

EMI Considerations in Selecting AC/DC Switching Power Supplies

Selecting a Power Supply Manufacturer
for OEM Power Applications

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Executive Summary

Design engineers in many industries report that they have system level EMI (Electromagnetic Interference) issues, and that difficulties in achieving compliance are a significant factor in their new product development programs. They often find that resolving EMI issues requires significant time, and sometimes leads to program delays. A system's power supply is often the primary source of unwanted EMI.

When EMI is a concern, it is crucial that an Original Equipment Manufacturer (OEM) select a power supply that is fully compliant with all applicable EMI standards in order to minimize issues when integrating the power supply into a system, with careful consideration given to the challenge of EMI.

However, it is important to note that due to system interactions and the high-frequency switching within an electronic power supply, there is no way to guarantee that a device and compliant power supply, once integrated with each other, will still remain compliant. Therefore it is vital that designers plan for these interactions, and proper EMI performance, as early in the design stage as possible.

In brief, this white paper will:

- Look at the extent to which switching power supplies contribute to system level EMI issues
- Enumerate the design considerations that impact EMI in power supply design, and
- Identify the steps (e.g., in design and process control) which world-class power supply companies take to minimize the prospect of impact to their customers' system level EMI issues.

Taken together, this document is intended to serve as a useful reference for design engineers evaluating AC/DC switching power supplies for upcoming programs as well substitution projects in existing programs.

Contribution of Power Supplies to EMI

Switching power supplies have almost completely replaced linear power supplies because of their great advantage in efficiency. However, this comes at the cost of considerably higher EMI. Switching power supplies generate more EMI because they switch large currents at very high frequencies, anywhere from 50KHz to 1MHz. At these high frequencies optimal power efficiencies and smaller components (primarily magnetics) can be achieved.

The theoretically optimal switching waveform in these power supplies approximates a square wave. However, the sharp edges of these waveforms produce considerable noise at the fundamental switching frequency and its harmonic frequencies. In addition, since the waveform is not sinusoidal, there is an additional edge frequency (the sinusoidal equivalent of the sharp rising and falling edges of the square wave), which generates a pseudo-frequency much higher than the fundamental switching frequency of the power supply. Both of the frequencies also have the normal associated harmonics. Therefore, there is a trade off between power efficiency and EMI.

While the switching MOSFETs, transformers, and output rectifiers are typically the greatest sources of radiated EMI, at high frequencies even PCB traces act inductively and radiate noise. It is critical for effective EMI suppression to ensure that all these elements have been considered when selecting a power supply for your project.

EMI Solution Methods

The following section identifies critical things to look for when selecting a power supply. Check to ensure that the vendor you are considering has addressed these issues thoroughly.

Transformer Design and Construction

The first element to consider for minimizing EMI in a switching power supply design is the transformer. Because it is a large inductive element subjected to high-frequency currents, the transformer is typically the noisiest component. It is also the component around which the rest of the supply is designed. It is in the design of the transformer where EMI reduction should begin.

Every facet of the transformer's design and construction can affect EMI, and each aspect can be critical. Approaches that can solve EMI issues in one design will often compound them in others. In this way, the design of a transformer for low EMI is often viewed as an art.

Introduction to EMI

In a switching power supply there are two modes of EMI – conducted emissions and radiated emissions.

Conducted emissions are caused when high frequency currents flow back through the input lines polluting the power source lines (power grid). These currents can be either common-mode or differential-mode currents.

Radiated emissions are electromagnetic fields that are emitted from the power supply to the environment. With regard to radiated emissions, these conductors can be the line and neutral power input lines (the radiated emissions being the radiated result of the high-frequency currents in these lines), or virtually any other set of conductors within the power supply. This second point is what makes tracking down and eliminating sources of radiated EMI such an extreme challenge.

Both types of EMI can cause interference or malfunction in other nearby devices.

Because of this, international regulatory agencies have established maximum emissions levels for EMI emitting devices such as power supplies. These agencies include the Federal Communications Commission (FCC), the International Special Committee on Radio Interference (CISPR), and Verband Deutscher Elektroniker (VDE).

We will observe, in brief, some of the transformer design and construction techniques that should be employed to reduce EMI.

- **Ferrite Core selection** is very important to EMI. There are peripheral reasons to choose any of the various core types, but typically, an RM type core is better at containing electromagnetic fields than an E or EER type core. This is due to the additional core material on all sides of the center leg acting as an electromagnetic shield. Another important consideration is how the core is gapped. By gapping only the center leg of the core, radiated EMI will be further contained. A gapped outer leg will leak radiated EMI through the gap, possibly requiring additional shielding to contain the stray EMI.
- **The switching drain of the MOSFET** will normally be connected directly to the primary winding of the transformer. One design technique that can help reduce EMI in a multi-layer winding is making this drain connection to the innermost winding of the transformer. By doing this, the EMI caused by these high-current, sharp-edged waveforms are contained and cancelled by the other windings and shields in the transformer.
- **Winding direction and orientation** plays a crucial role in reducing EMI as well. Winding a section from left to right, or vice versa, or starting the winding clockwise or counterclockwise around the core all have an effect on EMI, and so must be considered in the design.
- **Shielding** is commonly used to help further suppress EMI. The use of a Faraday shield between the primary and secondary winding will typically reduce EMI. This shield can be tied to the primary, secondary, or even both to achieve optimal suppression. Applying additional tape insulation between primary and secondary windings can also help reduce EMI. Also, a shield can be applied directly to the outside of the core. This shield can be tied to either the output common or the input return for optimal suppression. It is important to note however that each shielding layer on a transformer will increase the capacitive coupling, directly increasing the leakage current of the unit.

RM Core



E Core



EER Core



Faraday Shield

A Faraday shield is a conductive material used to contain or control an electric field. This shield can block or filter the transmission of electromagnetic fields through a particular region of space.

Leakage Current

A Leakage Current is any current that flows through a path not intended to carry that current. In power supplies, Earth Leakage Current is the current that flows through the ground connection to earth ground. This leakage current typically travels through a capacitive bridge between line voltage and earth ground. Agency regulations limit the amount of Earth Leakage Current that is acceptable in a power supply. For medical power supplies, these limits are considerably more stringent.

All of these techniques can be quite effective at reducing EMI, but they can also have undesirable effects. Designing a transformer is a balancing act between EMI suppression and transformer efficiency. Ultimately, a designer's understanding of electromagnetic fields and waves, and their design experience will provide the guidance for what to do. That said, even an experienced power supply designer may use many iterations of transformer construction before settling on a final design that performs as desired.

PCB Layout

The PCB traces in a power supply create parasitic inductance loops, which lead to conducted and radiated noise. Also, if multiple loops are in close proximity to each other, they can have a coupling effect that increases EMI levels. Careful attention must be given to the size, placement, and alignment of these loops.

Reducing these loop areas minimizes their capacity to radiate and conduct noise. Also, separating noisy loops from each other will minimize their coupling effect, further reducing their contribution to EMI.

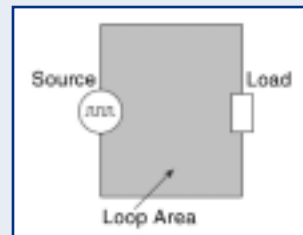
Separating high current traces from low current traces increases system stability and reduces EMI. A technique called star-point grounding runs all returns back to a single point. Doing this, or approximating it as closely as the design will allow, reduces the summation of high currents in any single trace, yielding lower EMI.

Also, a linear flow of components on the primary side, from the input line to the transformer, helps reduce coupling the switching waveforms back to the line voltage, ultimately reducing EMI.

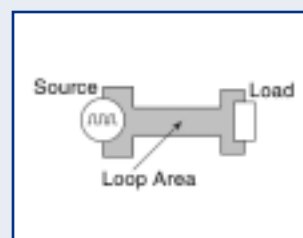
Another thing to consider is appropriately sized traces. In general, at least 2-ounce copper traces should be used, and the shorter and wider, the better.

The size of the trace will be limited by the size constraints of the PCB, as well as Agency creepage and clearance requirements. However, within those confines, the traces should be made as wide as possible.

Large Current Loop



Small Current Loop



Common-Mode and Differential-Mode Currents

Conducted EMI is the result of unwanted common-mode and differential-mode currents polluting the line voltage with noise. The common-mode currents flow through the line and neutral paths in the same direction and return to their source via the path of least impedance. Differential-mode currents flow in opposite directions and are out of phase with each other.

Capacitors

An effective technique for reducing EMI is the use of Y-type and X-type capacitors. Y-caps are typically used between the AC line and ground, AC neutral and ground, and between the primary and secondary returns. X-caps are placed between the AC line and neutral, and the primary and secondary lines. However, while using X and Y caps is quite effective at reducing EMI at all frequencies, these components contribute directly to increasing the total leakage current. In some applications (e.g. medical) this is tightly regulated. Therefore, these capacitors can only be used up to the point where the leakage current requirements are not exceeded. Beyond these limits, other solution techniques must be considered.

Inductors

The common-mode choke is another effective solution for lowering conducted EMI. It works similarly to a low-pass filter. These components can be placed before or after the rectified voltage depending on where they achieve optimal suppression. In some designs up to three of these will be used, usually two on the input, and one on the output.

An inductor can be also be used in combination with two capacitors in a Pi configuration to create a low-frequency filter (150-700 kHz). In this configuration, the rectified current is passed through a small electrolytic capacitor, then the inductor, and then a large electrolytic capacitor. This can greatly reduce low-frequency conducted EMI.

If the power supply uses Power Factor Correction (PFC), a differential-mode choke is often used in a Pi filter configuration with metal-film capacitors to reduce the differential-mode noise.

These components can be used without contributing to the leakage current of the device. However, these are very expensive components and cost targets often restrict their use.

Common-Mode Choke

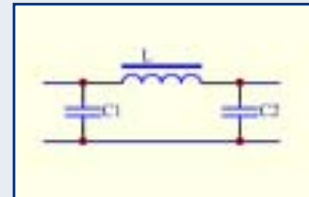


A common-mode choke is a noise filter designed to reduce common-mode EMI. It is basically composed of two identical differential filters, one on the input line and the other on the input neutral, coupled together by a single core.

Inductors for EMI Reduction



Pi Filter



A Pi Filter combines both capacitive and inductive filters in a Pi configuration, which can effectively remove the high-frequency ripple-currents that cause EMI.

Power Factor Correction (PFC)

Power Factor Correction is used to synchronize the current and voltage waveforms to maximize the power delivery of the line source, and to minimize the distortion and harmonics on the AC line.

EMI Compliance

A switching power supply is typically designed to meet emission standards as set forth by the FCC or CISPR. As such, an OEM user would be well advised to obtain a sample of a candidate power supply and perform a simple, low-cost conducted EMI test, to get a preliminary reading on the manufacturer's compliance.

However it is important to note that these standards are applied by self-declaration. So in order to show compliance, many power supply manufacturers test only a single unit to demonstrate emission levels beneath the maximum limits.

What this practice does not recognize is that there will inherently be some variation in the EMI levels from unit to unit since component tolerances and manufacturing variations will introduce deviations in the EMI levels during production.

As such, a power supply design which has been qualified by the customer can fail these EMI standards in production, and in some instances by considerable margins. This marginal practice can wreak havoc with a customer's program and cause system EMI failures before and after product release, costing time and money.

In addition, conformance to these standards by the power supply does not guarantee that when it is used in a larger system, the system will pass these EMI tests. The system itself can add noise to the EMI of the power supply. Furthermore, an active load can cause system interactions, which can amplify the EMI further at resonant frequencies. Therefore, it is vital that designers plan for these interactions, and proper EMI performance, as early in the design stage as possible.

World-class power supply manufacturers use several techniques including Statistical Process Control (SPC) to ensure that units from volume production runs do not exceed the EMI profile of an approved design. At first production, a statistically significant, representative sample of power supplies is tested in order to ensure that the power supply will always comply with the standard, even well into volume production.

Further, such leading-edge power supply manufacturers continue to audit their product's performance during ongoing production in order to ensure that nothing has changed with regard to EMI, preventing undue hardship and failures at the OEM customer.

FCC and CISPR

The FCC and CISPR standards have grown very close to being harmonized. Both are broken into Class A and Class B limits. Class B is the more stringent of the two, requiring a device to meet a lower threshold of EMI.

CISPR11 applies to ISM (Industrial, Scientific and Medical) devices and CISPR22 applies to ITE (Information Technology Equipment).

Summary

This white paper has reviewed many points of power supply design critical to effective EMI suppression. Among these are:

- Transformer core selection
- Transformer winding and shielding
- Component layout and loop size reduction
- Use of X and Y capacitors
- Use of inductors and common-mode chokes
- Techniques for ongoing management of EMI compliance in mature production used by world-class power supply manufactures.

For optimal EMI control at the OEM system level, it is crucial to ensure that all of these points have been considered when selecting an AC/DC switching power supply.

About Elpac

Elpac Electronics, Inc. manufactures power supplies with careful consideration given to minimizing EMI. At the design level, Elpac employs a robust design process, which focuses on EMI at its roots. By controlling EMI with careful transformer design prior to the use of suppression techniques, Elpac is able to achieve low EMI designs at minimized costs.

Furthermore, Elpac employs Statistical Process Control (SPC) to ensure ongoing compliance to EMI requirements in its production power supplies.

Elpac also has design and test capabilities in-house to work with a customer's end product to ensure that the entire system will pass required EMI tests, whether working with an Elpac standard unit or one custom-designed for the OEM's application. These test capabilities are also often utilized to evaluate candidate power supplies on behalf of the OEM customer to help in selecting the appropriate world-class power supply manufacturer.

Elpac is committed to providing excellent power supply solutions that exceed customer expectations of speed, cost, and performance.

Elpac's History in EMC

Elpac was founded in 1960 as a film capacitor manufacturing company. Its expertise in precision, high quality capacitor manufacturing led to supplying capacitors to an avionics prime contractor (AirResearch) for their manufacture of EMI filters, mostly for avionics applications.

During the early 1970's, Elpac was approached by AirResearch to manufacture the entire EMI filter, with designs furnished by AirResearch. Thus began a new product line for Elpac, fabricating the various EMI filter types required by this customer for their application to the environmental control systems on Boeing aircraft.

During the late 1970's, AirResearch began to downsize their engineering capability, thus requiring Elpac to develop its own in-house EMI filter design expertise. At the same time, Elpac encountered other customers, many as military prime contractors, who required custom EMI filter designs and manufacturing. Elpac excelled at this activity and built up this business during the 1980's by placing its products in a variety of programs such as the Space Shuttle Booster, the Martin Marietta Missile Master program, the Mark 48 Torpedo Guidance system and the Aegis rapid-fire defense program.

During the 1990's Elpac developed an offshoot from this EMI technology by designing and manufacturing high density, high voltage capacitance systems using newly developed dielectric films, which permitted much higher capacitance density than previous techniques. These units replaced older capacitance technologies to provide an improved reliability product that was often of smaller size and frequently more cost effective.

To this day, Elpac still manufactures the above-described EMI filters for global customers and high-density capacitor products that are used on the Boeing 737 aircraft.

About the Author

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