

Designing low leakage current power supplies

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Majority of AC/DC power supplies provide isolation from the high-voltage AC input to the low-voltage DC outputs. Safety standards, such as the UL1950, specify both the strength of the isolation barrier—e.g. a 3,000VAC withstand voltage—as well as the maximum leakage current. This is the current that flows across the primary to secondary isolation barrier when accessible parts are connected to the protective earth ground through a specified impedance

value. Standards in leakage current ensure human safety, preventing users from becoming part of a path for substantial current to ground when touching the output or the enclosure of a power supply.

The maximum leakage current allowed to flow is based on the specific classification of the application. In the past, low leakage currents were required only for special applications—such as medical equipment—where patient contact was either highly likely or necessary. Those applications had to meet limits, which were considerably more stringent than those required for

Equipment type	Condition		Limit
Information technology (IEC60950)	All equipment	From protective earth ground to accessible parts not connected to protective ground	0.25mA
	Handheld	From protective earth ground terminal (earthing conductor) to protective ground	0.75mA
	Portable	From protective earth ground terminal (earthing conductor) to protective ground	3.5mA
	Stationary		
Medical (IEC60601-1)		Patient leakage	100µA

Table 1: Examples of leakage (touch) current specifications.

IT equipment (Table 1).

However, there are other reasons why a low leakage design is desirable. For example, with many cellphones now en-

closed in metal housings, their chargers often must meet leakage-current specifications set by the handset manufacturer that are below those specified by the applicable safety standard.

This is to prevent users from feeling the “touch current” when they hold the phone while it is charging, especially in damp environments like a steamy bathroom. Power supplies that support telephone equipment (cordless phones, answering machines and DSL modems) must often have low line-frequency leakage to prevent the coupling of audible hum onto the telephone lines. There may also be potential cost savings from designing for low leakage, such as reducing the size and/or number of the EMI filter components required in the power supply.

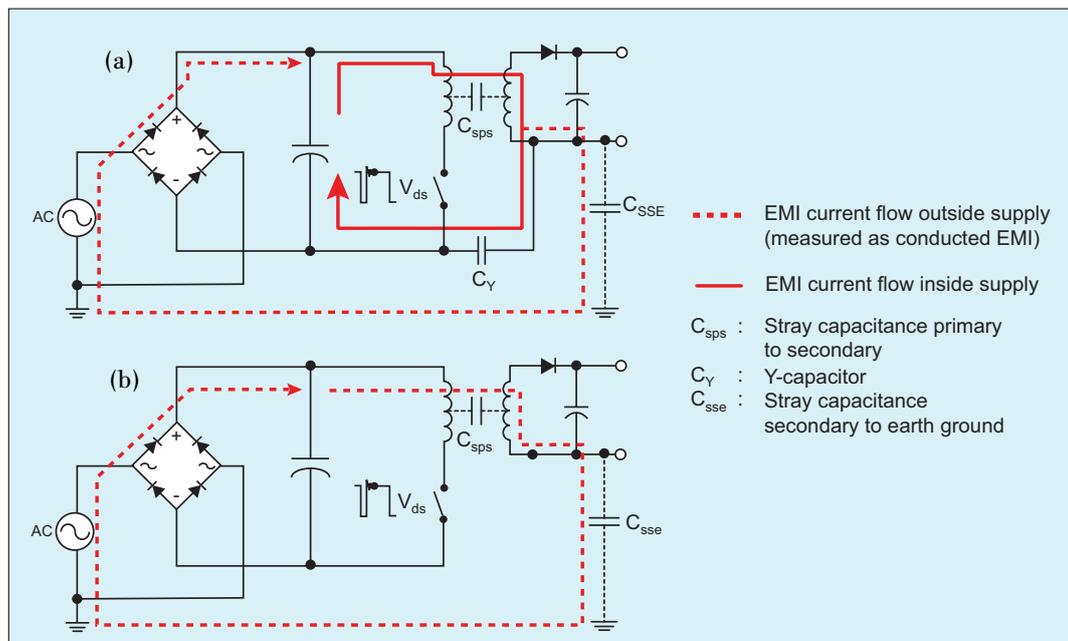


Figure 1: (a) The Y-capacitor shunts much of the EMI current, keeping most of it within the supply; (b) With no Y-capacitor, electromagnetic interference currents must flow external to the supply.

Leakage current source

One of the biggest contributors to leakage current in AC/DC

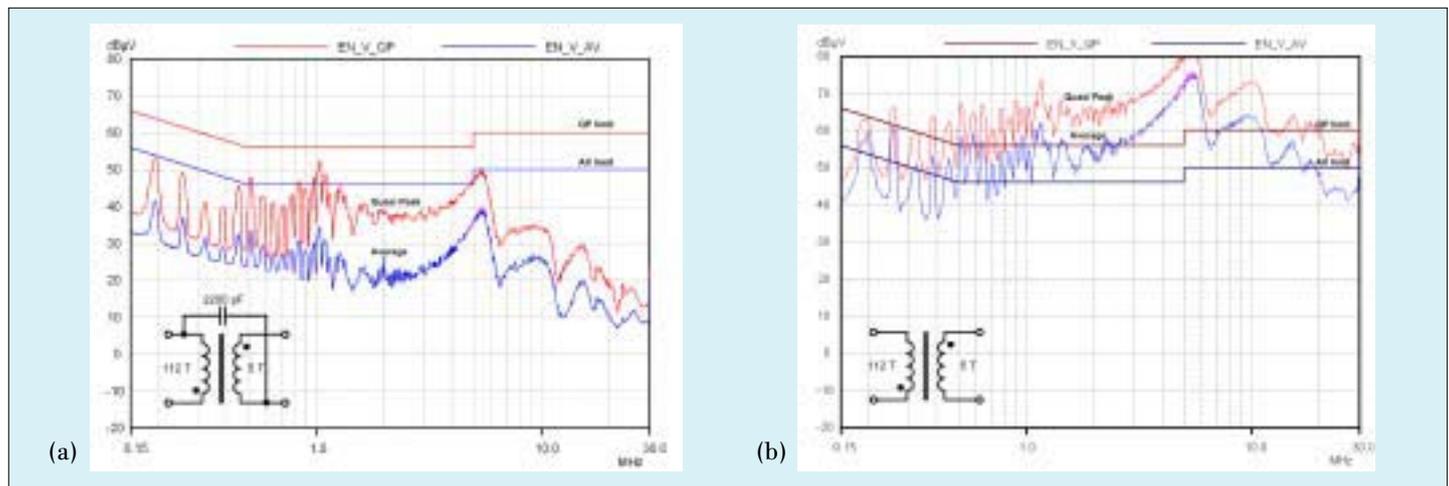


Figure 2: An example of conducted EMI for a 3W cellphone charger: (a) with, and (b) without a Y-capacitor.

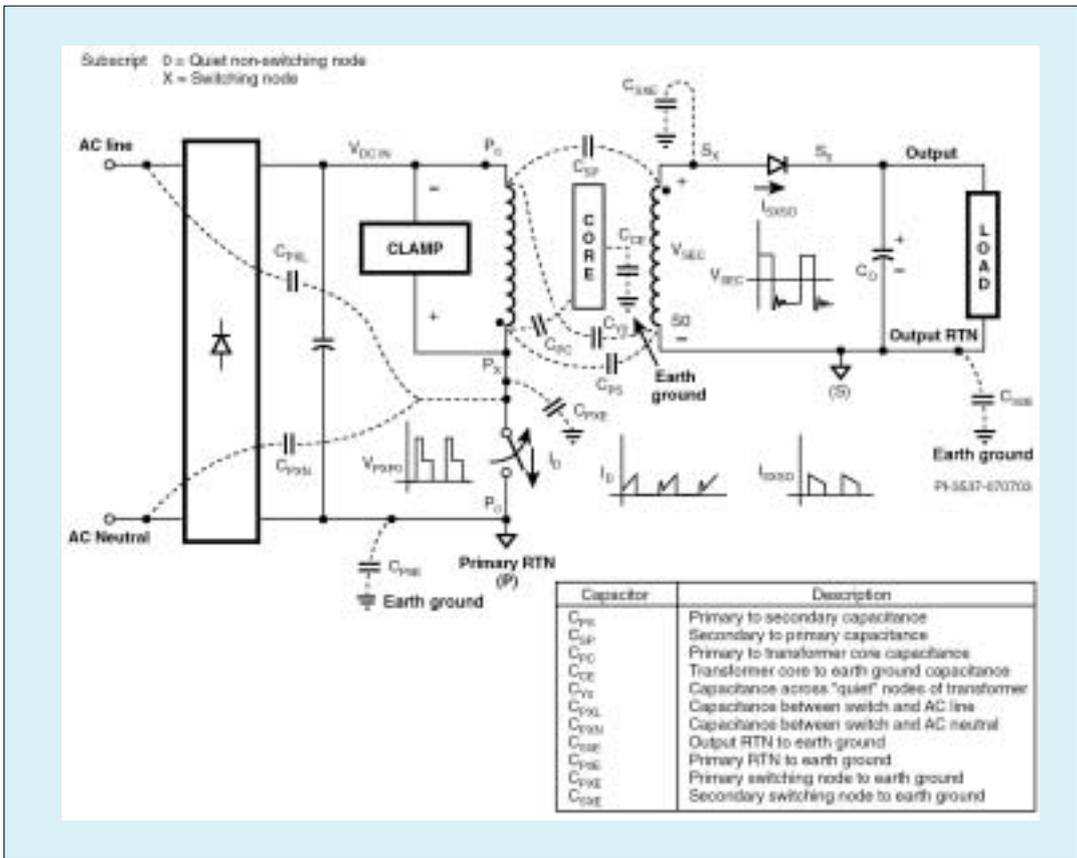


Figure 3: Overview of the paths where EMI currents flow as they are driven by the switching waveforms.

switching power supplies is the Y-capacitor—a safety agency rated capacitor (typically orange or blue in color) that can be used to bridge the isolation barrier (Figure 1a). It is used to return displacement currents (generated by the switching process) back to their source, preventing EMI. Any HF currents that flow out of the power supply will return via the AC input lines, producing what is measured as “conducted EMI.” In Figure 1a, the Y-capacitor shunts much of the EMI current, keeping most

Techniques	Pro	Cons
Extra tape between winding layers	Simple	Does not significantly reduce common mode EMI currents.
Adding a common mode input choke	Simple	Increases cost and board size, and may not provide enough improvement.
Slow down rise/fall time of switching waveforms: add snubbers or reduce MOSFET gate drive	Simple	Increases dissipation and lowers efficiency. Increased cost and board size. Typically does not provide enough improvement.
Modulation of switching frequency (jittering)	Provides up to 6dB reduction in quasi-peak and average EMI	Difficult to implement in discrete designs
Transformer shield windings	Large reduction in common mode EMI currents. Allows significant reduction or elimination of Y-capacitor. Low cost	Increased transformer complexity. Optimization of shields is time consuming. Extremely consistent transformer manufacturing is required to maintain consistent EMI performance.

Table 2: Techniques for reducing common-mode EMI currents.

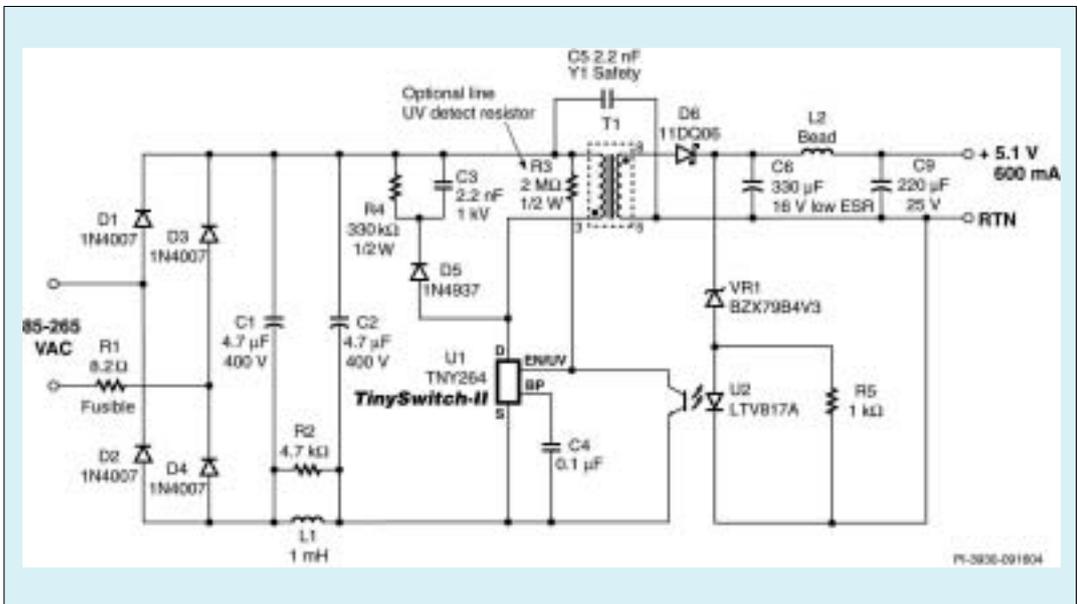


Figure 4: Circuit diagram of a TinySwitch-II based 3W (5.1V 600mA) “charger” power supply.

of it within the supply, while in Figure 1b, it all must flow external to the supply.

In general, the larger the value of the Y-capacitor, the lower the magnitude of the EMI that the supply generates. Conversely, the larger the value of the Y-capacitor, the higher will be the leakage current that flows across the isolation barrier. The expression:

$$C_{Y(MAX)} = \frac{I_{LEAK(MAX)}}{V_{AC(MAX)} \cdot 2 \cdot \pi \cdot f_{LINE}} = \frac{0.25 \cdot 10^{-3}}{265 \cdot 2 \cdot \pi \cdot 50} = 50pF = 2.95nF$$

Estimates the maximum value of a Y-capacitor that can be used, without exceeding the safety limits. For a two-wire (without a protective earth connection), universal input power supply with a floating output, rounding down to the next standard capacitor value gives a maximum Y capacitance of approximately 2.2nF. For a 100/115VAC-only design, this would increase to 3.3nF.

Simply removing or reduc-

ing the value of the Y-capacitor is usually not feasible, as doing so typically increases EMI significantly (Figure 2b). Moreover, adding a common mode choke or other filter components increases cost. Therefore, attention must be focused on reducing EMI currents that make use of a Y-capacitor necessary to begin with.

Reducing EMI currents

Figure 3 gives an overview of the paths where EMI currents flow as they are driven by the primary and secondary switching waveforms. Table 2 shows some of the ways of reducing common mode EMI currents. Techniques like using tape to increase the spacing between

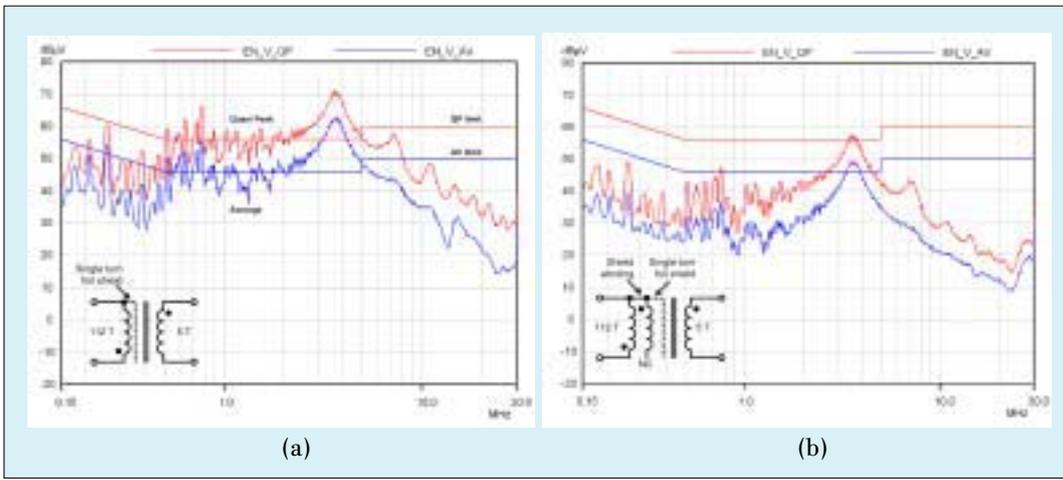


Figure 5: Using shield windings in a switching transformer is the most effective way to reduce common-mode electromagnetic interference currents, while having a minimal impact on the overall cost of the supply.

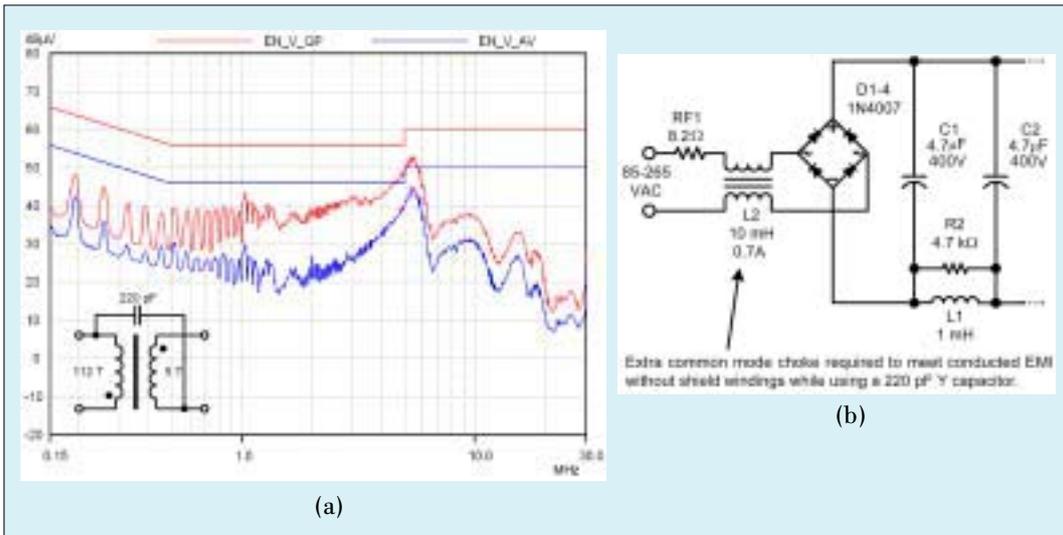


Figure 6: An example of (a) conducted EMI performance with (b) an additional EMI filter choke on the input.

winding layers can also reduce interwinding capacitance. This method alone reduces little EMI currents. Shield windings have long been used in line frequency transformers to reduce noise and coupling, and can be used in SMPS transformers as well. As the EMI plots in **Figure 5** show, the use of shield windings in a switching transformer is the most effective way to reduce common mode EMI currents, while having a minimal impact on the overall cost of the supply.

Figure 4 is the circuit dia-

gram of a 5.1V, 600mA power supply, based on a TinySwitch-II IC, and a simple two-winding transformer. The IC is self-powered, so an auxiliary transformer winding is not required. The design is typical of the type of adapter used as a charger for cellphones, PDAs or digital cameras.

The TinySwitch-II IC modulates its switching frequency (called jittering) to reduce EMI. However, without shield windings in the transformer, this design still requires a 2.2nF Y-

capacitor to meet conducted EMI (**Figure 2a**). Removing the Y-capacitor produces the EMI, which is clearly unacceptable (**Figure 2b**).

Adding a single turn foil shield between the primary and secondary windings reduces the measured EMI by about 10dB (**Figure 5a**). Supplementing that with an additional shield winding achieves a further 10dB reduction (**Figure 5b**). A good scan with 10dB of margin can be obtained with a Y-capacitor of only 220pF, which reduces the

leakage current from to 183μA to 18μA (**Figure 5c**). Close to the same EMI performance is obtainable without the shield winding, but requires a common mode choke L2—in addition to the existing differential mode filter inductor L1—in the input stage (**Figure 6a** and **Figure 6b**). Depending on the requirements of the particular application, a third shield could be added to the transformer, which could reduce the value of the Y-capacitor even further.

As shield windings react to the primary side switching and the secondary side commutation, they reduce or cancel the generation of common-mode displacement currents, making a detailed analysis unnecessary. However, the requirements for each design will vary due to factors such as component location on the PCB layout, the proximity of the board and magnetic components to chassis metal, transformer size, volt-seconds rating, turns wire gauge and winding turns ratios. Therefore, trial-and-error will be required to optimize the shield windings for each design. However, the basic principles of shield winding placement typically apply consistently.

Many of today's power supply specifications require lower leakage current values due to human interaction with the products being powered. Therefore, power supply designers are being asked to eliminate or reduce the size of the Y-capacitor that they use to make the design pass EMI. By using transformer shield windings, the value of the Y-capacitor can be significantly reduced or eliminated, to lower the leakage current while still meeting conducted EMI limits with adequate margin. Usable and affordable solutions for accomplishing this objective are readily available today. □