

Electromagnetic Compatibility For Power Converters

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Electromagnetic Compatibility (EMC) has become a household expression over the past decade. In the mid 90s, Europe required a reduction in the level of radiated and conducted emission in products that were to be sold into the region and, at that point, many products incorporated EMC testing into their design cycle. This trend has continued into today's product cycles.

A commonly asked question is, "what is EMC?" It is the ability of a device, product, or system to operate properly in its intended electromagnetic environment (presence of EMI), without degradation and without being a source of interference. EMC standards must be followed and these are regulated by such bodies as the International Electrotechnical Commission (IEC) and the Comité International Spécial des Perturbations radioélectriques (International Special Committee on Radio Interference: CISPR). This article discusses EMC regulations for both radiated and conducted (both common and differential mode) emissions, how power line filter designs can reduce noise either entering or leaving the system and, finally, offers some printed circuit board techniques that can also be used to reduce noise.

EMC Regulations

In order to achieve a solid EMC design, one must understand EMC requirements. Those that follow do not deal with module power supplies; rather they deal with system level standards common in both Europe and in North America.

The IEC is responsible for deriving the European requirements but in saying that, CISPR is responsible for the EMC testing, with CISPR 22 defining the strictest limits on conducted emissions. These limits (conducted emissions) are described in the product standards EN55022 (see Fig. 1) and EN55011 (see Fig. 2). The class A and class B requirements refer to the industrial standard and the domestic standard, respectively. Depending on the antenna used for detecting the noise, the European standards give two limits. The higher limit is for a quasi-peak antenna and the lower limit is for an average antenna, and both limits must be met for the equipment to pass. The FCC standards used in North America have similar specifications to the European EN requirements (see note below Fig. 2). Two European standards, the EN55011 and the EN55022, are used in testing power supplies and Figs. 3 and 4 show the radiated levels of EN55011 and the FCC part 15 subpart B (North America), respectively.

In North America, radiated EMI is most often measured in the frequency range of 30 MHz to 10 GHz (according to the FCC), while conducted EMI is most often measured in the frequency range of several kHz to 30 MHz (according to the FCC).

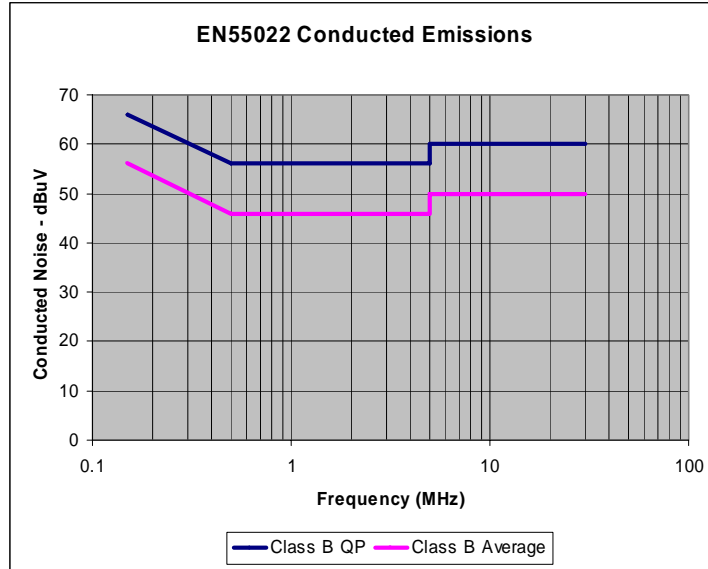


Fig. 1: EN55022 Conducted Emissions

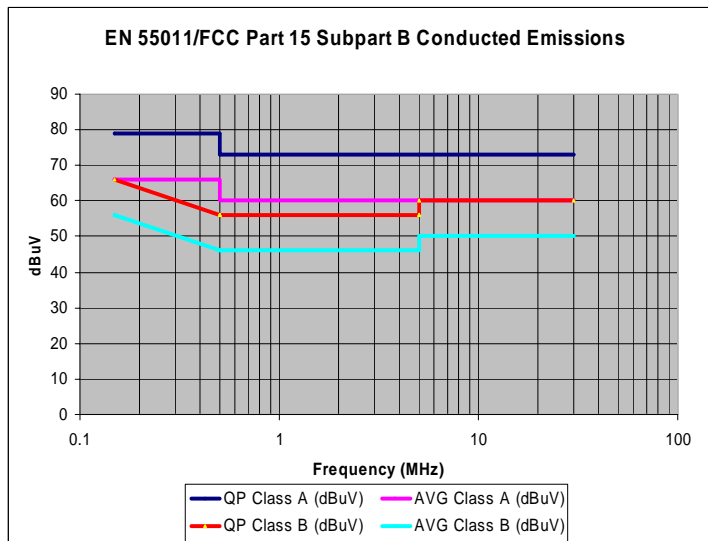


Fig. 2: EN55011/FCC Part 15 Subpart B Conducted Levels

Note: Since May 23, 2004, FCC part 15 subpart B and EN55011 have the same noise conduction level specifications.

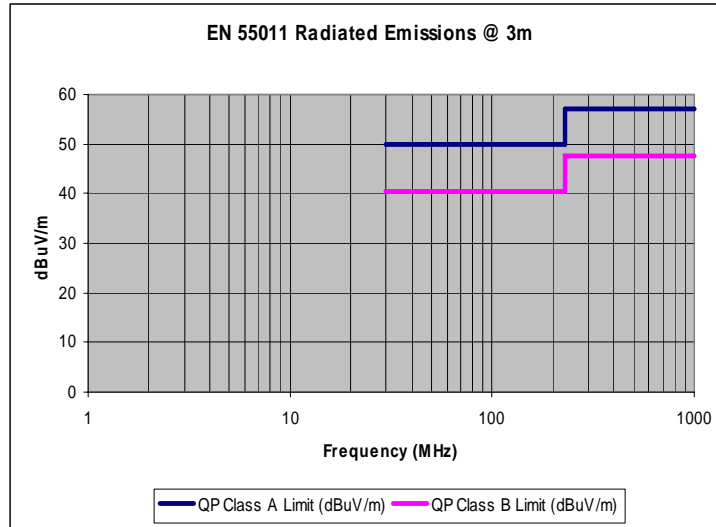


Fig. 3: EN55011 Radiated Emissions at 3 m

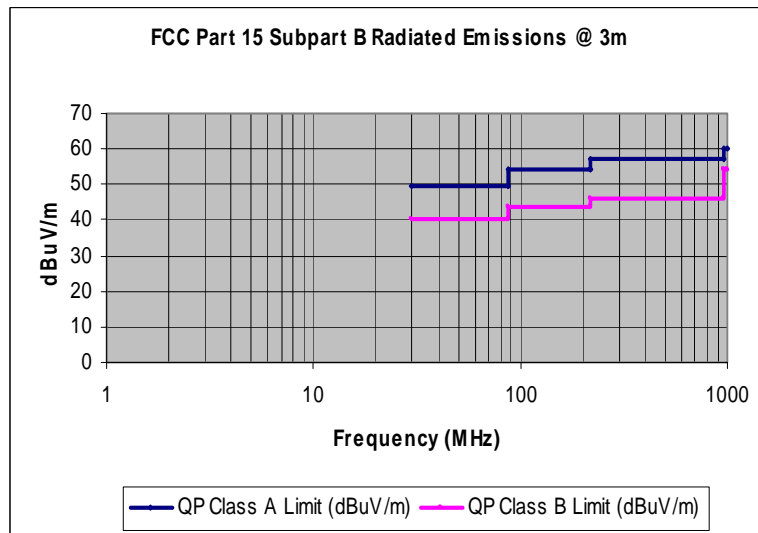


Fig. 4: FCC Part 15 Subpart B Radiated Emissions at 3 m

The goal here is to develop a system that can comply with some or all of the emissions presented above whether it is a standalone device or incorporated into a larger system.

Common-Mode And Differential-Mode Noise

There are two major sources of noise, common mode and differential mode. Common-mode noise (see Fig. 5) comes from a common-mode current. Common-mode energy is common to both lines in a single-phase system. This energy travels on all the lines, or wires, in the same direction, and is between all the wires and ground. Because the same level is on both wires at the same time no attenuation is given by any device between the lines.

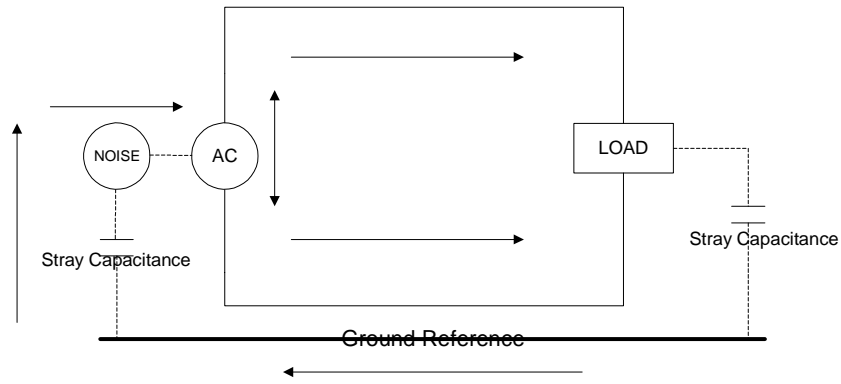


Fig. 5: Common-Mode Noise

Common-mode noise from common-mode current always exists on cables entering the device. One way to minimize these currents is to test the cables early on prototype models (this gives the designer the ability to make any changes necessary before the design is finalized for production) and prior to performing EMC compliance testing. In many cases if the device fails the common-mode current test, it will also fail the radiated-emission test. The common-mode current can be easily measured by using a high-frequency clamp on a current probe and a spectrum analyzer. A current probe with a response range of up to 250 MHz should be sufficient.

Differential-mode noise (see Fig. 6) is the opposite of common-mode noise. This noise is produced by current flowing along either the live or neutral conductor and returning by the other. This produces a noise voltage between the live and neutral conductors.

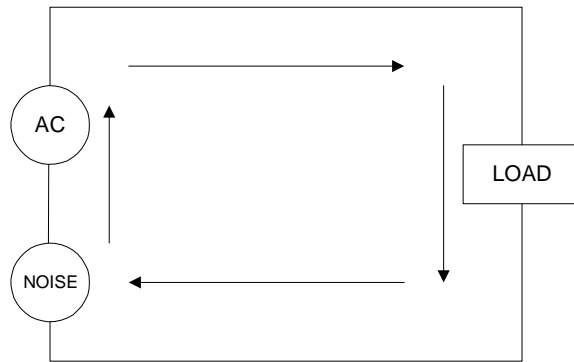


Fig. 6: Differential Mode Noise

Ac Power Line Main Filter

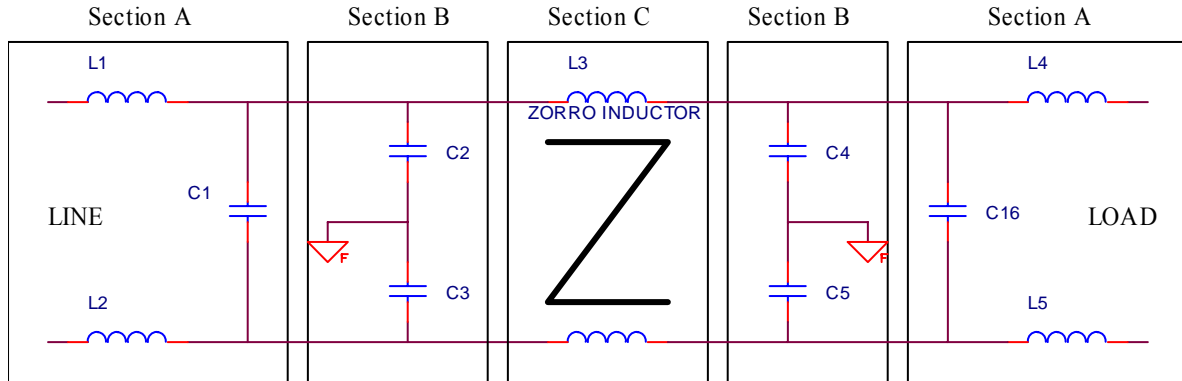


Fig. 7: Single Phase Ac Line Filter

Fig. 7 shows an example of a single phase ac line filter commonly used to reduce both differential- and common mode-noise from entering and leaving the power supply. The filter is divided into different sections to help better describe its overall function.

Note: The two Section A blocks and the two Section B blocks perform the same function with the only difference being one is for noise entering the device where the other is for noise exiting the device.

Blocks:

Section A

Inductors L1/L2 and capacitor C1 represent a differential filter for any noise trying to enter the power supply. Differential-mode noise is produced by current flowing along either the line or neutral conductor and returning by the other. The combination of L1 and C1, or L2 and C1, represent a voltage divider. Depending on the frequency of the noise, the capacitor C1 represents a smaller impedance (larger load) to the signal, thereby reducing any noise on the line. For example, if the impedance of L1 is 10 k Ω and the impedance of C1 is 1 k Ω at a particular frequency, the noise passing through the filter would be a 10th of its original strength or a reduction of 20 dB.

Section B

Capacitors C2 and C3 represent a common-mode filter with a reference to ground. Common-mode noise manifests itself as a current in phase with the live and neutral conductors and returns via the safety ground. This produces a noise voltage between live/neutral and ground. With C2, C3, C4, and C5 all being equal, any common-mode noise on these lines will be shunted to ground.

Note: Section B is not used in medical equipment due to leakage current.

Section C

Section C represents the Zorro Inductor (common-mode choke) without a reference. The direction of each winding is chosen to give an opposing current flow so any noise present will be

cancelled. Magnetic flux caused by common-mode current is accumulated, producing impedance, thereby reducing any noise on the line. Since, in differential mode, there are currents running in different directions, magnetic flux caused by differential-mode current cancels each other, and impedance is not produced, thereby having no effect.

Note: Capacitors C1 and C16 are X Class capacitors, used to reduce differential noise and are tested to withstand mains' voltages. X Class capacitors usually run in the 0.01 μF to 2 μF range. Capacitors C2 through C5 are Y Class capacitors for common-mode noise and are tested to ensure that they will not fail to a short circuit condition (more expensive than X Class). Y Class capacitors are smaller in value, usually running between 0.002 μF to 0.1 μF .

Design Guide To Reduce Internal And External Power Converter Noise

There are three areas of noise generation in an ac-to-dc power supply:

- Any noise already present on the ac mains entering the power supply unit (common mode/differential mode)
- The switching frequency of the power supply (common mode)
- The fast switching edges and ringing produced when the MOSFET is turned off (common mode)

1) AC Mains

With noisy power main lines, an ac power line filter is used making sure it is mounted as close to where the ac power line enters the PCB as possible (see Fig. 8). The ground connection to the filter should also be as short as possible with many vias to the ground plane of the primary side of the power supply.

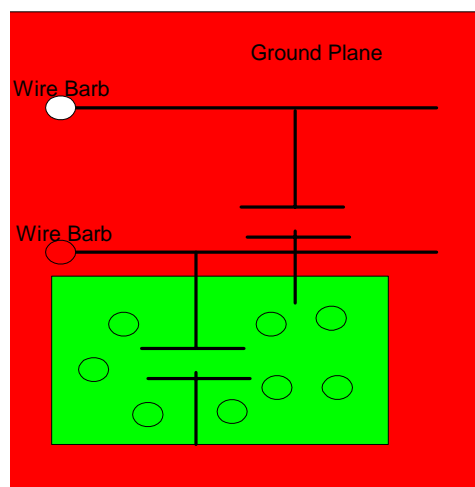


Fig. 8: Grounding The Common-Mode Capacitors To The Ground Plane

In order to reduce common- and differential-mode noise from leaving and entering the unit, an ac power line filter needs to be used. (See earlier section on ac Power Line Main Filter.)

2) Switching Frequency of the Power Supply

Just like in a system that uses a system clock; many power supplies have a pulse width modulator (PWM) device that operates at a frequency used to control the output voltage. So where a system clock needs to be carefully laid out on a PCB, so does the PWM controller.

In a flyback, forward or other topology design using a transformer, it is important to make the trace from the primary winding to the Drain of the switching MOSFET (either internal or external) as wide and short as possible (see Fig. 9). This reduces the inductance path and keeps the ringing to a minimum. It is preferable to ground both the MOSFET and PWM controller to a solid ground plane with the ground plane having a minimal number of holes (not looking like Swiss cheese). There should always be a ground running parallel to the trace for current return (if stray capacitance is not a problem); if there still is a noise issue remove the ground plane from under the trace (Fig. 10) to minimize the drain trace capacitance to the transformer. There are already parasitic capacitors within the MOSFET switch structure that pump current to and from ground. If the ground plane is not removed below the “sliced green” trace, then additional current will be passed into the ground causing more common-mode conducted noise.

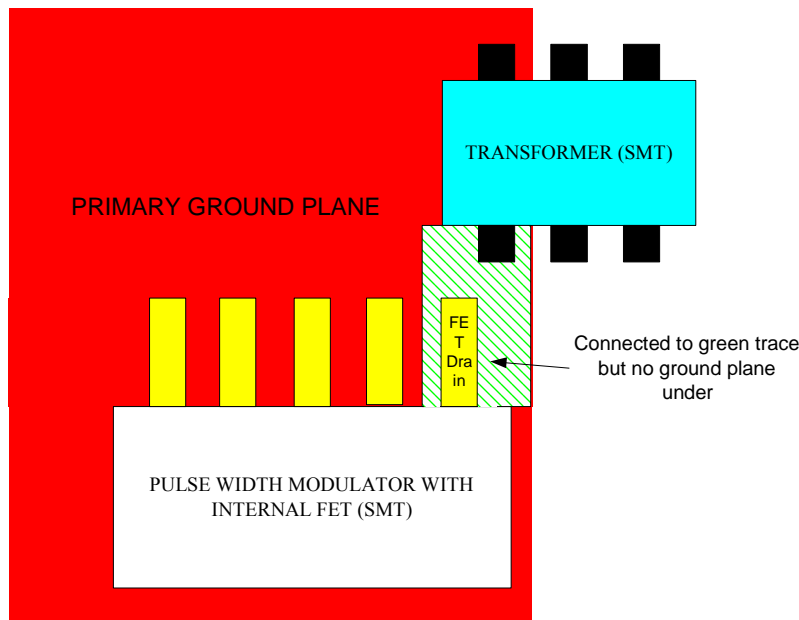


Fig. 9: Reducing Drain Trace Capacitance

The switching MOSFET's Source must have a solid connection to the primary side ground plane. To do this make a large landing pad for the ground terminal so that a proper number of vias (depending on the sinking current) can be used to make a solid connection to the ground plane (Fig. 10).

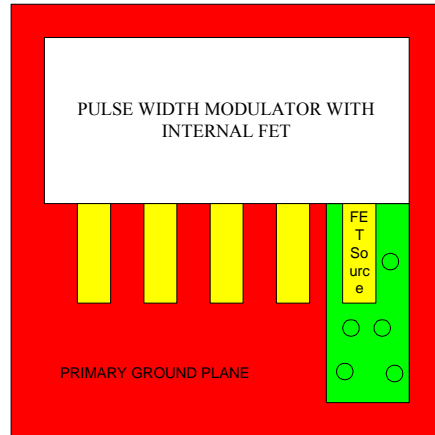


Fig. 10: Connecting The Source Of An Internal MOSFET To The Ground Plane With A Sufficient Number Of Vias

3) PWM Switching Edges and Subsequent Ringing

Fig. 11 shows a Resistor/Capacitor/Diode (RCD) circuit (R1, C1, and D1) that serves two purposes; first C1 slows down the collector voltage rise time (smoothing, reducing radiated EMI) when Q1 is turned off and secondly, it maintains the input voltage to $2V_{CC}$ as not to exceed the breakdown voltage of the switching MOSFET. In making C1 large enough, the rising collector voltage and falling collector current intersect so low that the transistor dissipation is decreased significantly.

The ringing circuit (C2 and R2) is also important and reduces the ringing of the primary side of the transformer, caused when the MOSFET relaxes to the input voltage of the power supply (Figs. 12 & 13).

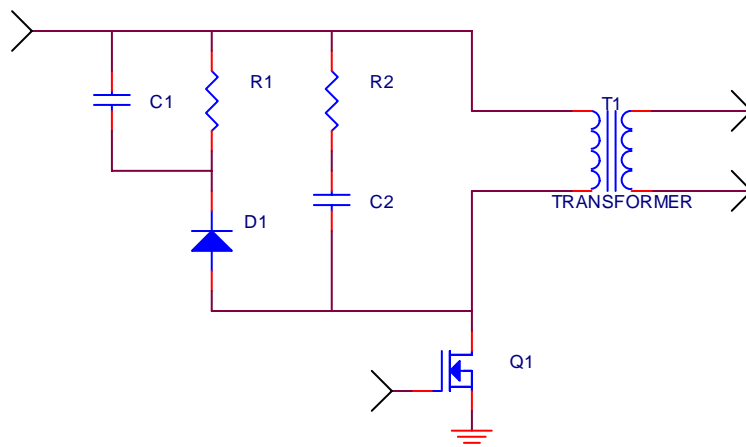


Fig. 11: RCD Snubber and RC Ringing Circuitry

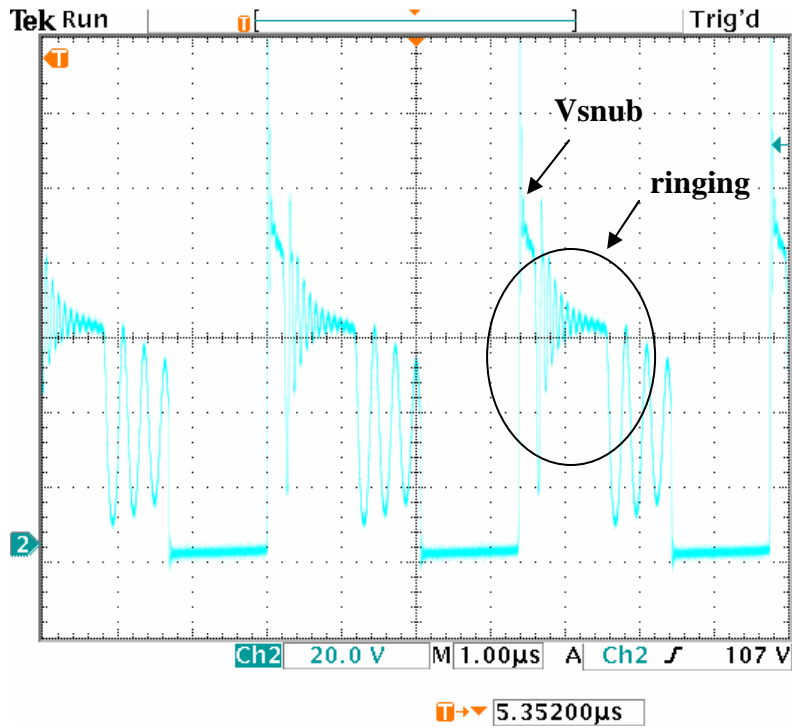


Fig. 12: Primary Voltage Waveform Without Ringing Circuitry (C2, R2).

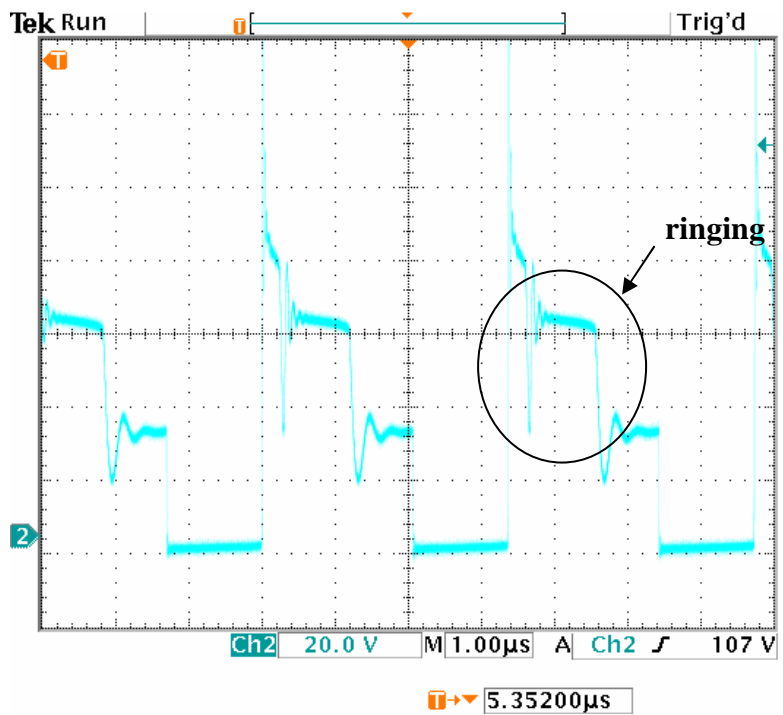


Fig. 13: Primary Voltage Waveform With Ringing Circuitry (C2, R2)

At a first pass, one method of determining the values for C2 and R2 is as follows:

- 1) Determine the frequency of the ringing waveform and calculate the period
- 2) Multiply the period, determined in step 1, by 5
- 3) Assume a value for the resistor (usually less than 100 Ω)
- 4) The value of the capacitor is the number from step 2 divided by the value in step 3

Note: The advantage of using the R2/C2 network is that it reduces the ringing (Fig.12) but the disadvantage is that the high-frequency ripple passing through capacitor C2 gets dissipated as heat in resistor R2. Proceed if noise reduction is more important than efficiency.

Printed-Circuit Board Guidelines

- Take the time to place and orient the components properly
- If heat sinks are used, make sure they are grounded
- A component shield may be required
- Common-mode capacitors should have low ESR values as well as maintain a short lead length to the grounding place
- If a snubber circuit is being used across the transformer to slow down the rise time of the MOSFET switch turning off, make sure that the trace lengths from the Drain and two primary transformer pins are short. If possible, place the snubber circuitry between the two primary pins
- Avoid slots in the ground and power (if used) planes
- Under 50 MHz (don't forget to consider the harmonics of the PWM controller) traditional decoupling methods are effective. Use one or two decoupling capacitors (often 0.1 μ F or 0.01 μ F) placed close to the IC power and ground pins. Consider the loop area formed between the decoupling capacitor and IC, and place the capacitor for minimum loop area
- Keep ground runs as short as possible and as thick as possible
- Avoid sharp corners on traces
- Try to group all noisy components in the same area in case shielding is required
- Use a multi-layer PCB if possible

Safety Dealing With Medical Equipment

Common mode-noise is a problem for sensitive equipment such as those used in the medical field. If a device touches a patient, the total system leakage is limited to 100 μ A. This means that most power supply designers want to restrict this leakage current 20 to 40 μ A. In order to meet this stringent requirement, common-mode filters with capacitors to ground are not used in medical equipment. Using common-mode chokes, feed-through capacitors (high-frequency noise is shunted to the chassis ground instead of signal ground) to ground and adding a transformer or isolating the power supply lines into the power supply reduces these common-mode conducted-emission pulses. Safety standard IEC950/UL1950 class II is used in medical equipment.

Conclusion

EMC is an important consideration in today's system designs and regulations will become more stringent as time moves on. One must keep in mind that when switching occurs, so does noise, whether it be conducted or radiated noise. This article showed board level techniques to reduce noise. If more noise reduction is required, especially on the radiation side, conductive enclosures

are an option. Of course, there are additional costs to add these options. Design engineers will want to evaluate the standard compliance, safety compliance, and costs of the final product.

About The Author

Philip Zuk earned a diploma in Electronic Engineering Technology from Red River College in Winnipeg, MB, then a BSc-EE and an MBA from the University of Manitoba. He has been recognized by the IEEE with a Life Member's Award and a Beta-Gamma-Sigma award in recognition of high scholastic achievement.

Philip has been actively involved in judging technical papers and other science/technology events. He worked as an electronics designer for Vansco Electronics, a custom electronics design house for OEMs, before joining Fairchild Semiconductor as a Staff applications engineer.

