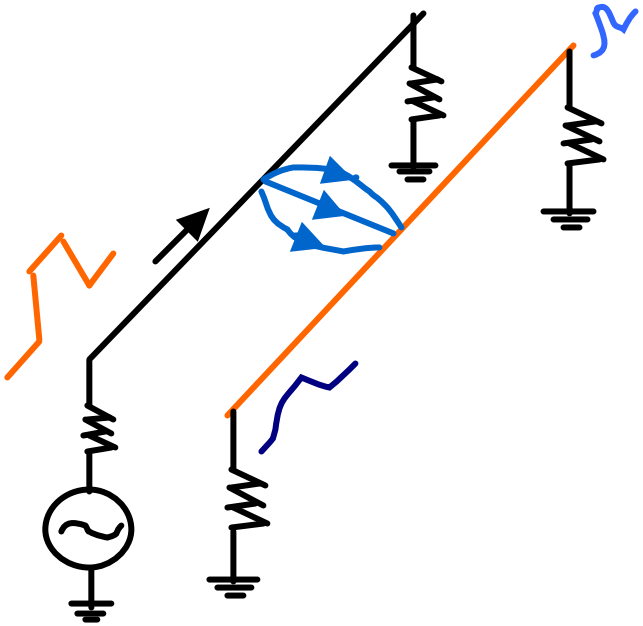
Transmitting Antenna



Receving Antenna

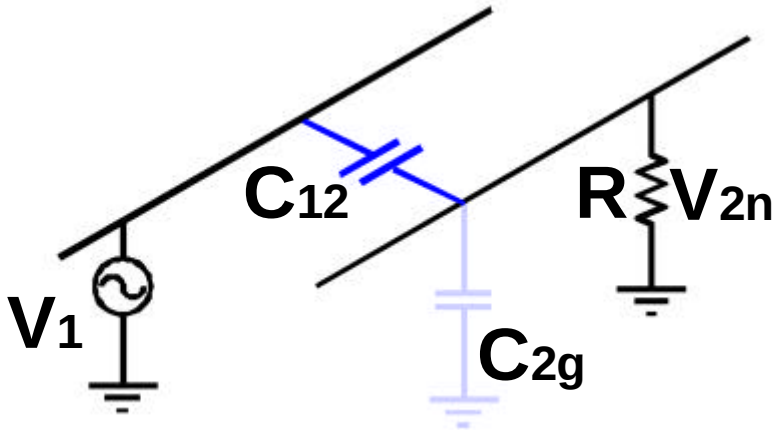


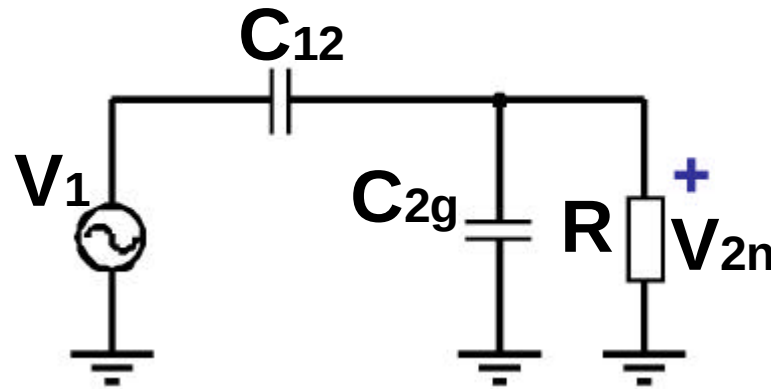
Cross Talk



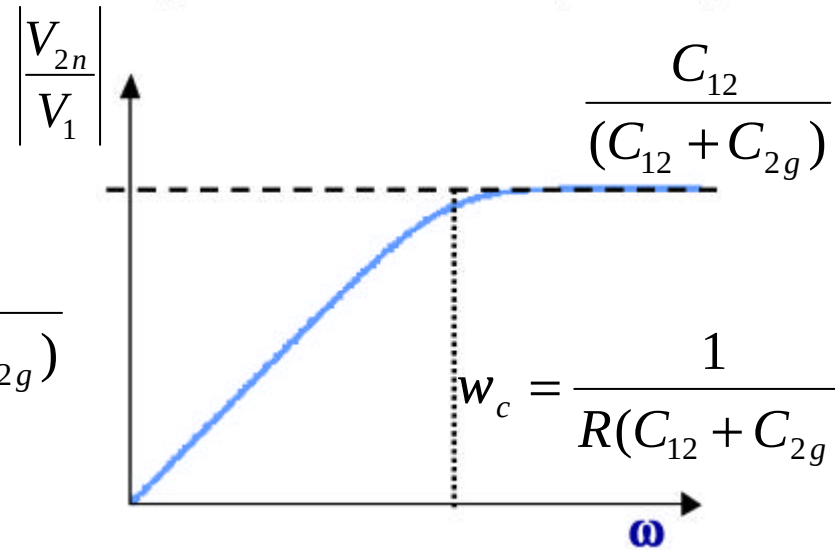
- **Capacitive Coupling**
- **Inductive Coupling**

Cross Talk — Capacitive Coupling

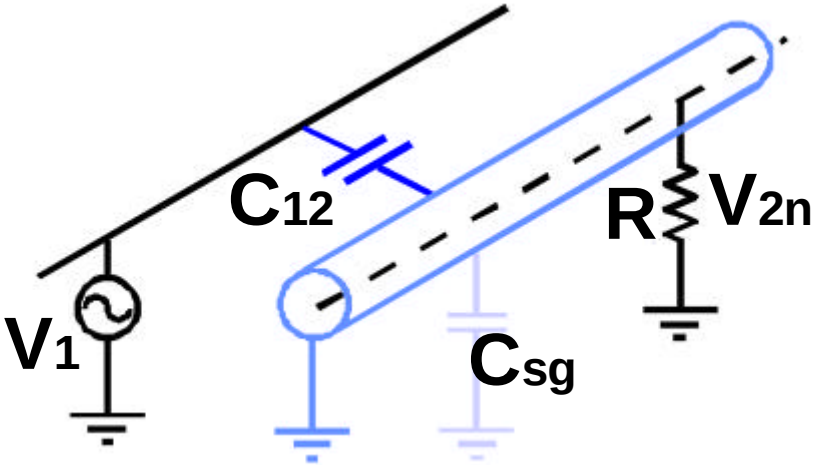


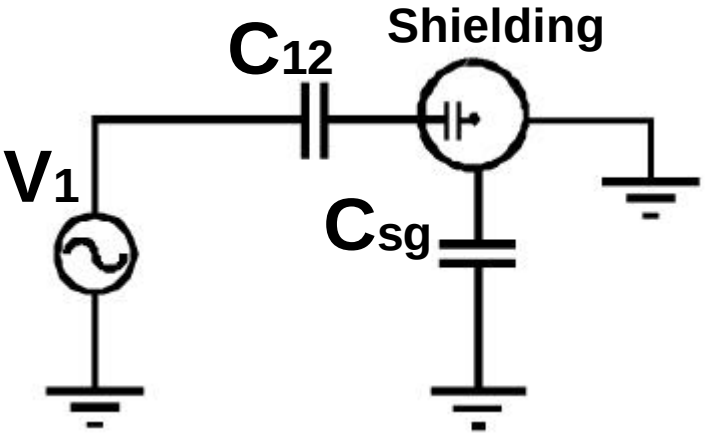


$$\left|\frac{V_{2n}}{V_1}\right| = \frac{jw}{jw + \frac{1}{R(C_{12}+C_{2g})}} \bullet \frac{C_{12}}{(C_{12}+C_{2g})}$$



Cross Talk — Capacitive Coupling

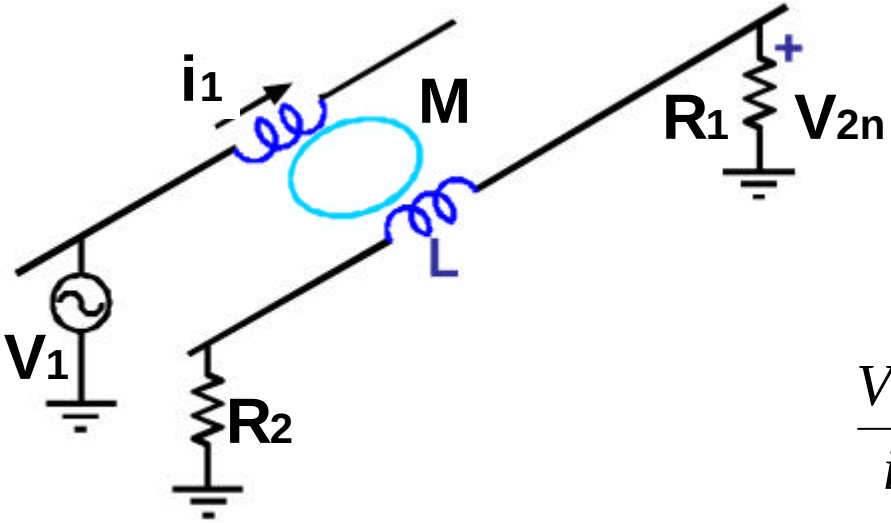


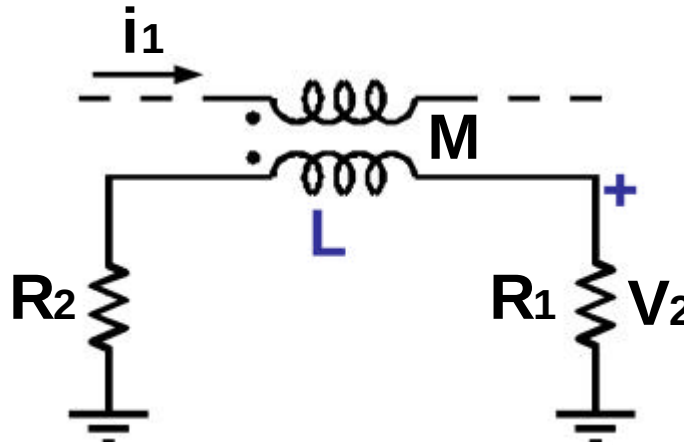


- GND Plane
- Guard Trace
- Termination

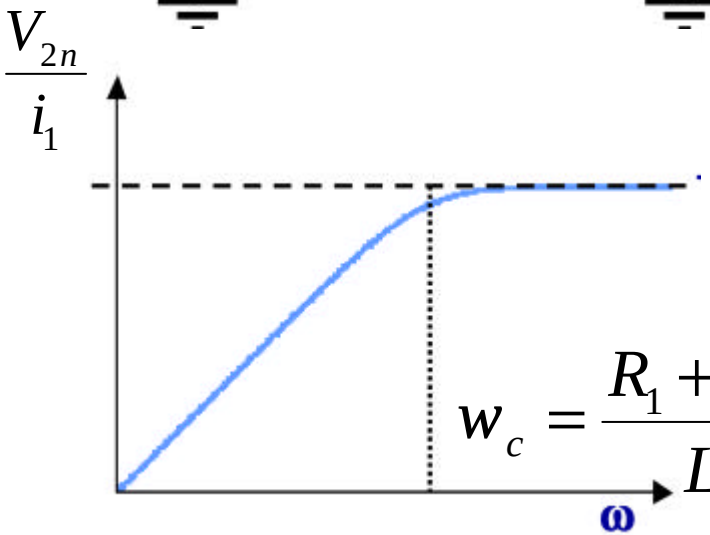
Groumded Shielding, V2n=0

Cross Talk — Inductive Coupling



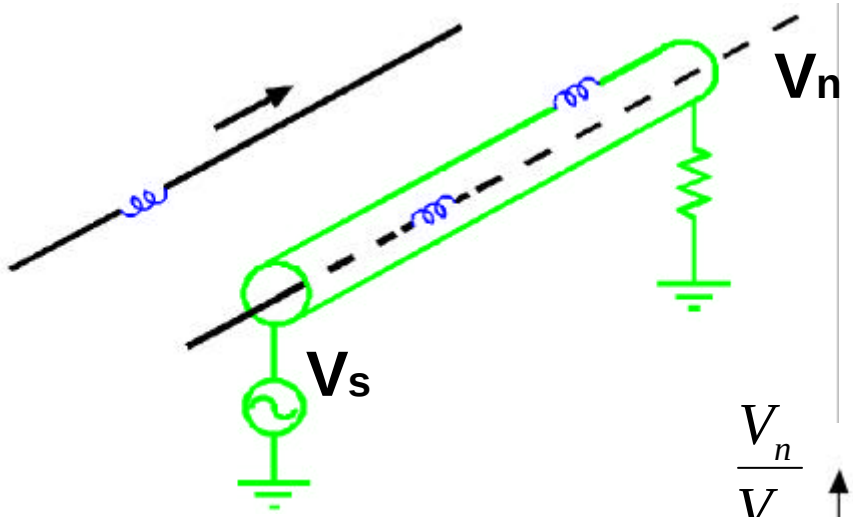


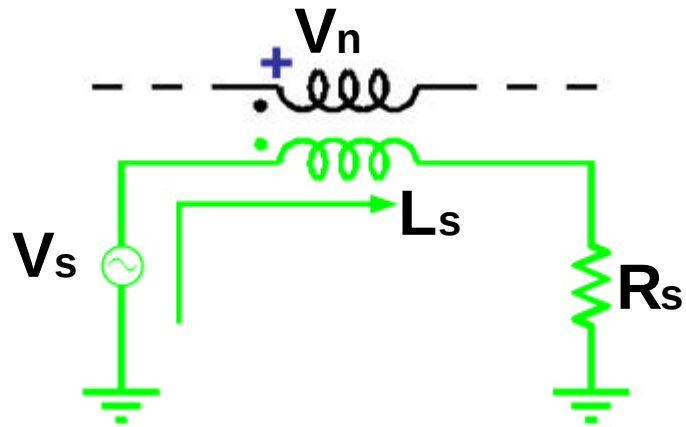
$$\frac{V_{2n}}{i_1} = \frac{jw}{jw + \frac{R_1 + R_2}{L}} \bullet \frac{MR_1}{L}$$



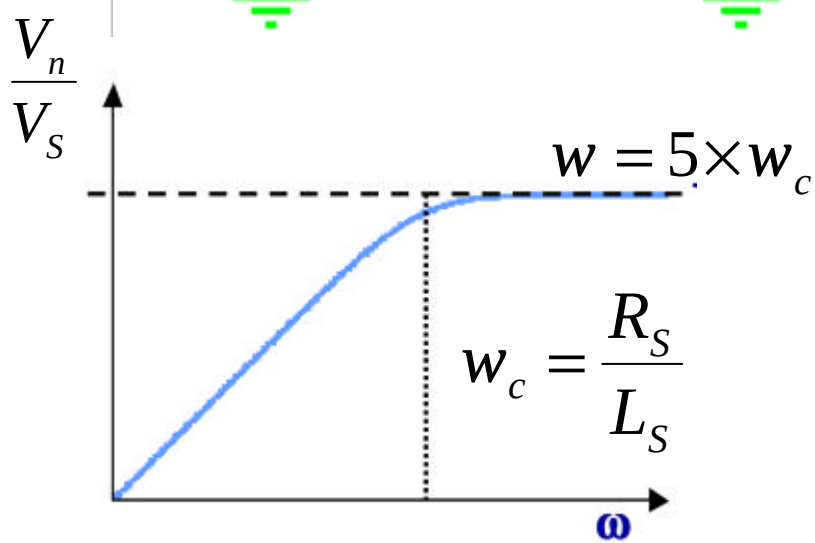
$$w_c = \frac{R_1 + R}{L}$$

Cross Talk — Shielding Cable

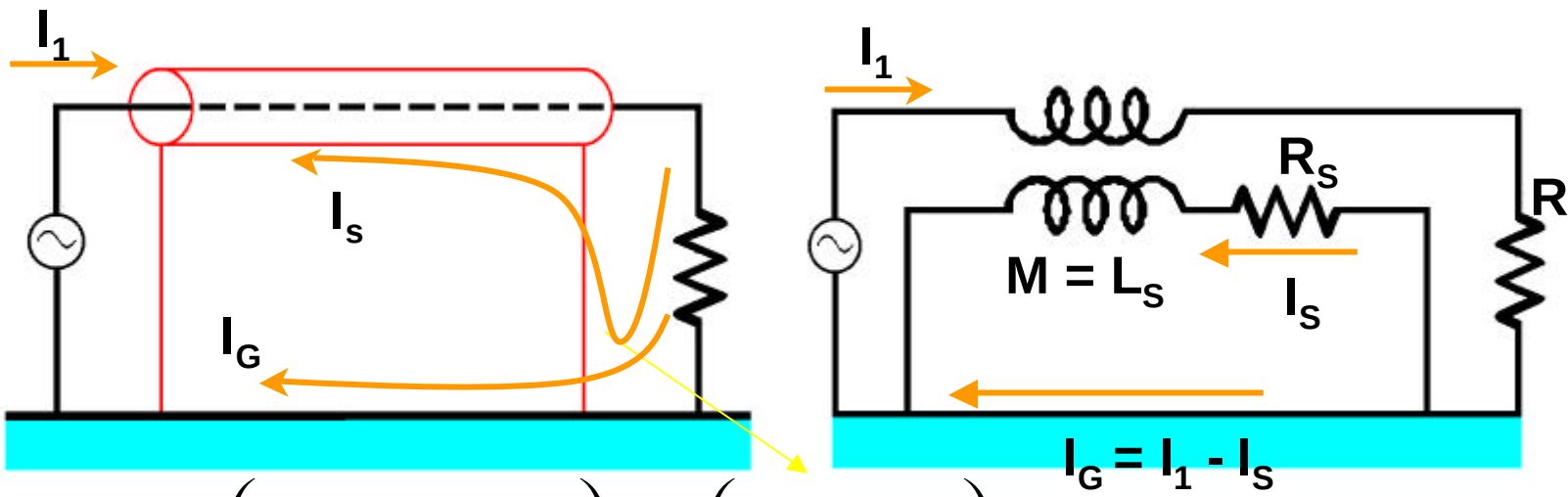




$$\frac{V_{2n}}{V_S} = \frac{jw}{jw + \frac{R_S}{L_S}}$$



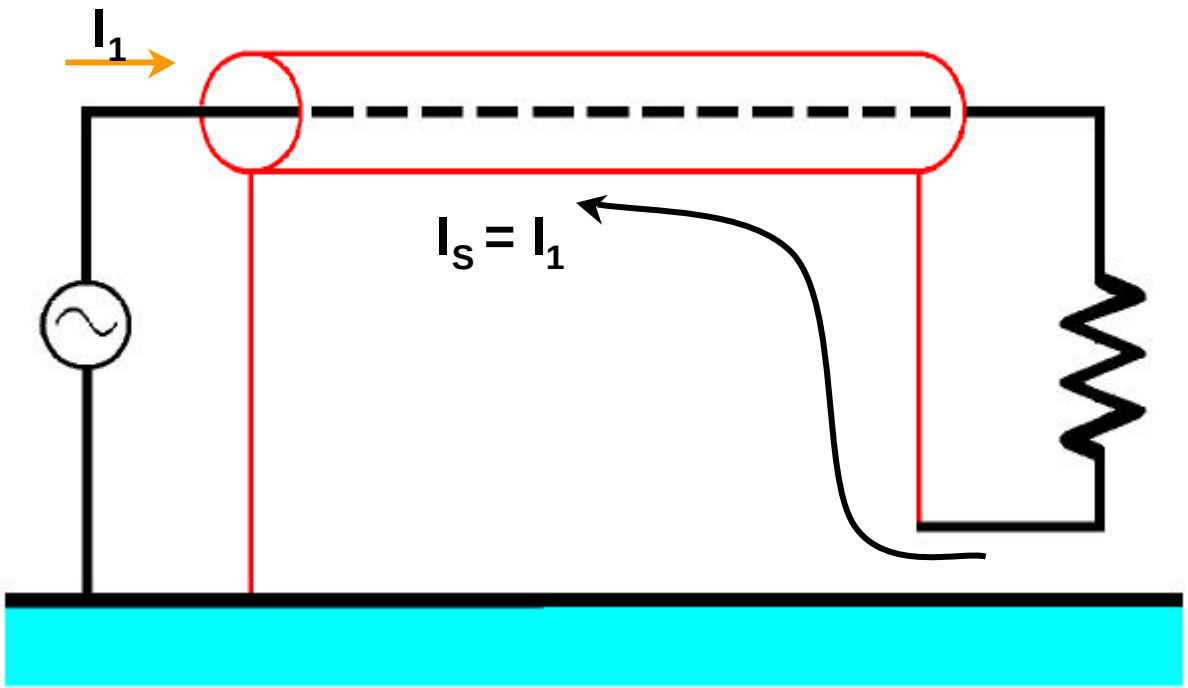
Cross Talk — Shielding Cable



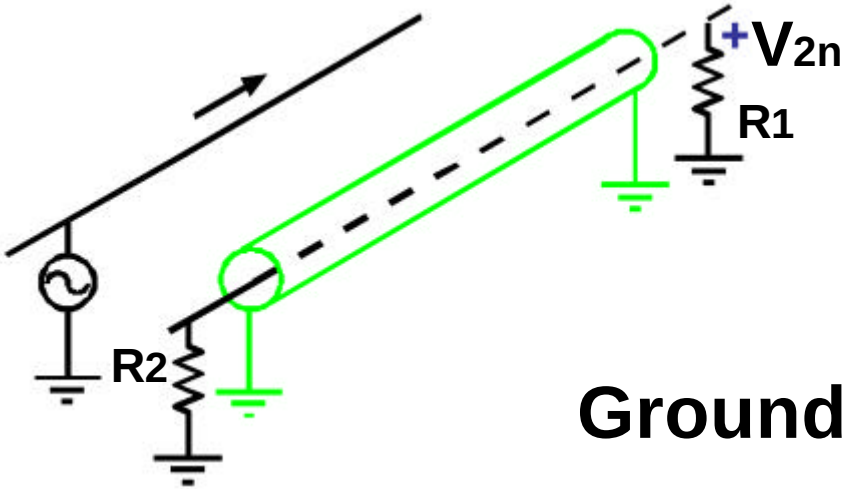
$$I_S = I_1\left(\frac{jw}{jw + R_S / L_S}\right) = I_1\left(\frac{jw}{jw + w_C}\right)$$

$$Where \quad w_C = R_S / L_S$$

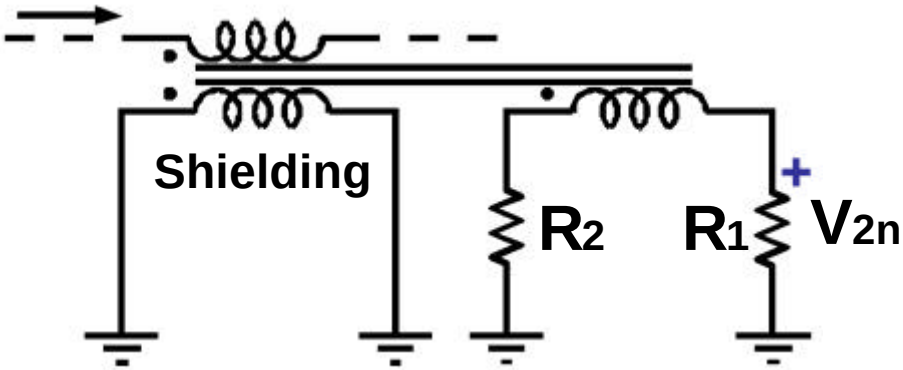
Cross Talk — Shielding Cable



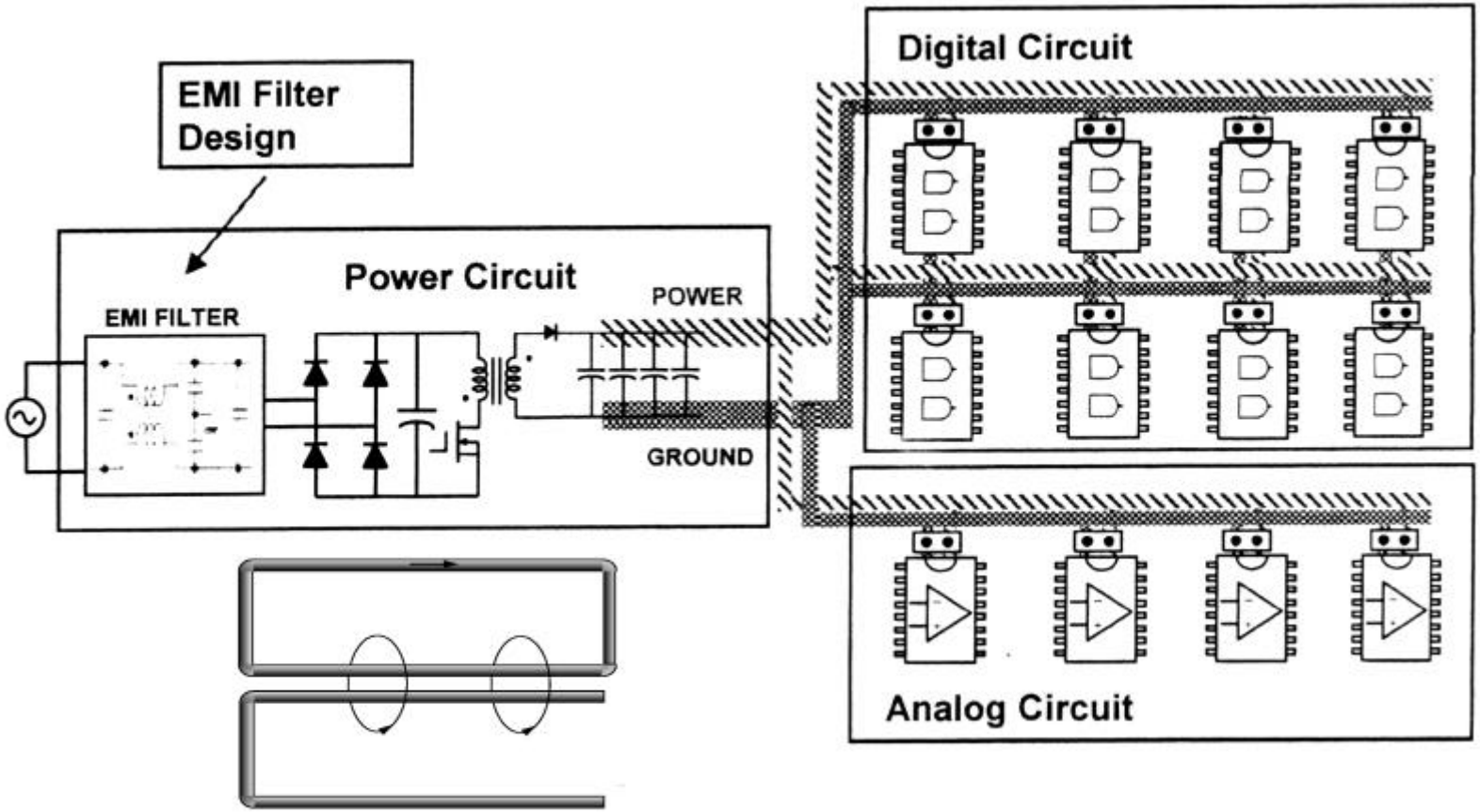
Cross Talk — Inductive Coupling



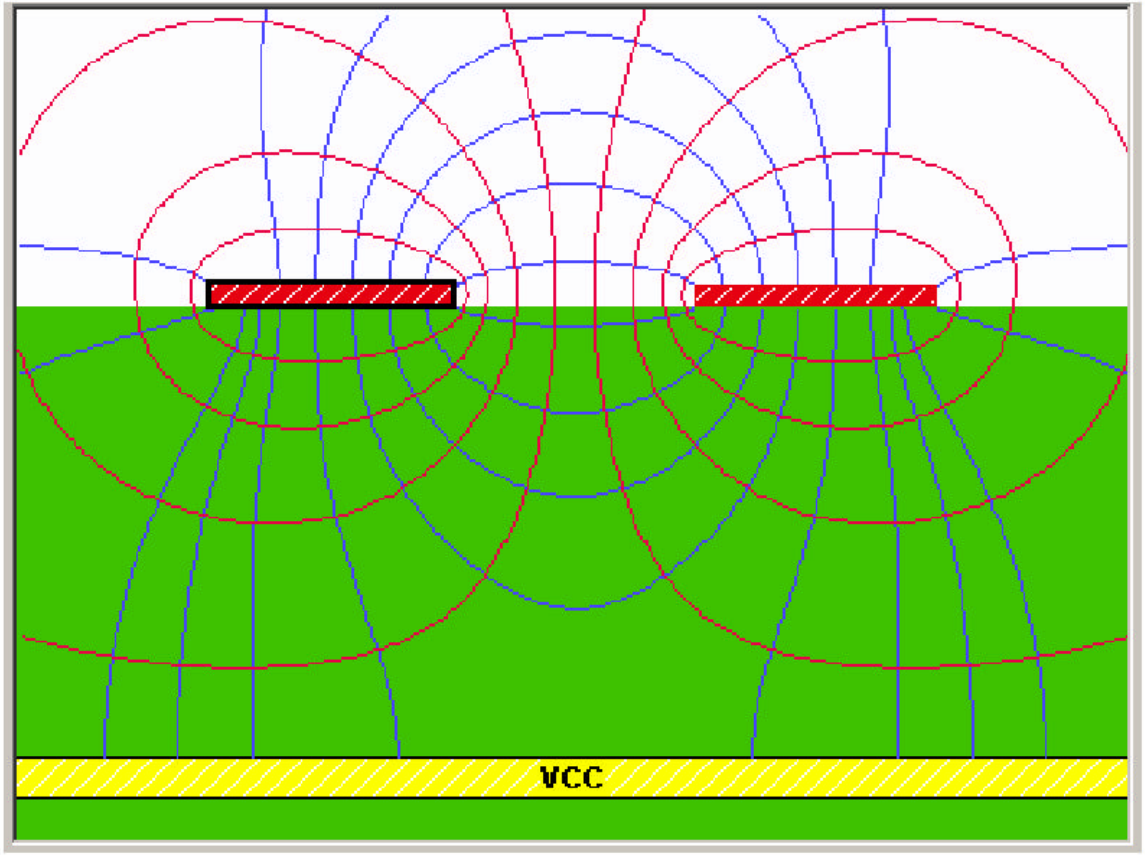
Grounded Shielding, V2n=0



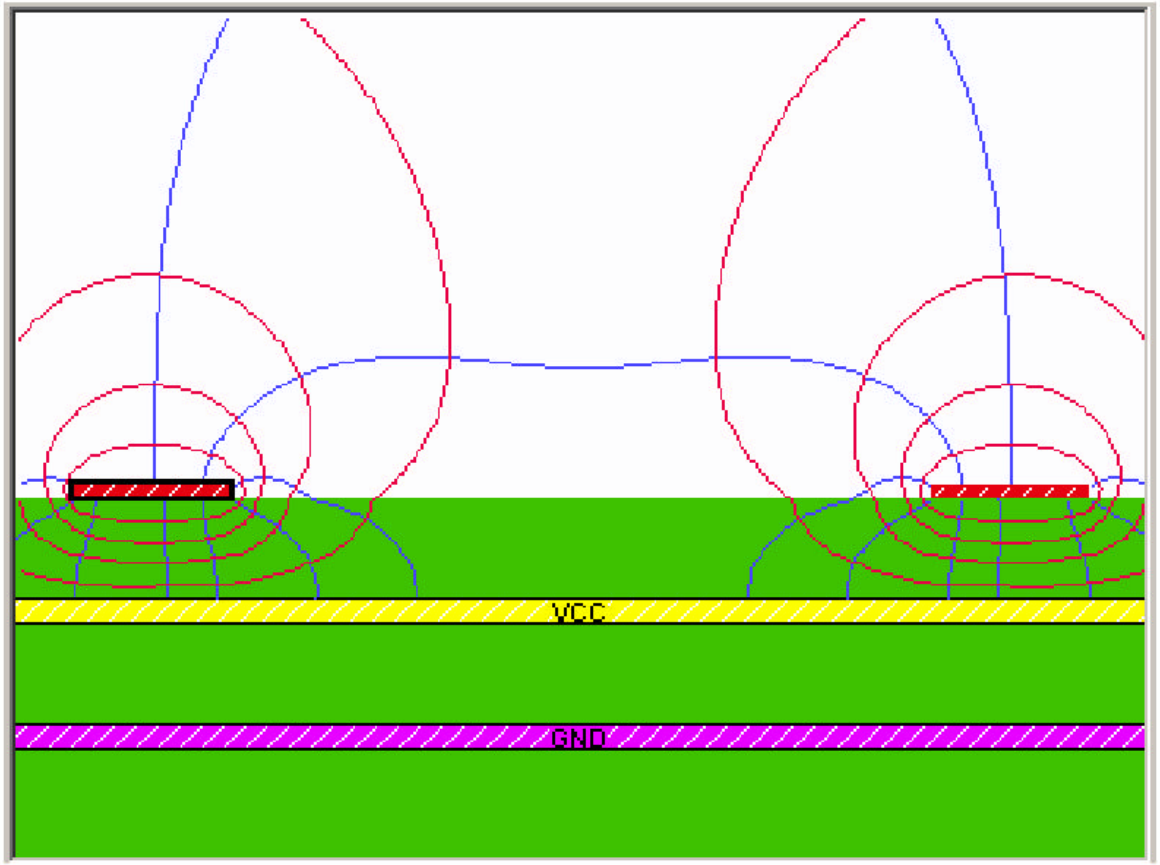
Reducing Inductive Coupling (Loop Area)



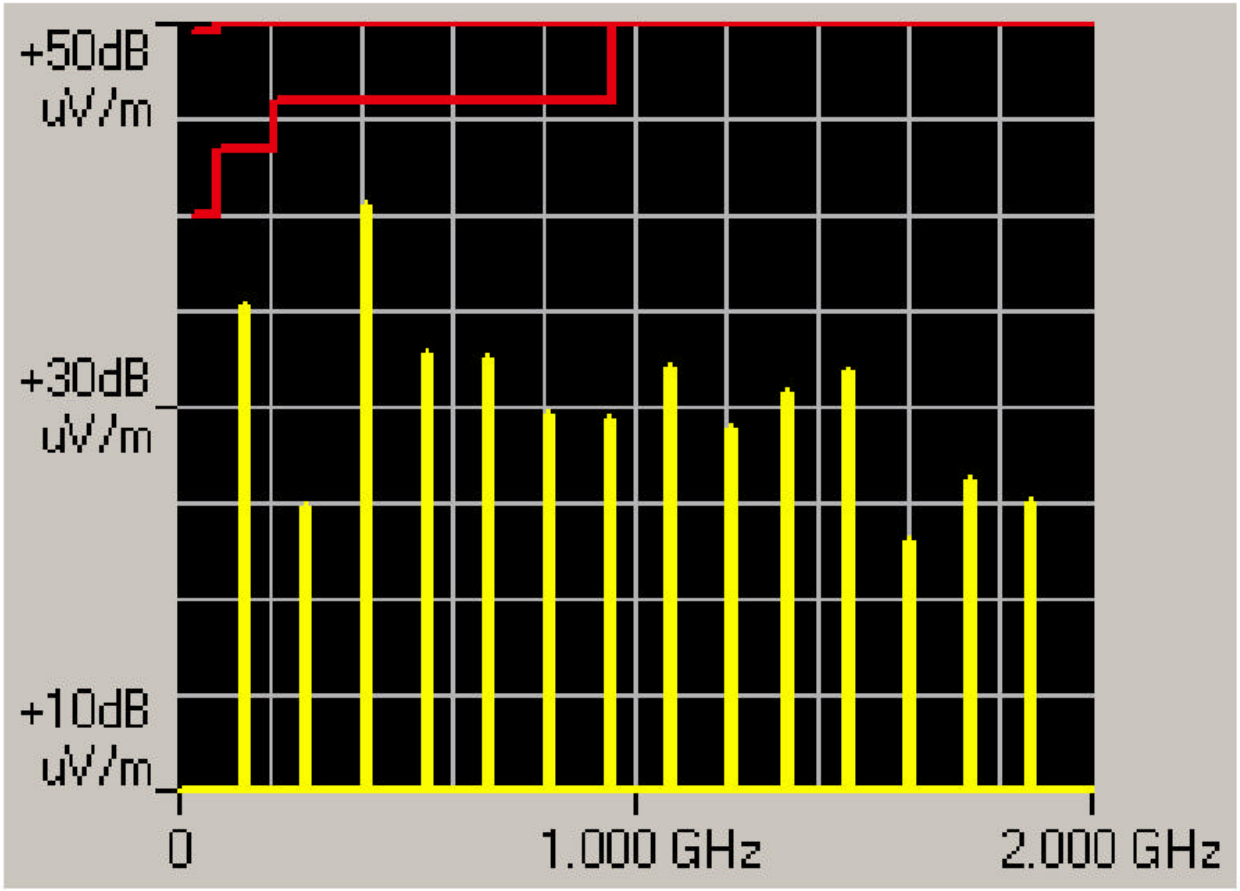
Traces Far from the Underlying Plane

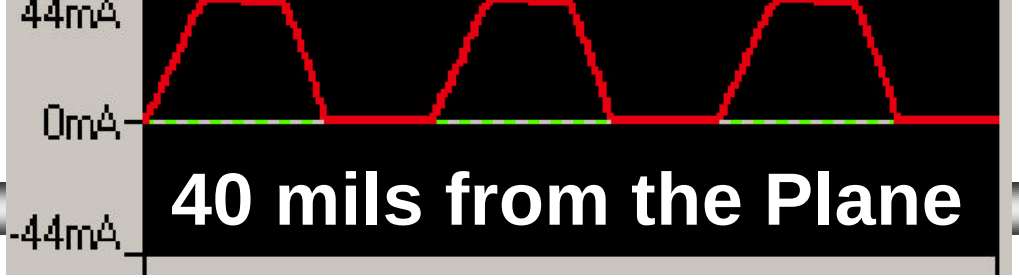


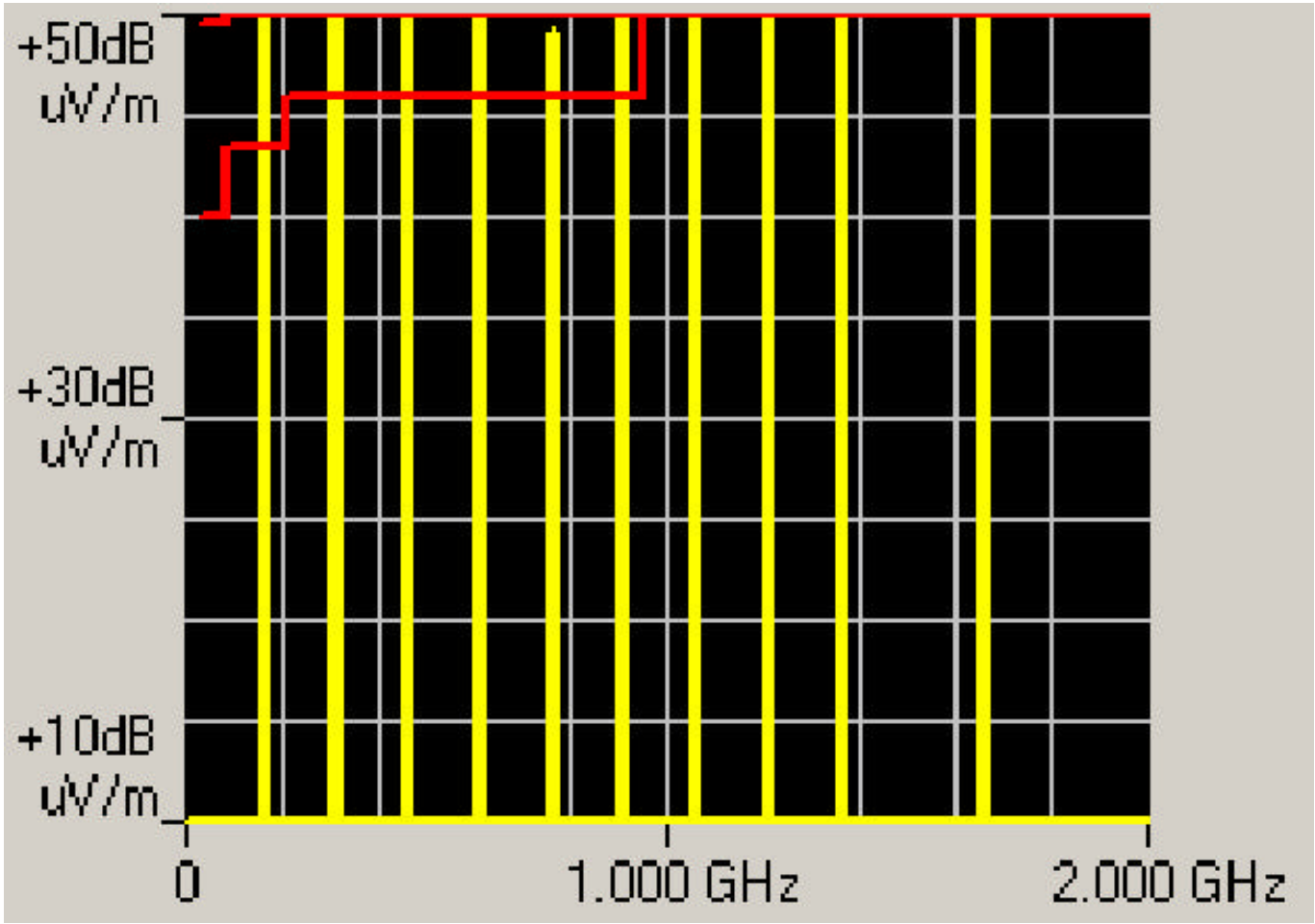
Traces Close to the Underlying Plane



Trace 5 mils from the Underlying Plane




44mA
0mA
-44mA
40 mils from the Plane


+50dB
uV/m
+30dB
uV/m
+10dB
uV/m
0
1.000 GHz
2.000 GHz

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9. **Shielding Material (absorption)**
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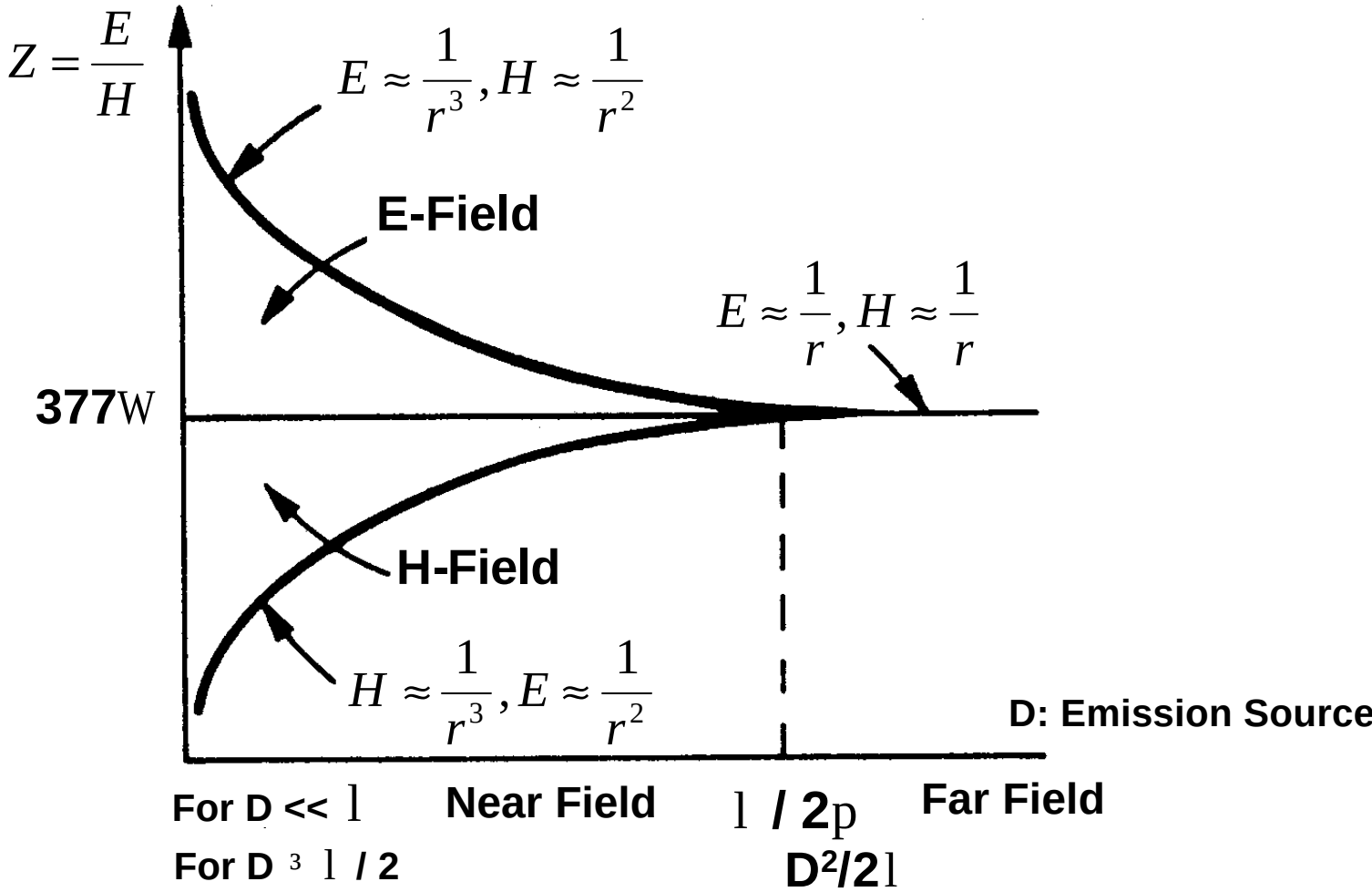
Far/Near Field Radiation

Frequency	$\lambda/2\pi$
1 MHz	48 m
10 MHz	4.8 m
100 MHz	0.48 m
1000 MHz	0.048 m

- **Far Field → $d < \lambda/2\pi$ → Induction**
- **Near Field → $d > \lambda/2\pi$ → Radiation**

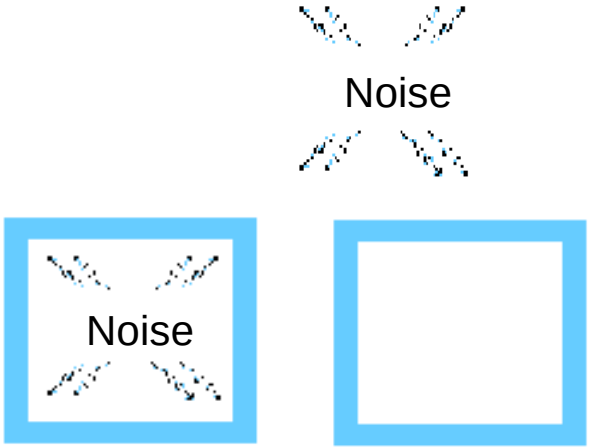
EM Field (Near & Far Field)



Shielding

$$S_E = 10Log_{10}\frac{P_{NS}}{P_S} = 20Log_{10}\frac{|E_{NS}|}{|E_S|}dB$$

$$S_H = 10Log_{10}\frac{P_{NS}}{P_S} = 20Log_{10}\frac{|H_{NS}|}{|H_S|}dB$$



Shielding Loss = Absorption Loss + Reflection Loss

$$S = S_{A(E,H)} + S_{R(E,H)} + B$$

B: nelgected if A > 10dB
(Multiple reflection)

Under any frequency (To Metal)

- **H-field → Lo Impedanc**
  - **→ Less Reflection**
  - **→ Mainly by Absorption**
- **E-field → Hi Imedance**

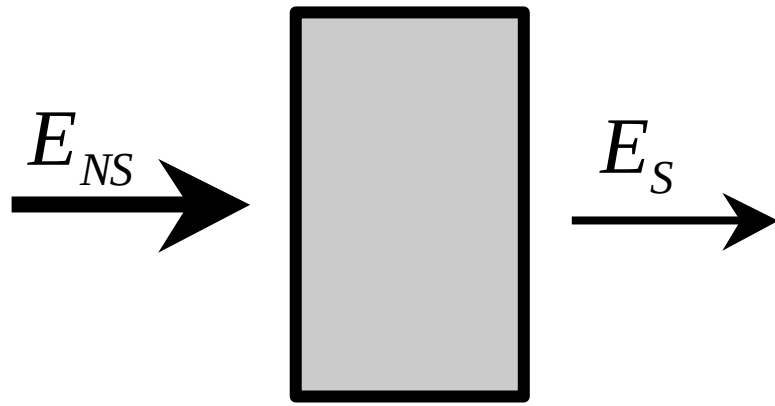
Absorption Loss (Eddy Ohmic Loss)

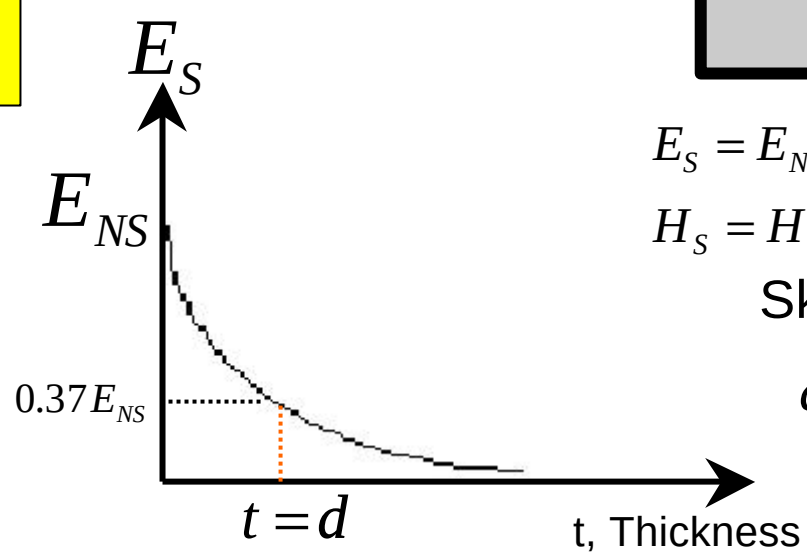
Absorption Loss,

$$S_A = 20\left(\frac{t}{d}\right)\log e, dB$$

$$= 8.69\left(t/d\right), dB$$

$$= 3.34t\sqrt{fms}, dB$$





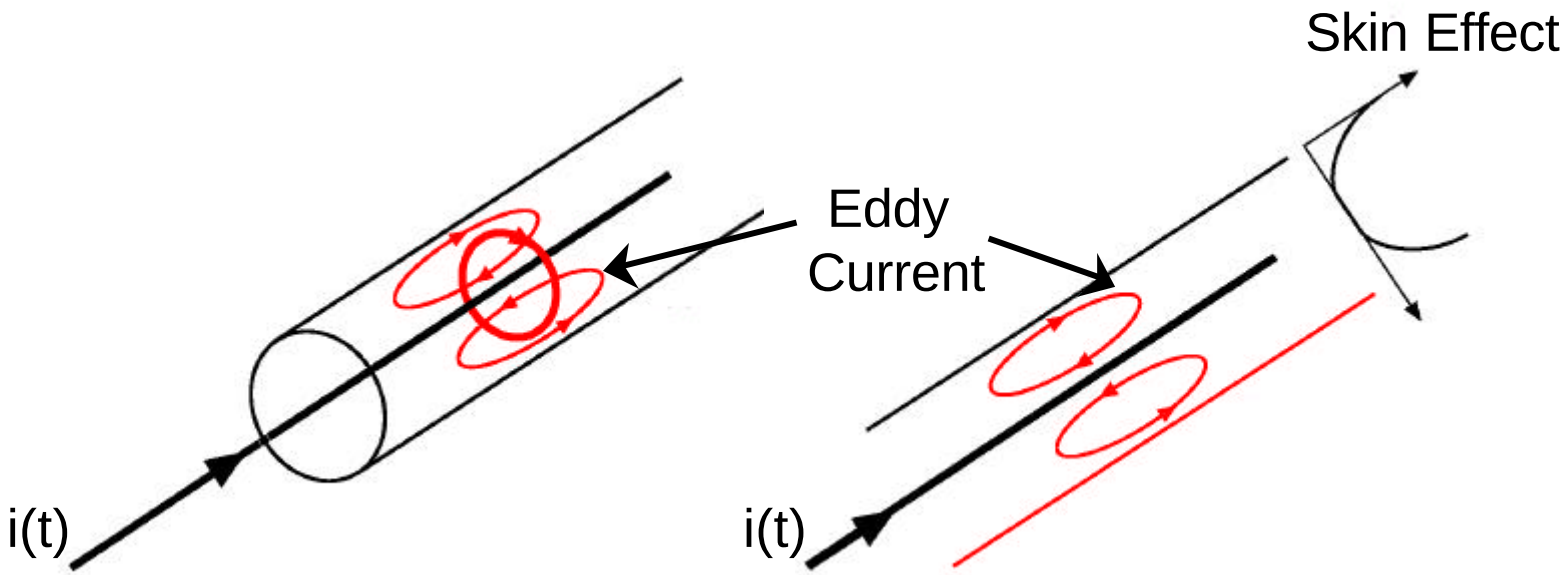
$$E_S = E_{NS}e^{-t/d} = E_{NS}e^{-1} \text{ (37\%}$$

$$H_S = H_{NS}e^{-t/d} = H_{NS}e^{-1}$$

Skin-depth, δ

$$d = \sqrt{2/wms} \quad m$$

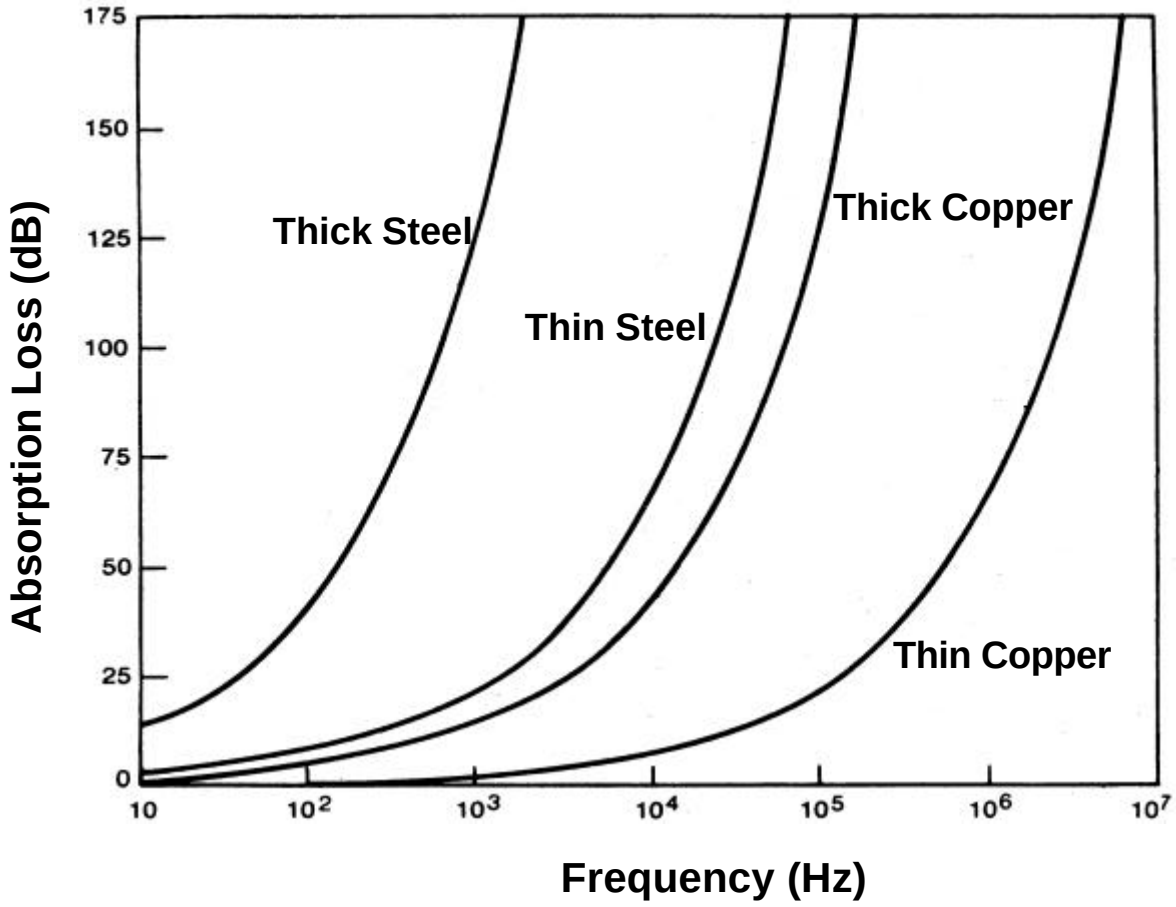
Skin- Effect (Eddy Current)



Skin Depth of Various Material

Frequency	Copper (in.)	Aluminum (in.)	Steel (in.)
60 Hz	0.335	0.429	0.034
100 Hz	0.260	0.333	0.026
1 KHz	0.082	0.105	0.008
10 KHz	0.026	0.033	0.003
100 KHz	0.008	0.011	0.0008
1 MHz	0.003	0.003	0.0003
10 MHz	0.0008	0.001	0.00008

Absorption Loss (Copper Vs. steel)



Characteristic and Wave Impedance

$$Z_o = \sqrt{jwm \big/ (s + jwe)}$$

$$Z_o \approx \sqrt{\frac{wm}{s}}, s >> jwe$$

$$Z_o \approx \sqrt{\frac{m}{e}}, s << jwe$$

$$Zair = 377\Omega$$

$$Z_{Cu} = 3.68 * 10^{-7} \sqrt{f}\,\Omega$$

$$Z_{Al} = 4.71 * 10^{-7} \sqrt{f}\,\Omega$$

$$Z_{Steel} = 3.68 * 10^{-5} \sqrt{f}\,\Omega$$

Material	Relative s_r	Relative m_r
Silver	1.05	1
Copper	1.00	1
Gold	0.70	1
Aluminum	0.61	1
Brass	0.26	1
Nikel	0.20	1
Tin	0.15	1
Steel	0.1	1000
Lead	0.08	1
Stainless (430)	0.02	500

$$m(4p * 10^{-7}\, H/m) \bullet e(8.854 * 10^{-12}\, F/m) \bullet s\ (5.821 * 10^{7}\, m\Omega/m)$$

Reflection Loss, S_R

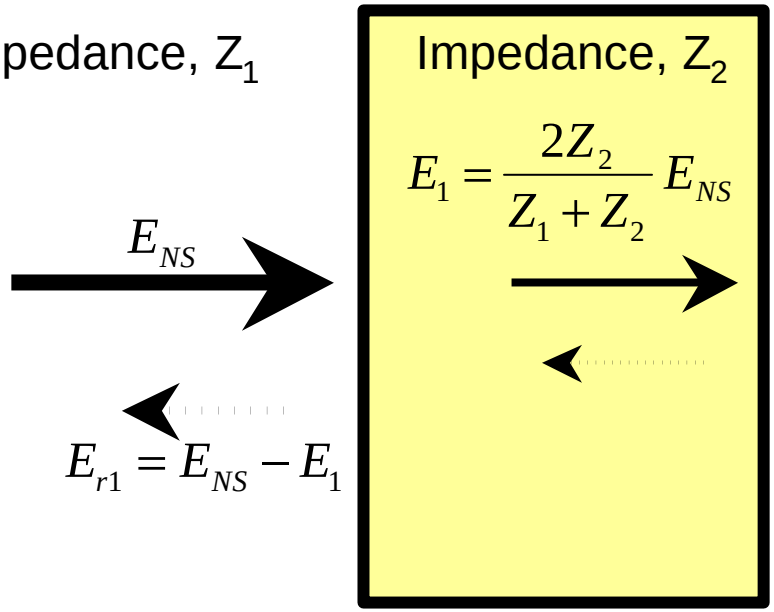
Impedance, Z_1

Impedance, Z_2

$$E_1 = \frac{2Z_2}{Z_1 + Z_2} E_{NS}$$

Impedance , Z_1

$$E_S = \frac{2Z_2}{Z_1 + Z_2} E_1 = \frac{4Z_1 Z_2}{(Z_1 + Z_2)^2} E_{NS}$$



When $Z_1 >> Z_2$

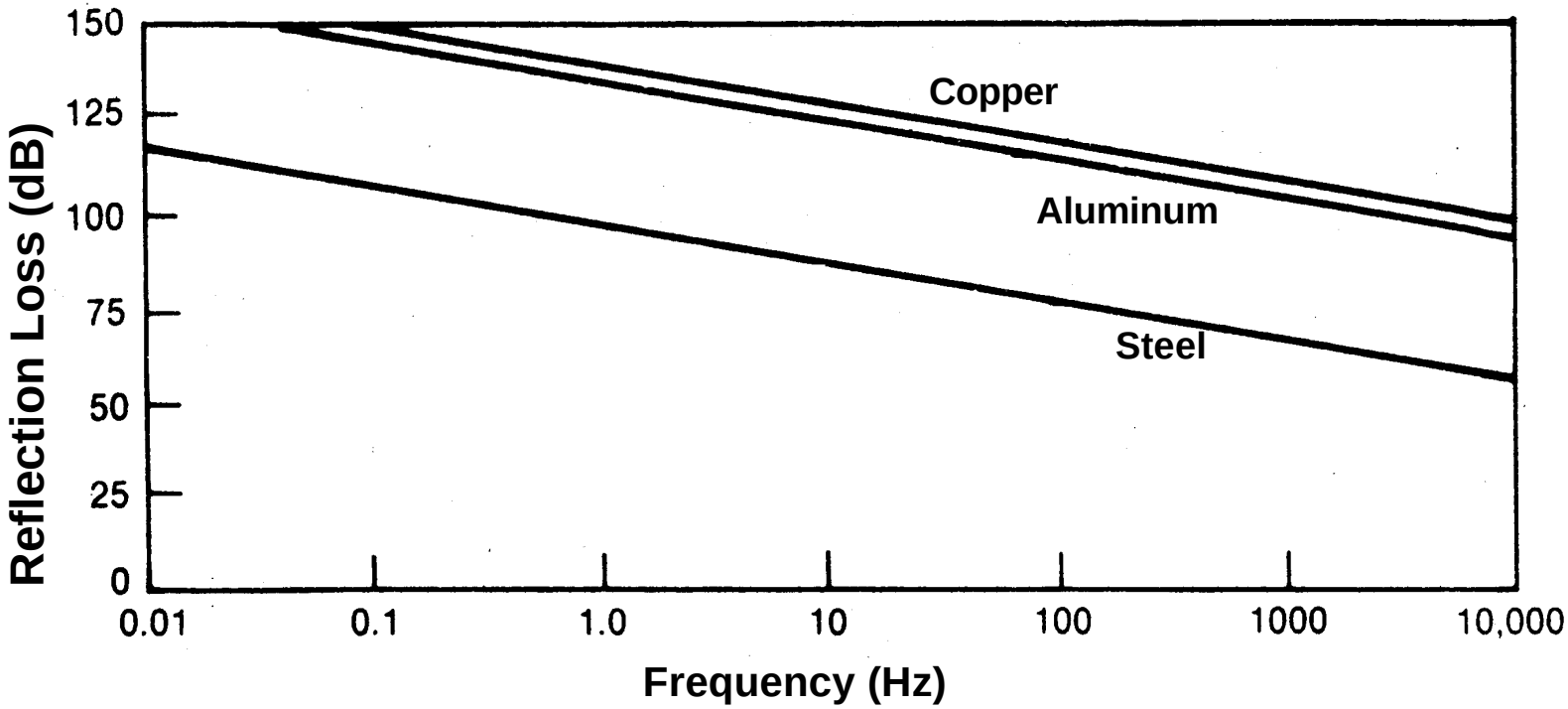
$$E_S = \frac{4Z_2}{Z_1} E_{NS}$$

$$S_R = 20 Log \frac{|Z_1|}{4|Z_2|}, \qquad Z_1 = 377\,\Omega$$

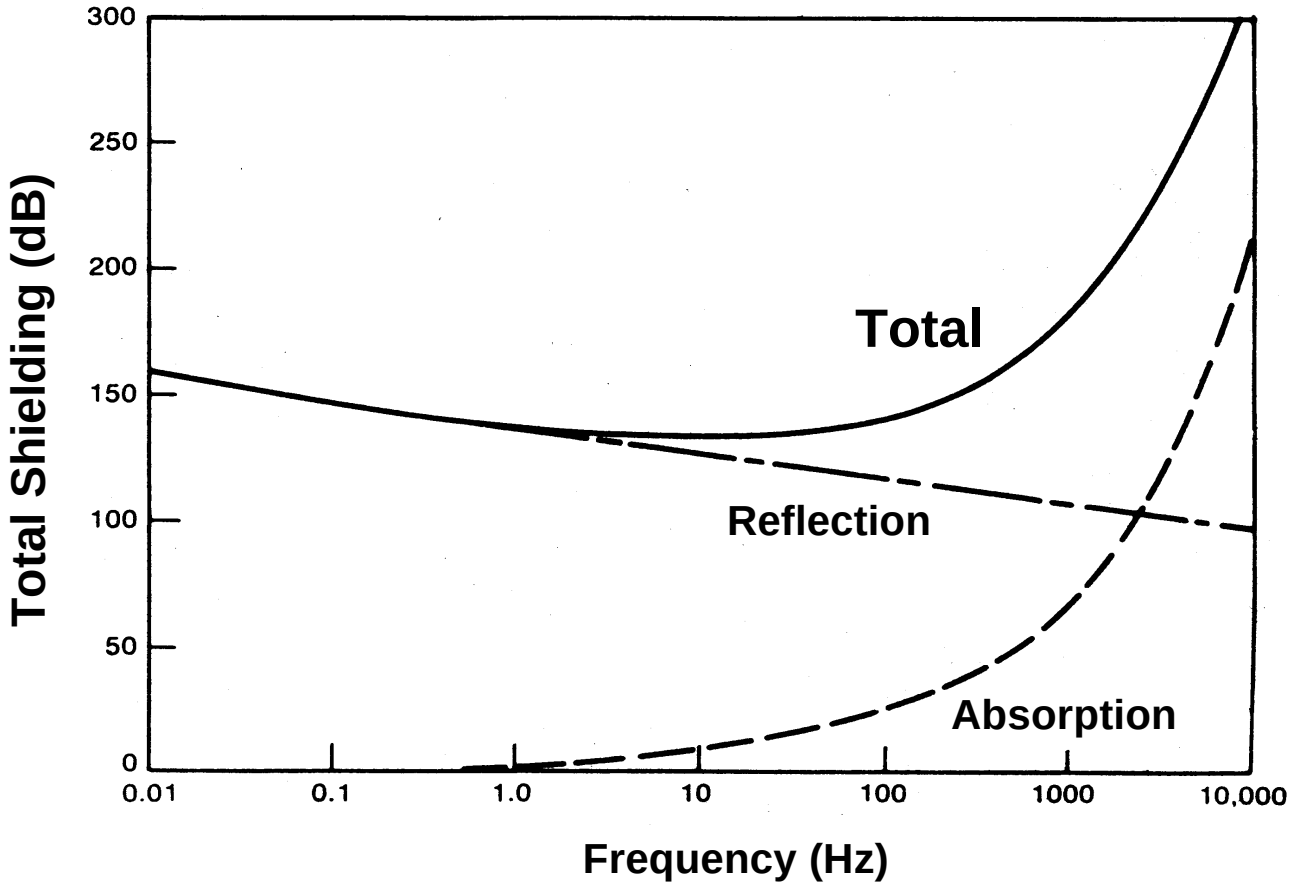
$$= 20 Log \frac{94.25}{|Z_2|} \qquad , dB$$

$$\boxed{S_R = 168 - 10 Log(m_r f / s_r) \qquad , dB}$$

Reflection Loss for Plan Wave



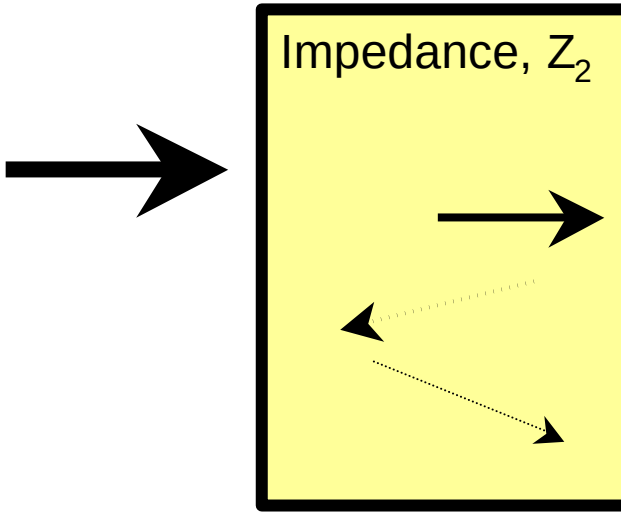
Shielding Effectiveness



Reflection Loss in the Near field

Near Field Wave Impedance

- Depending on source not medium
- Electric Field, Z_E
- Magnetic field, Z_H, (Multiple Reflection)
  (Primary by absorption)



$$Z_E = \frac{1}{2pfer} \qquad R_e = 20\log\frac{4.5x10^9}{fr|Z_2|} \qquad r \;\; in \;\; meter$$

$$Z_H = 2pfmr \qquad R_m = 20\log\frac{1.97x10^{-6}\,fr}{|Z_2|} \qquad r \;\; in \;\; meter$$

Magnetic Maaterial As a Shield

Replacing a good conductor:

- Increasing in μ but a decrease in σ
- Enhance absorption Loss

Absorption Loss,

$$S_A = 20(\frac{t}{d})\log e, dB$$

$$= 8.69(t/d), dB$$

$$= 3.34t\sqrt{fms}, dB$$

Things to be noted:

- Frequency dependence of μ
- Field Strength dependence of μ

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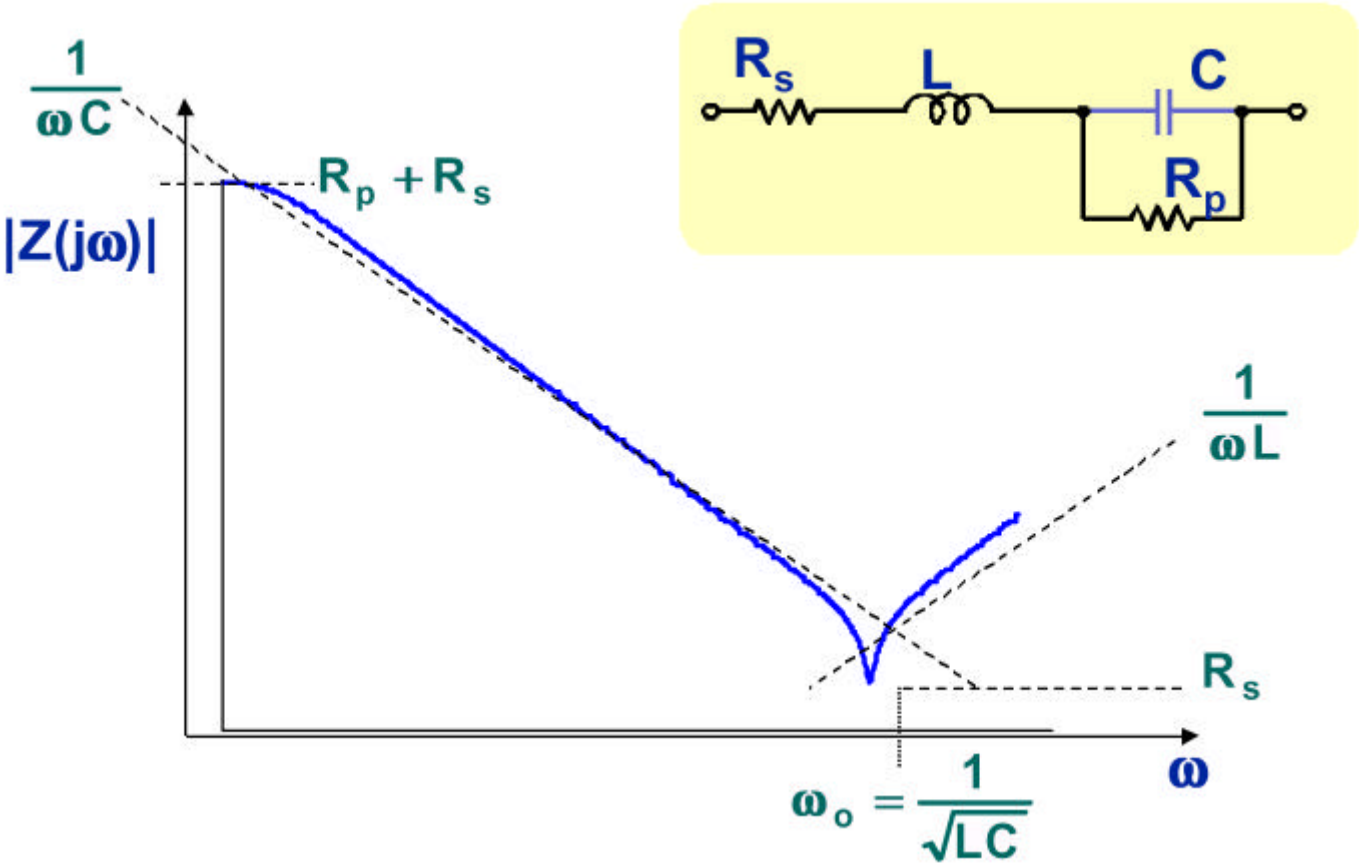
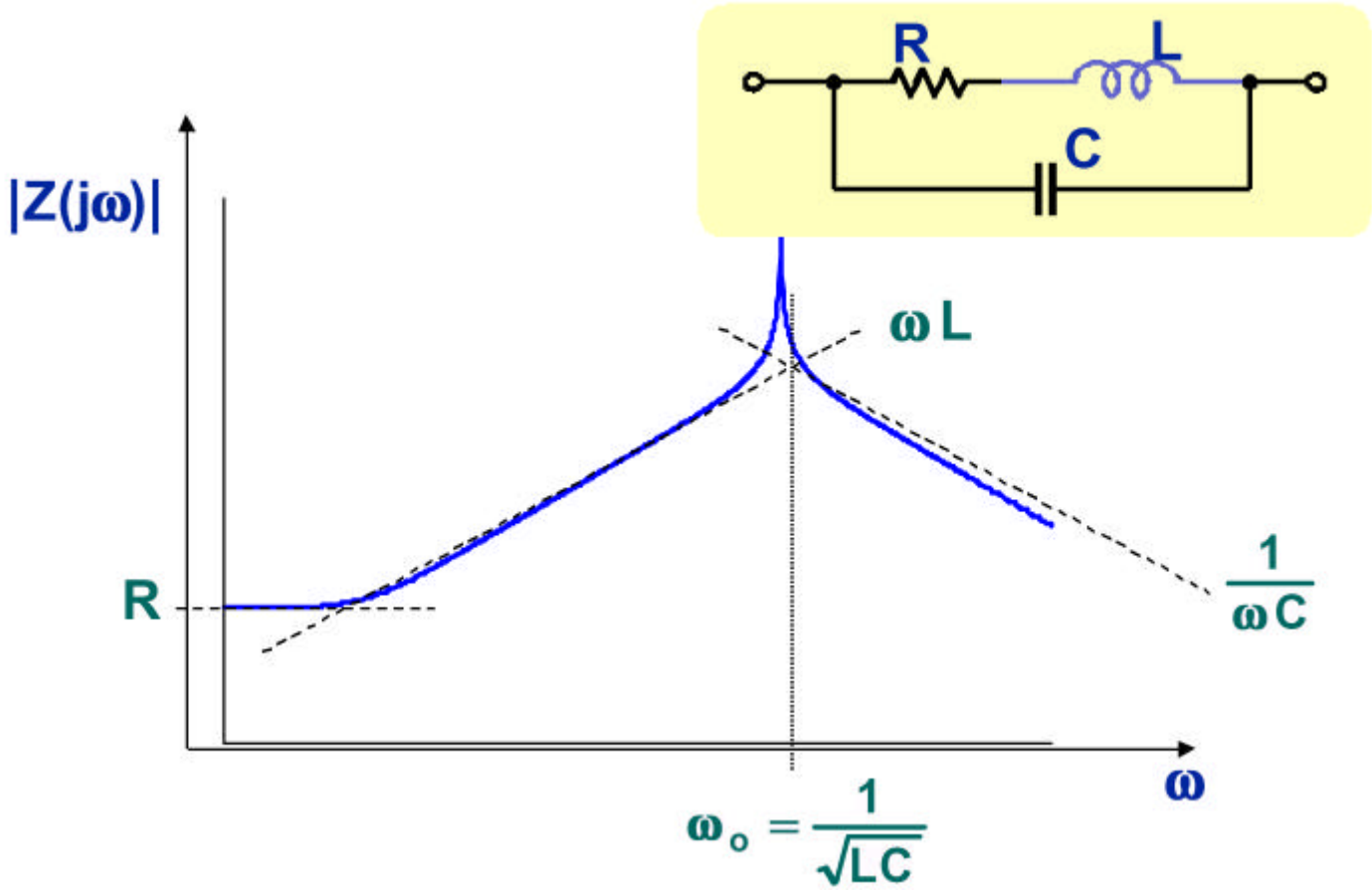
11. EMI Radiation

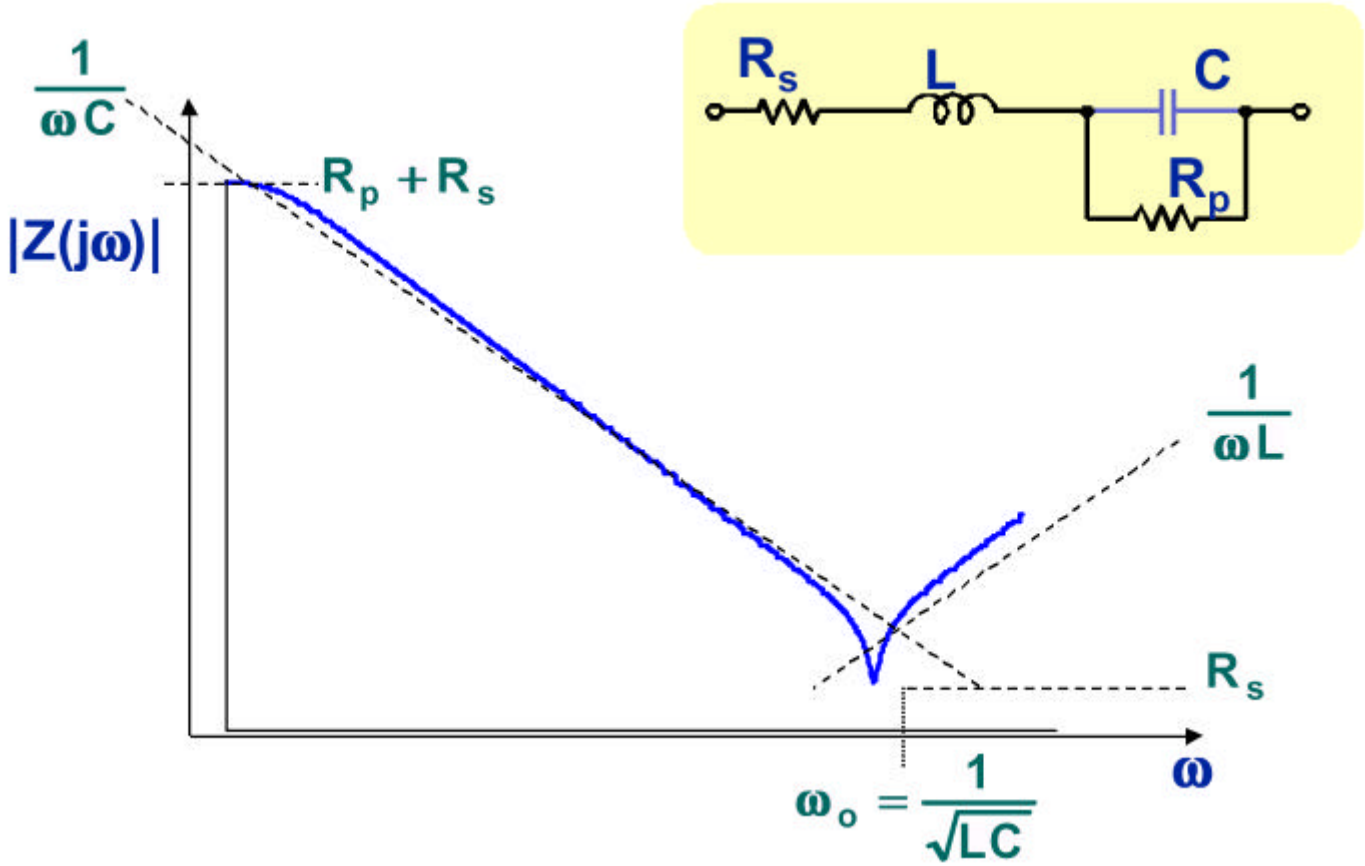
Equivalent CKT of Capacitor



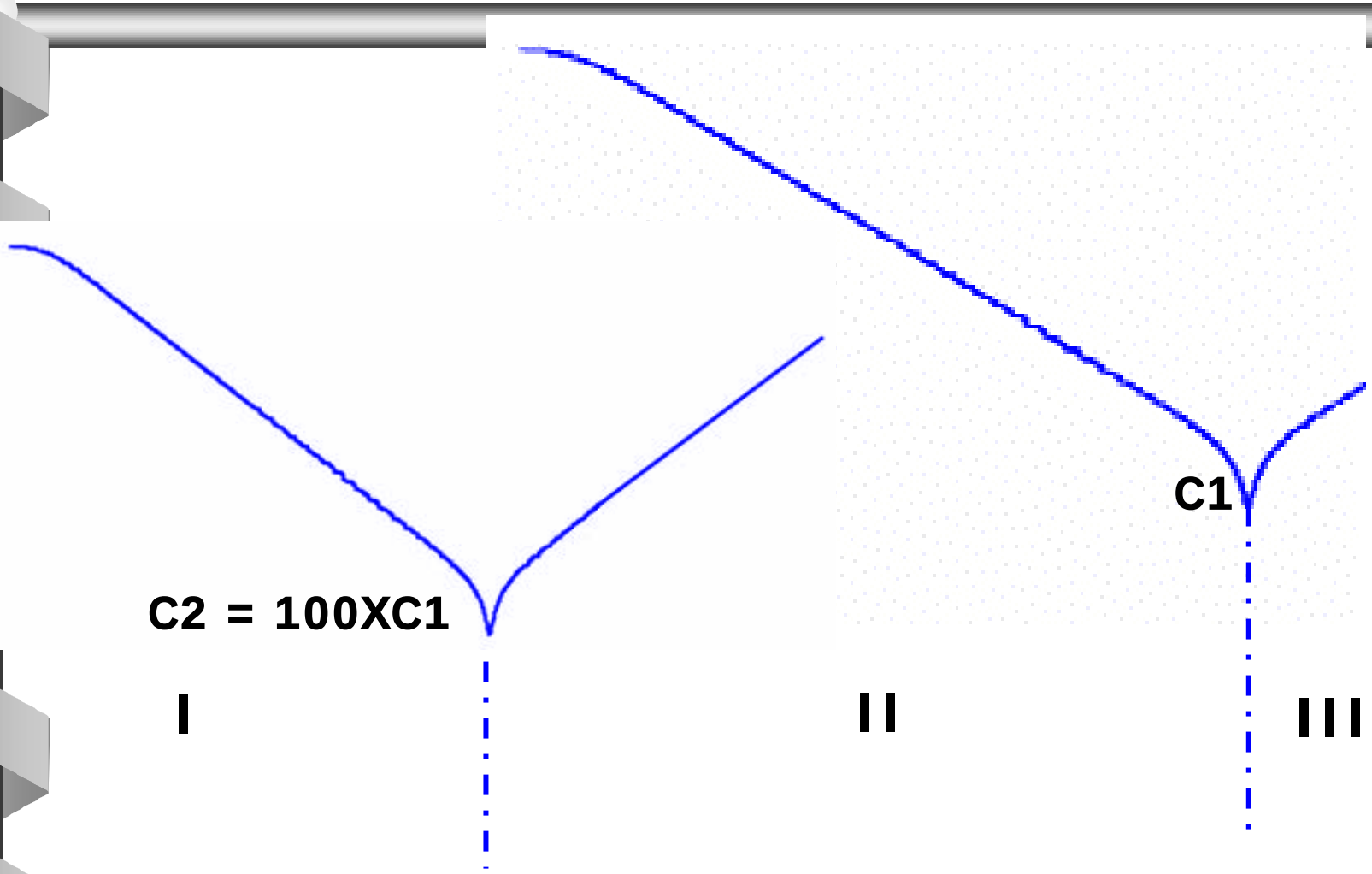
Equivalent CKT of Inductor



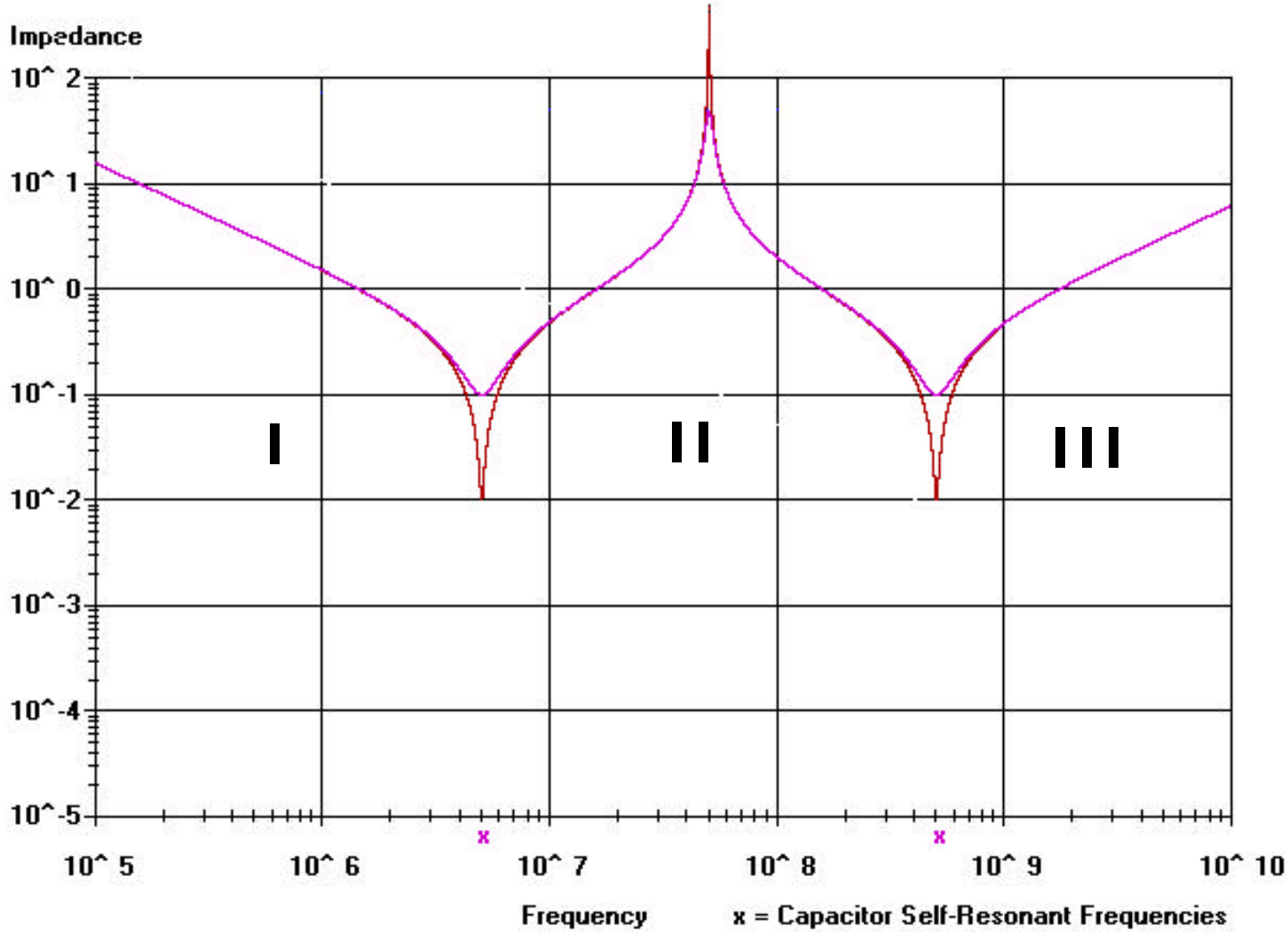
Equivalent CKT of Capacitor



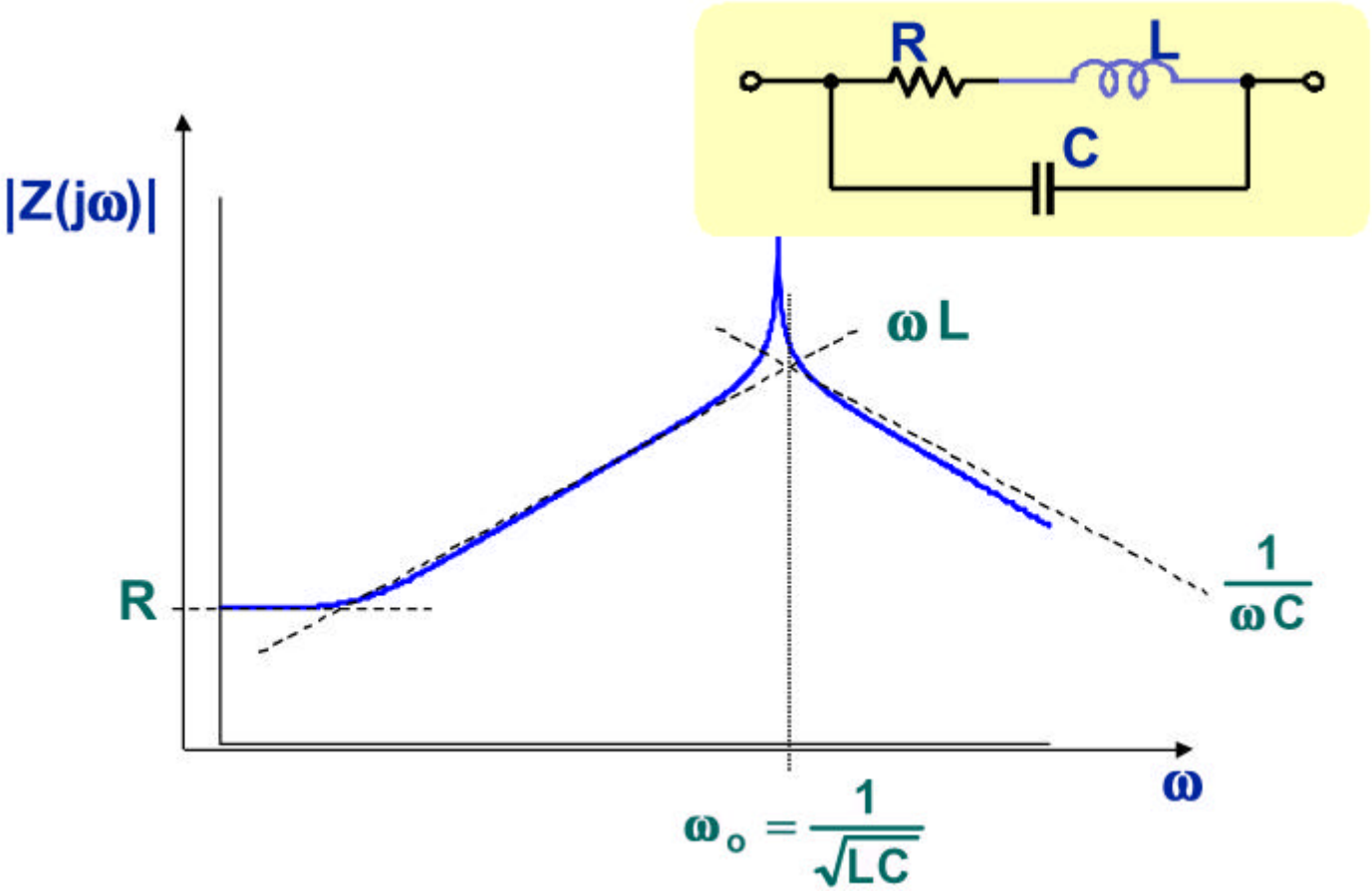
Decoupling in Parallel



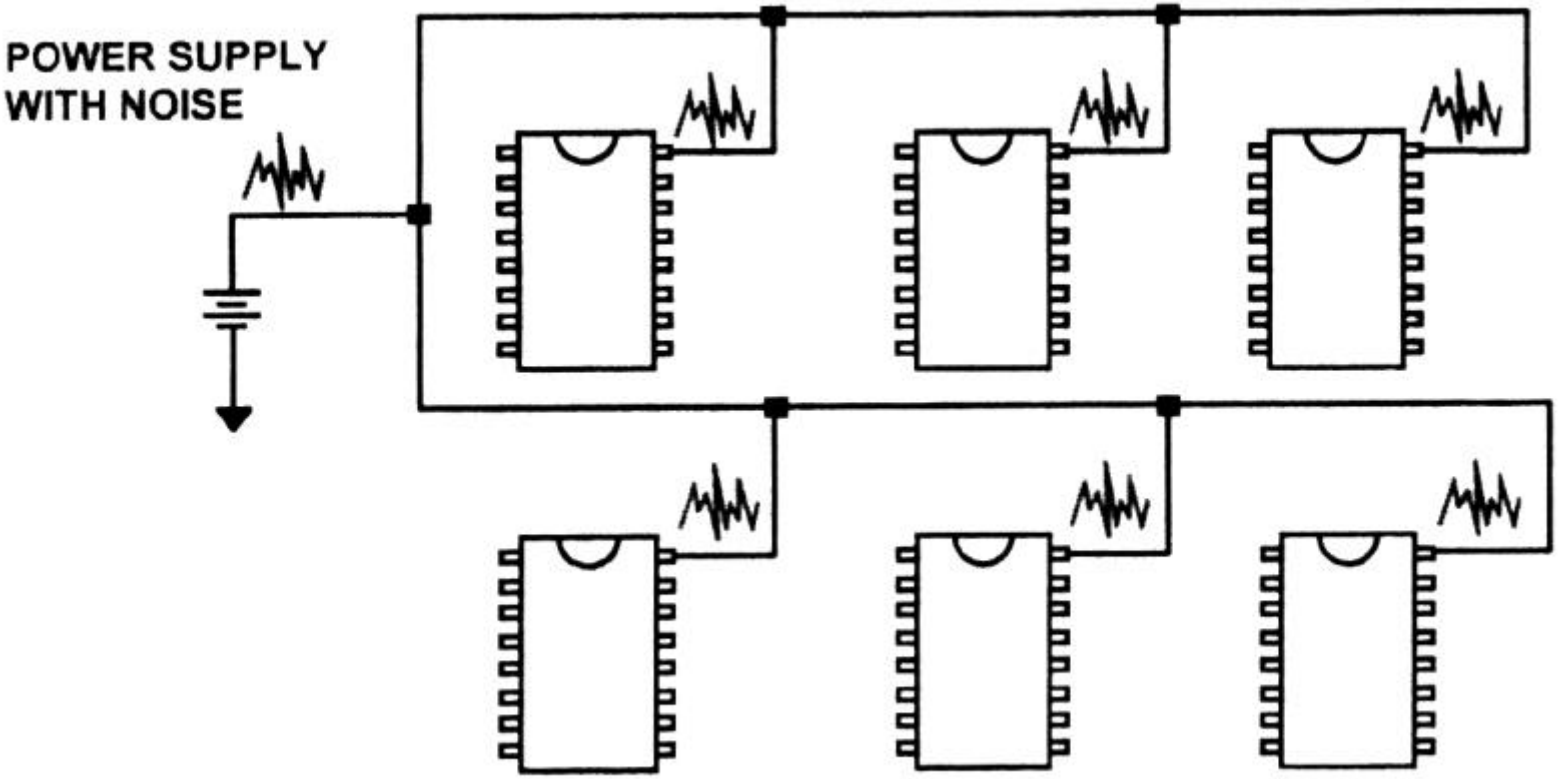
Decoupling in Parallel



Equivalent CKT of Inductor



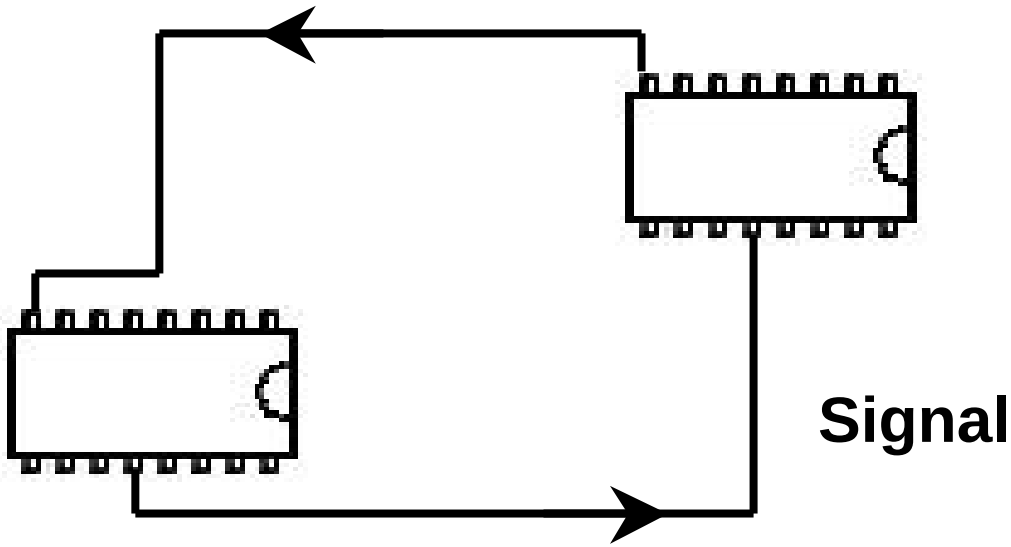
Conducted Noise via Vcc



Outline

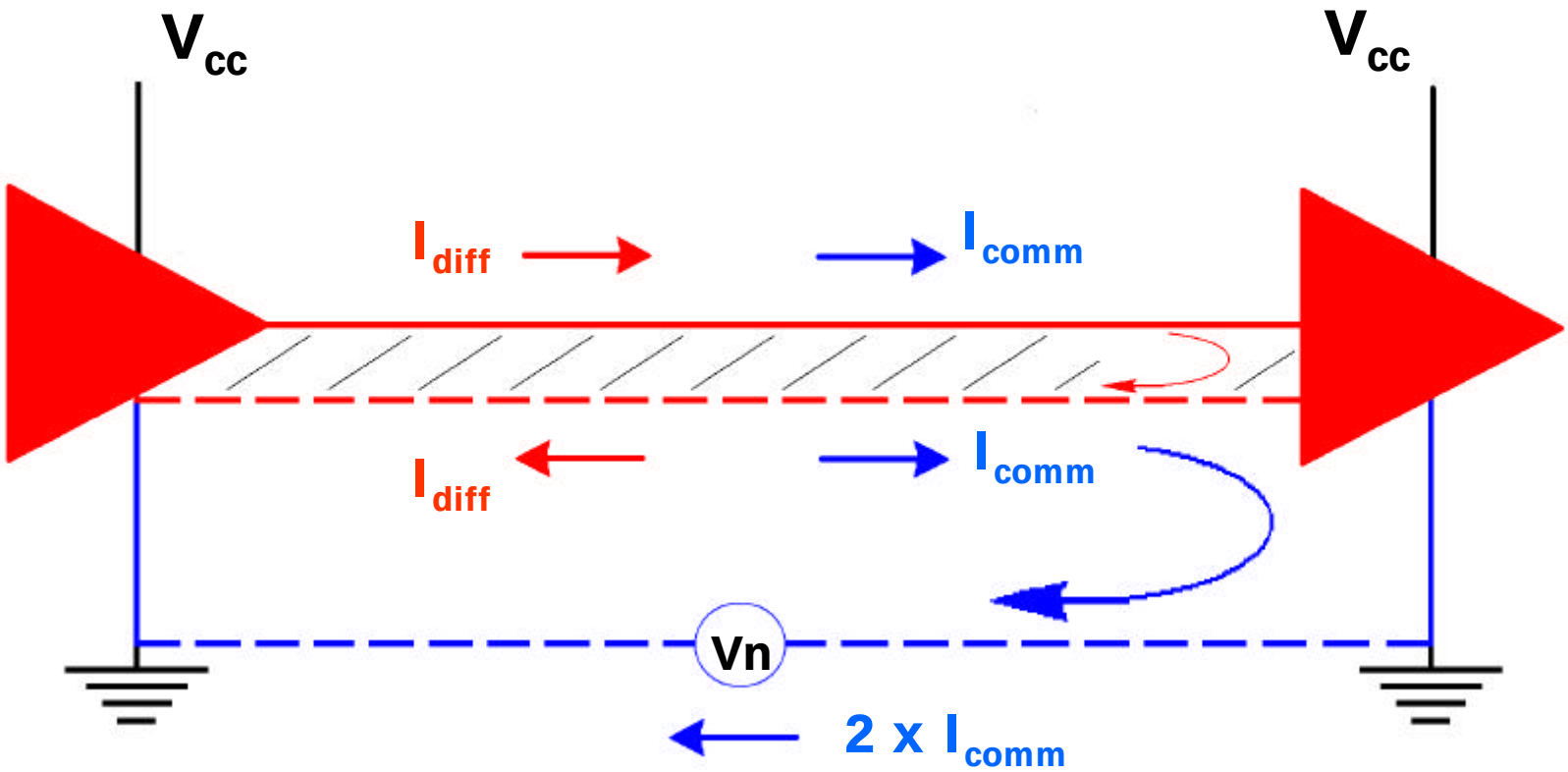
1. What is ElectroMagnetic Compatibility?
2. Causes of EMI and Signal Integrity
3. Grounding, Isolation and Separation
4. Power System
5. Impedance Control
6. Cabling & I/O Interconnect
7. Interference Couplings
8. Shielding Material (reflection)
9. Shielding Material (absorption)
10. Filtering (RLC Components) & Decoupling
11. **EMI Radiation**

Radiation → Differential Mode

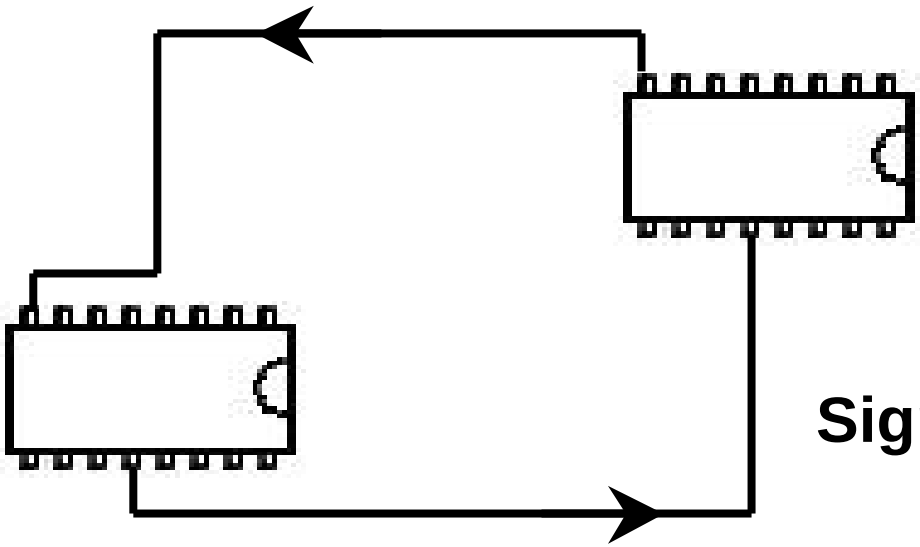


$$|E| = 1.32 \times 10^{-14} (f^2 AI) \left(\frac{1}{r}\right) \sin q \qquad \text{(V/m)}$$

Common & Differential Mode



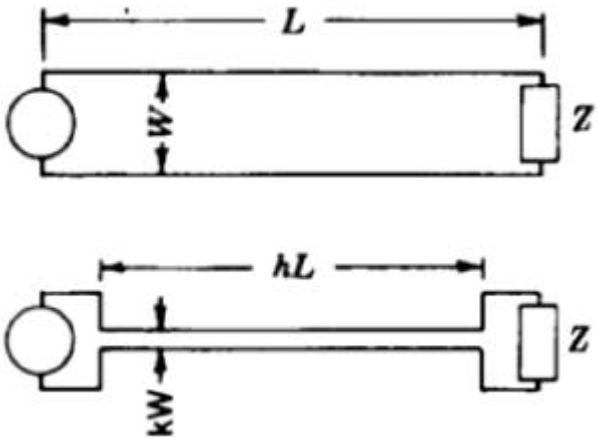
Radiation → Differential Mode

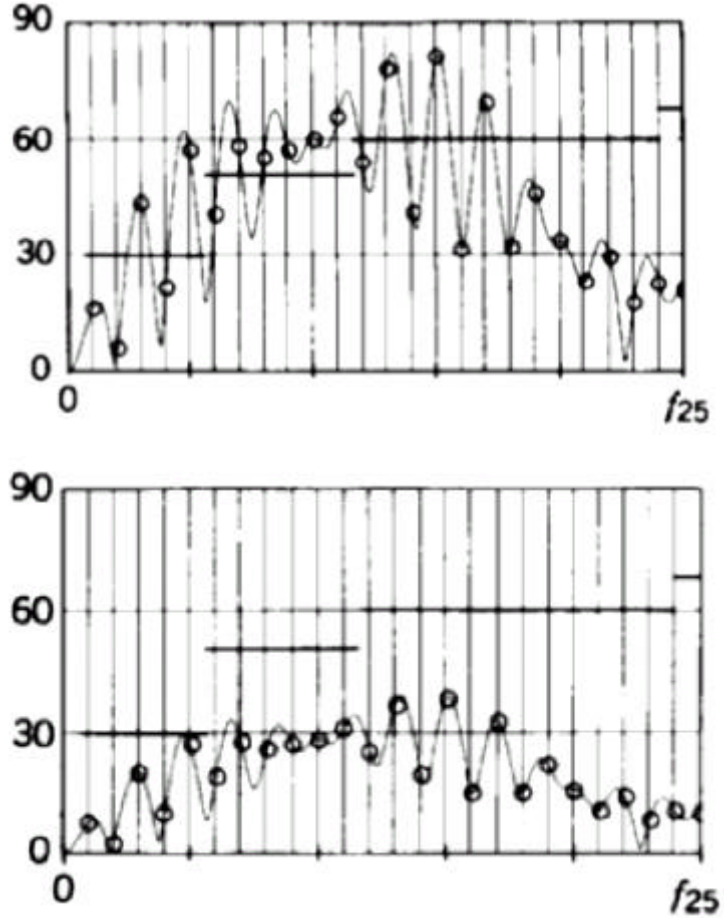


Signal

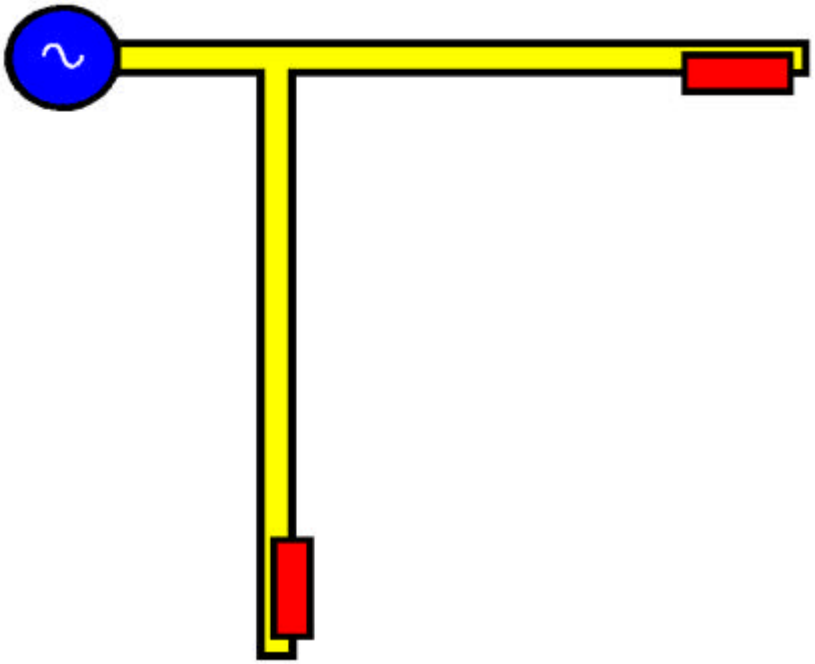
$$|E| = 1.32 \times 10^{-14} (f^2 AI) \left(\frac{1}{r}\right) \text{Sin}\, q \qquad \text{(V/m)}$$

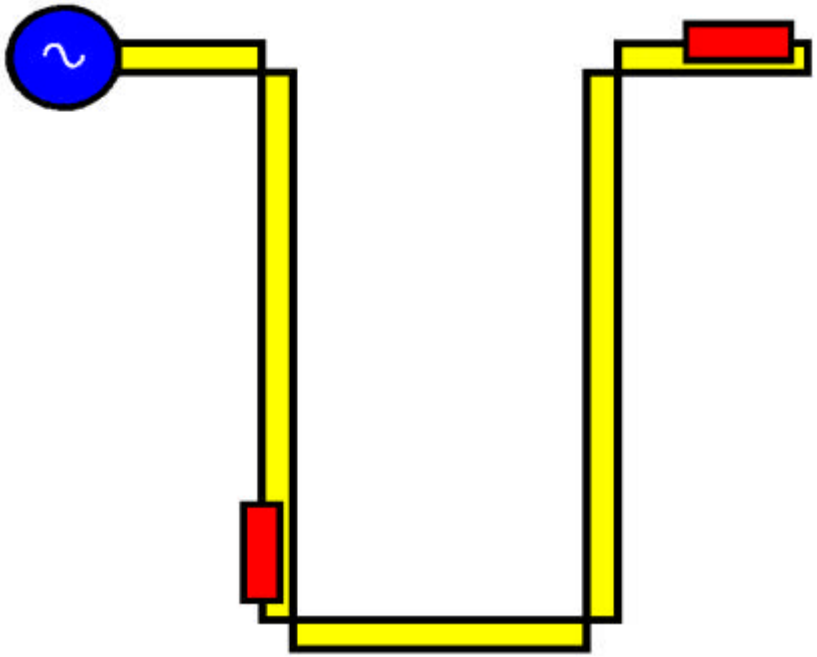
Effects of Loop Area



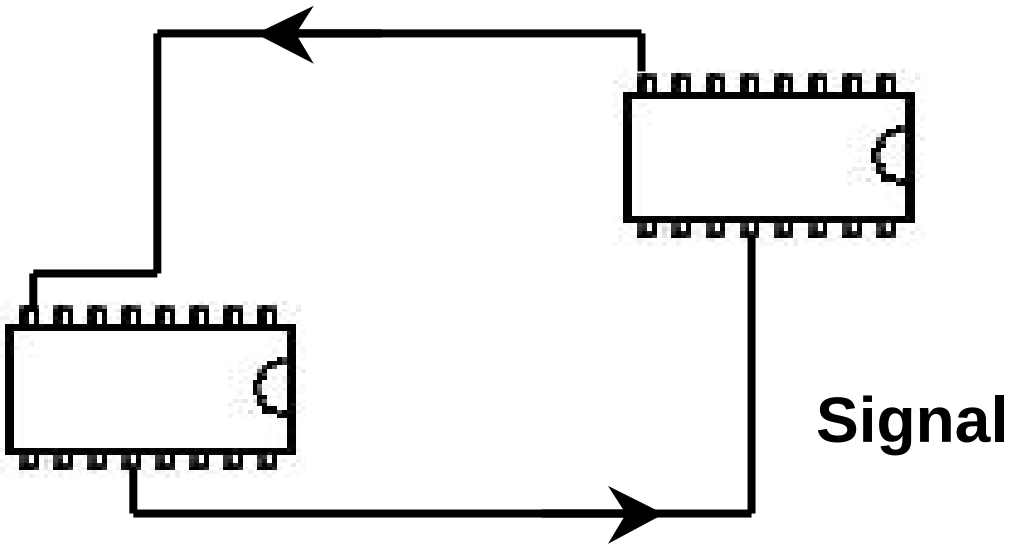


Concepts of Symmetry



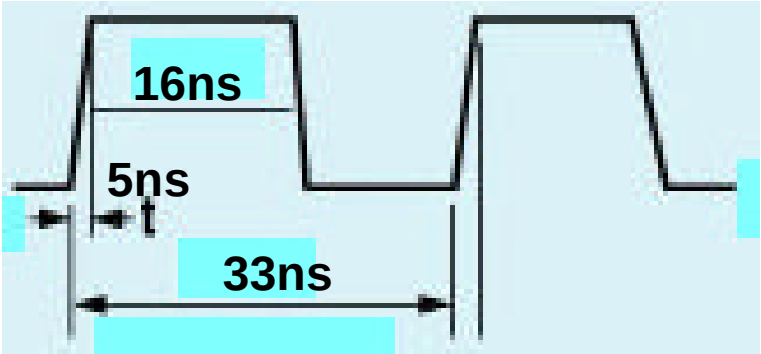


Radiation → Differential Mode

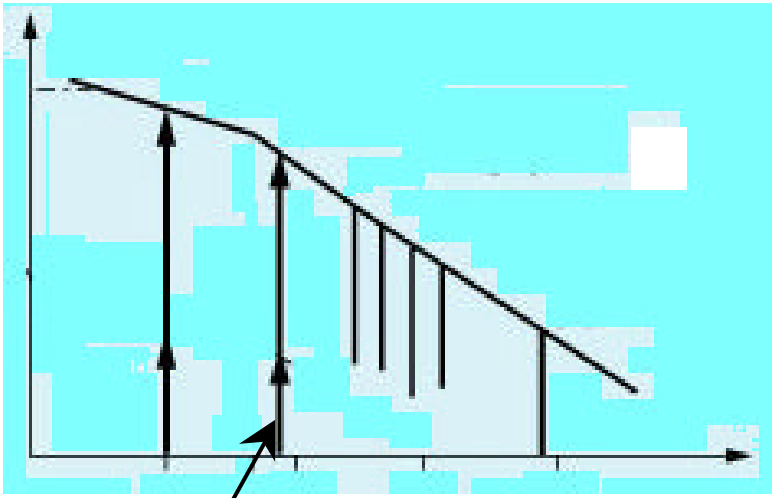


$$|E| = 1.32 \times 10^{-14} (f^2 AI) \left(\frac{1}{r}\right) \text{Sin}\, q \qquad \text{(V/m)}$$

Rise Time and Square Wave



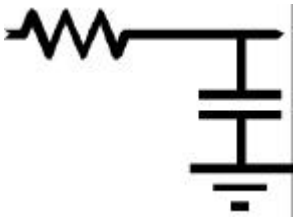
F_0=30MHz



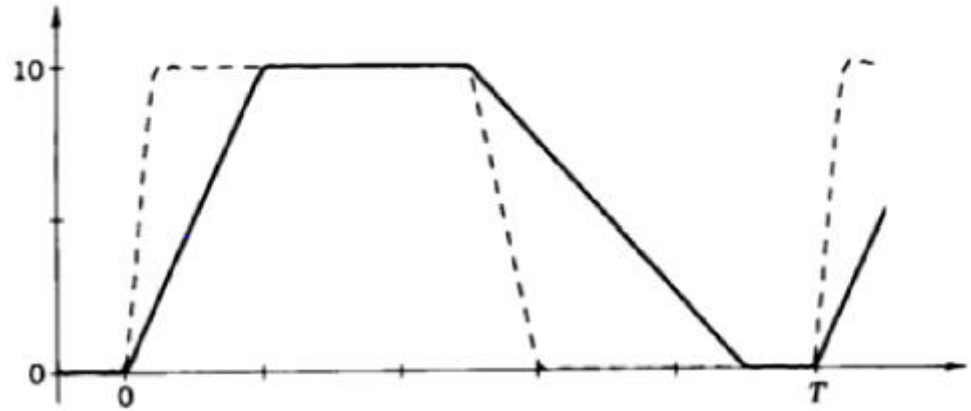
$$f = \frac{1}{p \times T} \approx 20\,\text{MHz}$$

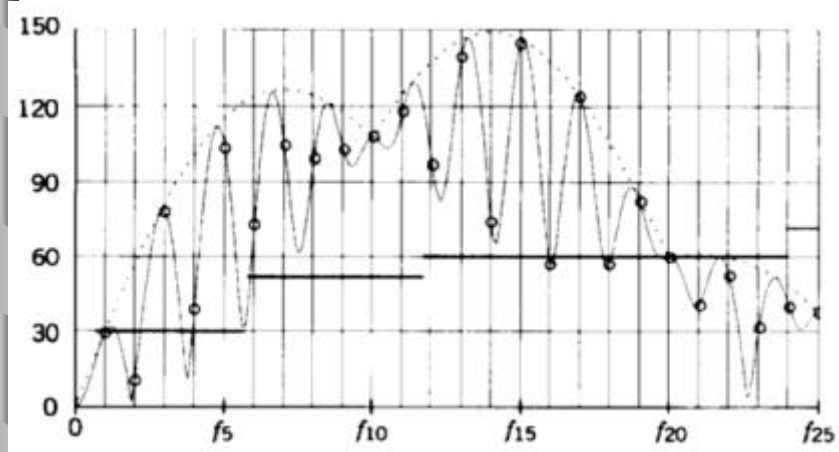
$$f = \frac{1}{p \times t_r} \approx 63\,\text{MHz}$$

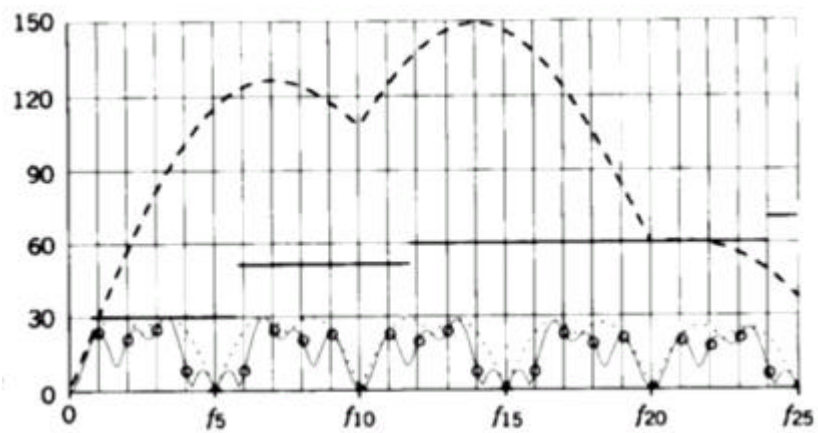
1st Significant Harmonic)



Effects of Rise Time



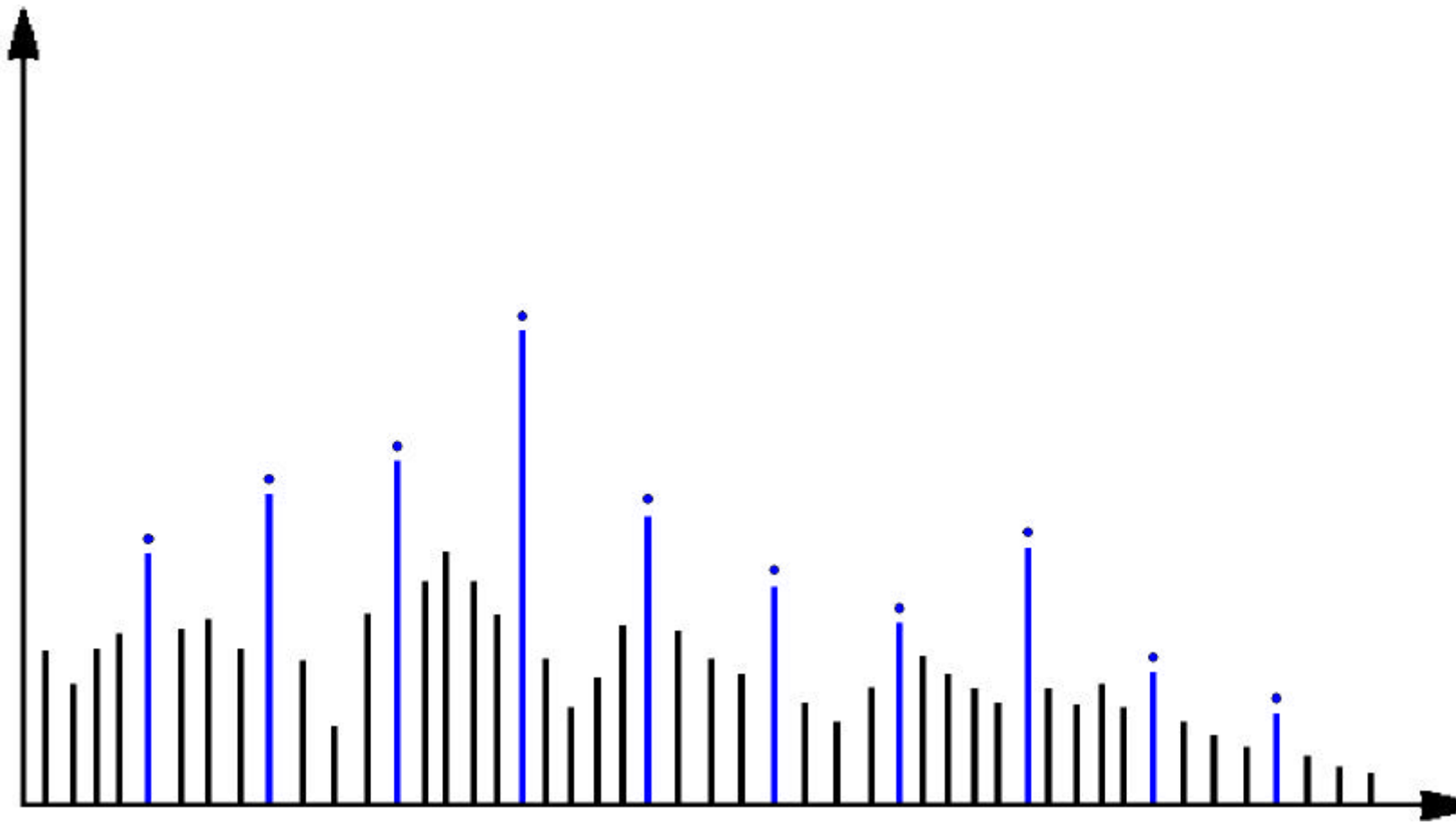




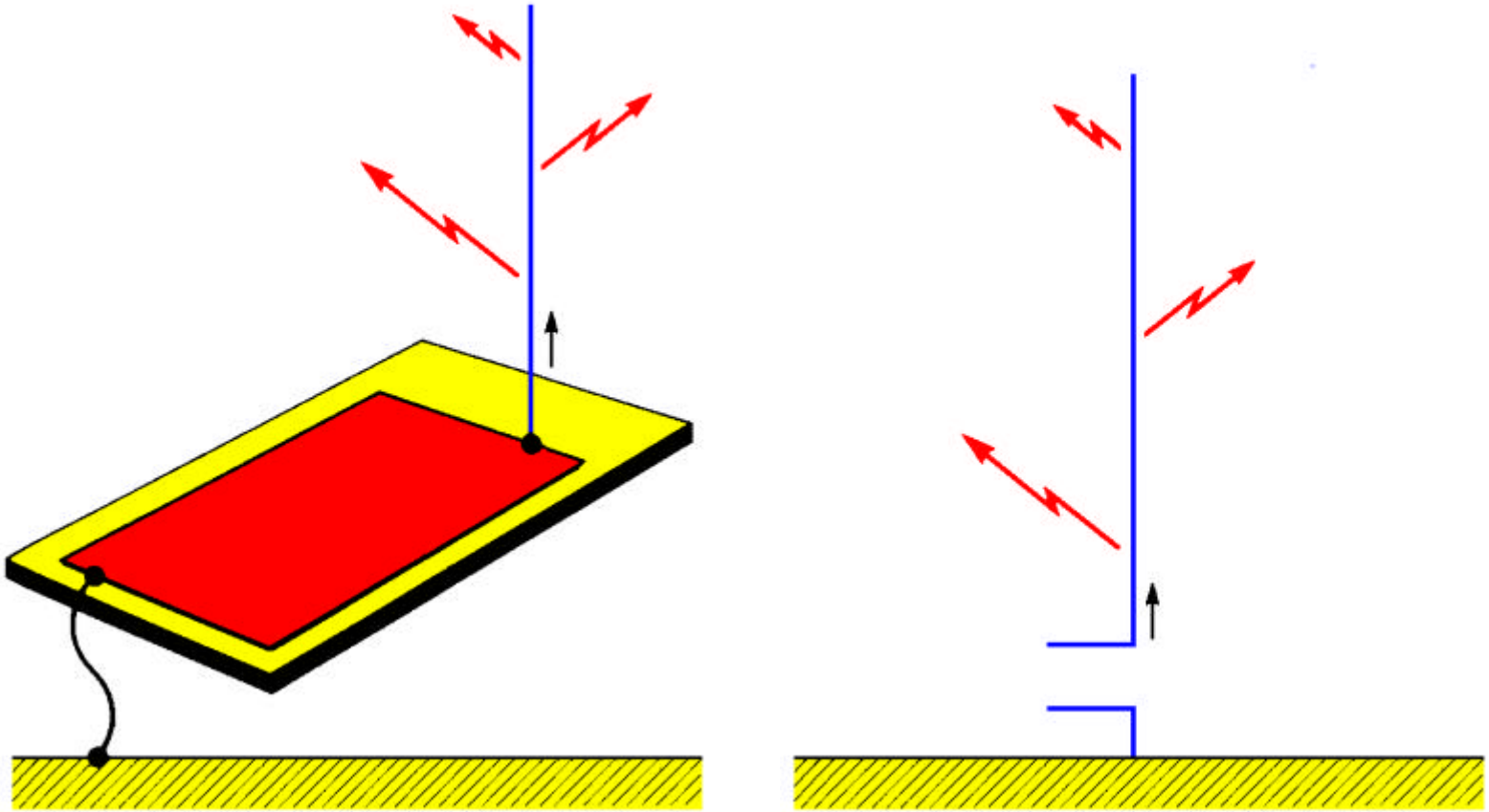
Characteristics of Logic Families

Logic Name	Voltage Swing (V)	I_{rise}/t_{fall} (ns)	Equivalent Bandwidth (MHz)	Input Capacitance (pF)	Output Resistance (L/H, Ohm)	Noise Margin (V)
CMOS, 3V	5	70/70	4.5	5	300/300	1.2
CMOS, 12V	12	25/35	12	5	300/300	3
TTL	3	10/8	40	5	30/150	0.4
TTL-LS	3	10/5	65	5.5	30/160	0.4
HCMOS	5	3.5/3.5	92	4	160/160	0.7
S-TTL	3	3/2.5	125	4	15/50	0.3
Fast & AS-TTL	3	3/2.5	125	4.5	15/40	0.3
ECL, 10k	0..8	2/2	160	3	7/7	0.1
GaAs	1	0.1	3200	1		0.1

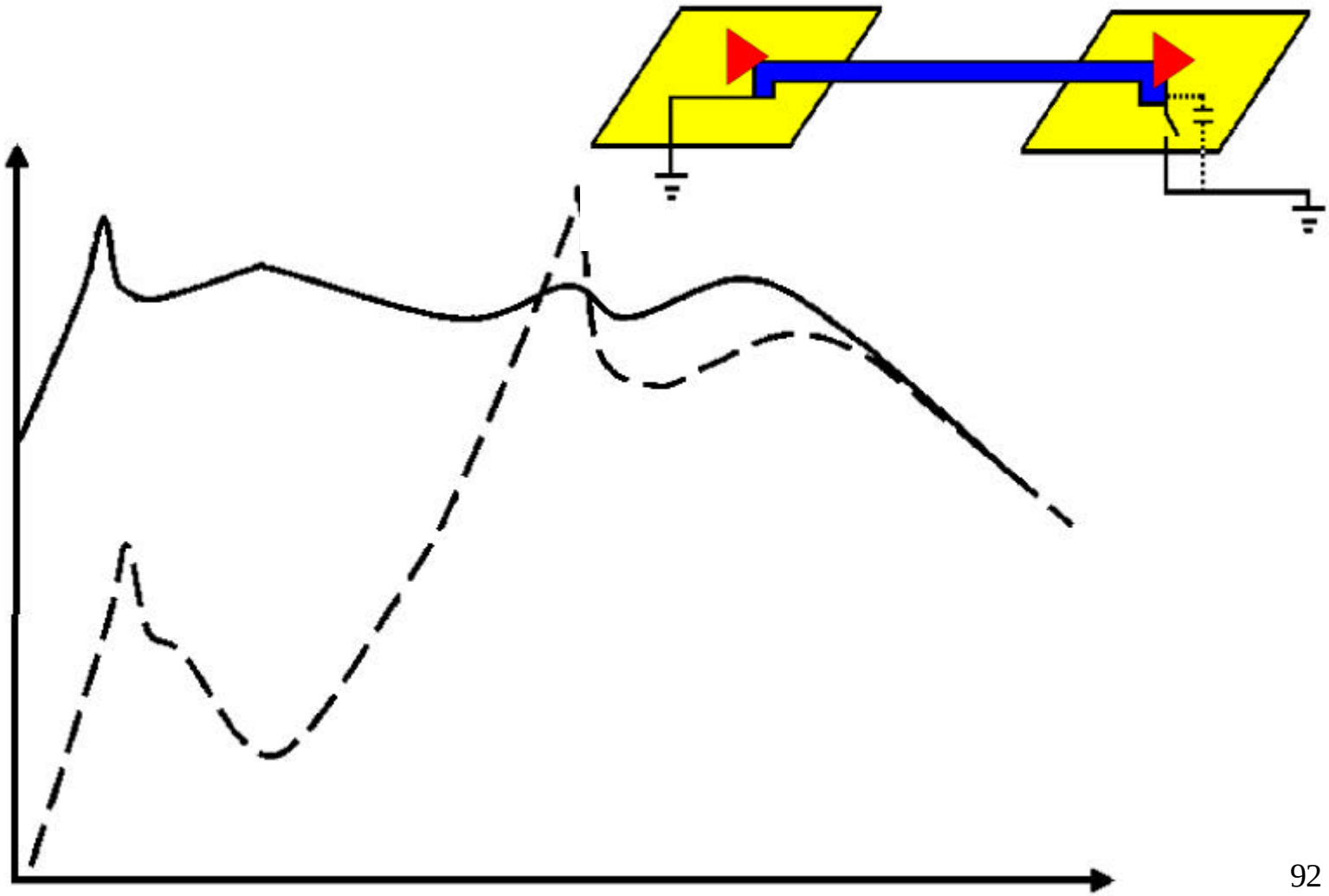
EMI Spectrum



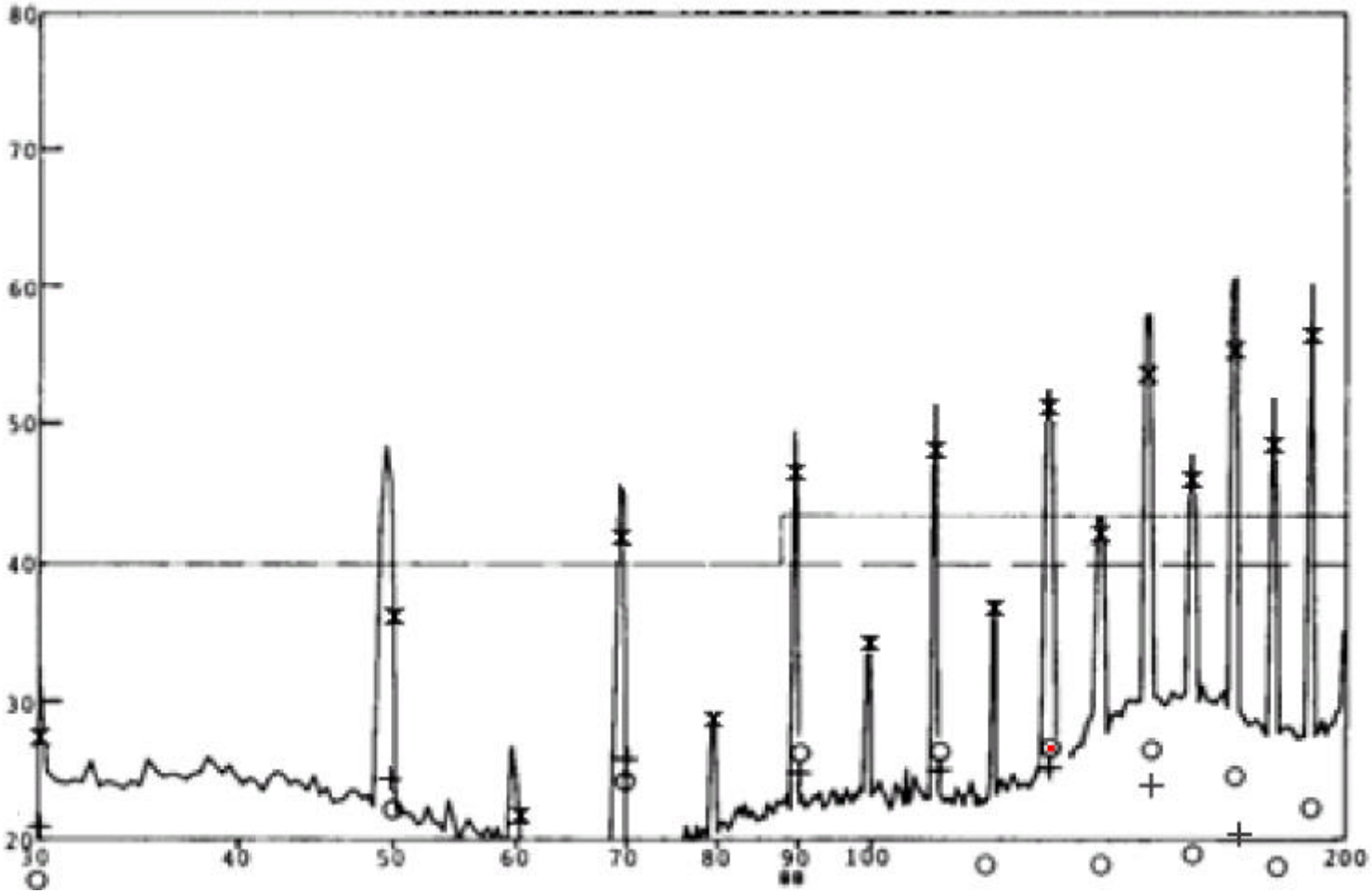
Radiation ➔ Common Mode



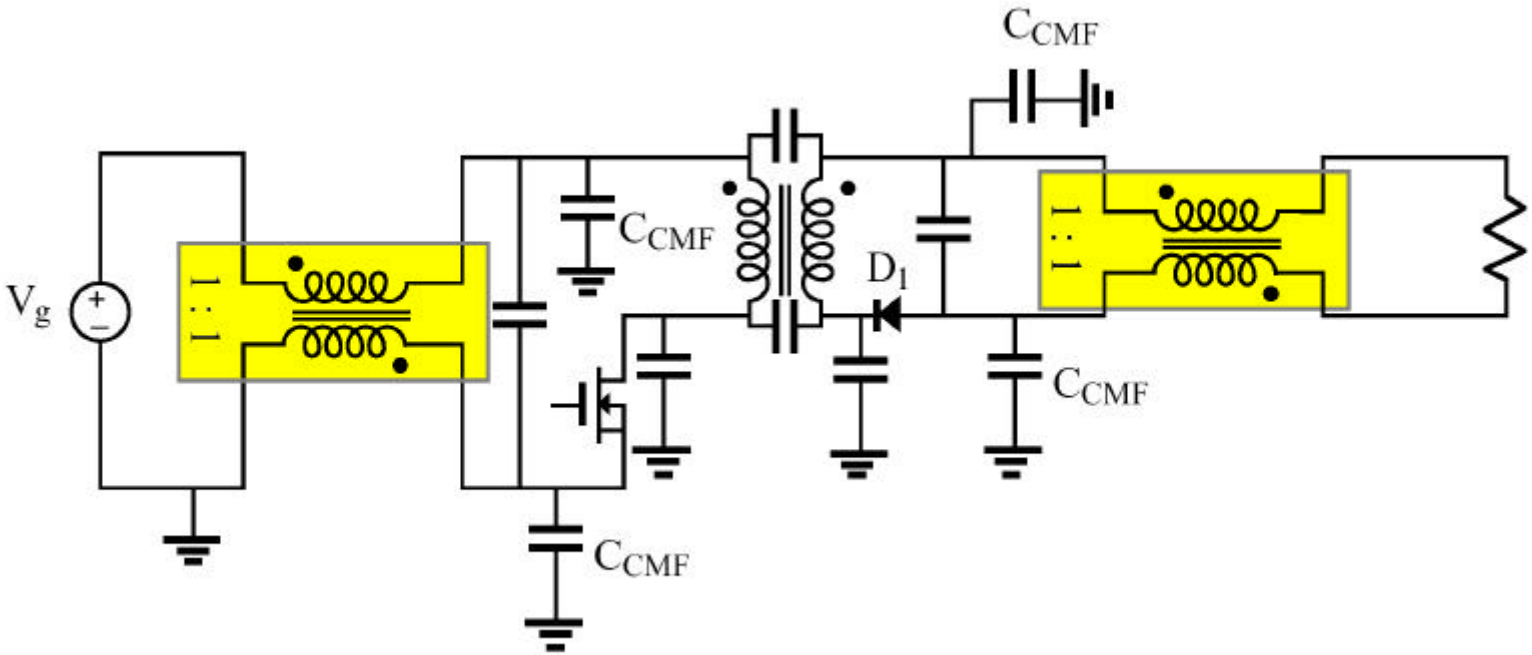
Effectiveness of Grounding



EMI Radiation

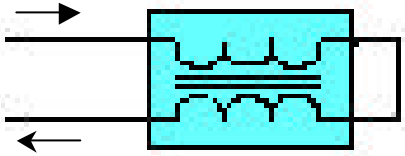


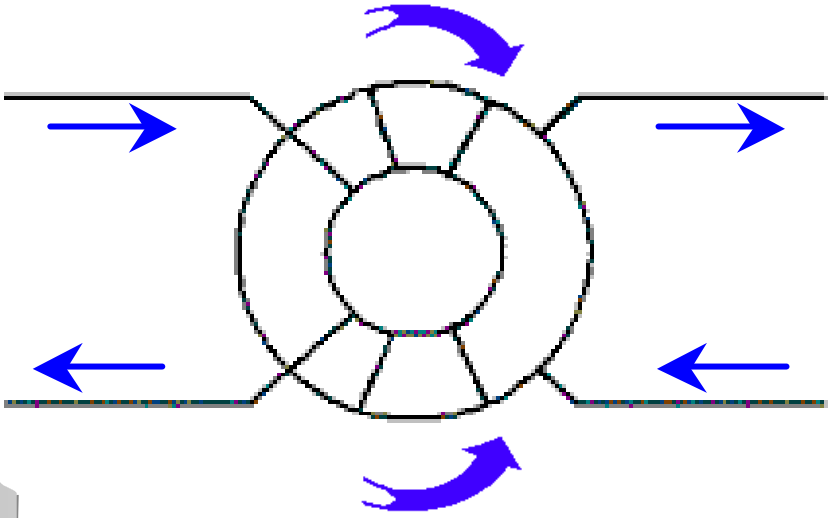
Common Choke Application

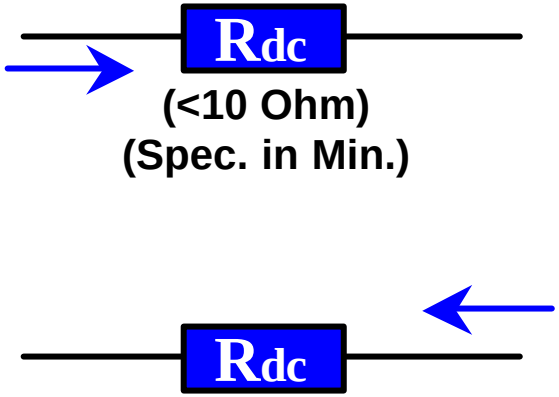


Application of Ferrite Core in PDP

Common Mode Filter

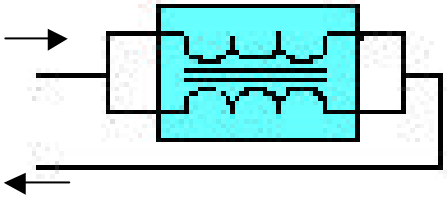


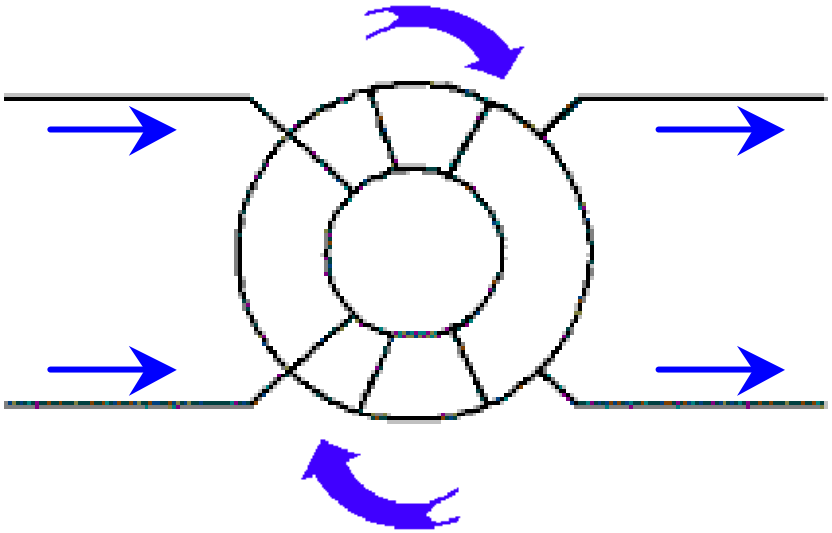


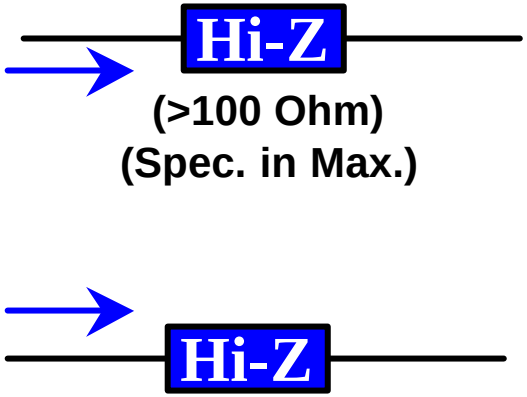


Normal mode mechanism

Common Mode Filter







Common mode mechanism