Chapter 6

Conducted Emissions and Susceptibility

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Outline

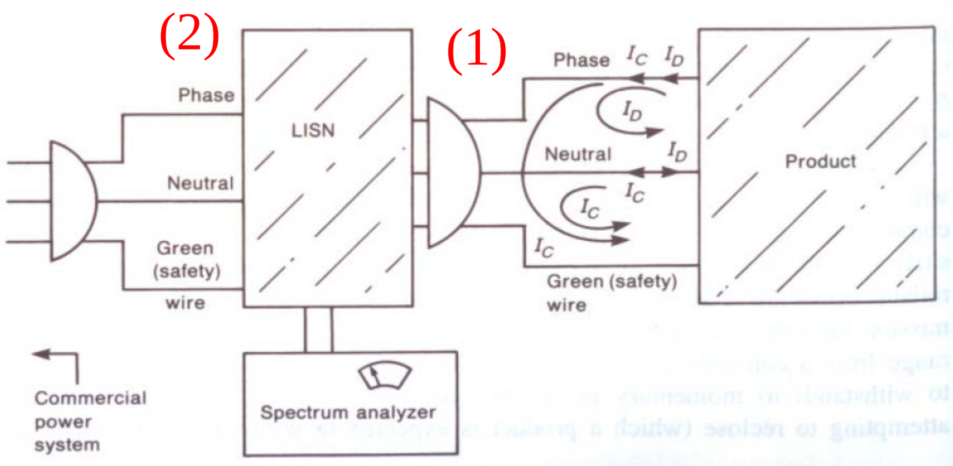
- Preview
- Measurement of Conducted Emissions
- Power Supply Filters
- Power Supplies
- Power Supply and Filter Placement
- Conducted Susceptibility

Preview

- Important Viewpoints
  - Ordinarily, the reduction of these conducted emissions is somewhat simpler than the reduction of radiated emissions.
  - If a product fails to comply with the limits on conducted emissions, compliance with the limits on radiated emissions is a moot point.
  - Disturbances such as those induced by lightning are of sufficient magnitude to cause interference by their direct conduction into a product via its ac power cord.

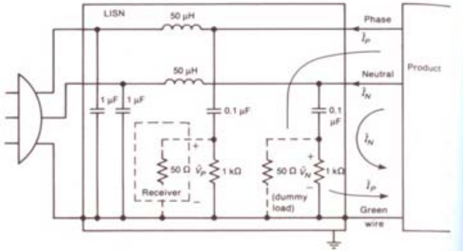
Measurement of Conducted Emissions

- The Line Impedance Stabilization Network (LISN)
  - Objective of the LISN
    - Present a constant impedance to the product's power cord outlet. (1)
    - Block conducted emissions that are not due to the produce being tested. (2)



Measurement of Conducted Emissions

- The Line Impedance Stabilization Network (LISN)



  - Objective of the LISN
    - Present a constant impedance (50Ω) between the phase conductor and the safety wire (the green wire) and between the neutral conductor and the safety wire.
    - Prevent external conducted noise on the power system net from contaminating the measurement.
    - Another subtle requirement for the LISN is that it be able to pass the 60Hz (50Hz) power required for operation of the product.

Measurement of Conducted Emissions

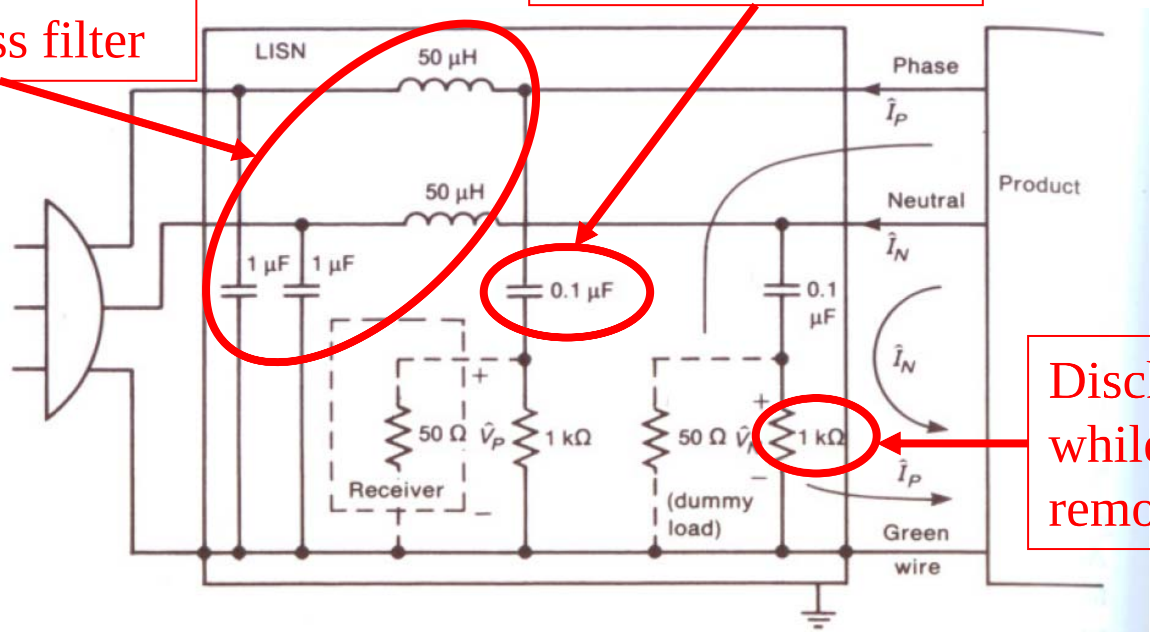
- The Line Impedance Stabilization Network (LISN)
  - Function of the LISN

Element	$Z_{150\,\text{kHz}}$	$Z_{30\,\text{MHz}}$
50 µH	47.1 Ω	9424.8 Ω
0.1 µF	10.61 Ω	0.053 Ω
1 µF	1.06 Ω	0.0053 Ω

    - The capacitors are low impedances and the inductor presents a large impedance over the measurement frequency range.

Absorption of DC

Lowpass filter



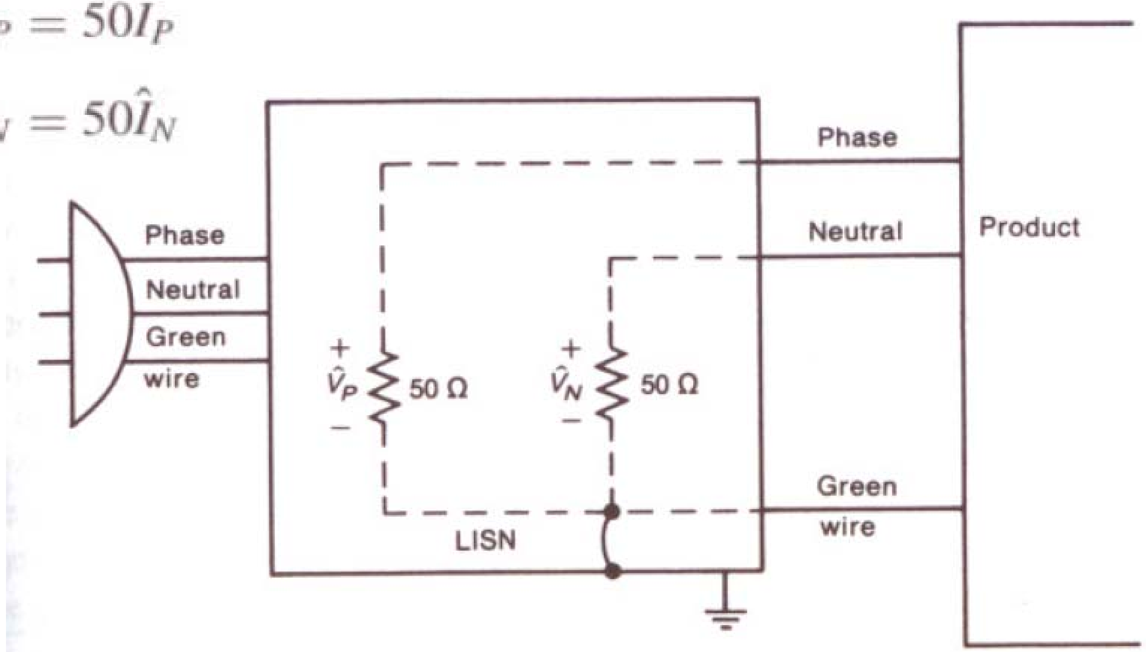
Discharging C while 50 Ω is removed.

Measurement of Conducted Emissions

- The Line Impedance Stabilization Network (LISN)
  - Simplified LISN during Operation
    - The voltages could be written as

$$\hat{V}_P = 50\hat{I}_P$$

$$\hat{V}_N = 50\hat{I}_N$$



Measurement of Conducted Emissions

- Common- and Differential-Mode Currents
  - Decomposition into Common- and Diff.-Modes
    - The currents on the phase and neutral conductors could be written as the combination of common- and differential- mode currents

$$\hat{I}_P = \hat{I}_C + \hat{I}_D \qquad \hat{I}_D = \tfrac{1}{2}(\hat{I}_P - \hat{I}_N) \qquad \hat{V}_P = 50(\hat{I}_C + \hat{I}_D)$$

$$\hat{I}_N = \hat{I}_C - \hat{I}_D \qquad \hat{I}_C = \tfrac{1}{2}(\hat{I}_P + \hat{I}_N) \qquad \hat{V}_N = 50(\hat{I}_C - \hat{I}_D)$$

    - Usually, one current dominates, we have

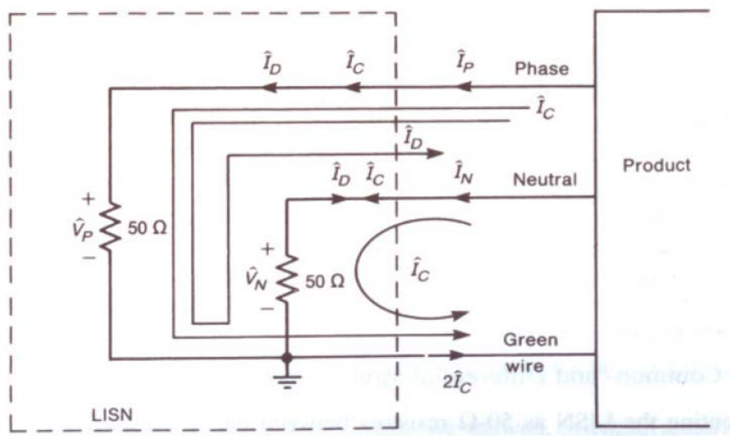
$$\hat{V}_P = 50\hat{I}_C, \quad \hat{I}_C \gg \hat{I}_D$$

$$\hat{V}_N = 50\hat{I}_C, \quad \hat{I}_C \gg \hat{I}_D$$

    - or

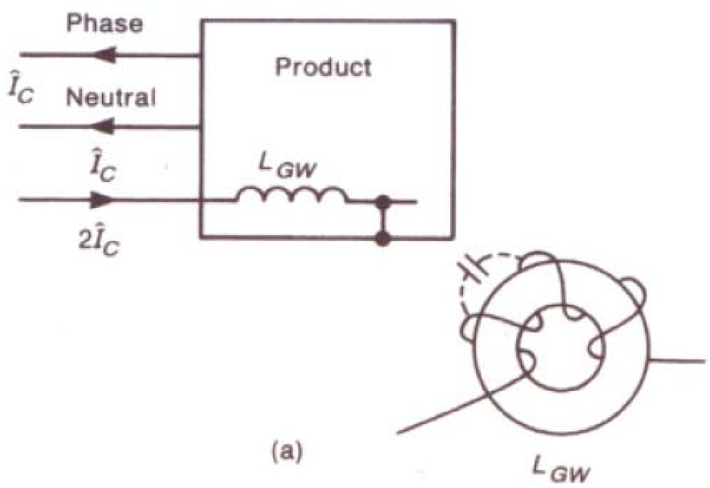
$$\hat{V}_P = 50\hat{I}_D, \quad \hat{I}_D \gg \hat{I}_C$$

$$\hat{V}_N = -50\hat{I}_D, \quad \hat{I}_D \gg \hat{I}_C$$



Measurement of Conducted Emissions

- Common- and Differential-Mode Currents
  - Reduction of Common-Mode Currents
    - An inductor is placed in the green wire to reduce the common-mode contribution to conducted emissions.
    - Parasitic capacitances between the windings of the toroid will typically cause its performance to deteriorate at the higher frequencies.

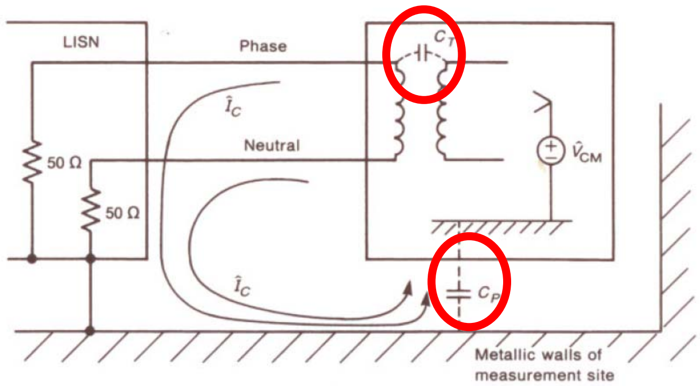


Measurement of Conducted Emissions

- Common- and Differential-Mode Currents
  - Reduction of Common-Mode Currents
    - The power cord of the product is reduced from three wires to two wires.
    - The elimination of the green wire in this type of product is frequently thought to eliminate common-mode currents.

Using a transformer results in two advantages:

1. Chassis could be connected to 2ndary side of the transformer, not directly to the neutral wire.
2. Don't mind which one is phase or neutral wire.



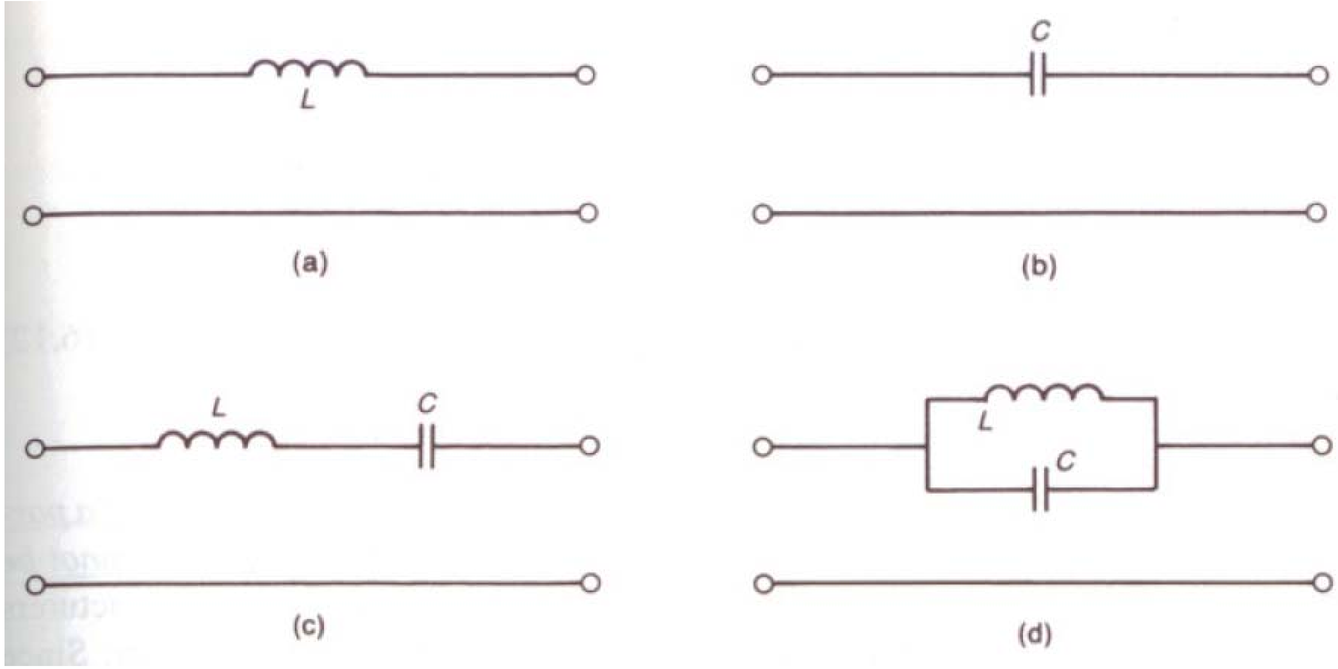
Common-mode currents still pass through these capacitors.

Power Supply Filters

- Introduction
  - Importance of Power Supply Filters
    - No electronic products today that can comply with the conducted emission regulatory requirements without the use of some form of power supply filter being inserted where the power cord exits the product.
    - Properly designed transformers can provide inherent filtering, and so can, in some cases, obviate the need for an "intentional filter".

Power Supply Filters

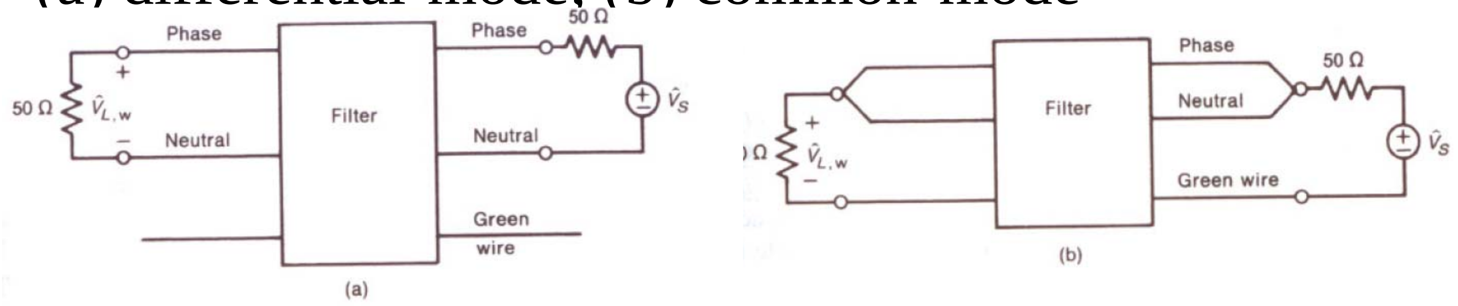
- Basic Properties of Filters
  - Different Types of Filters
    - (a) lowpass; (b) highpass; (c) bandpass; (d) bandreject.



(a) (b) (c) (d)

Power Supply Filters

- Basic Properties of Filters
  - Insertion Loss
    - The insertion loss of a particular filter depends on the source and load impedances.
    - The insertion loss data of the filters obtained from the manufacture are based on 50 Ω, which should be modified according to the practical source and load impedances.
  - Insertion Loss Test- Diff.- and Common-Modes
    - (a) differential-mode; (b) common-mode

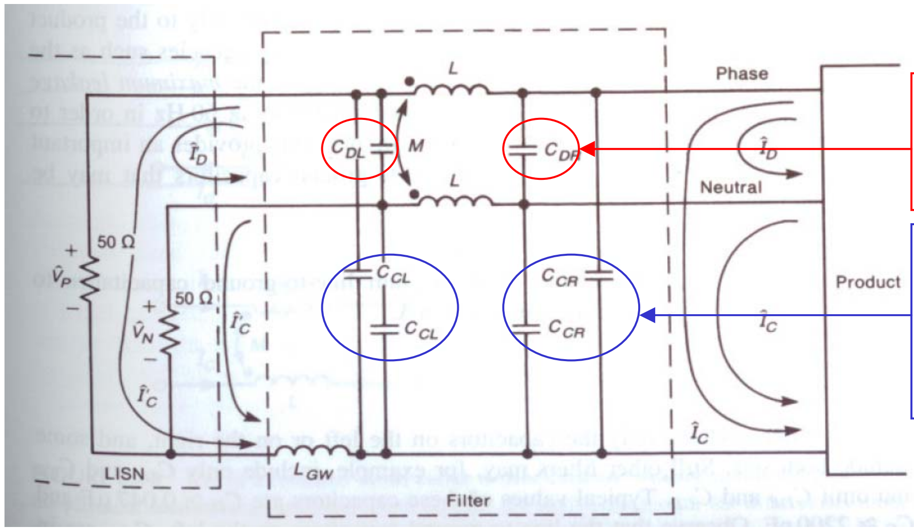


Power Supply Filters

- A Generic Power Supply Filter Topology
  - Basic Form
    - The object of the filter is to reduce the unprimed current levels to the primed levels such the primed currents give measured voltages

$$\hat{V}_P = 50(\hat{I}'_C + \hat{I}'_D) \qquad \hat{V}_N = 50(\hat{I}'_C - \hat{I}'_D)$$

    - which are below the conducted emission limit.



Divert differential-mode currents

Divert differential- and common-mode currents

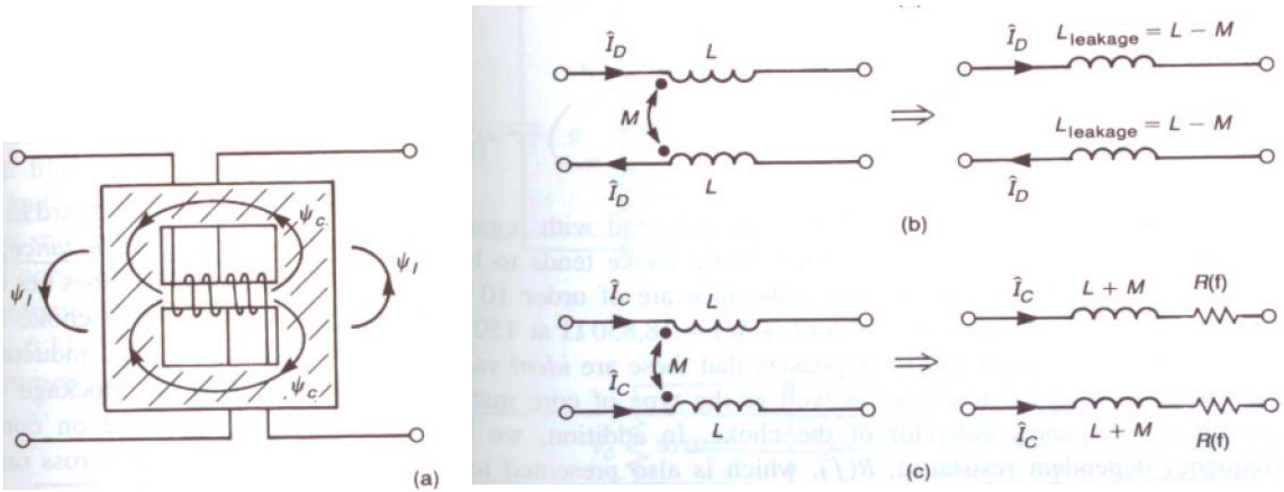
Power Supply Filters

- Effect of Filter Elements on Common- and Differential-Mode Currents
  - Common-Mode Choke
    - For differential-mode voltage on one wire, we have

$$\hat{V} = j\omega L\hat{I}_D - j\omega M\hat{I}_l = j\omega(L-M)\hat{I}_D$$

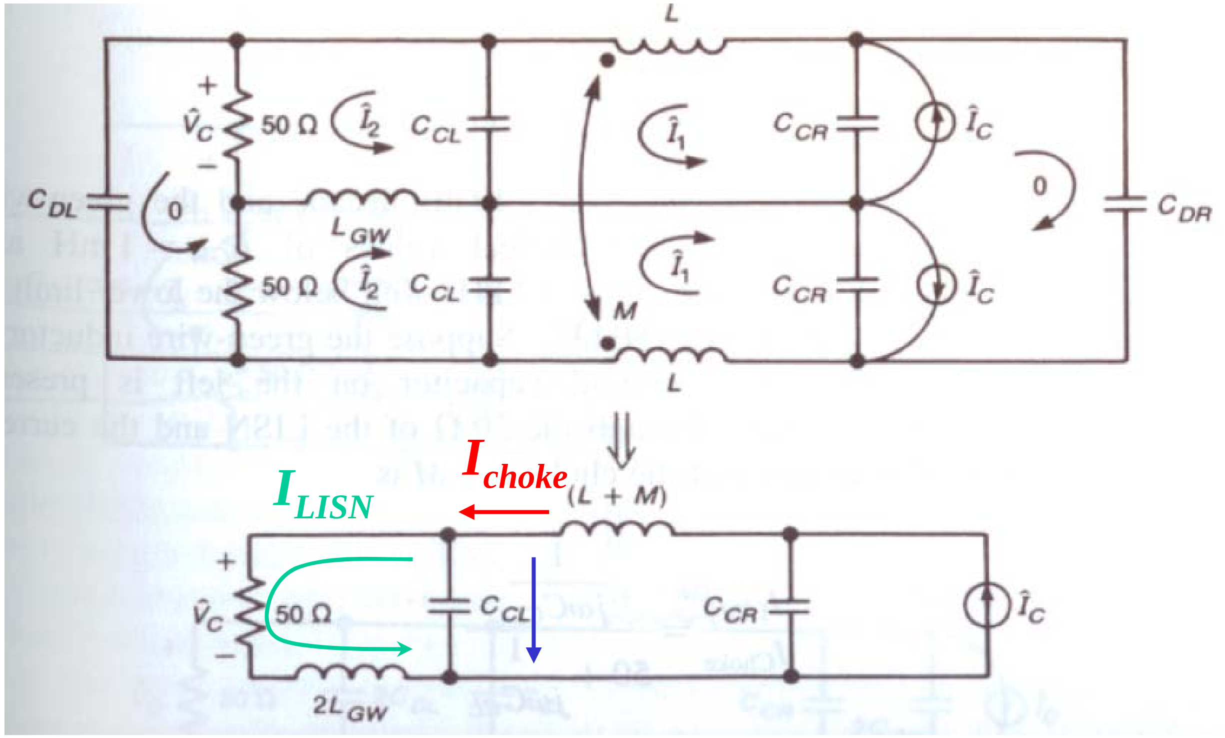
    - For common-mode voltage on one wire, we have

$$\hat{V} = j\omega L\hat{I}_C + j\omega M\hat{I}_C = j\omega(L+M)\hat{I}_C$$



Power Supply Filters

- Effect of Filter Elements on Common- and Differential-Mode Currents
  - Common-Mode Equivalent Circuit
    - Due to symmetry, the equivalent circuit is shown below



Power Supply Filters

- Effect of Filter Elements on Common- and Differential-Mode Currents
  - Effect of Green-Wire Inductor
    - In order for the green-wire inductor to have any effect, the line-to-ground capacitors on the left must be present, $C_{CL} \neq 0$.
    - The current ratio is

Lowpass response with -40dB/decade

$$\frac{I_{\text{LISN}}}{I_{\text{Choke}}} = \frac{\frac{1}{j\omega C_{CL}}}{50 + j\omega 2L_{GW} + \frac{1}{j\omega C_{CL}}} = \frac{1}{1 - \omega^2 2L_{GW}C_{CL} + j\omega 50 C_{CL}}$$

    - The break frequency is

$$f_0 = \frac{1}{2\pi\sqrt{2L_{GW}C_{CL}}}$$

For typical values of L_{GW} = 1mH and C_{CL} = 3300 pF, this break frequency is f_0 = 62 kHz well below the lower limit of the conducted emission regulation of 150 kHz.

Power Supply Filters

- Effect of Filter Elements on Common- and Differential-Mode Currents
  - Effect of Green-Wire Inductor
    - Suppose the green-wire inductor is absent, L_{GW}=0, but the line-to-ground capacitor on the left is present, $C_{CL} \neq 0$.
    - The current ratio is

Lowpass response with -20dB/decade

$$\frac{I_{\text{LISN}}}{I_{\text{Choke}}} = \frac{\frac{1}{j\omega C_{CL}}}{50 + \frac{1}{j\omega C_{CL}}} = \frac{1}{1 + j\omega 50 C_{CL}}$$

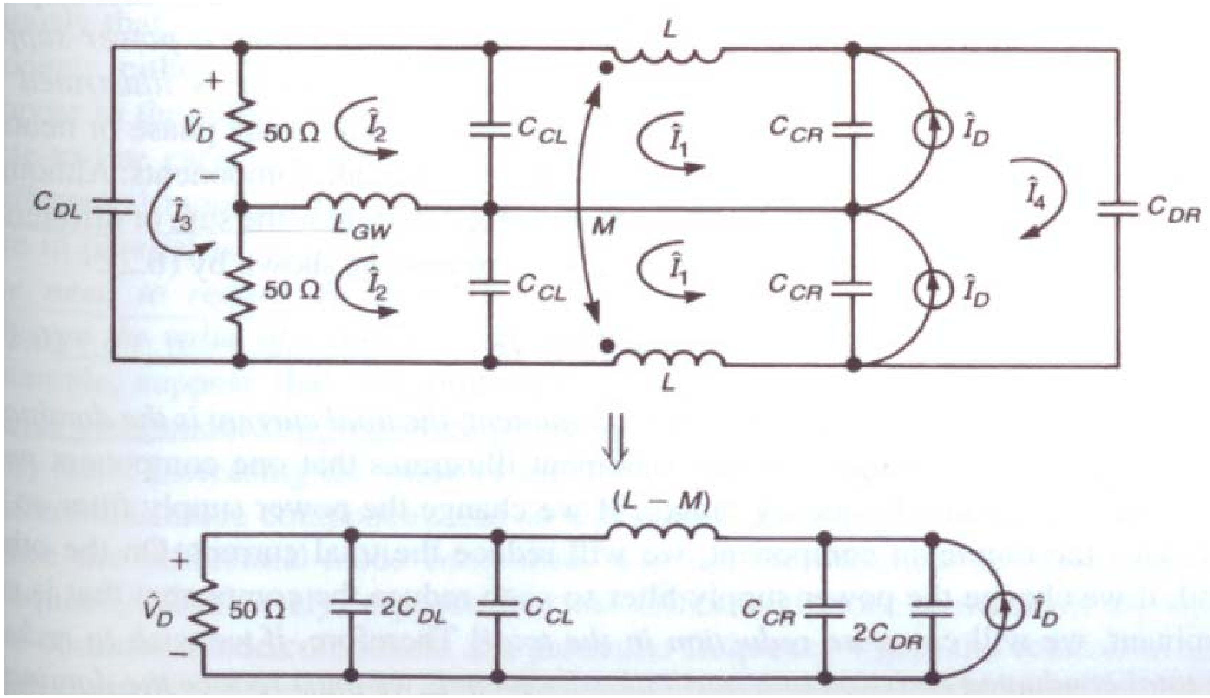
    - The break frequency is

$$f_1 = \frac{1}{2\pi 50 C_{CL}}$$

For typical value of C_{CL} = 3300 pF, this break frequency is f_1 = 965 kHz or just below 1MHz, which is far above the lower limit of the conducted emission regulation of 150 kHz.

Power Supply Filters

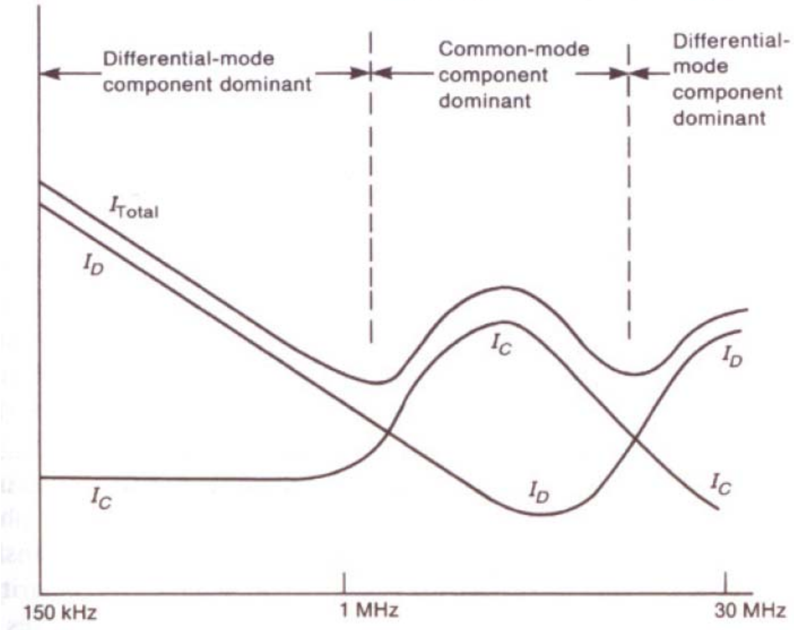
- Effect of Filter Elements on Common- and Differential-Mode Currents
  - Differential-Mode Equivalent Circuit
    - Due to symmetry, the differential-mode equivalent circuit is shown below.



Power Supply Filters

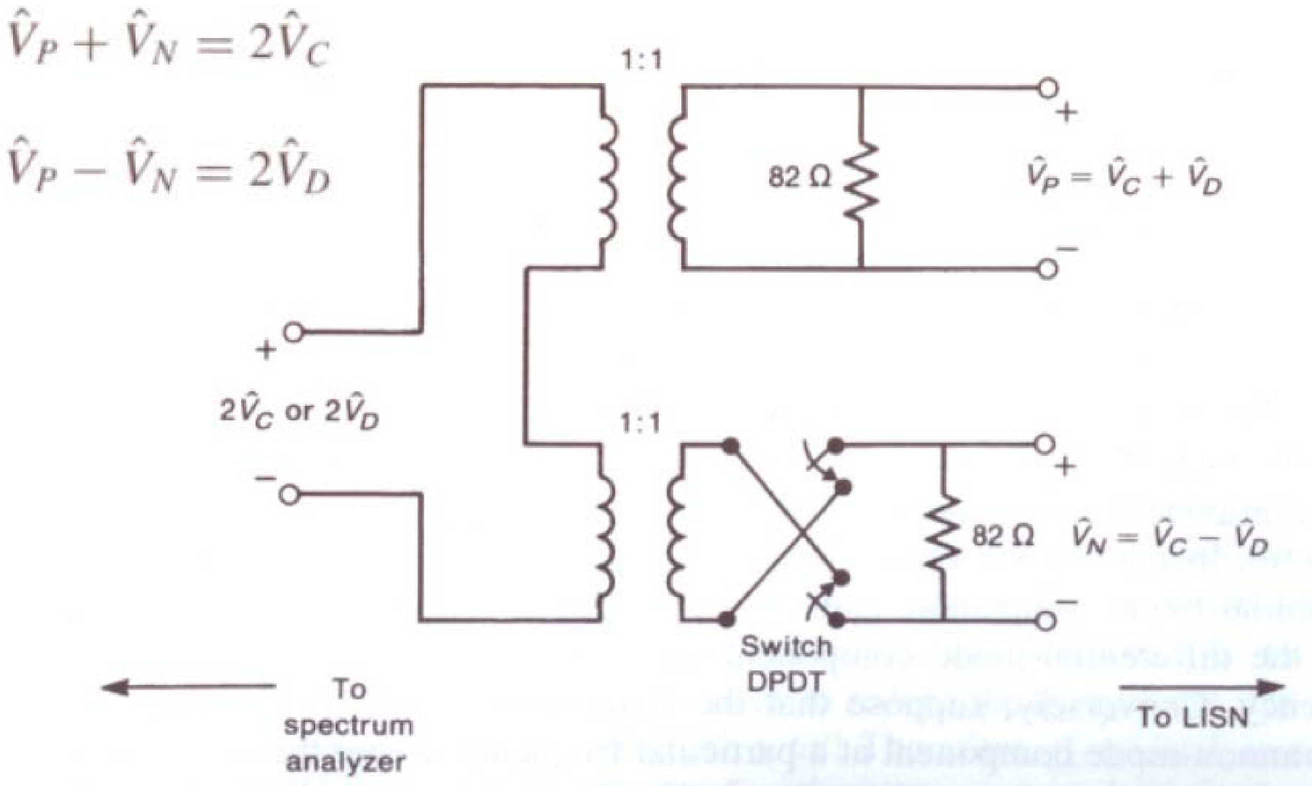
- Separation of Common- and Differential-Mode Currents
  - For Diagnostic Purposes
    - If we know which current is dominant, we could modify the elements of that equivalent circuit to improve the conducted emissions. $\hat{I}_{\text{Total}} = \hat{I}_C \pm \hat{I}_D$

If we need to reduce the level of a particular (dominant) component, we must change the value of a power supply filter element that affects that component.



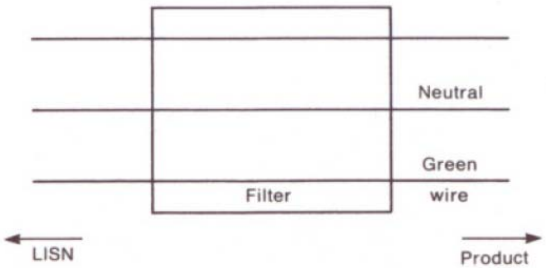
Power Supply Filters

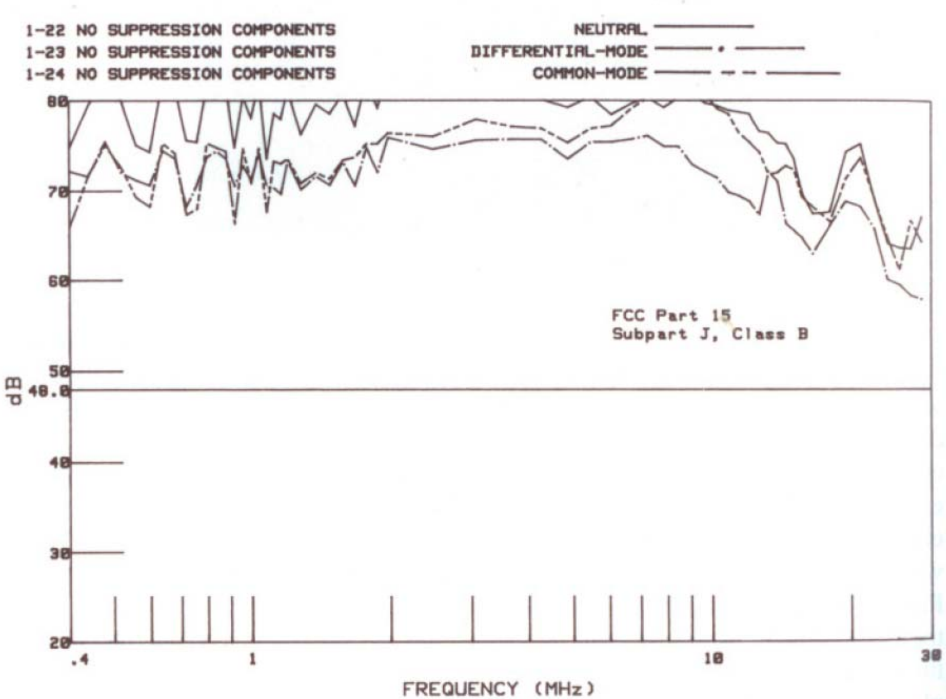
- Separation of Common- and Differential-Mode Currents
  - Circuit for Separating the Two Currents



Power Supply Filters

- Effects of Filter Elements
  - No Filter Elements
    - Both the conducted emissions for common- and differential-mode currents exceed the FCC Class B limit by over 30 dB.

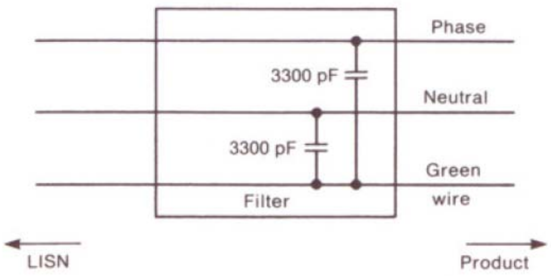


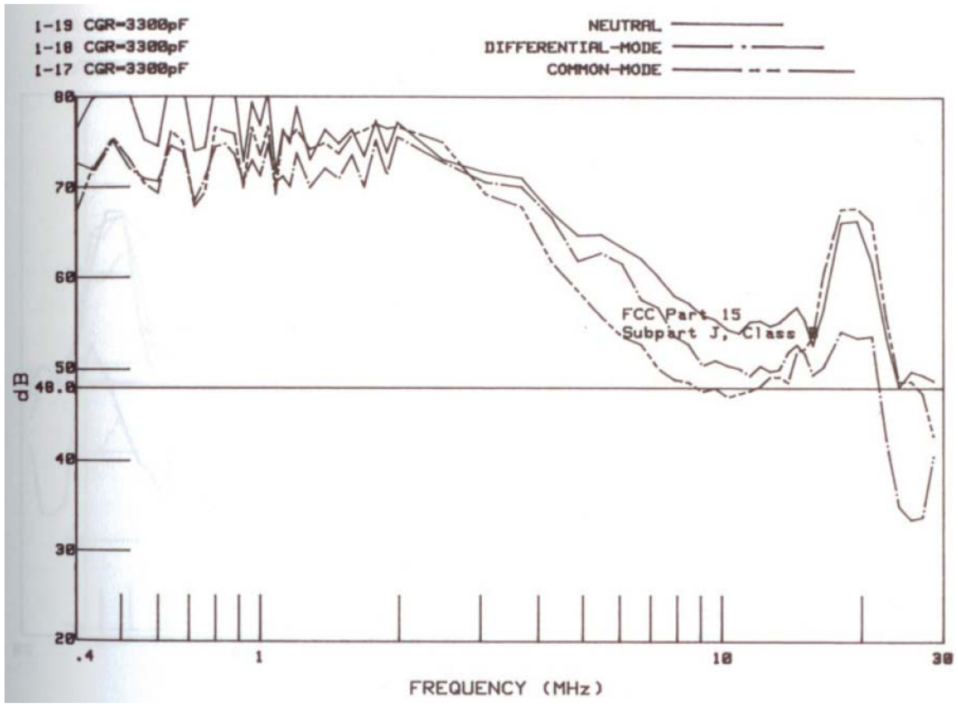


Power Supply Filters

- Effects of Filter Elements
  - Line-to-Ground Capacitors Added
    - Both the conducted emissions for common- and differential-mode currents are reduced.

High frequency components of the currents are reduced.

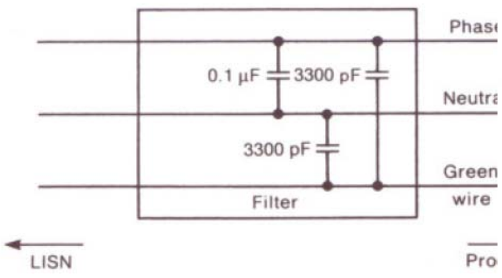


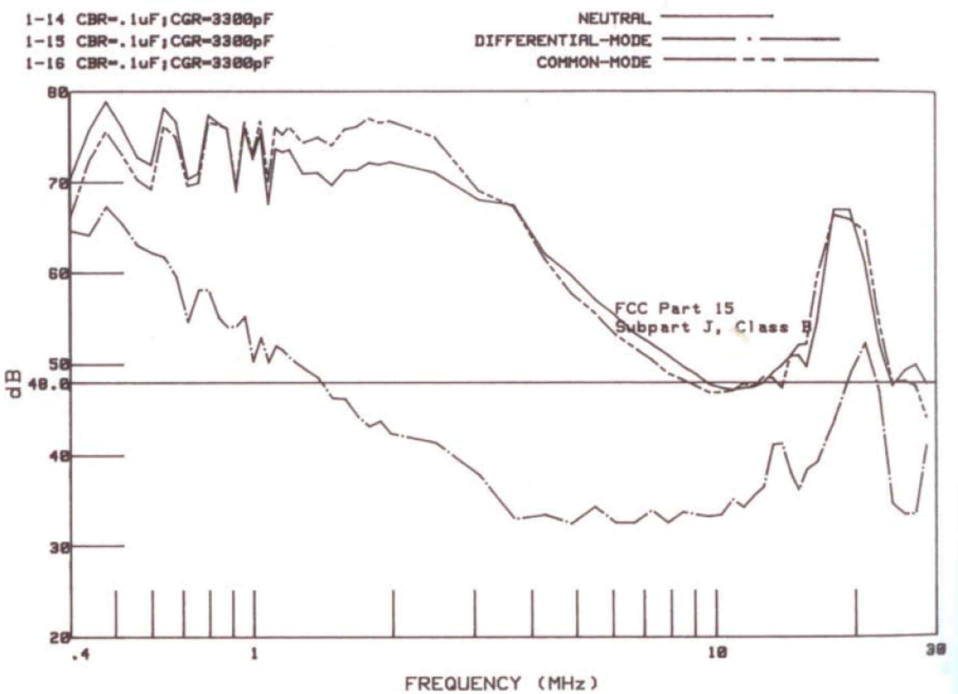


Power Supply Filters

- Effects of Filter Elements
  - Line-to-Line Capacitors Added
    - Only the conducted emission for the differential-mode current is reduced more.

High frequency components of the currents are reduced.

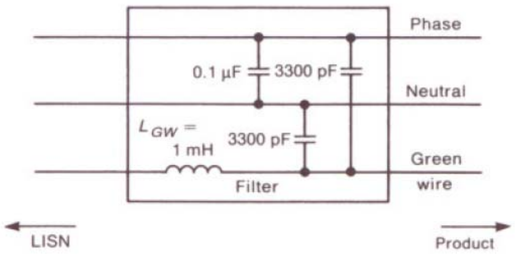


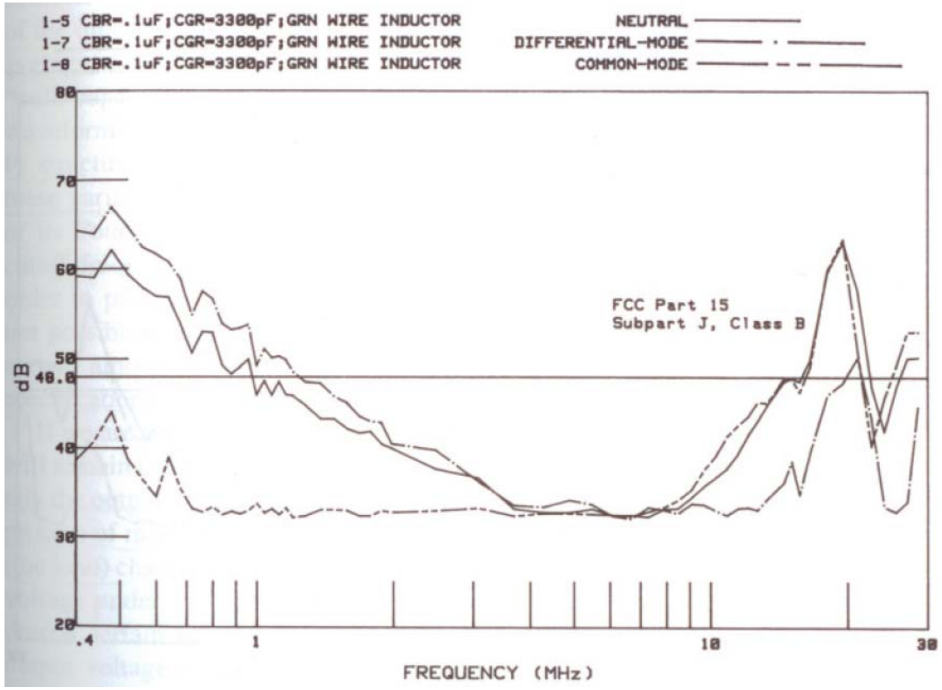


Power Supply Filters

- Effects of Filter Elements
  - Green-Wire Inductor Added
    - Only the conducted emission for the common-mode current is reduced more.

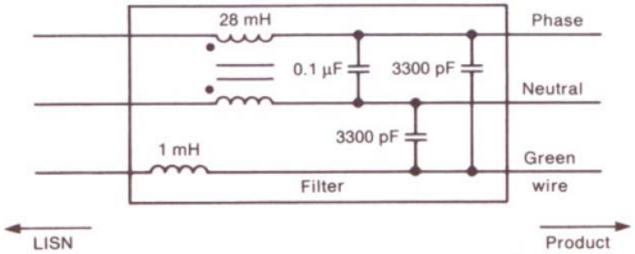
Low frequency components of the currents are reduced.

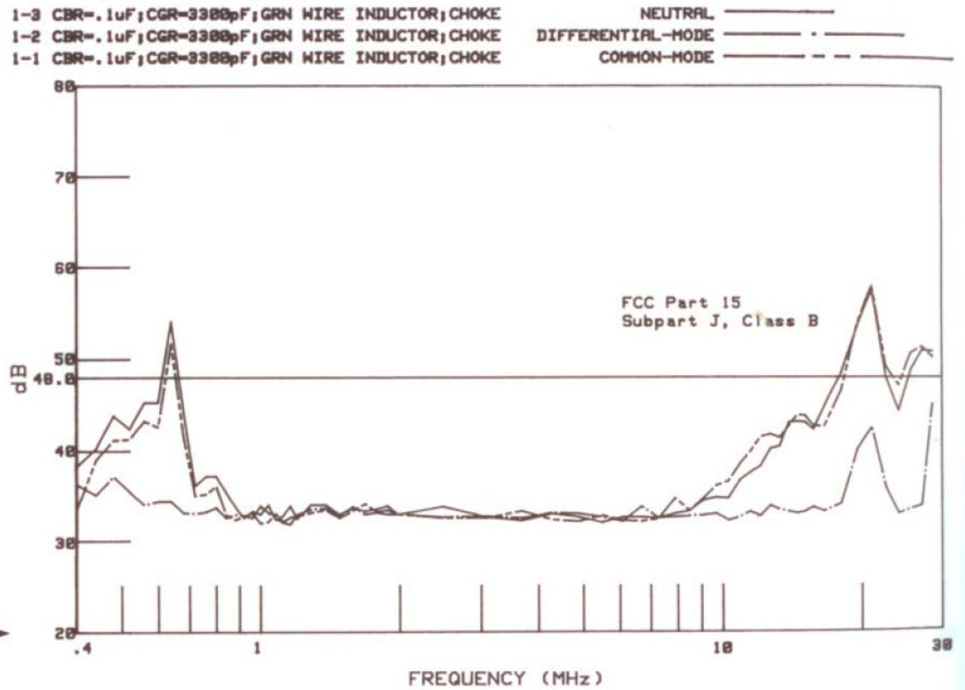




Power Supply Filters

- Effects of Filter Elements
  - Common-Mode Choke Added
    - Both the conducted emissions for common- and differential-mode currents are reduced more.
    - L+M and L-M are not zero.

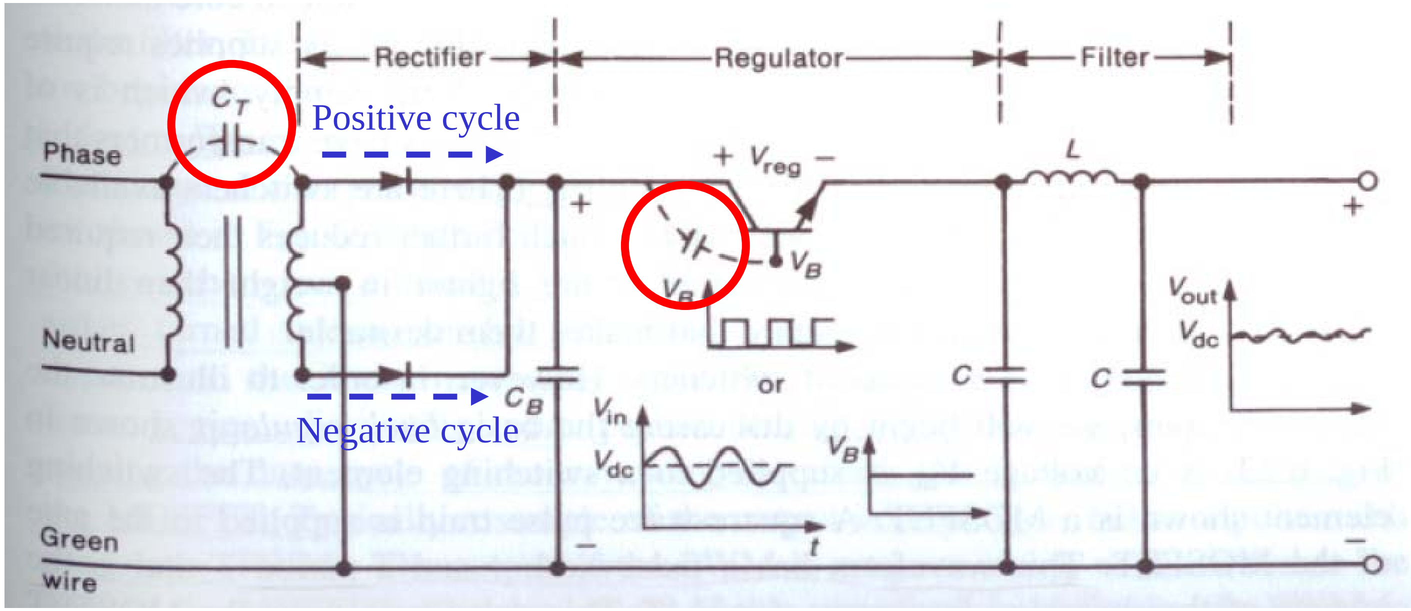




Power Supplies

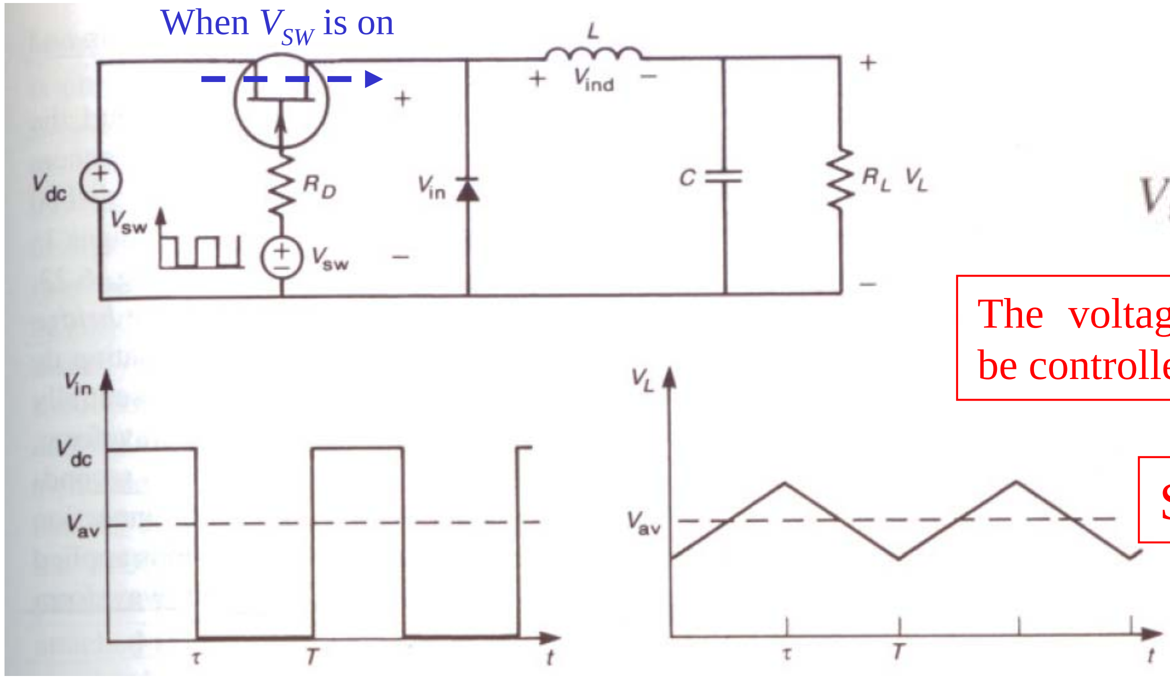
- Linear Power Supplies (Low Efficiency)
  - Functions of Each Parts
    - The transistors acts to maintain the output voltage level in the presence of changes in the load on the supply. $V_{out} = V_{in} - V_{reg}$

Please notice the parasitic capacitances in red circles.



Power Supplies

- Switched-Mode Power Supplies (SMPS, High Efficiency)
  - Basic Operation Function
    - Also, this type is lighter due to lighter transformer since the switching frequency is 20-100 kHz.



$$V_{av} = \frac{\tau}{T} V_{dc}$$

The voltage level could be controlled by τ / T.

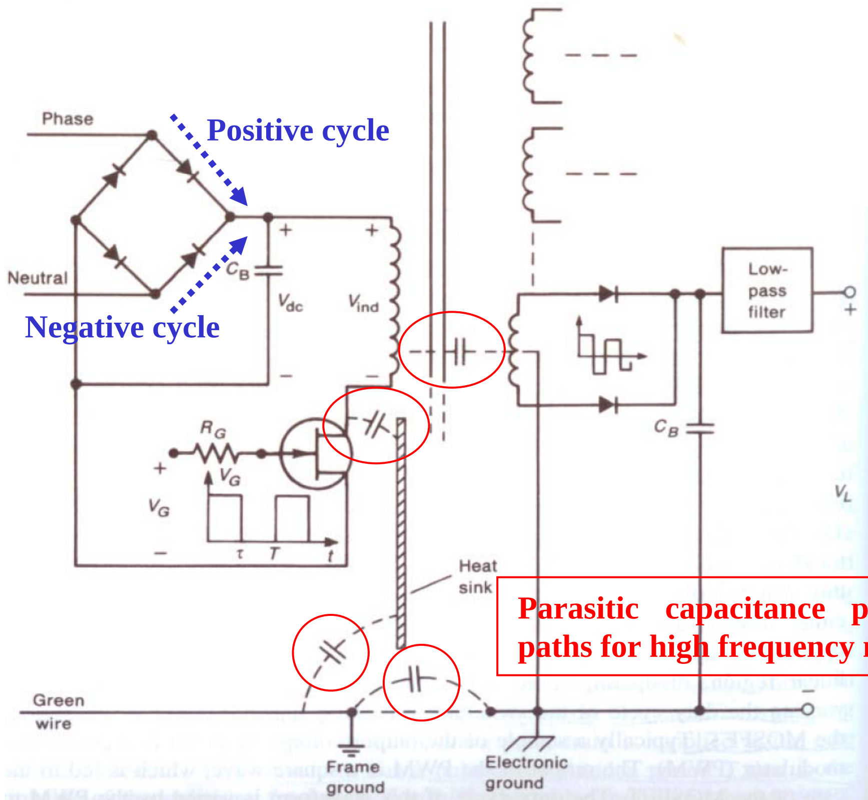
Steady state

Power Supplies

- Switched-Mode Power Supplies (SMPS, High Efficiency)
  - Primary-Side Switching Power Supply

Effect of resistor R_G: change the rise/falltimes of the pulses that are applied to the gate. Increasing the value of this resistor "rounds the sharp edges" of the waveform. This causes more power dissipation but reduces high-frequency contents.

Please notice the parasitic capacitances in red circles.



Parasitic capacitance provides paths for high frequency noises.

Power Supplies

- Effect of Power Supply Components on Conducted Emissions
  - Diodes
    - When the diode is turned off, the charge in the parasitic capacitance must be removed. (Figure (a))
    - To prevent the fast-recovery diodes from generating high frequency content, an RC "snubber" circuit is used. (Figure (b))

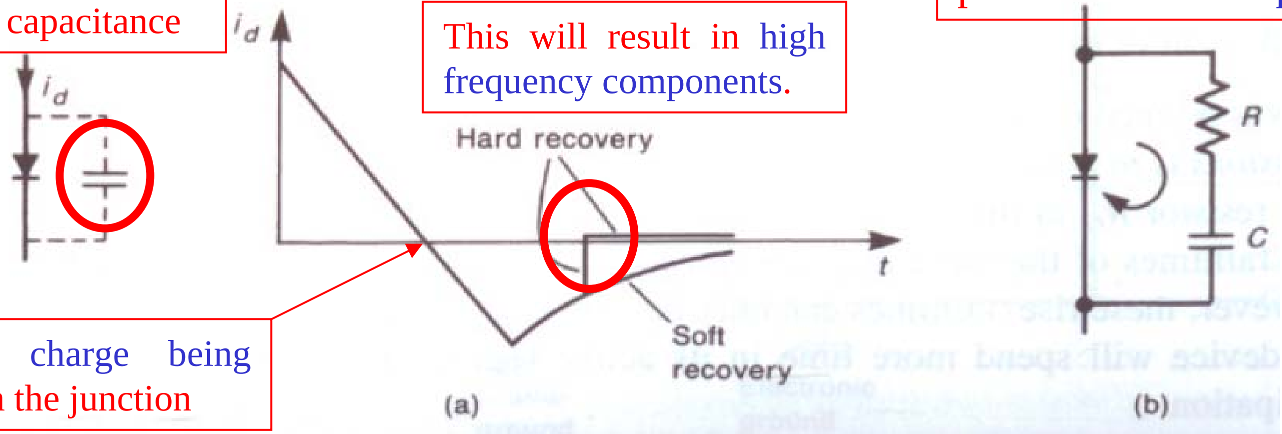
There are two kinds of diodes:
1. Fast-recovery diodes → hard recovery
2. slow-recovery diodes → soft recovery

The RC circuit should be placed as close as possible.

Parasitic capacitance

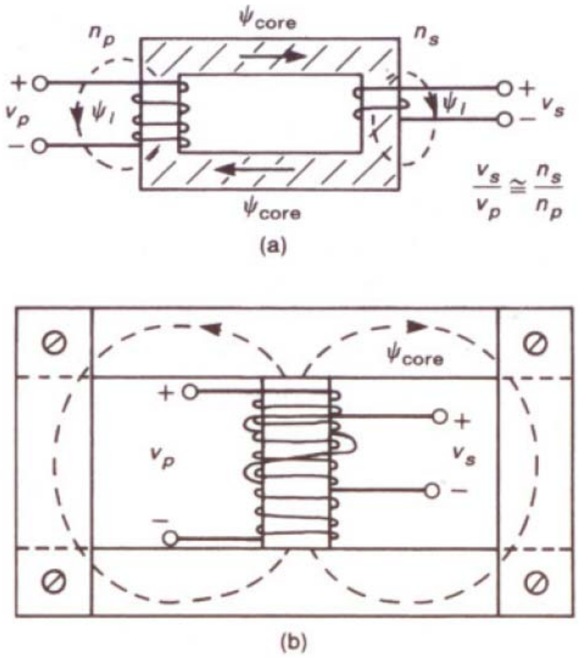
This will result in high frequency components.

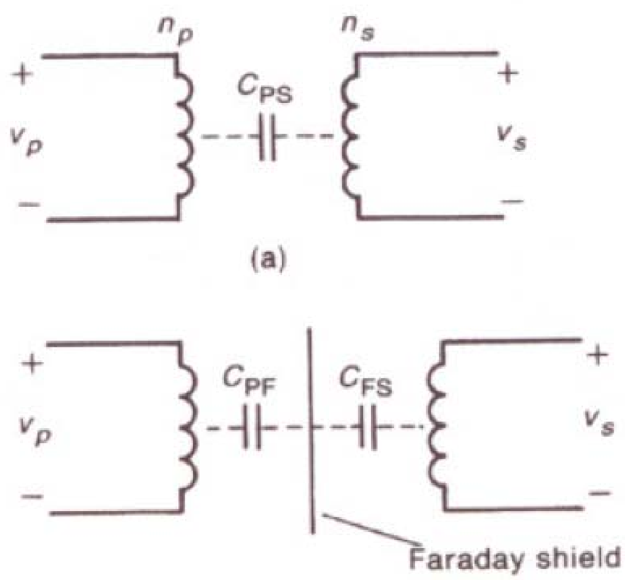
Point when charge being removed from the junction



Power Supplies

- Effect of Power Supply Components on Conducted Emissions
  - Transformers
    - A Faraday shield is used to reduce the capacitive coupling between the primary and secondary coils.

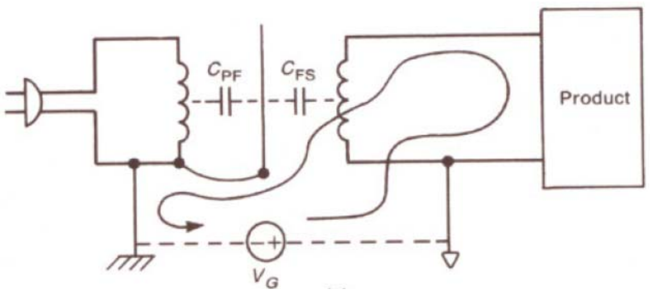




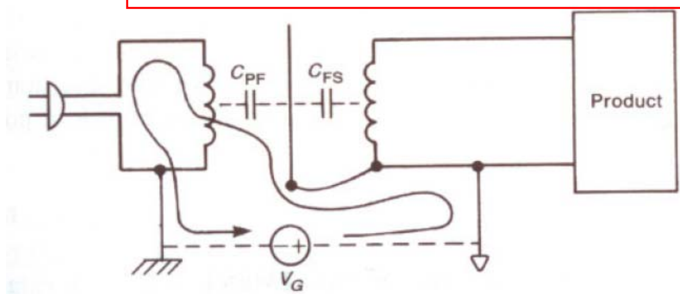
Power Supplies

- Effect of Power Supply Components on Conducted Emissions
  - Transformers
    - To which side should a Faraday shield be connected?
    - In order to prevent the noise current from flowing through the receiver input, the shield should be grounded at the receiver input.

Noise from the input will flow through the product.



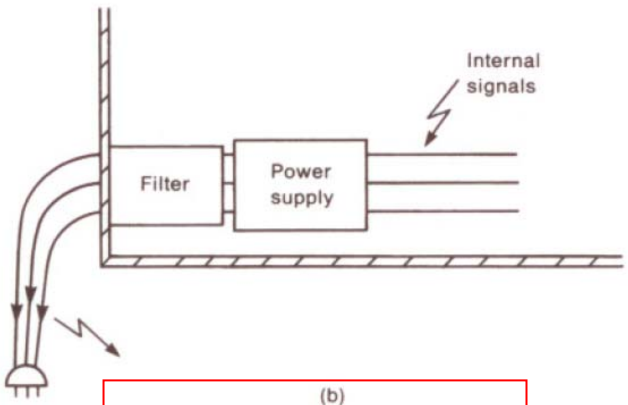
Proper connection



Improper connection

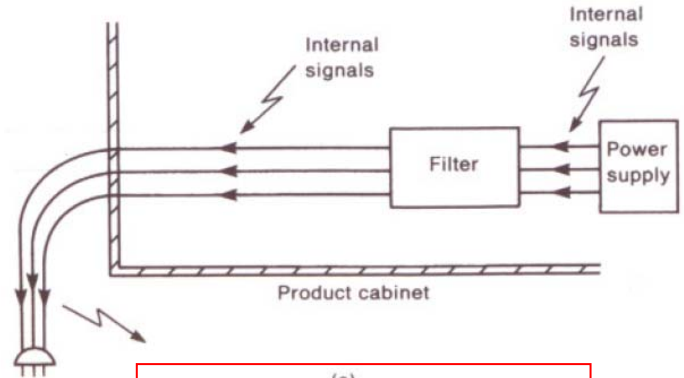
Power Supply and Filter Placement

- Proper and Poor Filter Placement
  - Descriptions
    - Location of components and routing of wires within a product are important considerations in the reduction of conducted and radiated emissions of the product.
    - The power supply filter should be placed directly at the exit of the power cord from the product.



(b)

Proper placement



Poor placement

Conducted Susceptibility

- Regulatory and Unregulatory Emissions
  - Regulatory Emissions
    - The noise signals coming out from products are generally too small to cause interference by direct conduction from the power net into another product via its ac power cord.
  - Unregulatory Emissions
    - Large transients placed on the power distribution net by lightning strokes can cause EMC problems in a product by direct conduction into that product's ac power cord.