HOW2POWER TODAY
Your Power Design Newsletter

ISSUE: January 2015

Common-Mode Transformer Aids Noise Reduction In High-Power Supplies

by Dennis Feucht, Innovatia Laboratories, Cayo, Belize

In a typical switched-mode power supply transformer, the capacitance between primary and secondary windings is distributed along the windings. This interwinding capacitance can be represented by an equivalent capacitor, C_{seq}, across the middle of the primary and secondary windings, as shown in the figure. This interwinding capacitance offers a path for parasitic currents, which result from voltage differences across the primary and secondary windings.

Those parasitic currents, in turn, can become a source of noise, which is particularly troublesome in power supplies with higher power output. However, these parasitic currents can be avoided with the addition of a common-mode transformer as seen in the figure. At a glance, this CM transformer might be mistaken for the type of CM transformer applied in input EMI filters in a wide range of power supply applications. Although both transformer types are intended to provide noise reduction, they operate differently as explained in this article.

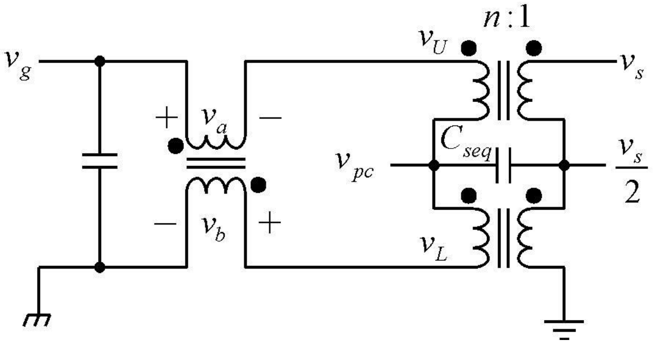

Figure. The interwinding capacitance in a power supply's transformer can be modeled as an equivalent capacitor, C_{seq}.

Equalizing Voltages Across The Windings

Voltage changes across the primary and secondary windings can be reduced to minimize current through C_{seq} so that v_{pc} and $v_s/2$ vary together. The primary CM voltage is defined as

$$v_{pc} = \frac{v_U + v_L}{2}$$

and can be made present on both windings by adding a CM transformer between the primary winding and bipolar (ac) supply, v_g. It causes the converter transformer to float from primary ground so that its CM voltage can change along with that of the secondary winding.

The circuit equations follow from the diagram:

$$v_U = v_{pc} + n \cdot \frac{v_s}{2}$$

and

$$v_L = v_{pc} - n \cdot \frac{v_s}{2}.$$

For the CM voltages of the windings to be equal and thus track each other, and for no voltage difference to appear across the primary and secondary grounds,

$$\Delta v_{CM} = v_{pc} - v_s/2 = 0\text{ V} \Rightarrow\ v_{pc} = v_s/2.$$

Then substituting,

$$v_U = v_{pc} \cdot (1+n)\,,\ v_L = v_{pc} \cdot (1-n)\,.$$

Working backwards from the secondary, for a secondary CM voltage of $v_s/2$, the primary terminal voltages must satisfy the above conditions for v_U and v_L for $\Delta v_{CM} = 0$ V. The CM transformer winding voltages add to the primary terminal voltages so that the CM voltage at the v_g port is 0 V. Then when the differential voltage of v_g is applied to the primary through the CM transformer, the CM condition is satisfied. For 0 V at the v_g port,

$$v_U = v_{pc} \cdot (1+n) = -v_a$$

and

$$v_L = v_{pc} \cdot (1-n) = v_b\,.$$

The turns ratio for the CM transformer is thus

$$\frac{N_a}{N_b} = \frac{-v_a}{v_b} = \frac{v_U}{v_L} = \frac{n+1}{n-1}\,.$$

If the secondary winding voltage is inverted from that of the primary (secondary winding dot moved to bottom end of winding), then

$$\frac{N_a}{N_b} = \frac{v_U}{v_L} = \frac{n-1}{n+1}\,.$$

This CM rejection scheme is not commonly found in lower-power converters because of the cost and space taken by the CM transformer. Over 1 kW, CM rejection for noise reduction can become a significant consideration. At these power levels, the need for CM rejection for noise reduction becomes greater while the cost and size of the CM transformer becomes less notable relative to the other components.

It is not uncommon for power supplies of over 50 W to have a *current* CM transformer at the input port for EMI suppression. Instead of achieving zero Δv_{CM} for the converter transformer, the noise-suppressing CM transformer maintains equal currents through its windings with a turns ratio of one.

In the current CM transformer, the dots are on the same ends of the windings so that the fluxes of the two windings cancel with equal currents of opposite polarity, one current going into a dot and the return current coming out of a dotted terminal. For the currents to become unequal (and the two branches of the input port unbalanced), the difference current must be made to flow through the large magnetizing inductance of the CM transformer. This presents a high-reactance path to currents that otherwise would flow back to the v_g supply by some other path. It deprives spurious reactive paths (parasitic capacitances) from returning current to the v_g port—paths that can cause either conductive or radiated noise.

The same scheme is sometimes used in test and measurement applications. Here, the cable for an oscilloscope probe is looped a couple of turns through a ferrite toroid. This causes high-frequency ground return currents to flow through the outer conductor of the probe cable instead of through the devious paths of equipment earth grounds.

A current CM transformer used for EMI filtering does not serve the same purpose as CM voltage reduction, and the two uses should not be confused. The EMI filter reduces whatever spurious CM current might find its way back to the v_g source while reduction of CM voltage across the converter transformer prevents such current in the transformer. By reducing Δv_{CM}, current through C_{seq} is reduced so that there is less of this parasitic current to find a way back to v_g through capacitance between the two grounds.

In both uses of CM transformers, the general purpose is the same: to reduce parasitic currents. The means of doing this, however, is different. If the prevailing cause for spurious current is the CM voltage imbalance across the converter transformer, then the scheme presented in this article can be used to minimize it. By eliminating this major cause of spurious current, the need for an additional EMI CM transformer might be eliminated.

About The Author

Dennis Feucht has been involved in power electronics for 25 years, designing motor-drives and power converters. He has an instrument background from Tektronix, where he designed test and measurement equipment and did research in Tek Labs. He has lately been doing current-loop converter modeling and converter optimization.

For more on magnetics design, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category, and select “Magnetics” in the Design Area category.