Technical Article

How to characterize a power transformer for EMI performance

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Power transformers are often the main source of common-mode noise in isolated switching power converters. Why? Because inside the transformer, the windings on the primary and secondary sides of the isolation barrier are in close proximity—usually separated by less than 1 mm—resulting in significant parasitic capacitance between the adjacent windings.

The voltages that appear on these windings typically have large AC content. For example, in the flyback converter shown in Figure 1, the primary winding connects to the drain of the primary switch, which has a voltage waveform with large AC content across many frequencies. This AC voltage injects common-mode currents from primary to secondary through the parasitic capacitance, which is often the source of many electromagnetic interference (EMI) problems.

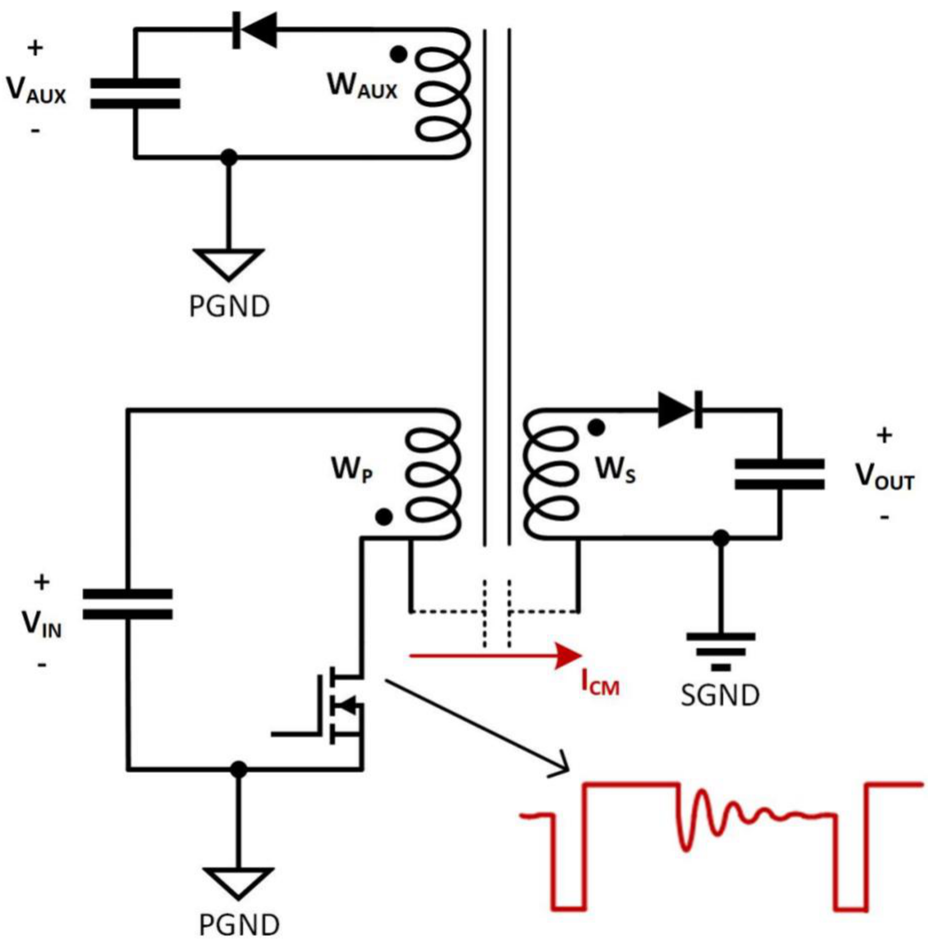

Figure 1. Common mode noise created by a flyback power transformer. Source: Texas Instruments

Thankfully, transformer design techniques such as shielding and common-mode balancing can minimize the transformer impact on EMI, as discussed in the Texas Instruments Power Supply Design Seminar paper, "Flyback Transformer Design Considerations for Efficiency and EMI". It can be quite difficult and time consuming, however, to check how much your transformer contributes to EMI and how to optimize the transformer construction. For each transformer design that you want to test, you need to solder the transformer into the PCB, take your power converter to an EMI test fixture, and run the scans. If the EMI performance of your transformer is not acceptable, you need to unsolder it from your PCB and try again.

In this Power Tip, I will show you a very easy way to check the EMI performance of your transformer before ever soldering it into your board.

Using only a function generator and an oscilloscope, you can mimic the conditions seen by the transformer in the circuit and measure the transformer's common-mode EMI signature. The diagram in Figure 2 shows how to configure this measurement for the transformer used in Figure 1. Notice that this transformer has two windings on the primary (W_P and W_{AUX}) and one winding on the secondary (W_S).

First, use a short piece of wire to tie the AC quiet nodes together on the primary. An AC quiet node is any pin on the transformer that ties to primary ground in the circuit, either directly to or through a capacitor. In this example, both Pin 2 and Pin 3 are AC quiet nodes on the primary side of the isolation barrier. If you have a transformer with multiple windings on the secondary, you will also need to tie all of the secondary quiet nodes together, but do not connect them to the primary quiet node.

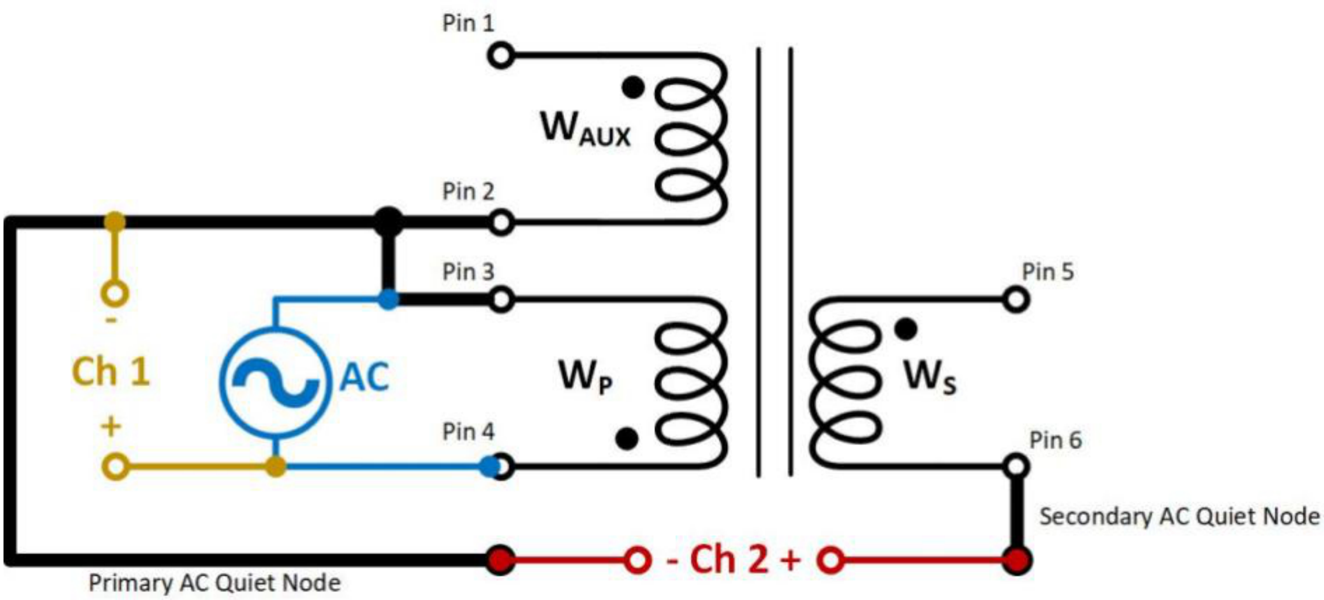

Figure 2. Transformer CMRR test setup that uses a short piece of wire to tie the AC quiet nodes together on the primary and secondary, and applies a small sinewave across the primary winding to measure the ratio between the voltage induced between the primary and secondary AC quiet nodes and the voltage injected by the function generator, or CMRR. Source: Texas Instruments

Next, use the function generator to apply a small sinewave across the primary winding of the transformer. This mimics the primary winding voltage, but now you are testing at a single frequency with a safe and low voltage. The amplitude of the signal is not significant, as the parasitic capacitances of the transformer are largely independent of the voltage amplitude.

Finally, using one channel of the scope, measure the voltage injected by the function generator. With another channel, measure the voltage induced between the primary and secondary AC quiet nodes. The ratio of these two signals is essentially the common-mode rejection ratio (CMRR) and is an indication of how much your power transformer will contribute to common-mode noise at that frequency.

Figure 3 shows the results of this test at 100 kHz for two different transformers. The construction used for transformer #1 results in a CMRR of –39.6 dB, while the CMRR for transformer #2 is higher, measuring –31.4 dB. This indicates that transformer #1 will produce less common-mode noise than transformer #2. With the function generator, you can investigate the transformers' characteristics at different frequencies.

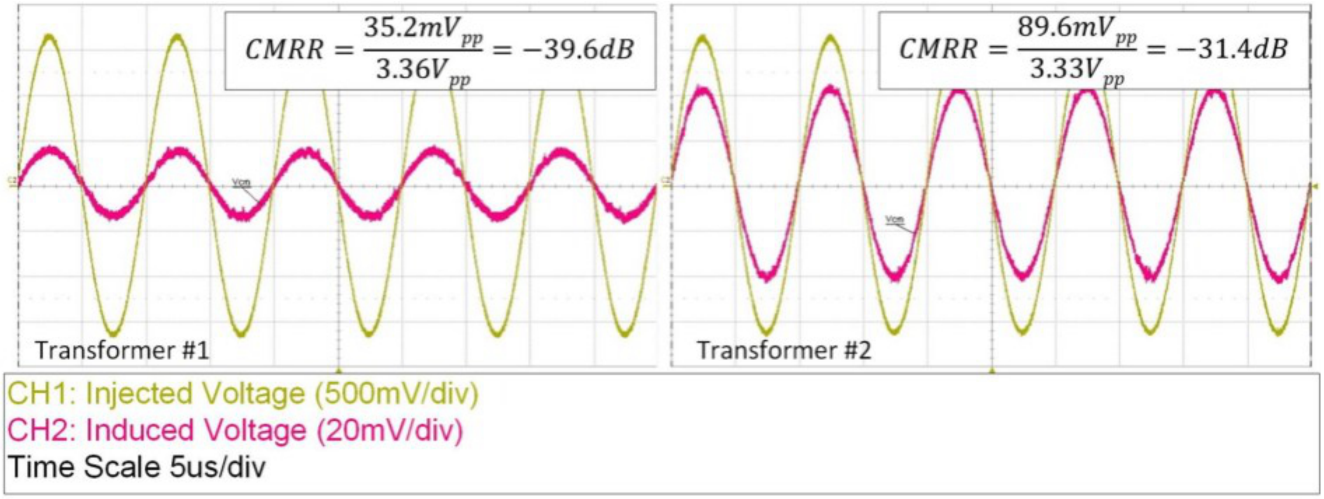

Figure 3. The time domain transformer CMRR test results that indicates that transformer #1 produces less common-mode noise than transformer #2 at the test frequency of 100 kHz. Source: Texas Instruments

Alternatively, you can perform this same test using a frequency response analyzer (FRA) to sweep the frequency of the injected signal across the entire frequency range of interest. Figure 4 shows the FRA measurements of the same two transformers across a wide frequency range of 100kHz to 30MHz. Notice that the gain is very flat over a wide range from 100kHz to around 4MHz. The gain at 100kHz correlates very well with the function generator test, indicating that the function generator test at 100kHz is sufficient to characterize these transformers across this band of frequencies. At frequencies above a few megahertz, you should measure the CMRR of these transformers at the frequency of interest.

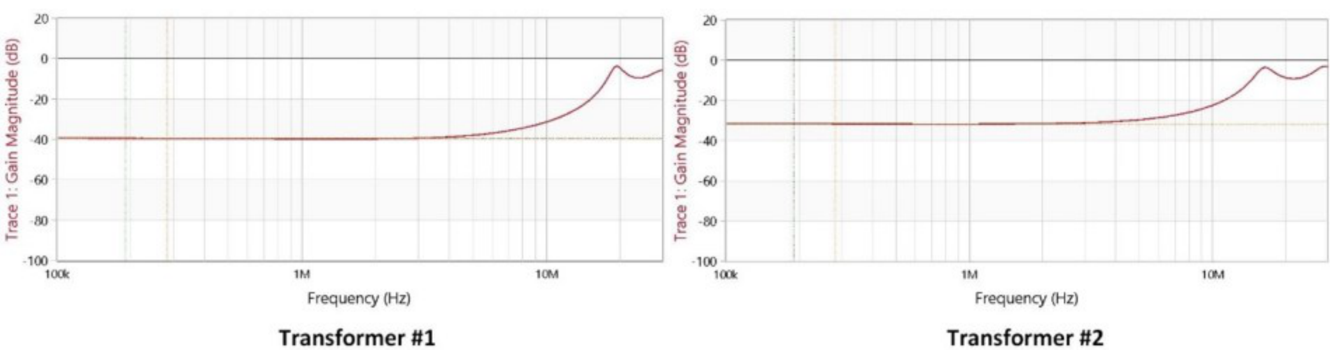

Figure 4. Frequency domain transformer CMRR test results for transformer #1 and #2 across a wide frequency range of 100 kHz to 4 MHz using an FRA. Source: Texas Instruments

Figure 5 shows the results of soldering both of these transformers into the PCB of a switching power converter measuring the conducted EMI against Comité International Spécial des Perturbations Radioélectriques (CISPR) 32 Class B limits. The top limit line corresponds to the quasi-peak measurement, and the lower limit line corresponds to the average measurement. As expected, the EMI results for transformer #2 are worse than transformer #1. In fact, transformer #1 passes with decent margin, whereas transformer #2 barely fails.

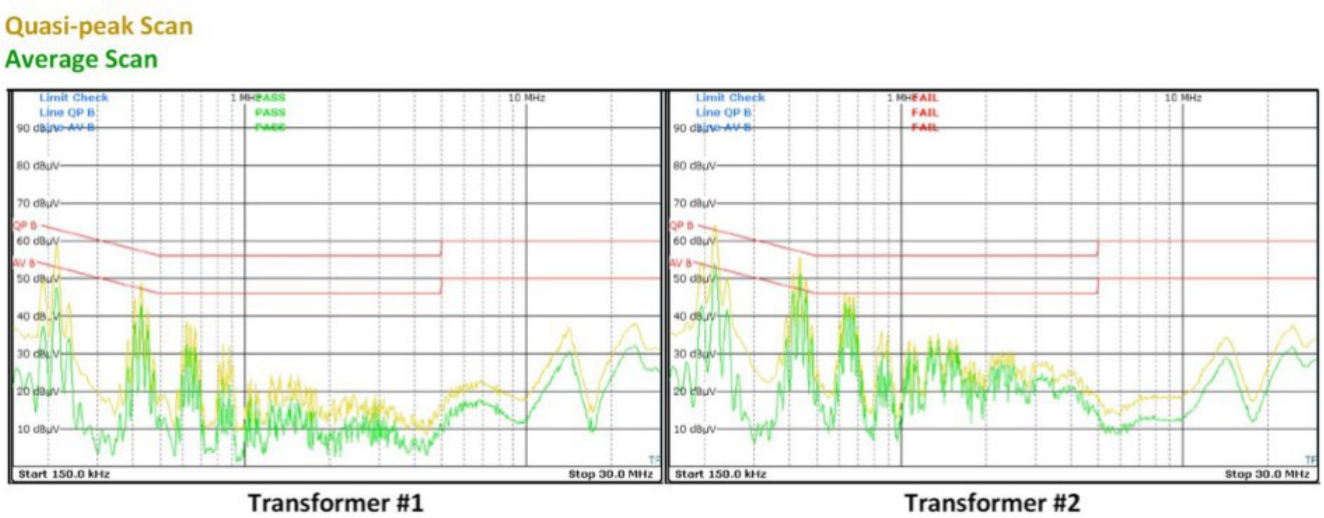

Figure 5. Conducted EMI test results for transformers where transformer #1 passes with margin and transformer #2 barely fails. Source: Texas Instruments

Interestingly, both transformers in this example have the same winding structure and construction. The differences in CMRR are completely attributable to variations in the manufacturing process, demonstrating how sensitive EMI can be to transformer construction. Small variations such as the exact placement of individual strands of wire within the transformer or the thickness of insulating layers can have profound effects.

For the example in transformer construction, it's clear that you can't be confident that all units in production will pass CISPR 32 conducted EMI limits. One solution is to increase the EMI filtering in the circuit to provide more margin. Another option is to employ the function generator test to screen every transformer sample during production. This test is very similar to the types of tests commonly used to test and screen transformer turn ratios between windings, so no special equipment is required. In the example, only passing transformers with a CMRR less than –38dB offer a high probability that all units will pass EMI when assembled into a power converter system.

The transformer's impact on EMI

Debugging EMI issues is fraught with many obstacles and difficulties. The simple measurement technique described in this Power Tip can save you significant time and frustration on the solder bench and in the lab. For your next isolated power-supply design, take a few minutes to measure the CMRR of your power transformers before soldering them into the circuit boards, and then compare the CMRR to the resulting EMI. You will gain a better understanding of the transformer's impact on EMI, and what level of transformer CMRR will pass EMI in your system.

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