

AnalogDialogue

Does the Assembly Orientation of an SMPS Inductor Affect Emissions?

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The spectrum of EMI emissions produced by switch-mode power supplies (SMPS) are a function of a number of parameters, including the size of the hot loop, switching speed (slew rate) and frequency, input and output filtering, shielding, layout, and grounding. One potential source of emissions is the switching node, referred to as SW on many schematics. The SW node copper can act as an antenna, transmitting the noise generated by fast and efficient high power switching events. This is the main source of emissions for most switching regulators.

The amount of top layer SW node copper certainly should be minimized to limit the antenna size. With a monolithic switching regulator (power switch within the IC), the SW node runs from the IC to the inductor with a short trace on the top layer. With a controller (power switch external to the switch controller IC) the SW node can be self-contained at the switches, away from the IC. SW node copper connects to one side of the inductor in buck and boost switcher topologies. Because of a number of performance parameters involved, layout of the Layer 1 SW node in the XY plane of the PCB, or on internal layers, is a bit of a black art (see Figure 1).



Figure 1. SW node highlight in XY plane of Layer 1 on DC3008A LT8386 low EMI LED driver.



Figure 2. White stripe on the Coilcraft XAL inductor marks the short coil lead because coil leads are not visible. It indicates the direction of terminals and short lead. Connect high dv/dt here for lowest EMI.

Inductor Geometry

Of course, the SW node also extends vertically (in the Z plane) when the inductor terminals are considered. The vertical orientation of the inductor terminals can increase the antenna effect of the SW node and increase emissions. Furthermore, internal inductor windings may not be symmetrical. Even if an inductor's symmetrical terminals suggest a symmetrical construction hidden in the package, the polarity indicator on the top of the component tells a different story. Figure 2 shows the internal winding structure of Coilcraft's XAL inductor series. The flat wire winding starts at the bottom of the component and ends at the top, so one terminal ends up being much shorter than the other in the Z plane.

Furthermore, inductors with an exposed SW node on the side may perform worse than those with shielded vertical metal, as shown in Figure 3. A board designer could choose inductors with the least amount of vertical and exposed terminals to reduce EMI, but what about the orientation of the two inductor terminals and the relative effect on emissions?

Emissions Tell the Story

Low emissions performance of a board under test is a combination of IC emissions performance and layout considerations. Even with a low emissions monolithic IC, care must be taken regarding layout while also taking into account the assembly of the critical emissions components. To prove this point, we examined the orientation effects on the board of the main inductor, L1, of an LT8386 demonstration circuit (see Figure 4). In this case, the inductor manufacturer, Coilcraft, specifies the short terminal of XAL6060-series inductors with a white line on the top mark of the component. Standard CISPR 25 conducted emissions (CE) and radiated emissions (RE) tests in the EMI chamber show that the placement direction (see Figure 5) of this inductor critically affects performance.



M1: Vishay S02309ES Figure 4. SW node highlighted in schematic view of DC3008A LT8386 low EMI LED driver. Place the short-side terminal at Orientation 1 and Orientation 2 to compare the complete emissions results.

vr

≷ 10 kΩ

1000 pF

SS

Ι

100 nF

NO SSEM

C1: Suncon 63CE22BS

FB1, FB2: Taiyo Yuden FBMH3225HM601NTV FB3: Taiyo Yuden FBMH2012HM221-TV L1: Coilcraft XAL6060-223 L2: Coilcraft XAL5050-103

RT

294 kΩ }

340 kHz

Ī

1μF

100 V

91 kΩ



Figure 5. Coilcraft XAL6060-223MEB inductor orientation emissions testing with a DC3008A LT8386 LED driver. An L1 Orientation 1 (left) with short terminal on the SW node and L1 Orientation 2 (right) with long terminal on the SW node. Emissions results are shown in Figure 6 through Figure 8.

Figure 6, Figure 7, and Figure 8 show that the emissions performance of DC3008A is directly affected by the orientation of L1 on the demonstration circuit, with no other component changes. Specifically, low frequency RE (150 kHz to 150 MHz) and FM bands CE (70 MHz to 108 MHz) have lower EMI with Orientation 1—that is, the short-side terminal placed on the SW node. A 17 dBµV/m to 20 dBµV/m difference in the AM band cannot be ignored.

Not all inductors are created equally. The winding direction, the shape of the terminals, the shape of the terminal connections, and even the core material can vary. Strength of the H-field and the E-field with different core materials and construction differences might play a role in varying emissions amongst inductors. However, this case study reveals an area of concern, which can be used to our advantage.



Figure 6. Radiated emissions show that the inductor orientation on DC3008A makes a significant impact on results. With the short-side terminal attached to the SW node for the smallest SW antenna (red), radiated emissions (RE) are drastically improved.



Figure 7. Current probe method conducted emissions (CE) show improvement (>3 MHz) with the short-side terminal of the inductor attached to the switch node vs. the alternative polarity.



Figure 8. Voltage method conducted emissions (CE) show improvement above 3 MHz with the short-side terminal of the inductor attached to the switch node vs. the alternative polarity.

1k

Inductors Without Polarization Indicator

Orientation is easily determined if the inductor manufacturer indicates a difference in internal terminal size with a top silkscreen mark or dot. If one of these inductors is chosen for a design, it is wise to indicate the mark on the silkscreen of the PCB, the assembly diagram, and even in the schematic. Unfortunately, some inductors have no polarization or short terminal indicator. The winding structure inside could be close to symmetrical, or there could be a known structural difference. There is no ill intent here—manufacturers may not be aware of this very particular assembly direction trade-off inherent in their product. Regardless, we suggest evaluating emissions in both orientations in a certified chamber of a selected inductor to ensure repeatable high performance measurements.

Sometimes there is no external mark, and assembly direction of the inductor is unavoidably arbitrary—yet the inductor is desirable for other parameters. For instance, Würth Elektronik's WE-MAPI metal alloy power inductors are small and efficient. They have terminals that only reside on the bottom side of the case. Each part has a dot on the top near the WE logo, but the dot is not indicated on the data sheet as a start of winding indicator (see Figure 9). Although this presents some confusion at first, the part is expected to perform the same in both assembly orientations with a rather symmetrical internal winding structure. The dot on the top of the IC therefore does not have to be indicated on the assembly silkscreen. Still, if used in an EMI-critical circuit, it might be wise to test in both directions to be sure.

Another Example: Würth WE-XHMI

We tested the DC3008A with a high performance Würth inductor whose start of winding is indicated with a dot on top of the package and in the data sheet (see Figure 10). The 74439346150 15 µH inductor is a great fit for the LT8386 form factor and current requirements. Again, for comparison with Coilcraft, emissions tests are run with this inductor mounted in both directions (see Figure 11).

The results (see Figure 12) are similar to the Coilcraft inductor. The emissions results show us that the orientation of the inductor in assembly has a significant effect on emissions. In this case, Orientation 1 in Figure 11 is clearly the best direction for lowest emissions. Lower frequency AM band (RE) and FM band (CE) emissions are clearly better with Orientation 1.



Figure 9. The WE-MAPI inductor data sheet does not indicate a start of winding dot, although there is a start of winding dot on the top marking of the component. These inductors may have no orientation-emissions effects, but one should test to be sure.



Figure 10. The start of winding for a WE-XHMI series inductor is indicated by the top-part marking.



Figure 11. Würth 74439346150 ("WE 150") inductor orientation emissions testing with a DC3008A LT8386 LED driver. An L1 Orientation 1 (left) with a short terminal start of winding on the SW node and L1 Orientation 2 (right) with a long terminal on the SW node. Emissions results in Figure 12 show that the start of winding should be connected to the SW node for the best results.

2-Switch-Node Buck-Boost ICs (Results to Follow)

It is evident that inductor orientation can have an effect on emissions in a single switch-node boost LED driver. We can assume that boost voltage regulators have the same characteristic emissions results from the SW node since the power conversion and switching elements are the same in both voltage regulator and LED driver circuits.

We can also assume that buck regulators have similar SW node design priorities with regards to minimizing the antenna effect of the inductor terminals. Still, since the SW node of the buck regulator is closer to the input side of the converter, follow-up work might help determine if the effects of the inductor orientation are the same in regions of RE and CE as the boost regulator. For 2-switch-node buck-boost converters, there is a bit of a predicament. Popular buck-boost converters such as those in the LT8390 60 V synchronous 4-switch buck-boost controller family have important low EMI features such as SSFM and small hot loop architecture. The single-inductor design creates a less clear picture of how inductor orientation might affect emissions. If the short terminal is placed on one SW node, then the long terminal acts like an antenna on the other SW node. In these designs, which orientation is best? What happens when all four switches are switching in the 4-switch operation region (V_{IN} close to V_{OUT})?

We will explore this question in a future article, where a 4-switch buck-boost controller with two SW nodes is EMI tested against inductor orientation. Food for thought: maybe there are more than two choices, 180° apart, for this topology?



Figure 12. Radiated and conducted emissions show that the assembly orientation of Würth 74439346150 high performance inductor has a significant impact on emissions results.

Conclusion

Assembly orientation of the inductor in switching regulators does matter. When measuring emissions, note both the inductor orientation and its repeatability—be aware of any differences regarding the chosen inductor, test in both directions,

and communicate clearly to board production any possible assembly pitfalls if orientation cannot be determined. Improved emissions could just be a simple 180° inductor rotation away.



About the Author

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Frank Wang received an electrical engineering master's degree from the University of Texas at Dallas and worked in an independent, accredited compliance lab before joining Analog Devices. He has four years of relevant work experience as an EMC/EMI test engineer and project lead. Frank has experience in standard testing, arranging schedules, debugging with engineers, calibrating testing instruments, and chamber maintenance. He can be reached at frank.wang@analog.com.



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