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EMI For Wisdom Seekers (Part 3): Differential Mode Versus Common Mode Noise

by Patrice Lethellier, Noizgon, Salt Lake City, Utah

Having discussed why designers of power supply packaging need an understanding of electromagnetic interference (EMI) and provided a practical introduction to the topic in the parts 1 and 2 (see the references), we now introduce the concepts of differential-mode noise and common-mode noise. These two sources of EMI have different causes and different treatments.

Let's say we have two noise signals in our power supply application. We'll call them A and B. These noise signals A and B can be seen as the combination of a common-mode noise (A+B)/2 which is the average of both signals and of a differential-mode noise (A-B) which is the difference between both. The following equations show the relationships algebraically, while Fig. 1 depicts the relationships with a vector diagram.

$$A = (A + B)/2 + (A - B)/2$$

$$B = (A + B)/2 - (A - B)/2$$

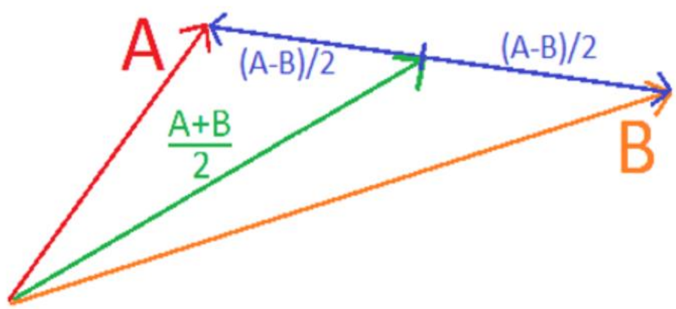

Fig. 1. Common-mode noise (A+B/2) and differential mode noise (A-B) are produced by summing or subtracting of noise signals in a system.

So, we are not going to talk in terms of A and B anymore but rather in terms of differential and common mode. In doing so, we take a big step forward because the common mode and the differential mode are different. They are different types of noise and they are not created by the same phenomena. What is even more important is that they cannot be cured the same way.

Differential-Mode Noise

The differential noise is the nice one, the one that everybody is familiar with. It is a spike across the input line, it is the ripple across a capacitor. It is the noise that we usually see and care about in a simulation.

It is also very easy to solve. Brute force is possible and works for the differential-mode noise. Put a bigger capacitor, a bigger inductance, a bigger filter and we are done.

Common-Mode Noise

The common-mode noise is the monster, the abomination. It pervades everything and is impossible to get rid of. A capacitor between both wires will do nothing for common mode.

You need to put a capacitor between each wire and ground and you cannot put a large one. Safety standards like UL limit the ground leakage current for people's safety.

Even if you could use large capacitors, it would do almost nothing because the ground is inductive. Yes, the green ground wire (dear to UL) is very inductive, and performs well only at 50/60 Hz. At high frequency, however, it might as well not be there.

It is possible to filter the common-mode noise with common-mode inductances (obviously). But these common mode inductances are large and require a special expensive construction. They need a large number of turns and that brings parasitic capacitances, which will bypass them.

Common-mode noise is very difficult to filter.

The only practical solution is not to create any common-mode noise in the first place (see Fig. 2).

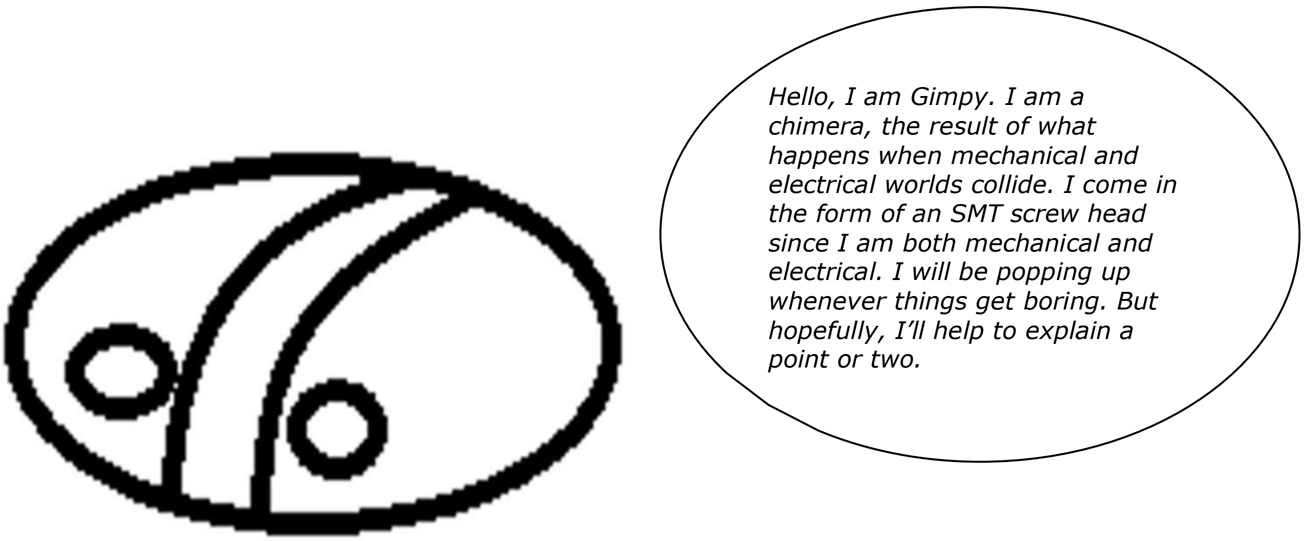

Fig. 2. Gimpy the screw head lives in both the mechanical and electrical worlds and knows a thing or two about EMI.

But what is the mechanism of the common-mode noise generation?

The common-mode noise is caused by fast and large voltage swings pushing through parasitic capacitors. The large voltage swings are coming from the normal operation of a PWM-based switching power supply. A linear power supply does not have such voltage swings. The parasitic capacitors are the result of circuit proximity due to tight packaging.

What can be done to avoid creating common-mode noise?

Simply put, limit the voltage swings.

Yes but linear power supplies are ten times larger and are not efficient. Resonant power supplies, another option, are tricky and the operating range is limited. A third possibility, soft commutations, do limit the voltage swing but it is still there.

Another tip is to reduce the parasitic capacitances.

Where are the parasitic capacitances?

In the power transformer. A power transformer requires a tight coupling, even sometimes a sandwiched construction. This leads to a large parasitic capacitance between primary and secondary. The large voltage swing on the primary winding pushes on the secondary through the parasitic capacitor. This creates common-mode noise between primary and secondary. A resonant power supply works with a loose coupling and will have less parasitic capacitance.

The heatsink is another source of parasitic capacitance. The same voltage swing found on the silicon of the power switches is found on the heatsink. This is without consequence if the active voltage switch node is free to swing without interference (Fig. 3) However, the heatsink needs to be mechanically secured to the chassis to use the chassis' thermal mass. The parasitic capacitance introduced by the heatsink will create common-mode noise on the dc rail (Fig. 4.)

Fig. 3. If an active power supply switch node (analogous to Gimpy's tail) is able to "swing free" electrically, (i.e. the heatsink is electrically floating), the presence of the switch-node voltage on the heatsink would not produce conducted EMI on the dc power rails.

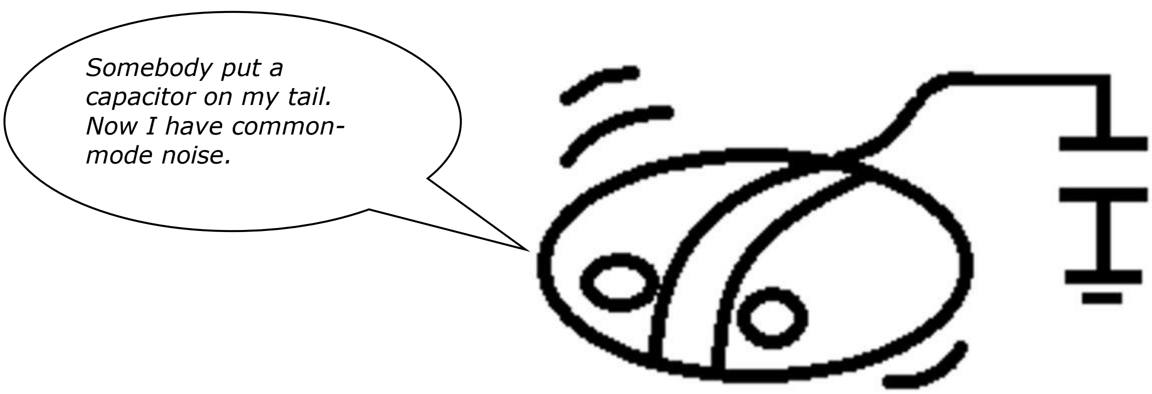

Fig. 4. The parasitic capacitor on Gimpy's tail tries to hold the tail quiet but the whole of Gimpy is swinging. Gimpy cannot move its tail anymore but keeps trying and is now shaking (this is common-mode noise). Put another way, the parasitic capacitance between the heatsink and the chassis means that the heatsink is not floating with respect to ground, so the presence of the switch-node voltage on the heatsink produces common-mode EMI on the dc rails.

Once created, the common-mode noise reaches everywhere in the design. On the switch node side (represented by Gimpy's tail) it will send noise into the ground and create a ground loop. The whole enclosure has now been compromised and carries high-frequency noise. On the dc rail side, the common-mode noise will try to escape to the outside through the input lines. The common-mode noise which has been injected is very sharp and has the amplitude of the dc rail. We are talking about a noise of several hundred volts.

Fig 5 depicts waveforms associated with a totem pole configuration of two MOSFETs. The red and green are the + and - of the input dc rail. Without the capacitor (as shown on left) the waveforms are clean. This is like the case where Gimpy moves its tail but is not moving its body because there is no cap on the tail (i.e. the switch node). Then, when we place a cap on the tail/switch node, it cleans up the tail/switch node. As shown on the right, the blue edges of the switch-node waveform are much softer now. But the noise has migrated to the dc rail because the noise generator is still pushing.

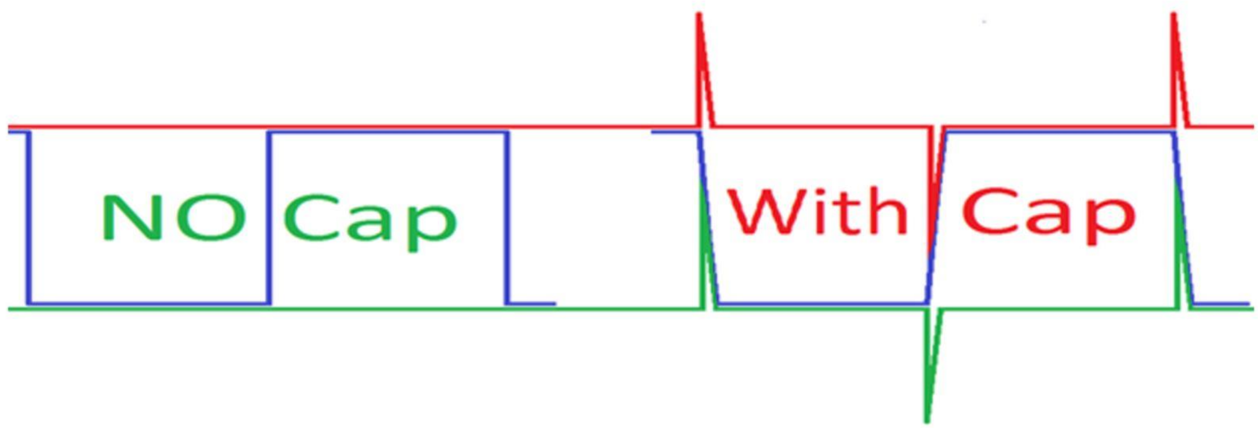

Fig. 5. Switch-mode waveforms (blue) and dc rail waveforms (red and green) for the case of a totem-pole configuration of two MOSFETS. As depicted by the waveforms on the right, the parasitic capacitance between the heatsink and chassis leads to a common-mode noise signal as big as the switch-node signal riding on the dc rail.

In order to clean up one side of a noise generator, the other side needs to be able to swing freely. Parasitic capacitive coupling of a high dV/dt node to ground is the worst possible packaging problem. It is the absolute killer for solving EMI and should be eliminated up front before any other consideration.

There are several possible solutions. Some are purely electrical, some are purely mechanical. Other solutions are 50/50.

For capacitive coupling inside the transformer, there are certain solutions. For the capacitive coupling caused by heatsinking, there are other solutions. An EMI specialist can help you to select the best solution for your application.

We are going to describe here one of the purely mechanical solutions solving the heatsinking problem. This is to show that an electrical problem can be solved by a packaging improvement.

The mechanical engineer in charge of the packaging design should be involved with the EMI problem. That's because the packaging is of uttermost importance to solving EMI. Unhappily, EMI solving techniques are not very familiar to most MEs.

In the case of the heatsink-induced EMI, the challenge is to provide a very good thermal link without electrical capacitive coupling. However, there is a material which can provide a good thermal link even with a subsequent thickness, which is needed to minimize capacitive coupling.

We are talking here of a thick slab of aluminum nitride (Al-N). The only better material is beryllium oxide (Be-O) but we do not want to use this one because of its toxicity. But I believe that Be-O is used in the military (missiles) where even Al-N is not good enough.

Aluminum nitride will provide the thermal conduction without virtually any capacitive coupling. Aluminum nitride is a ceramic which is very hard and cannot be machined after it has been fired. This solution is not widely used because of the cost but in some instances, it is the only one possible. For example, in the 200-kW unit I was discussing at the end of part 2, $10,000 worth of aluminum nitride was used to thermally couple the heatsink to the chassis.

References:

1. "EMI For Wisdom Seekers: (Part 1): What New EEs And MEs Need To Know" by Patrice Lethellier, How2Power Today, November 2017 issue.

2. "EMI For Wisdom Seekers (Part 2): Keeping It Simple" by Patrice Lethellier, How2Power Today, December 2017 issue.

About The Author

Patrice Lethellier is a consultant with Noizgon where he specializes in preventing and solving power supply EMI problems, while also consulting on most other aspects of power conversion. Results oriented, all of his consulting work relates directly to proactive and productive design. Patrice has over 40 years of experience in industry as a power supply design engineer in OEM and merchant power supply companies and as an application engineer in power semiconductor companies. Since 2014 Patrice has been a senior engineer with Wave, where he has developed wireless battery charging solutions from 50 kW to 200 kW for electric buses.

Prior to this, he served as an application engineer with notable power semiconductor companies such as Volterra, National Semiconductor and Semtech. Before that, he worked as a design engineer at various power supply and system companies including C&D Power Technology, Pioneer Magnetics, Elgar and Unisys. Patrice holds a total of 20 patents in various fields with some currently in process. He has an Engineer Diploma from ISEN in Lilles, France.

For more information on EMI, see How2Power's Power Supply EMI Anthology. Also see the How2Power's Design Guide, locate the Design Area category and select "EMI and EMC".