Controlling EMI in Transformers and Switch-Mode Power Supplies

Part I: Introduction

Uncontrolled electromagnetic (EM) energy can hinder communications systems and interfere with the proper operation of sensitive electronic equipment. In diagnostic equipment, such as used in medical applications, unwanted EM interference (EMI) can cause false readings and, in extreme cases, disrupt the proper operation of life-sustaining electronic devices, such as cardiac pacemakers. A great deal of EMI is due to leakage from microprocessors and clock sources, although transformers and switched-mode power supplies (SMPS) can also contribute to EMI. Fortunately, EMI can be controlled by proper design and layout strategies. EMI is generated by nearly all active electronic devices (those requiring a power source), at varying levels. EMI leaks can occur at almost any point in a design, even within cables and connectors if not properly terminated and shielded. Power transformers, which handle high voltage and current loads, have the potential to produce strong EM fields, and must be incorporated into a design with extreme care. SMPS designs operate at switching frequencies (and harmonics of those frequencies) that fall well within the frequency bands commonly allocated for communications, such as high-frequency (HF), very-high frequency (VHF), and ultra-high-frequency (UHF) bands (see Table 1).

Table 1 — Standard frequency bands.

BAND	FREQUENCY RANGE
ELF	30 – 3000 Hz
SLF/VF	300 – 3000 Hz
VLF	3 – 30 kHz
LF	30 – 300 kHz
MF	300 – 3000 kHz
HF	3 – 30 MHz
VHF	30 – 300 MHz
UHF	300 – 3000 MHz

National and international agencies set the standards for acceptable levels of EMI and radio-frequency interference (RFI) under different environmental conditions and frequency ranges. In the United States, the Federal Communications Commission (FCC) exercises authority over radiated energy within designated operating frequencies. For example, the FCC's Part 15 regulations set precise limits on the amount of allowable EMI from electronic products, such as computers, chiefly to prevent interference with broadcasting and communications systems. The International Electrotechnical Commission (IEC) establishes global standards for accepted levels of radiated EM energy. Such agencies carefully review different sources of EM radiation, including transformers and power supplies, requiring designers and end users of these components to be aware of their radiating capabilities.
For linear supplies operating at standard power-line frequencies, such as 50/60 Hz, EM emissions usually fall into harmonically related bands, such as 100 and 120 Hz, in the ELF and VLF regions. Since such low- frequency interference is characterized by long wavelengths, it can propagate through traditional conductive barriers and is difficult to attenuate or control. Effective transformer design and good grounding techniques have usually kept the emissions from causing problems to nearby equipment.

In contrast, the switching frequencies of SMPS designs often result in EMI and RFI that fall within communications bands of VHF and beyond. As a result, their leakage signals represent a potential source of interference to the majority of consumer, commercial, and military communications services worldwide, as well as other analog and digital electronic systems, such as radars and medical electronic systems, that may be hindered by the interference.

What causes high-frequency interference in a SMPS? Much of the noise is generated as a direct consequence of the switching process. In its open position, an ideal switch provides infinite resistance to the flow of electrical current. In its closed position, the ideal switch offers zero resistance, allowing current flow with negligible drop in voltage. An ideal switch would control the conduction of high-speed pulsed waveforms without adding transient events or causing voltage spikes. Unfortunately, real switches do not change states instantaneously but require transition periods known as rise and fall times. These transition periods tend to impose distortion on the harmonic components of high-frequency SMPS waveforms. The switching process produces voltage spikes resulting in EMI and RFI that can reach well past 100 MHz. The voltage spikes are caused by short-duration charging and discharging of parasitic capacitances in the power-supply circuitry.

Part II: Problems and Solutions

How much of the radiated EMI in a SMPS is due to the transformer? A transformer can both conduct and radiate noise within a system, requiring that its placement within the system be carefully considered.

By its magnetic nature, a SMPS transformer and its windings generate an EM field with amplitude dependent upon the size of the transformer, the number of turns, the input current and voltage, the type of material used for the transformer, and various other factors. The transformer produces an EM field that is directional in nature, so that positioning of the transformer within a circuit or system is critical. The effects of the transformer's EM field on surrounding components can be minimized by aiming the transformer's radiation away from the most sensitive components and potential "antennas," such as transmission lines and connectors.

The strength of an EM field is inversely proportional to the square of the distance from the source. So, whenever possible, the transformer should be moved far enough away from surrounding components to make its interference insignificant.

In designing a transformer, its radiated emissions can also be minimized by considering the core size and the number of turns. For example, the transformer's magnetic flux density can be reduced by choosing a large core area or by increasing the number of turns on the transformer.

When necessary, electrostatic shields can be placed between a transformer's primary and secondary windings in order to minimize radiated emissions from primary-winding voltage spikes being transmitted to the secondary windings. A Faraday shield is one type of structure that is commonly placed between a transformer's primary and secondary windings to reduce EMI. It usually consists of one turn of thin copper foil around the primary coil that is attached to the circuit or system ground plane (Fig. 1). This shield prevents high-frequency current from coupling from the primary to the secondary windings; coupling of these unwanted currents normally occurs as a result of interwinding capacitance.

Fortunately, the weight of this thin copper foil is very little, adding only an insignificant amount to the total weight of an electronic system. In low-power designs, the need for the isolation of a Faraday shield can be satisfied by the use of a split-bobbin transformer.

In extreme cases where transformer or SMPS EMI levels are high, the interference can be controlled by the use of a magnetic shielding enclosure. Such an enclosure surrounds the transformer, captures stray magnetic flux or EM radiation, and channels the unwanted energy to a ground plane.

Unfortunately, such enclosures add cost, weight, and manufacturing complexity to a design, and should be used only in cases where the EMI from a transformer is excessive and cannot be isolated by physical placement or other means.

The choice of configurations for transformers and inductors used in SMPS designs can also play a role in controlling EMI. Rod, bobbin, and "E" cores contribute to high levels of EMI, while toroids, PQ cores, and pot cores lead to reduced levels of EMI. The open configurations of rod-and-bobbin-type transformers do not fully contain the generated EM fields (Fig. 2). Transformers with toroid and pot cores, on the other hand, are nearly fully enclosed by ferrite material, effectively containing EM fields within close proximity of the transformer (Fig. 3). The tradeoff is higher price for the toroid and pot-type transformers, restricting their use to those applications requiring the greatest amount of EMI suppression.

High-frequency EMI tends to be reradiated by surrounding components more easily than lower-frequency EMI, since its relatively short wavelengths can be distributed by components and wires (transmission lines) that are at multiples of quarter- and half-wavelengths of the EMI frequencies. While there is no single foolproof method of eliminating EMI from a SMPS or its transformer, effective ground connections are a good place to start. All components capable of reradiating EMI from a SMPS should be properly grounded. All cables and transmission lines should be grounded carefully to avoid loops in cables where signal induction can take place. All input and output connections should be filtered to avoid transmission of EMI. As mentioned early, components should be placed carefully with regard to EMI sources, such as a SMPS or transformer, especially those components that might be suspected of being good EMI "receivers."

A power-supply transformer can contribute to unwanted coupling of other EMI sources within a system, such as a clock oscillator in a computer. This can occur even as the result of preventive measures, such as a Faraday shield, that reduce the transformer's own emissions but serve as antennas for other radiation sources. The radiation from secondary sources is transferred through the driven side of the primary windings to the Faraday shield and to ground. Better isolation can be achieved by connecting the Faraday shield to the nondriven side of the primary windings, so that the driven side is capacitively coupled to the shield and inherently isolated from the secondary windings. In effect, signals incident on the Faraday shield are sent back to the primary windings rather than being transferred to the secondary windings.

A transformer's secondary windings can also transfer energy through capacitive coupling. Fortunately, a double-shielding technique can be used to effectively reduce this vehicle for EMI. By placing a second shield between the shield connected to the primary windings and the nondriven side of the secondary windings, high-frequency interference signals picked up by the secondary windings are reflected back through the secondary windings rather than being transferred to the primary windings.

Although a transformer is part of a power supply, it is difficult to evaluate separately as part of product EMI compliance testing. When a product fails such compliance testing, analysis and redesign can be expensive and time consuming. Preventive measures at the design stage can ensure full compliance by controlling EMI at the component level. Such preventive measures include the selection and design of low-EMI transformers, careful placement of SMPS circuitry with regard to susceptible components, proper grounding, and effective shielding of transformers and SMPS circuitry. Attention to the preventive measures outlined above will generally produce a payback in design time and materials, in faster compliance testing, and in better product acceptance by the marketplace.