Understanding and Optimizing Electromagnetic Compatibility in Switchmode Power Supplies

Definitions

EMI = Electro Magnetic Interference
EMC = Electro Magnetic Compatibility (No EMI)

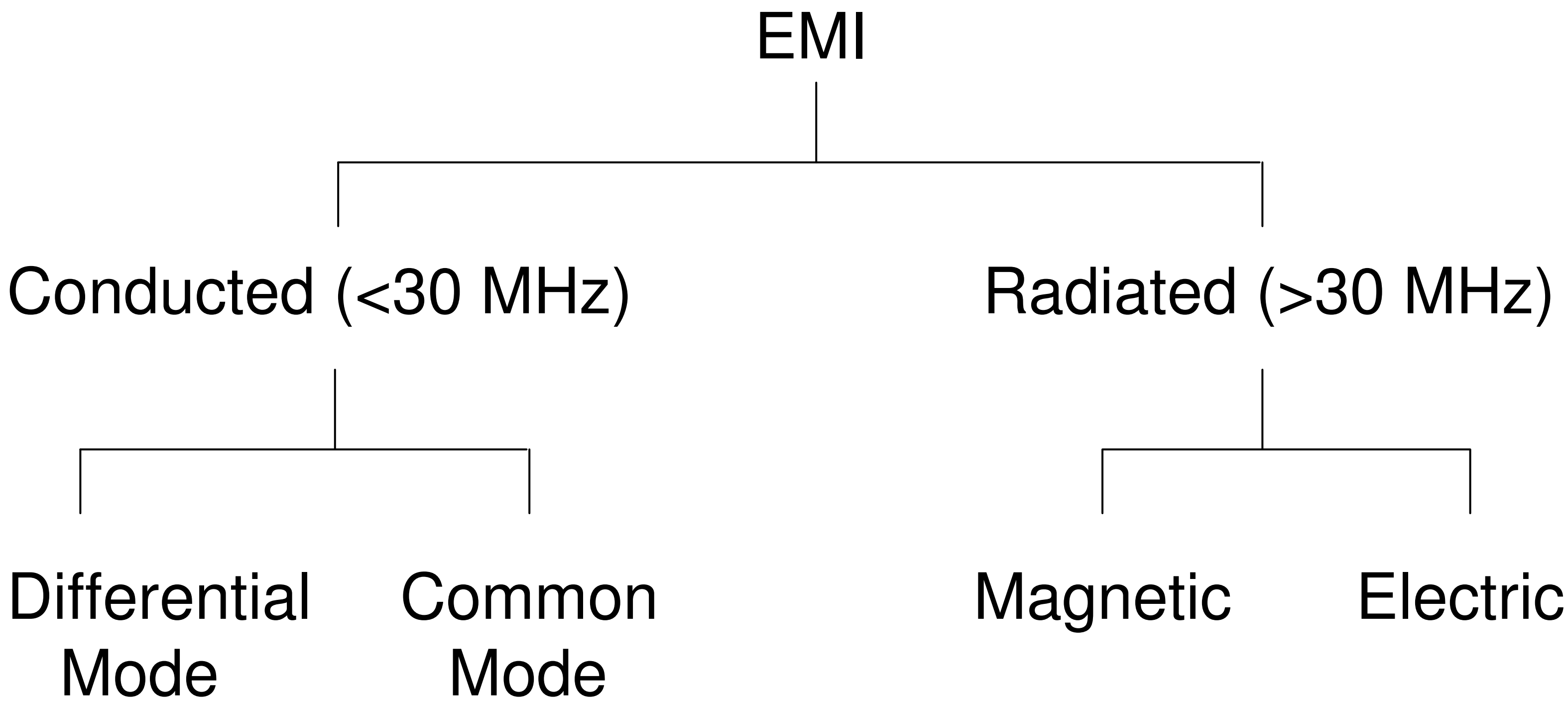
Three Components of EMI:

- Noise generator (source)
- Noise transmission (coupling)
- Noise receptor (victim)

Understanding EMI

- Electromagnetic Fields Caused by Changing Currents and Voltages
- Maxwell's Equations: $e = M\frac{di}{dt}, \quad i = C\frac{dv}{dt}$
- Slower Rise/Fall Times (with tradeoffs)
- Low Energy Phenomenon
  - At 1 Mhz, 20 nW can fail FCC limits

Categorizing EMI



System Usage: Class A - Industrial and Commercial
Class B - Includes Residential

EMI Specifications

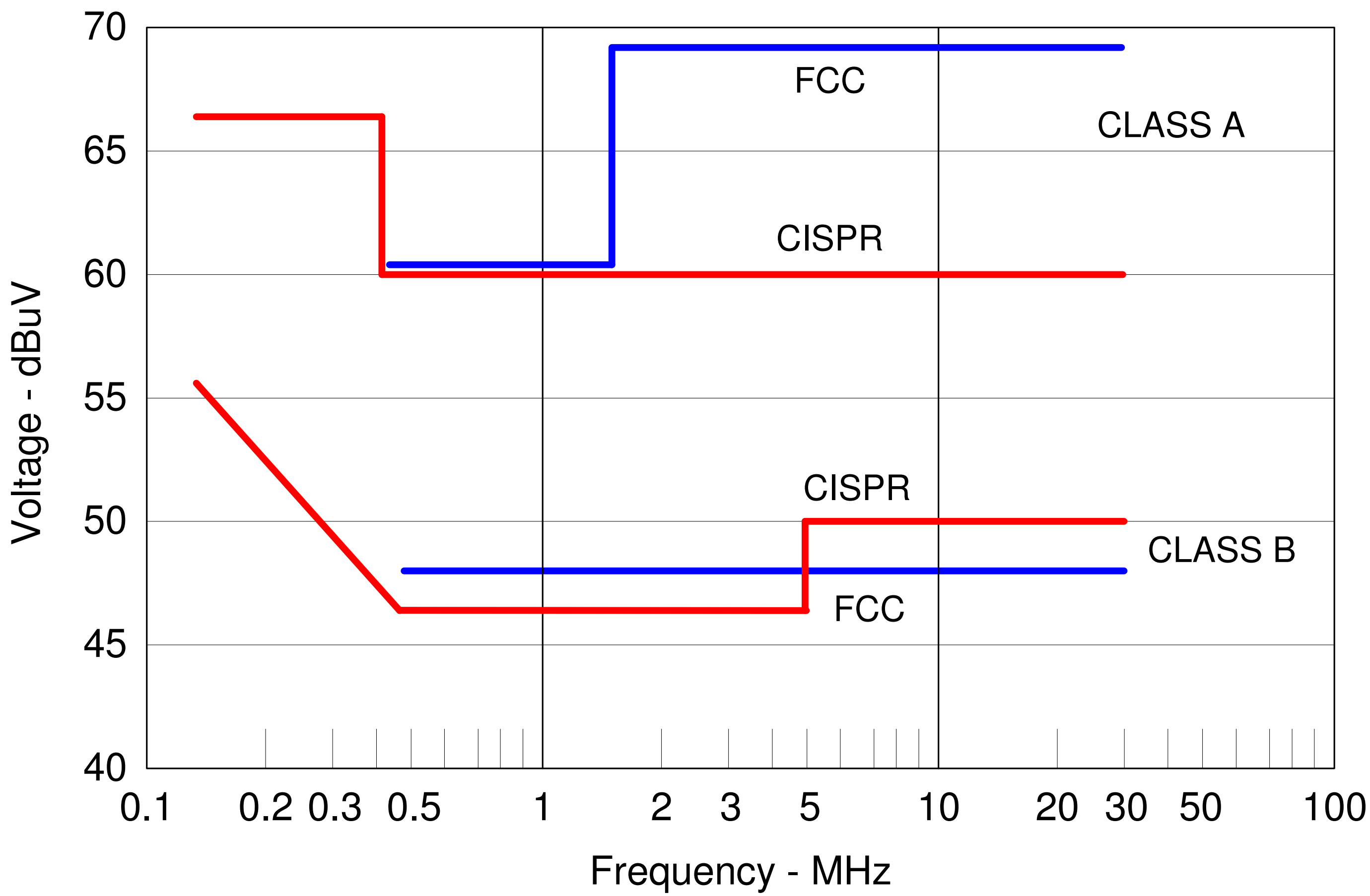
USA -	FCC:	CFR Title 47, Part 15 (etc.)
Europe -	IEC:	EN50081 (and others)
French -	CISPR:	Publication 22

Frequency Ranges (FCC) -

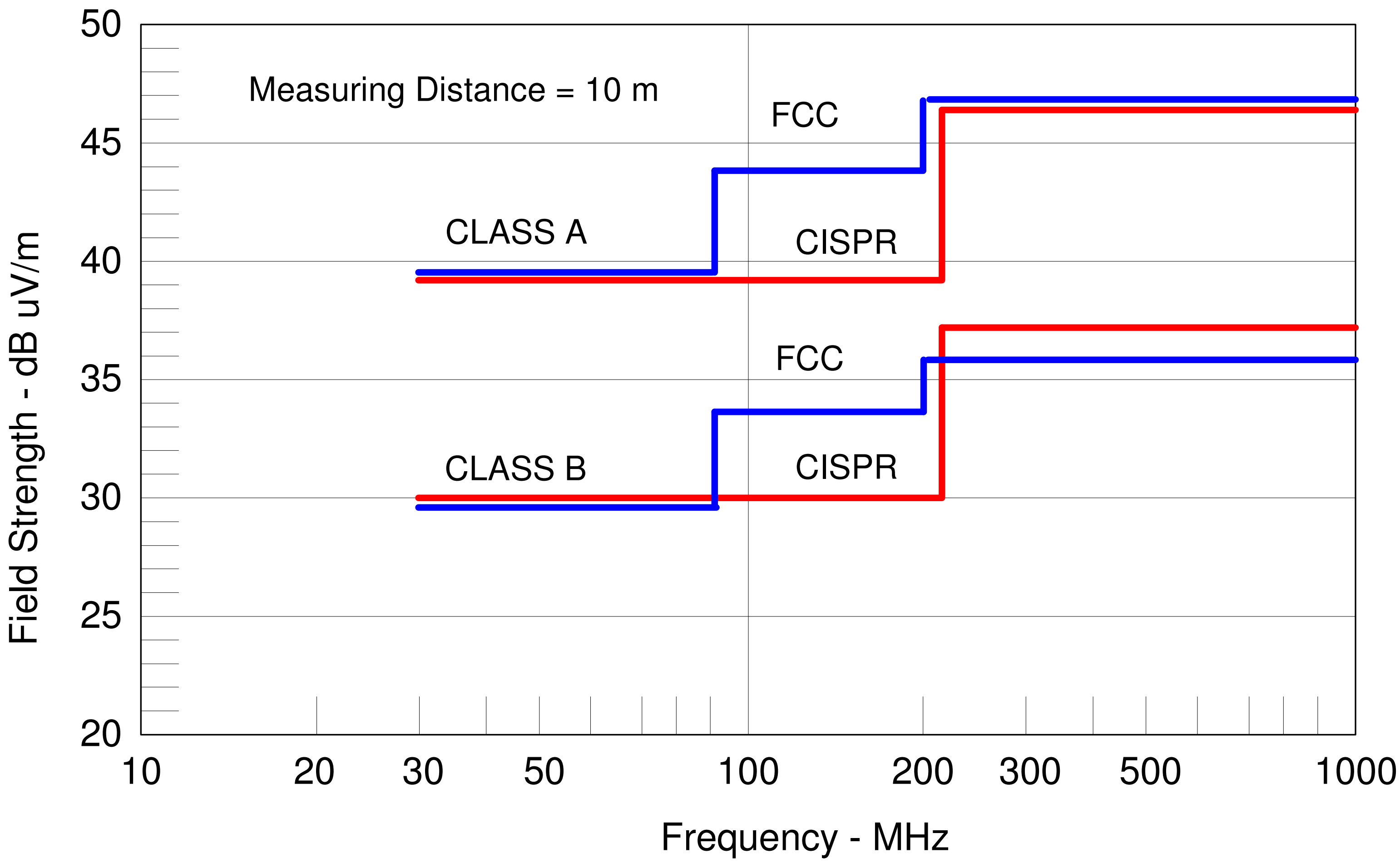
Conducted EMI:	450 kHz to 30 MHz
Radiated EMI:	30 MHz to 1 GHz

Note: Measurement dependencies on operating conditions

Conducted Noise Limits
(FCC vs CISPR)

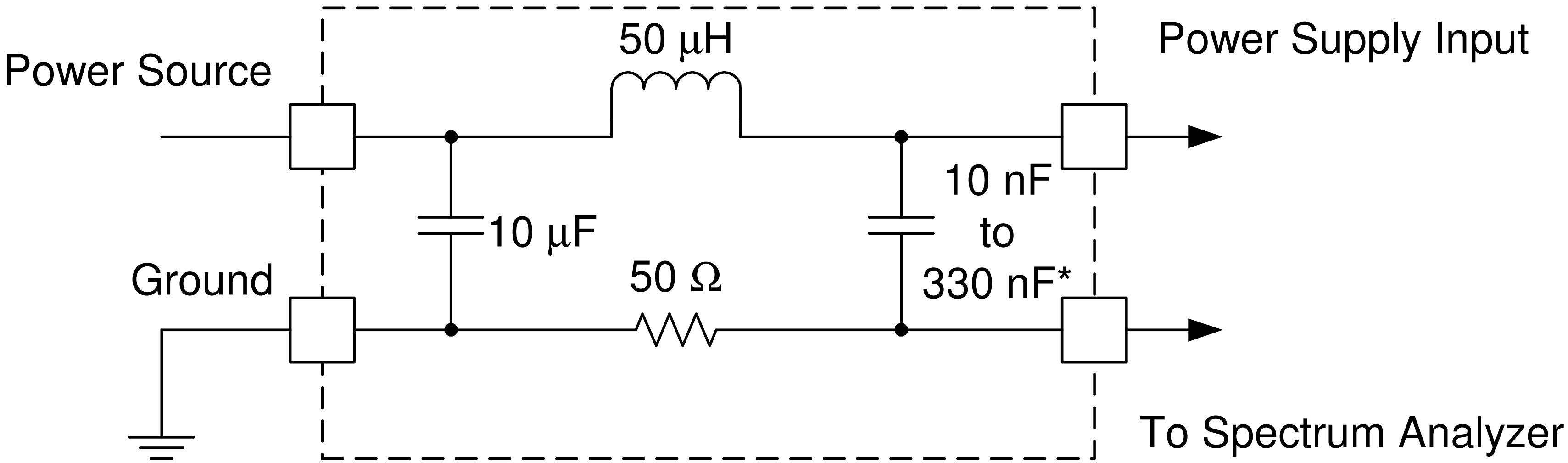


Radiated Noise Limits
(FCC vs CISPR)



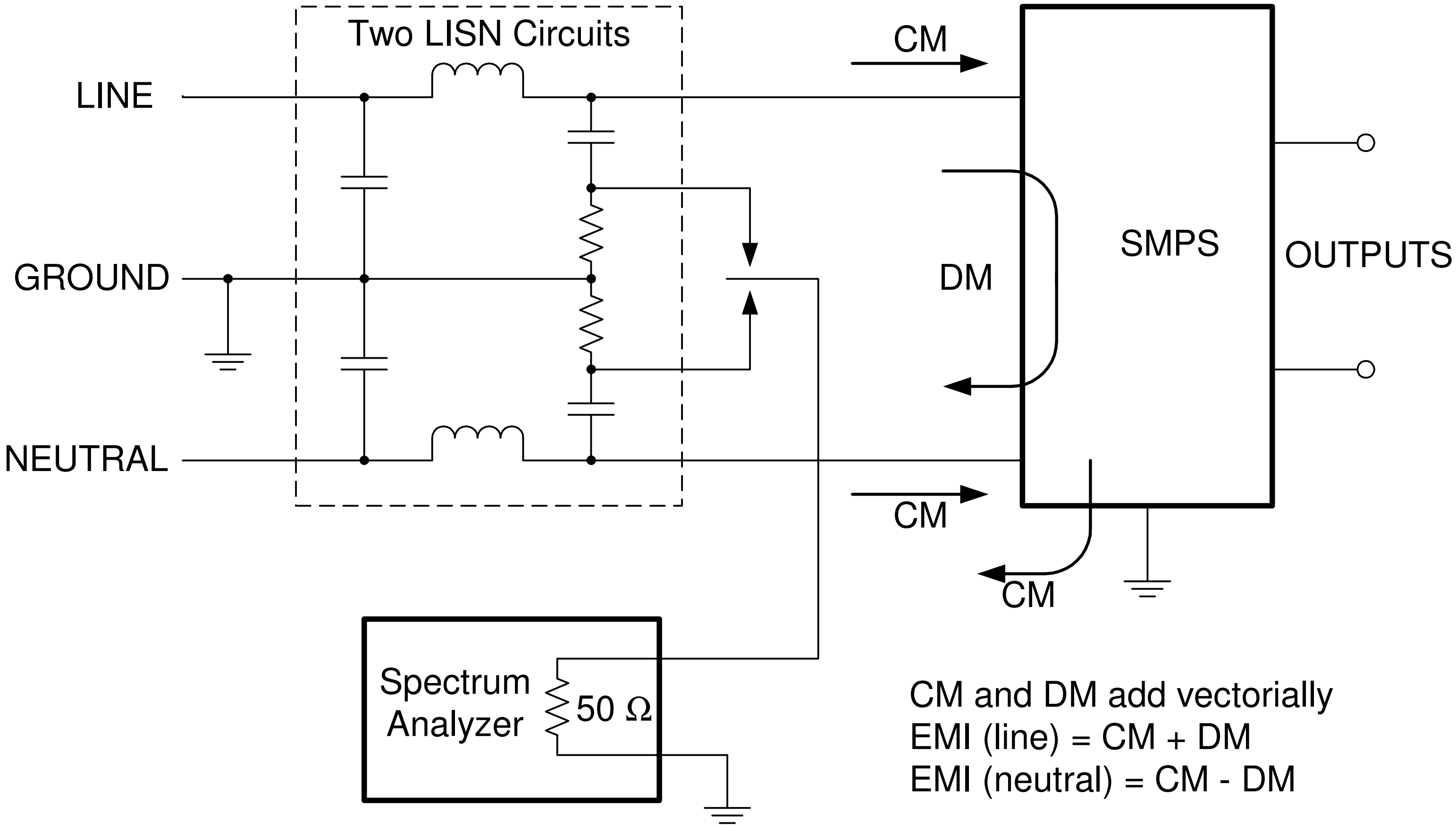
Measuring Conducted Noise

Line Impedance Stabilization Network (LISN)



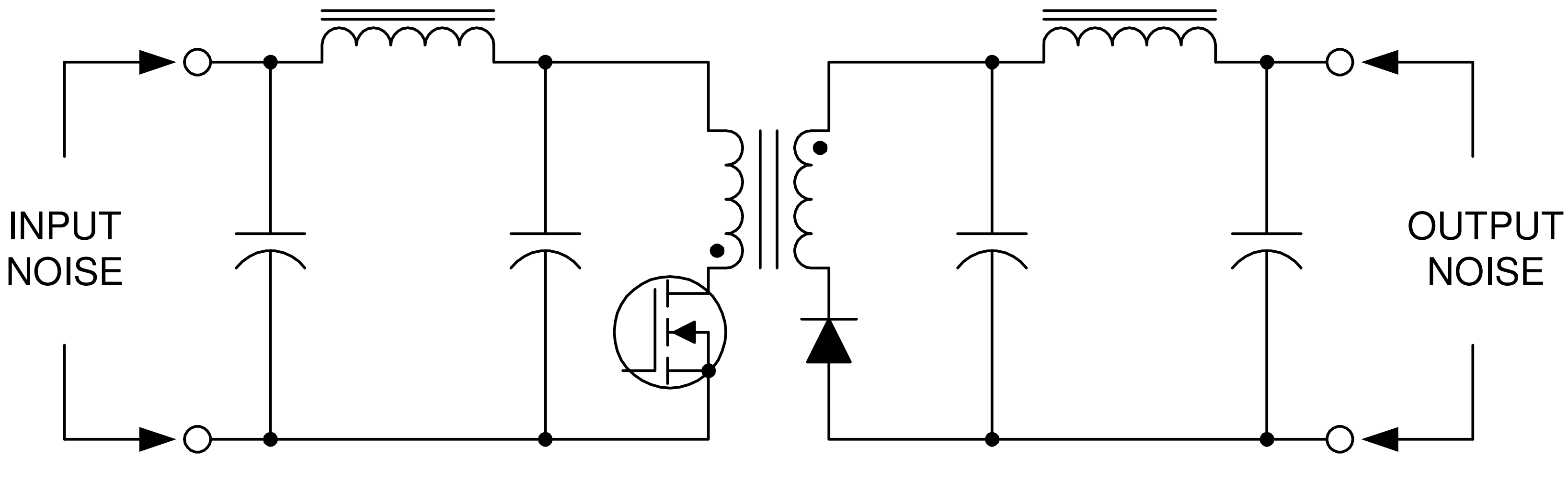
* Capacitor value determined by lowest specified frequency

Elements of Conducted Noise



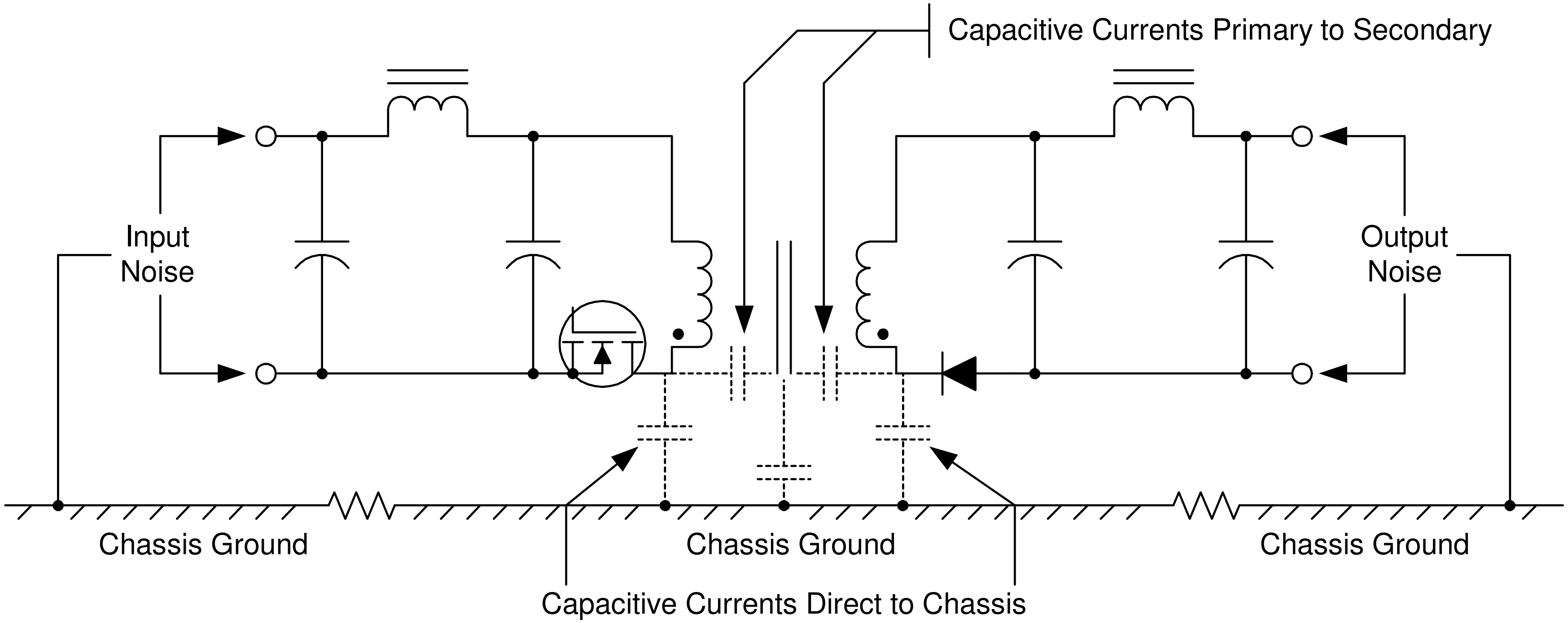
CM and DM add vectorially
EMI (line) = CM + DM
EMI (neutral) = CM - DM

Sources of Differential Mode Noise

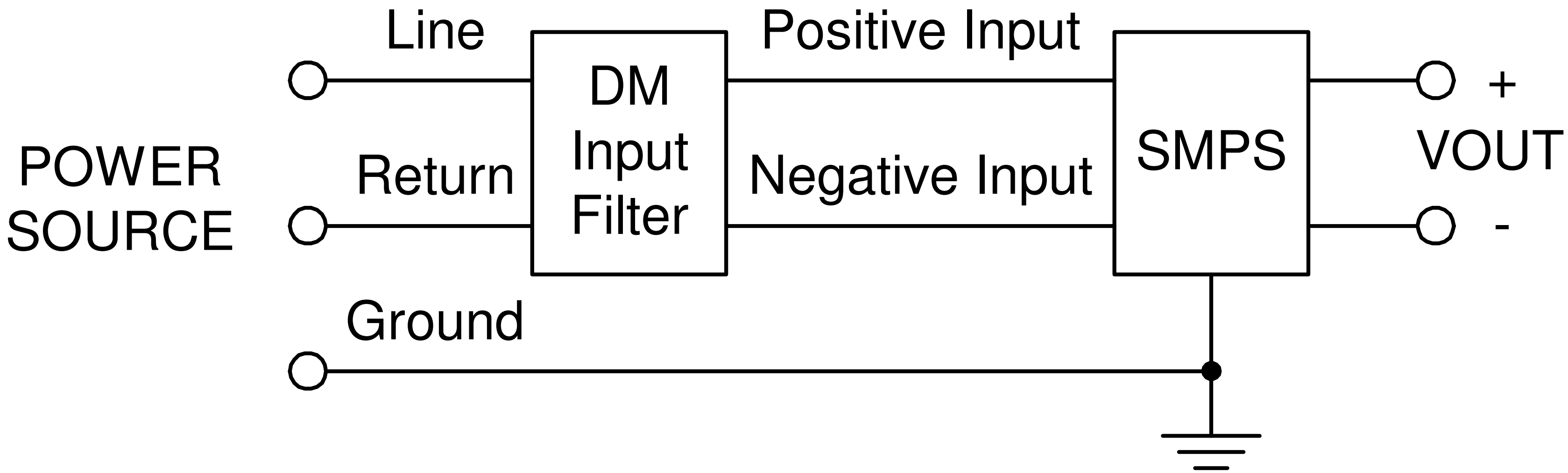


Switching action causes current pulses at input and output.

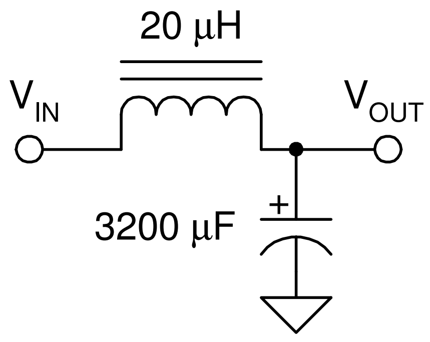
Sources of Common Mode Noise

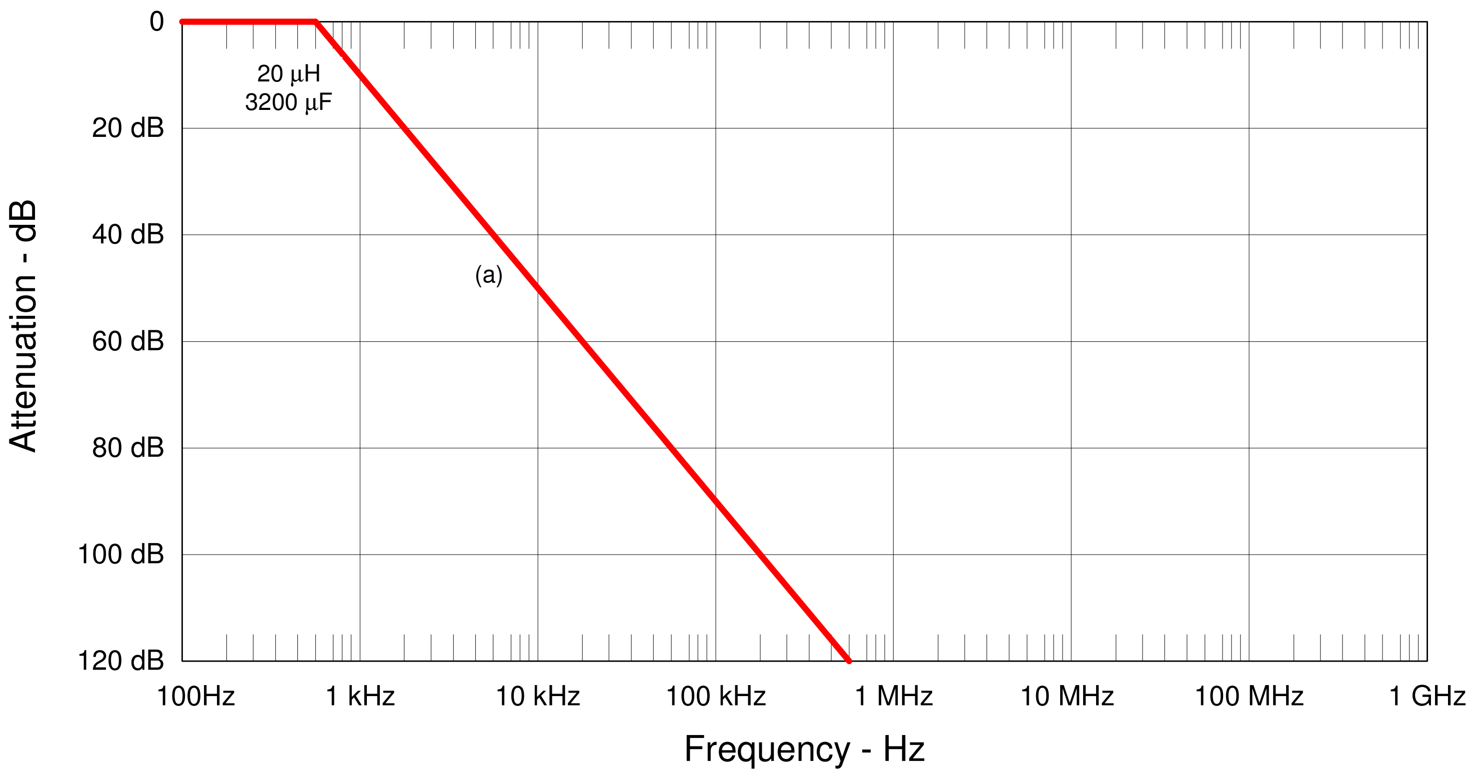


Combating Differential Mode Noise

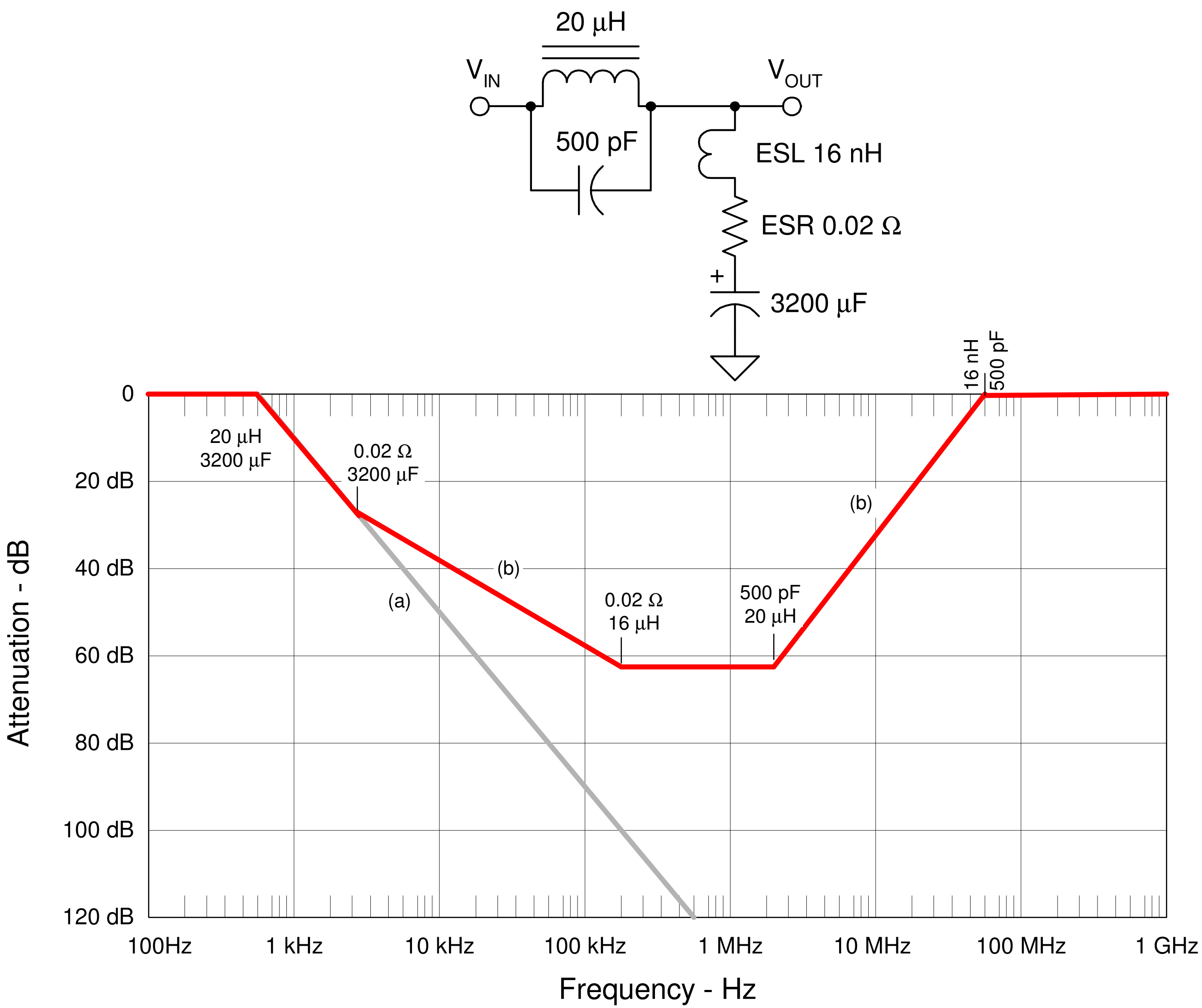


Basic Ideal Filter

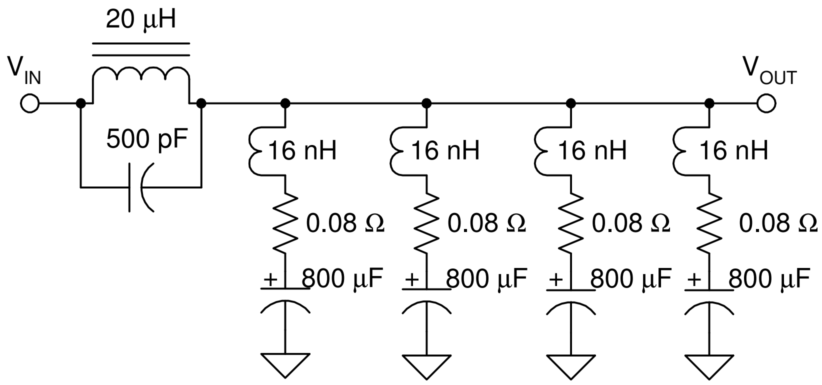


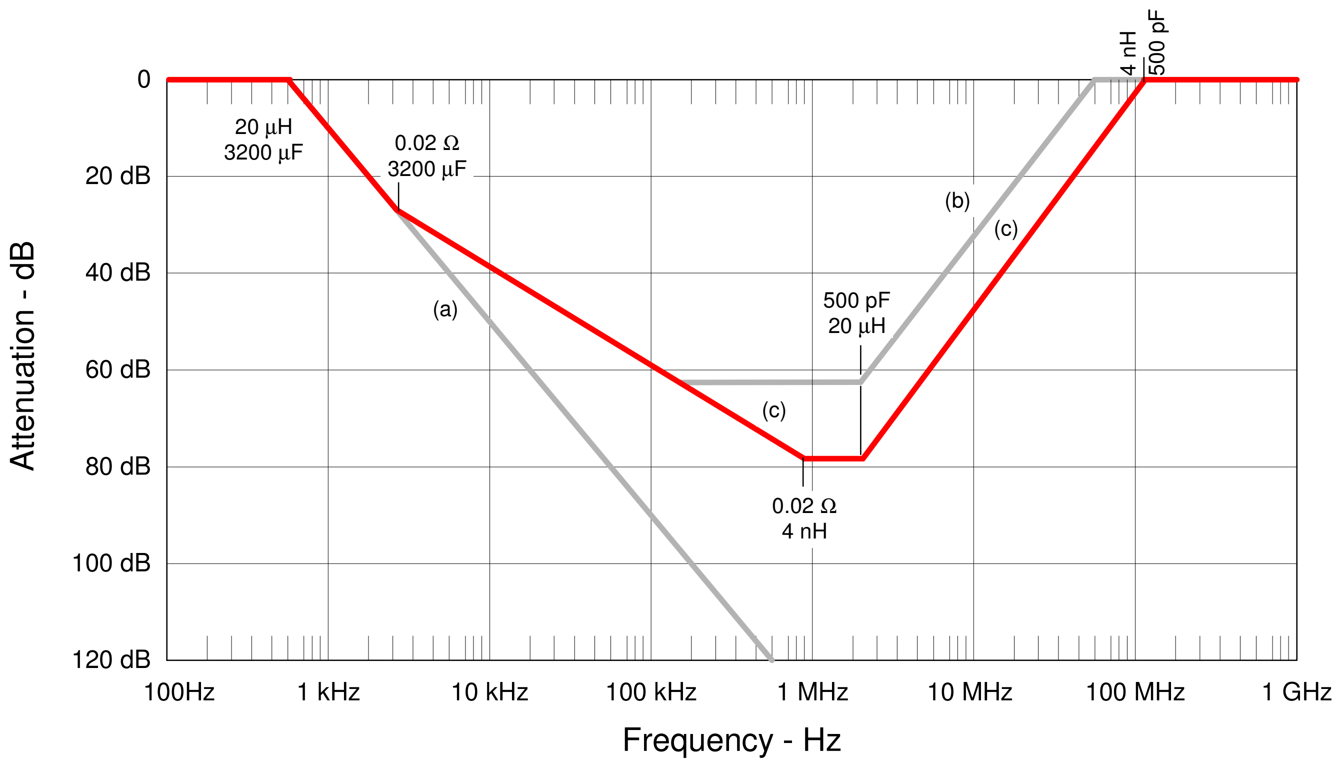


Actual Filter with Parasitics

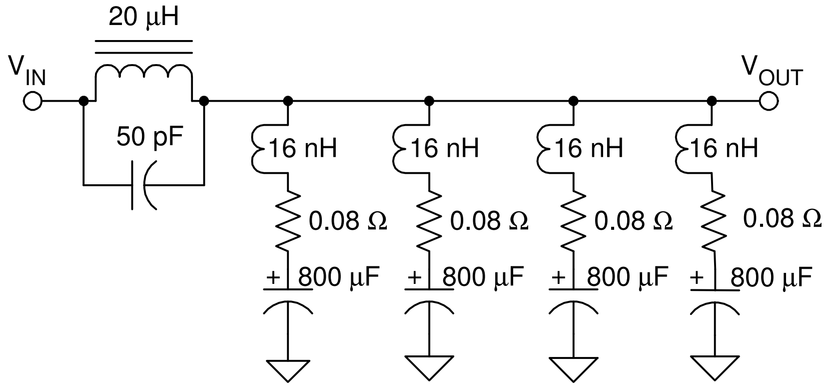


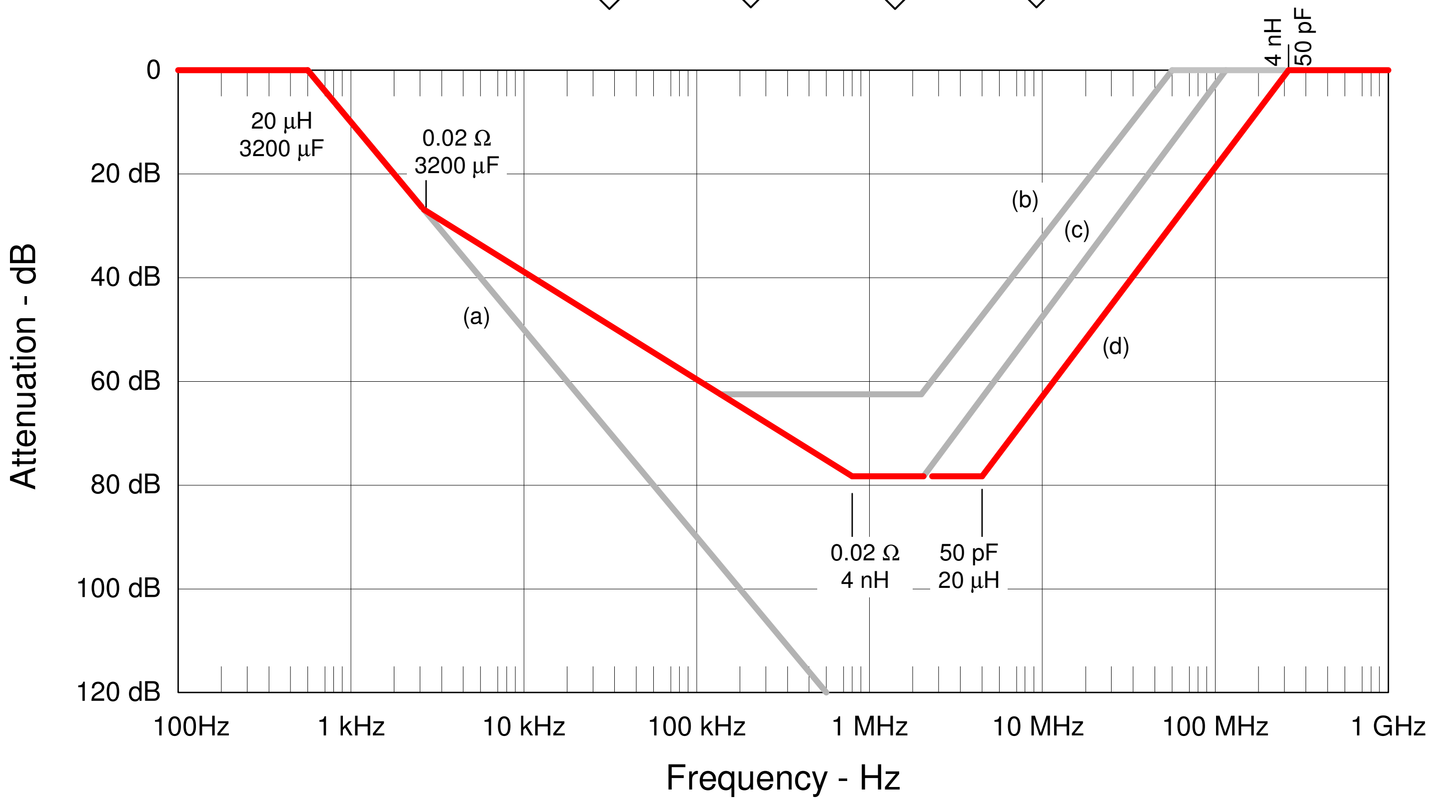
Four Paralleled Capacitors Reduces ESL



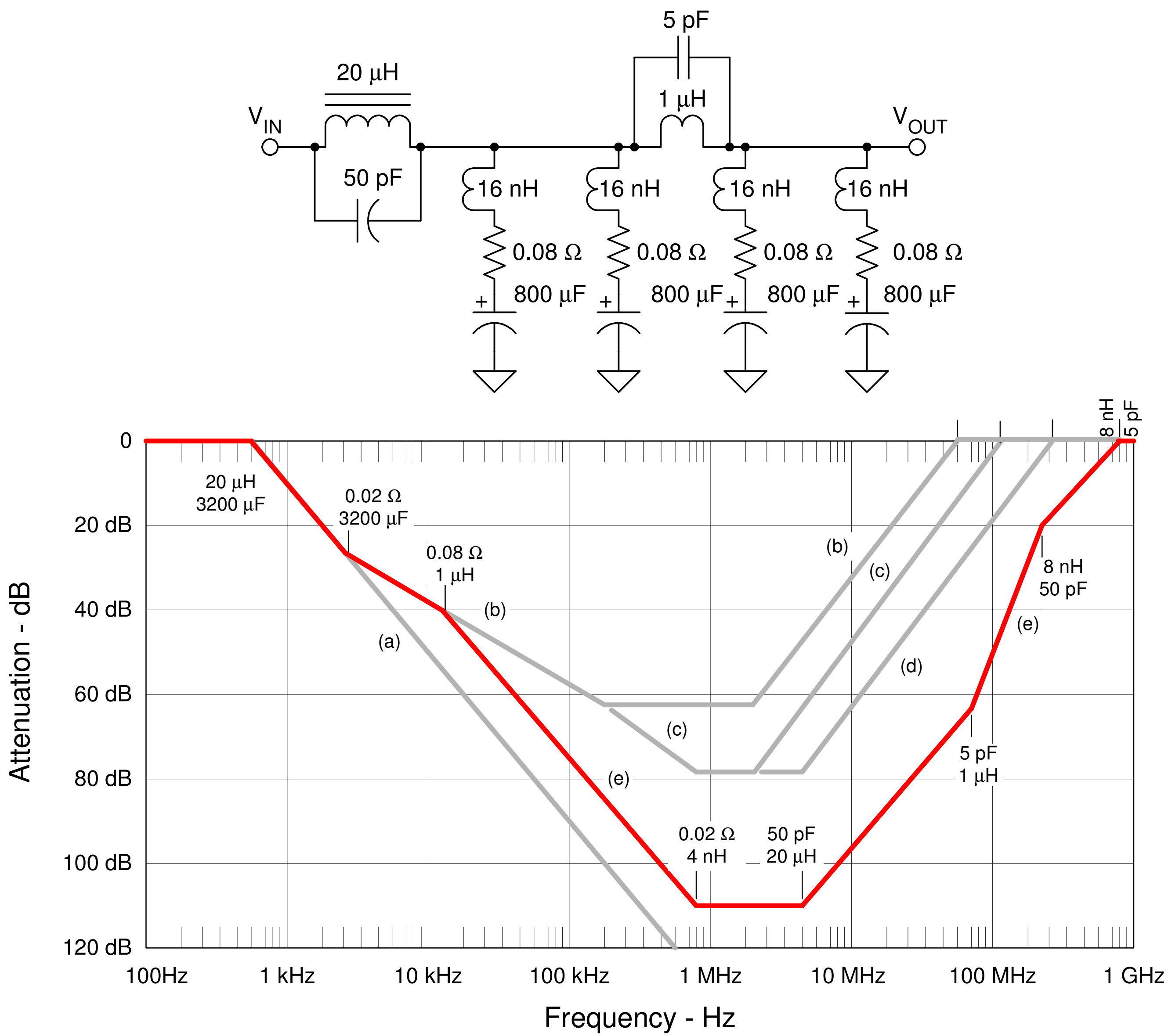


Improved Inductor Reduces Shunt C

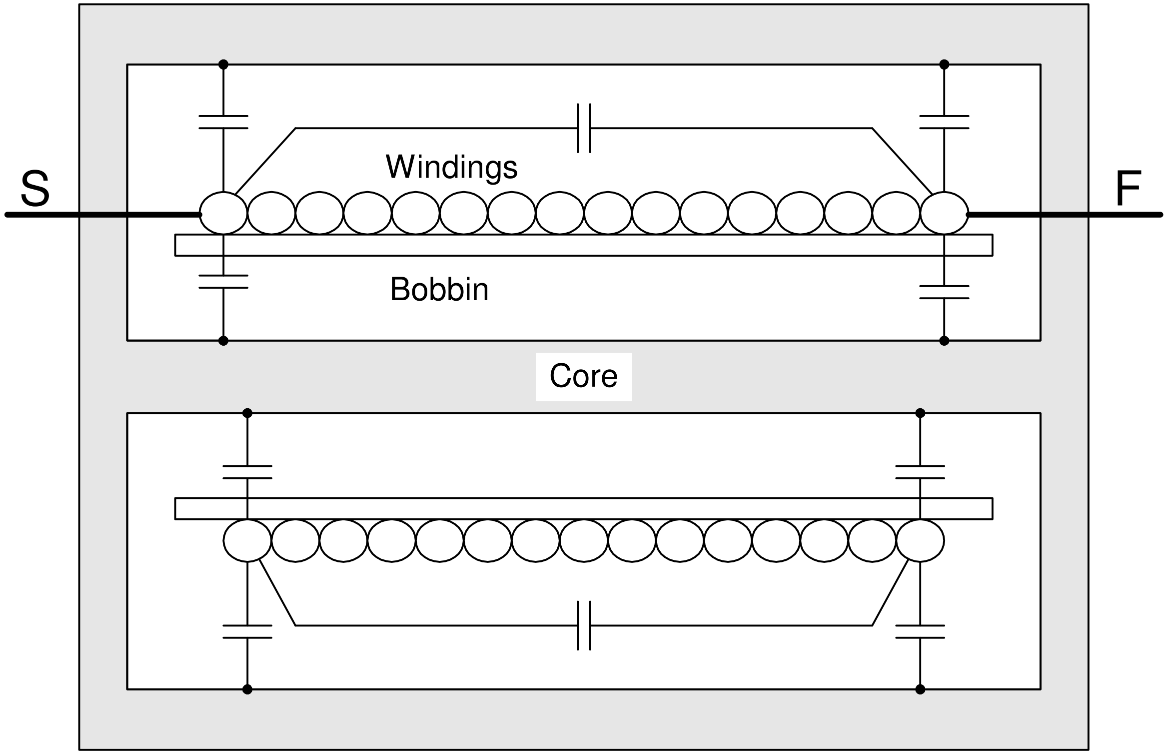




Adding a Second Stage Inductor



Reducing Inductor Parasitic Shunt Capacitance



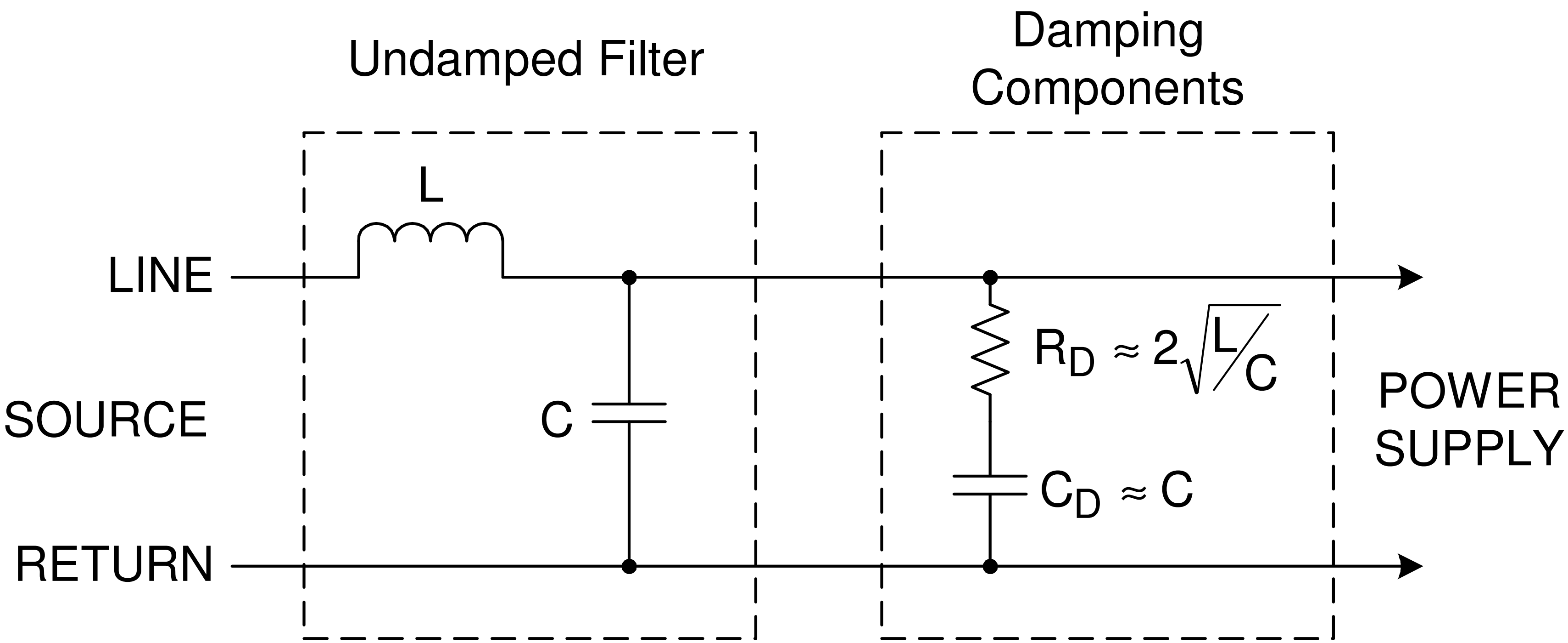
Filter Resonance

Natural Resonant Frequency = $\dfrac{1}{2\pi\sqrt{LC}}$

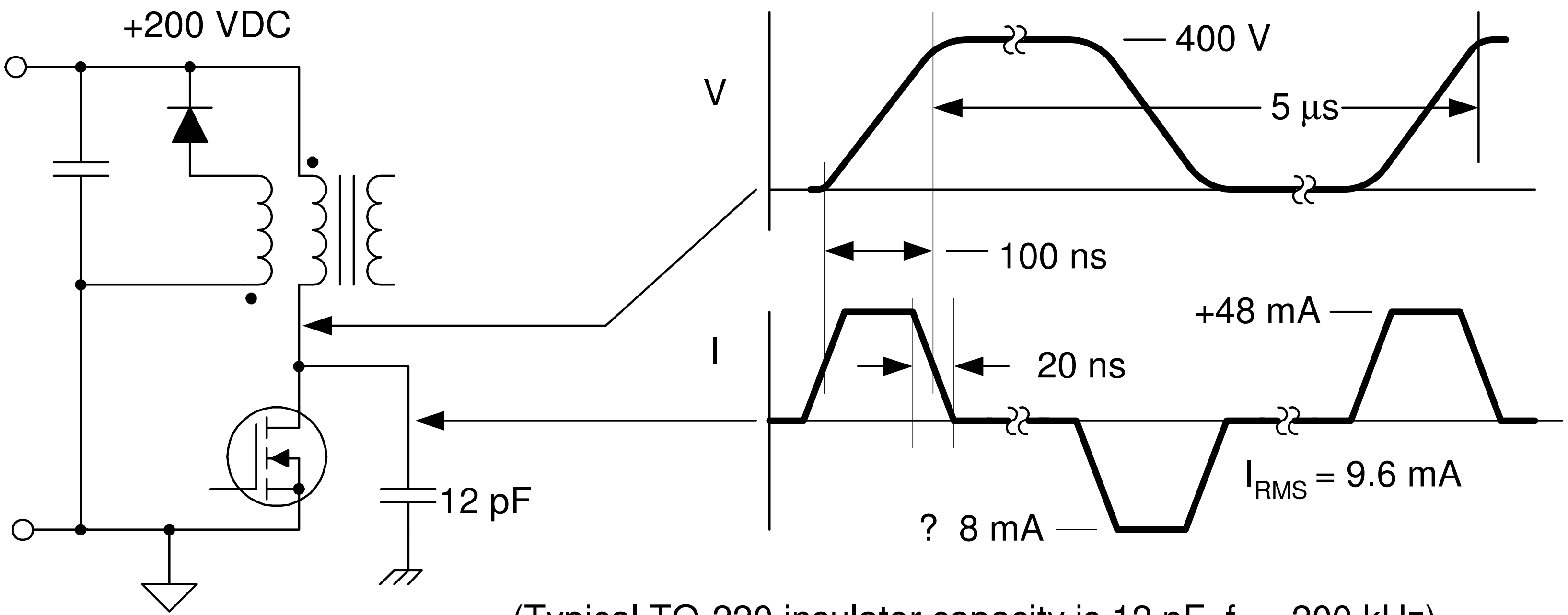
Three Potential Problems:

1. Step application of input voltage could ring to $2V_P$.
2. High frequency noise at input could be amplified by “Q” of filter.
3. Filter output impedance rises at fr with potential oscillation with Z_{IN} of converter.

Filter Damping

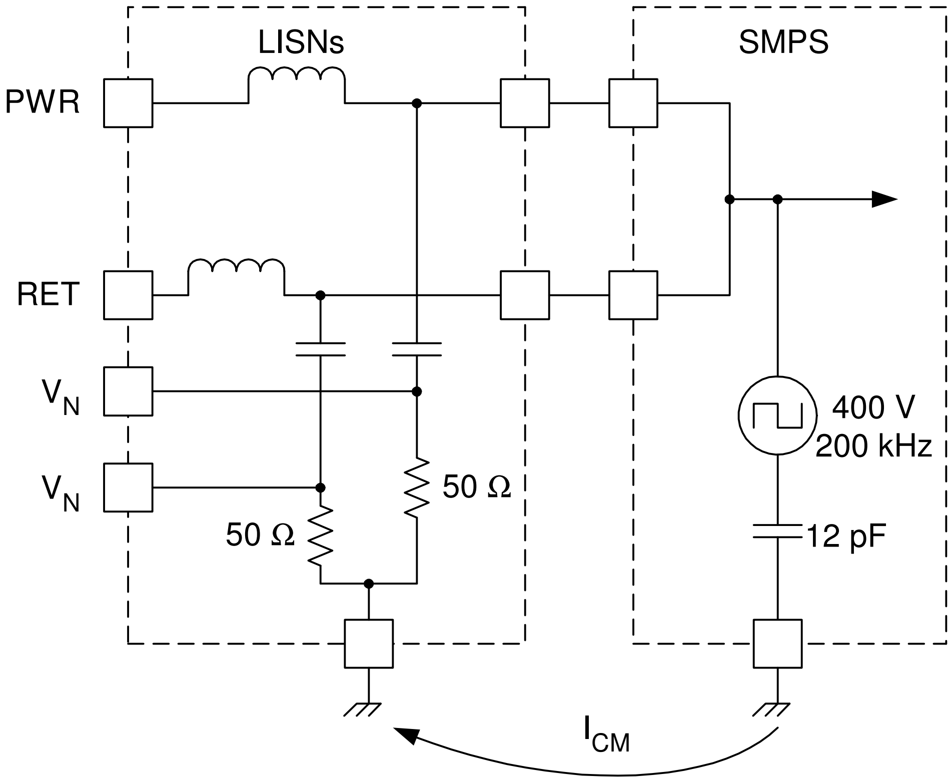


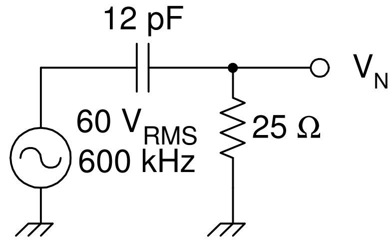
Combating Common Mode Noise



(Typical TO-220 insulator capacity is 12 pF, f_s = 200 kHz)

Common Mode Noise Analysis

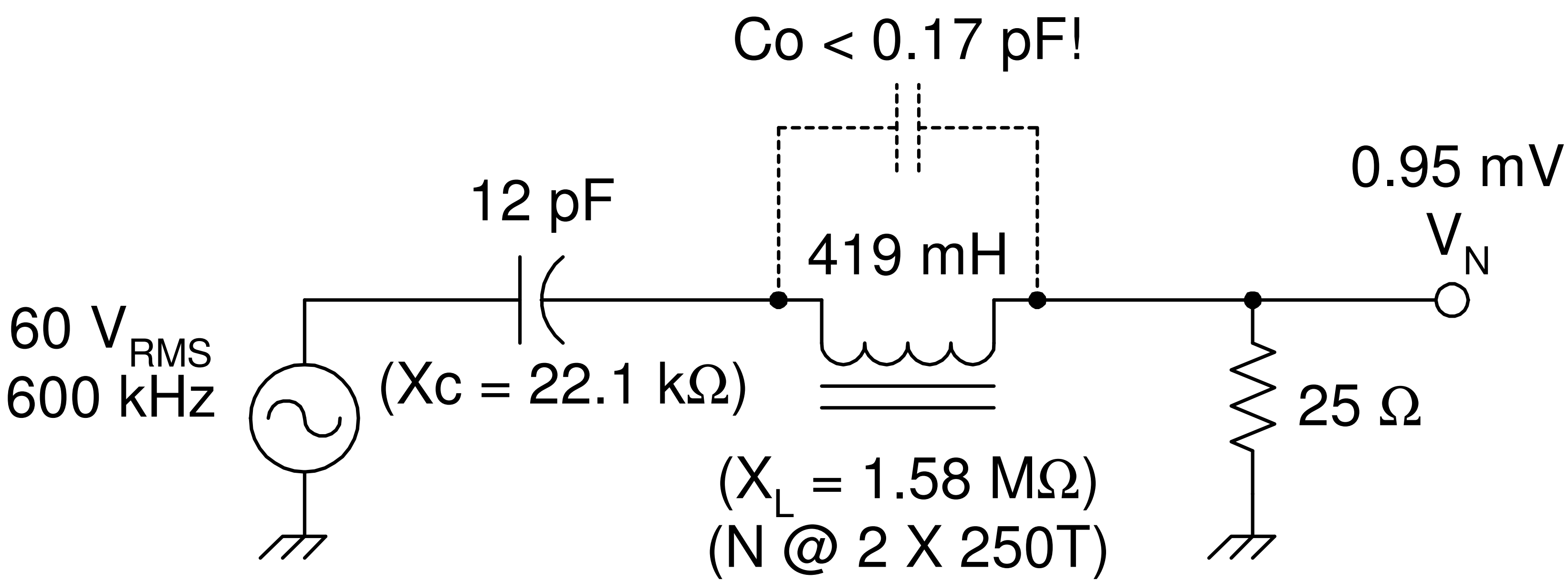




3rd harmonic equivalent noise voltage circuit

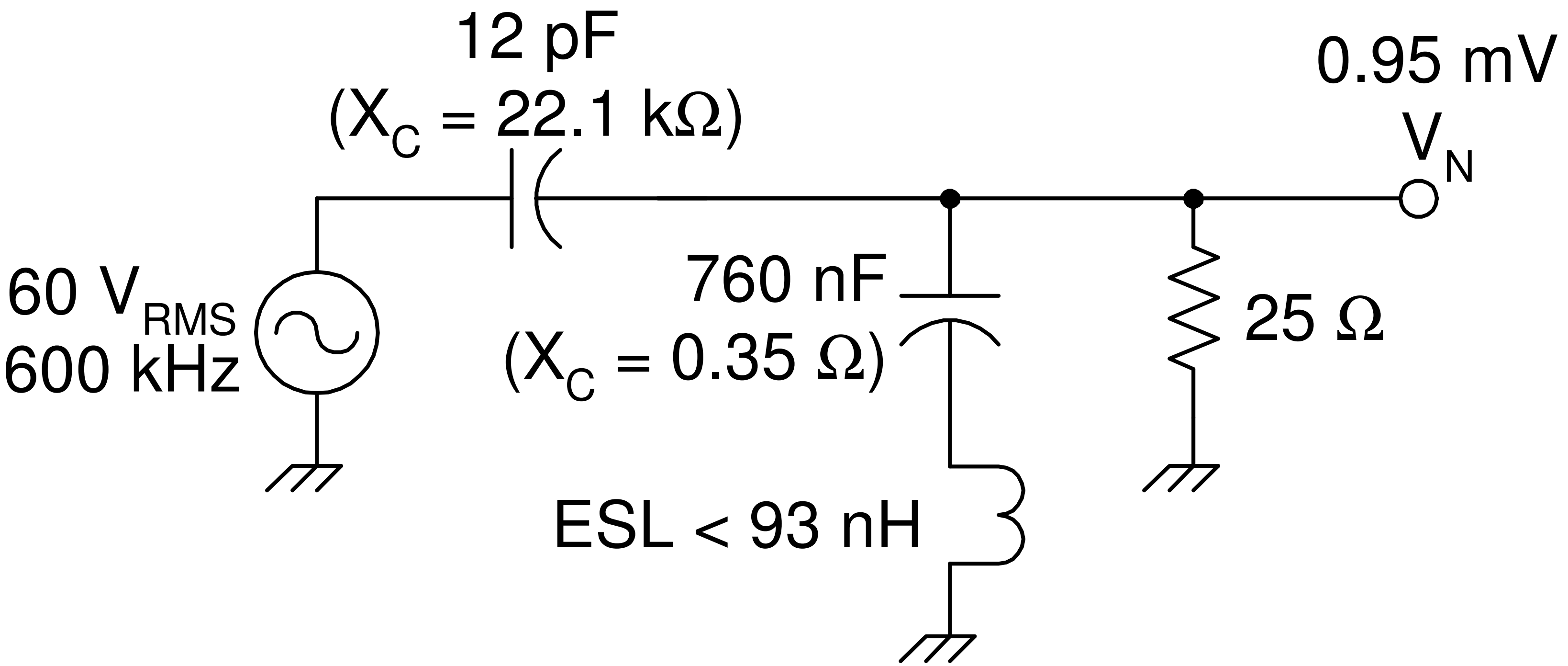
- V_N = 68 mV
- FCC Limit (class A) = 1.0 mV
- Required noise filter attenuation:
  37 db at 600 kHz

Achieving 37 dB Attenuation With Series Inductor



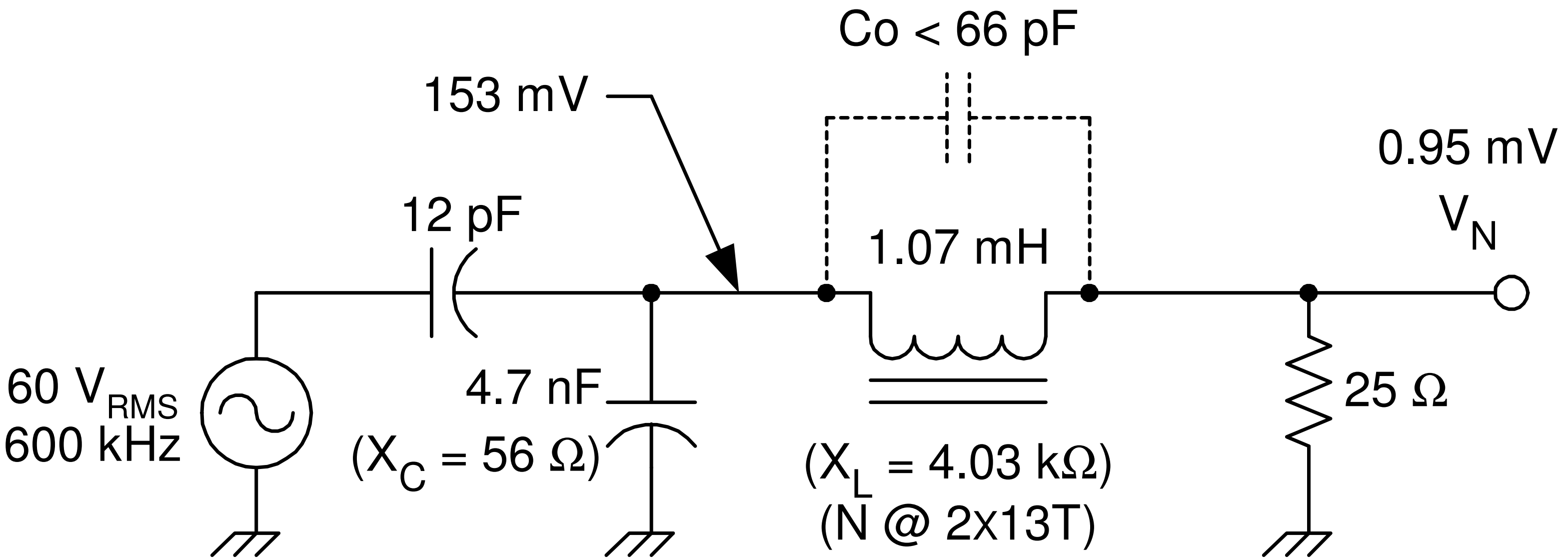
Allowable parasitic capacitance is unrealistic.

Achieving 37 dB Attenuation With Shunt Capacitor

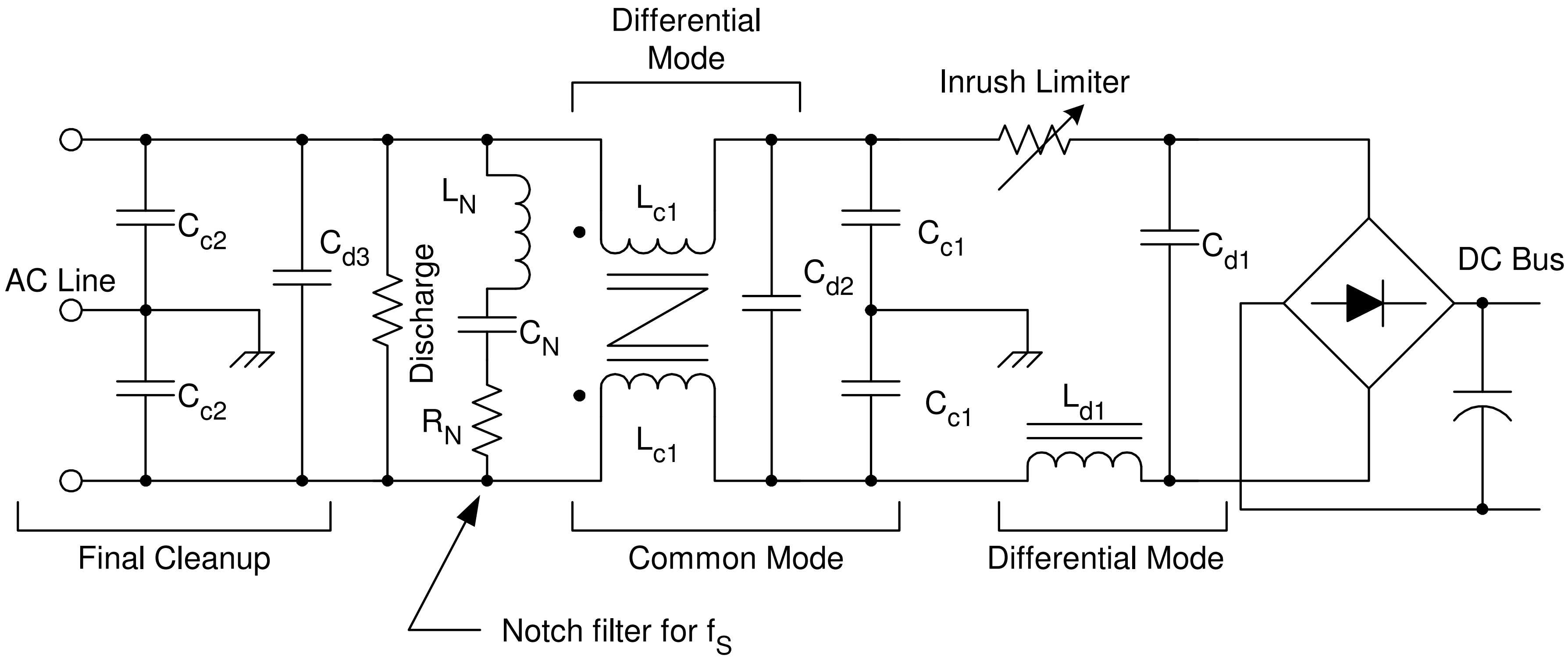


Required capacitor will not meet safety specifications.

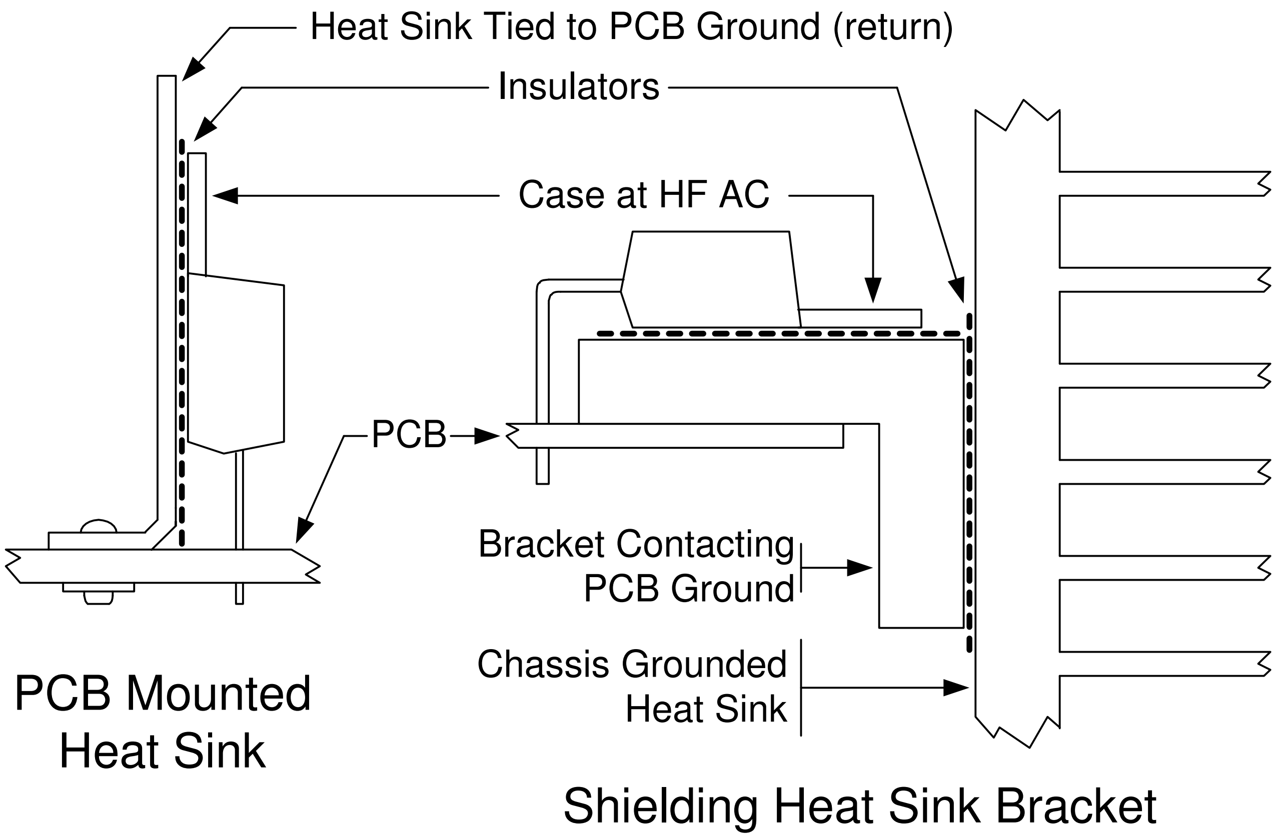
Optimum Solution Uses Both L and C



Complete Input Filter for Both DM and CM Conducted Noise

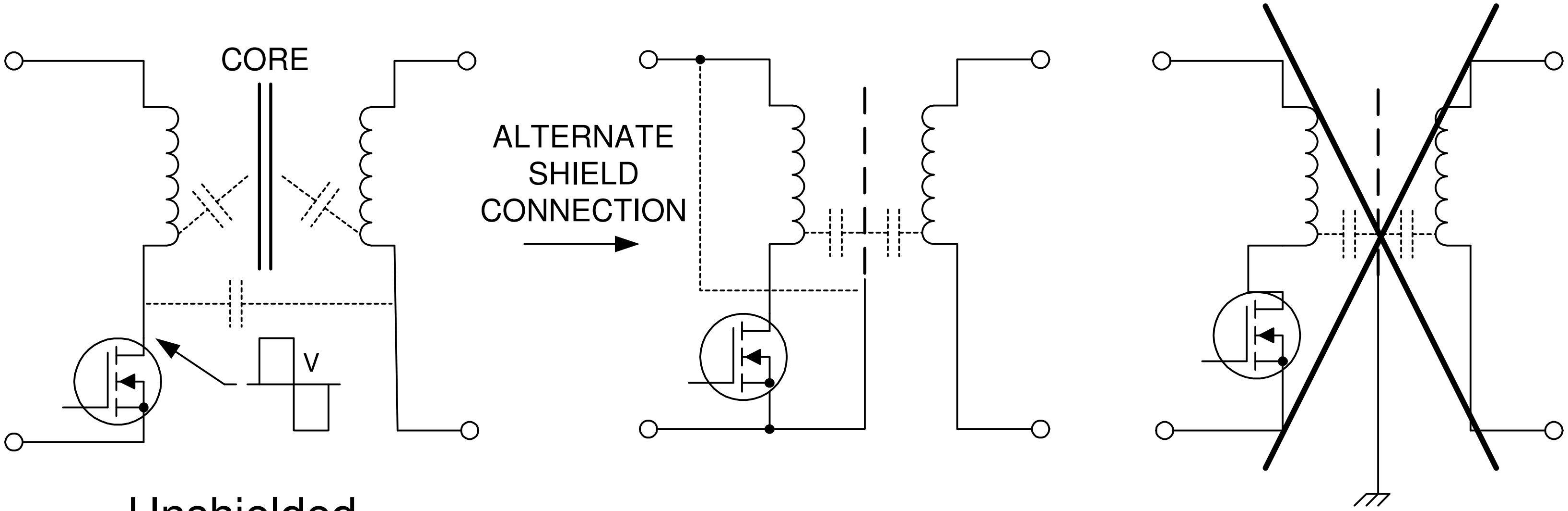


Minimizing CM Noise Injection



Electrostatic Shielding

Use of Primary Shield



Unshielded Transformer

Correct

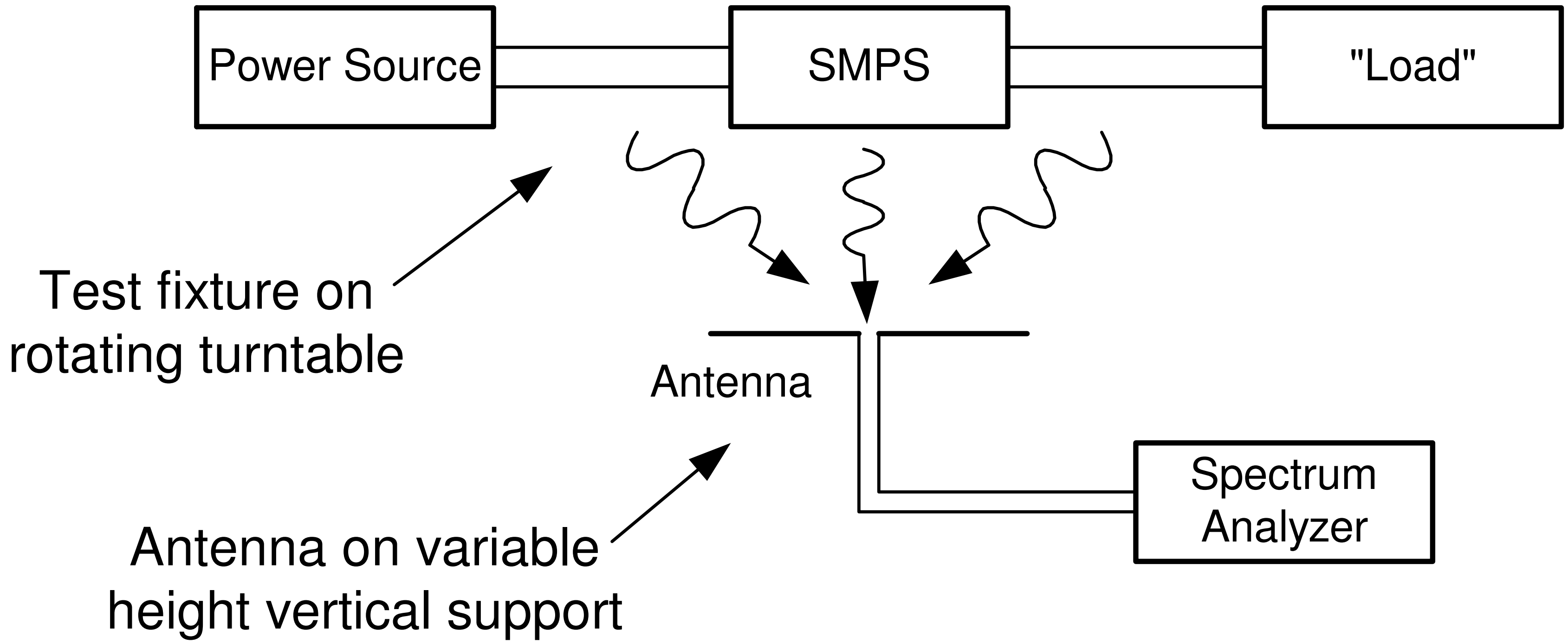
Incorrect!

- Also called a Faraday shield
- Connect to V+ if turn-off is fastest, to return with faster turn-on

Radiated EMI

- Noise is easily transformed back and forth between conducted and radiated form
- Conductors become antennas and antennas become receivers
- Testing more difficult
  - Frequency > 30 MHz
  - Test environment and fixturing is critical

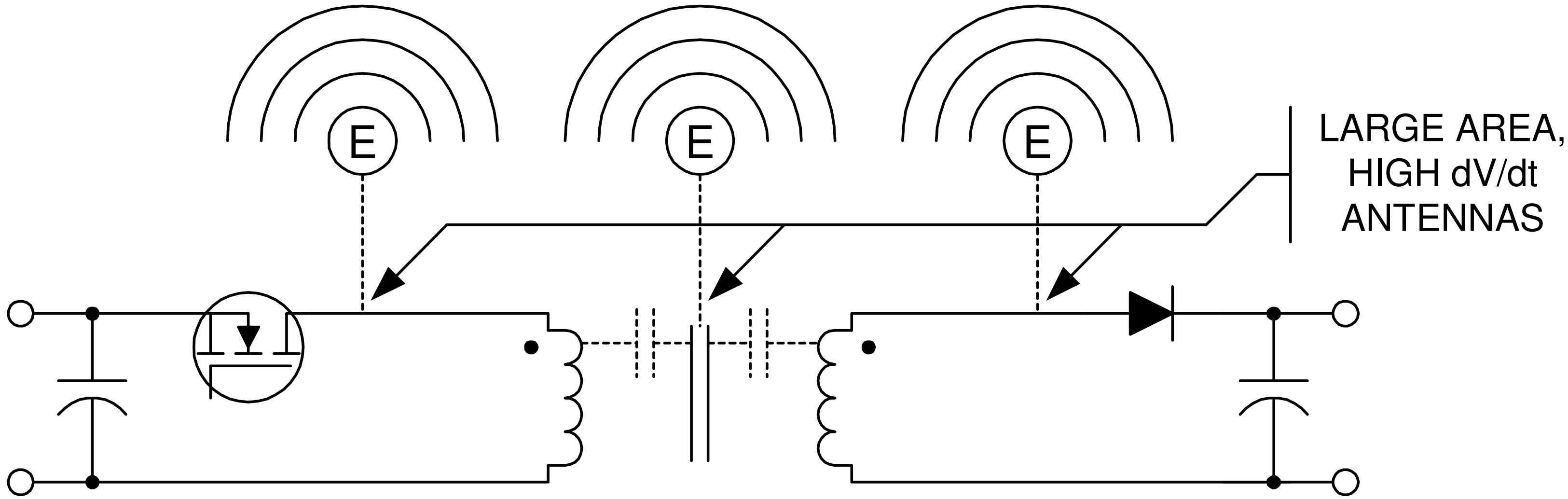
Radiated Noise Measurements



Characteristics of Radiated Noise

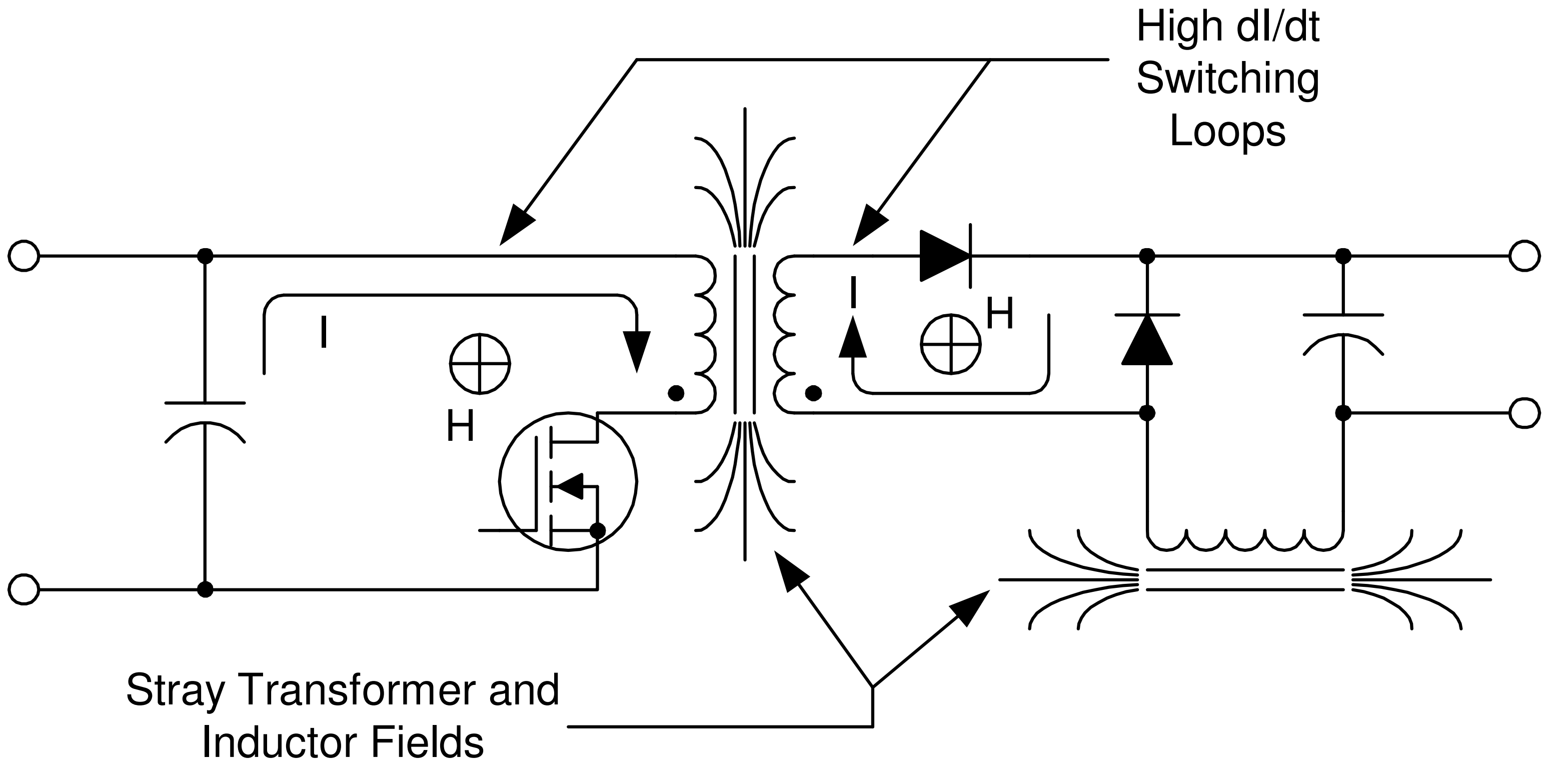
- Electric Field: $E = C\left(\frac{dv}{dt}\right)$
  - Minimize high dv/dt on large surfaces
- Magnetic Field: $H = M\left(\frac{di}{dt}\right)$
  - Minimize high di/dt in conductive loops
- Near Field: $< \frac{\lambda}{2\pi}$
  - Electric and magnetic fields act independently
- Far Field: $> \frac{\lambda}{2\pi}$
  - Electric and magnetic fields merge
- At 1 MHz, $\lambda = 300$ meters

Potential Electric Field EMI Sources



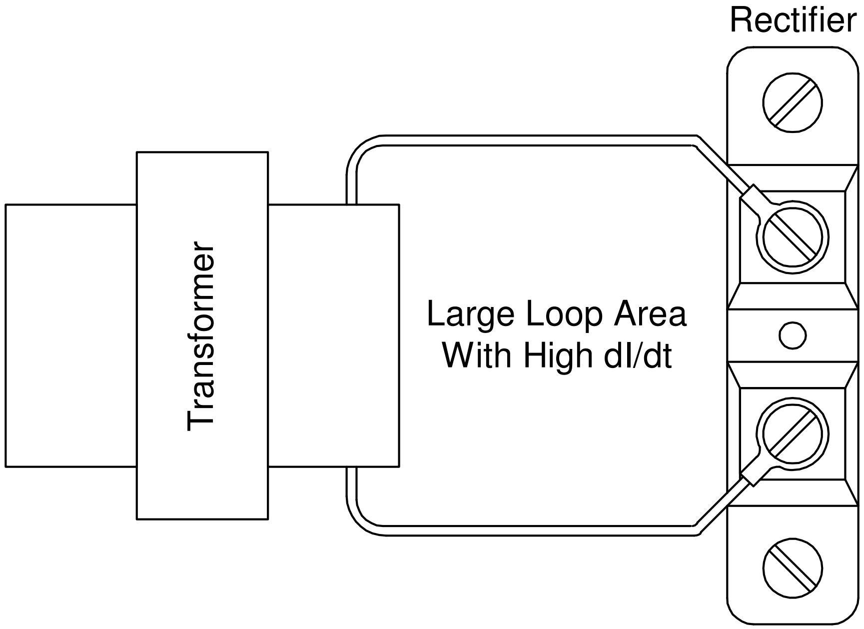
- Shielding possible

Magnetic Fields from Transformers and Inductors

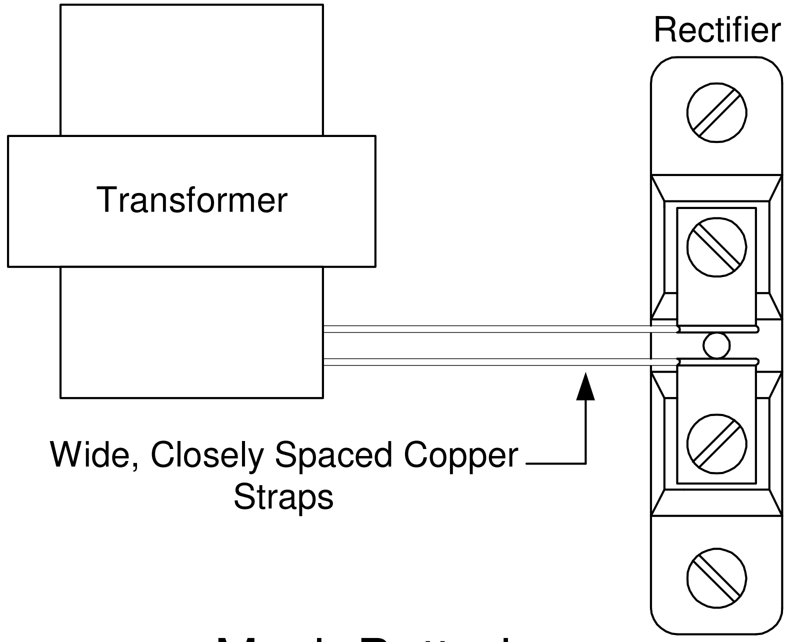


- Shielding difficult

Potential Magnetic Field EMI Sources

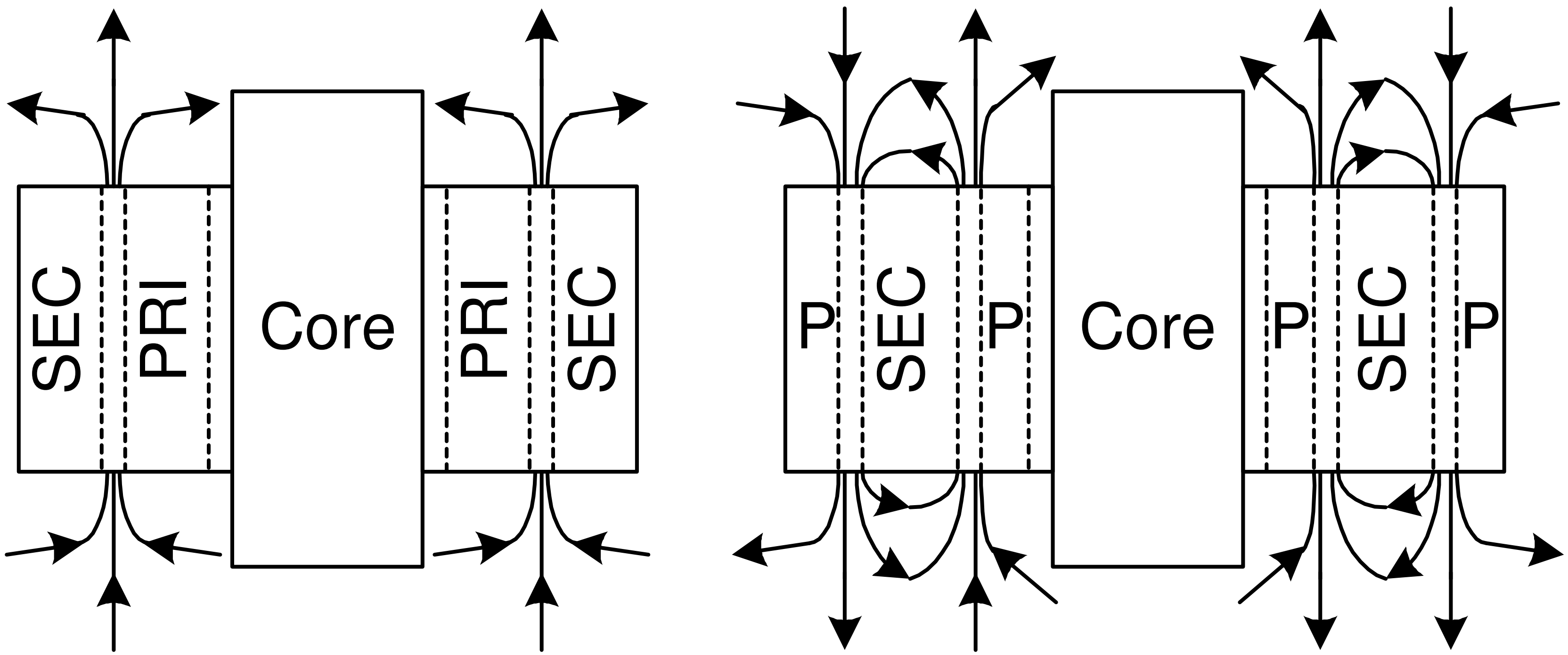


Worst case!



Much Better!

Magnetic Fields from Leakage Inductance

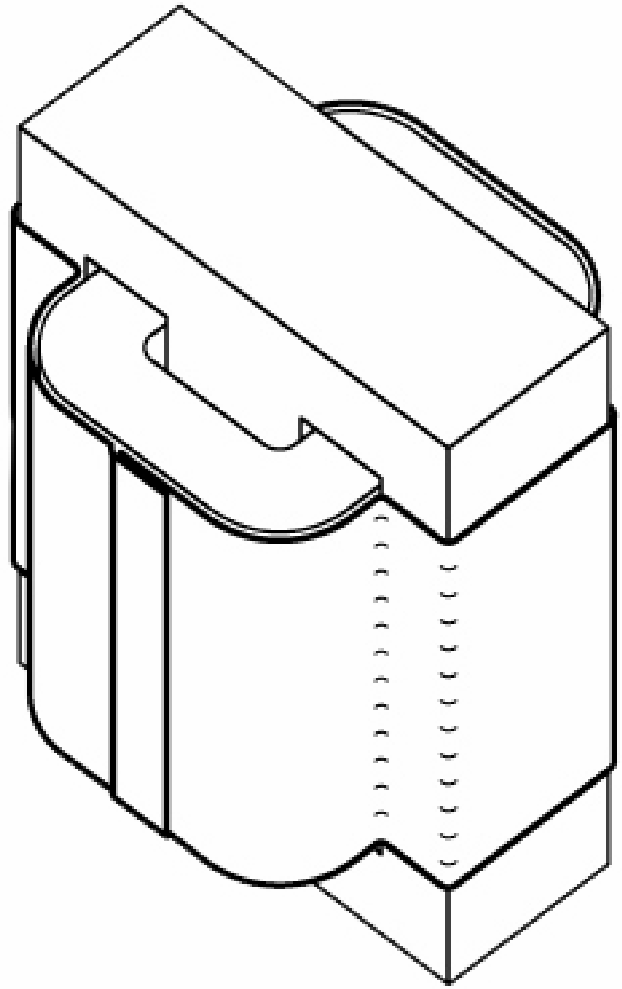


Leakage fields radiate with intensity of $\frac{1}{d^3}$

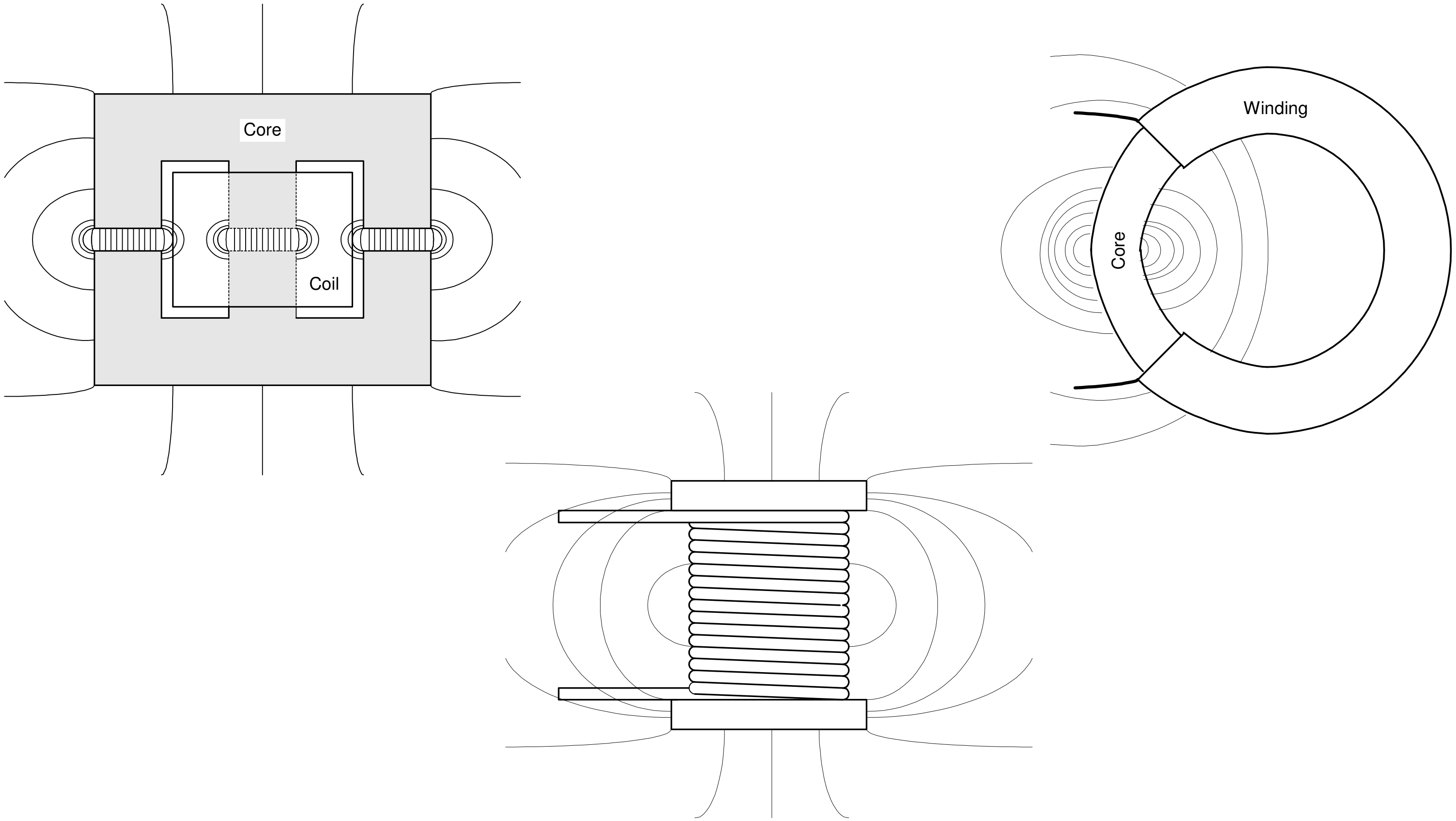
Opposing fields tend to cancel with intensity of $\frac{1}{d^4}$

Minimizing Stray Magnetic Fields in Transformers

- Continuous copper strap around both windings and core.
- Converts stray magnetic fields to eddy current.
- Eddy current creates a canceling magnetic field.



Minimizing Stray Magnetic Fields in Inductors



Poor Construction Techniques

Summary

- Presented a general overview
- Defined various categories of noise
- Described measurement techniques
- Discussed ways to minimize noise generation
- Did not cover shielding or techniques to minimize susceptibility
- Should mention frequency modulation
- Valuable additional references listed