Keywords: EMI, electromagnetic interference, CISPR 22, EMI noise, power solution design, power module, EMI compliance, switching power supplies

APPLICATION NOTE 6729

MITIGATING EMI FOR A CISPR 22-COMPLIANT POWER SOLUTION

Abstract: System engineers dread the prospect of not passing electromagnetic interference (EMI) compliance testing at the end of a product development cycle. If this happens, it can cause a major setback to the product shipping schedule and could also trigger a costly total power re-design. This application note examines how to achieve first-pass EMI success using a well-planned power solution design that utilizes a proper filter, low EMI components, low EMI power regulator ICs, and/or low EMI power modules, along with good PCB layout and shielding techniques.

Understanding EMI Noise

When an electronic device is connected to, shares the same power source with, or is near another electronic device that generates electromagnetic interference (EMI), EMI can disrupt operation of the device. EMI is either conducted or radiated, and EMI related problems can prevent adjacent pieces of electronics equipment from working alongside one another.

There are many common examples of EMI:

- Interference from a microwave oven can impact the nearby Wi-Fi® signal
- Transmitters can hamper local TV stations from displaying pictures, causing either the whole picture to disappear or patterning of the picture
- A cell phone's handshake with the communication tower to process a call can result in interference, which is why airliners ask passengers to switch off their cell phones during flights
- An aircraft flying at low altitude can disturb the audio/video signals on the radio or TV

Given the prevalence of electronic equipment in our lives, the issue of electromagnetic compatibility (EMC) has become an important topic. As a result, standards bodies have emerged to ensure proper performance of electronic equipment even with EMI to make it possible to operate mobile phones and other wireless devices near almost any electronics equipment with little or no effect. Designers have taken steps to ensure that equipment does not radiate unwanted emissions and to make equipment less vulnerable to radio frequency radiation.

Designing to EMI Specifications

The CISPR 22 EMI specification (often referred to as EN55022 in Europe) divides equipment, devices, and apparatus into two classes:

- Class B: Equipment, devices, and apparatus that are intended to be used in the domestic environment and meet CISPR 22 Class B emission requirements.
- Class A: Equipment, devices, and apparatus that do not meet the CISPR 22 Class B emission requirements but comply with the less stringent CISPR 22 Class A emission requirements. Class A equipment must have the following warning: "This is a Class A product. In a domestic environment, this product may cause radio interference, in which case the user may be required to take adequate measures."

Table 1, **Table 2**, **Table 3**, and **Table 4** show the CISPR 22 specification.

EMI testing consists of conducted and radiated emission testing. Conducted emission testing is done in the frequency range of 150kHz to 30MHz, which is where the AC current is conducted into the line source and is measured using two methods: quasi-peak and average. Each method has its own limits.

Radiated emission testing is done in the higher radio frequency range of 30MHz to 1GHz. This range is the radiated magnetic field from the device under test (DUT). The testing upper range of 1GHz applies to the DUT that has an internal oscillator frequency up to 108MHz. Table 5 lists the extended upper ranges, which are dependent on the maximum internal oscillator frequency.

Table 1. CISPR 22 Class B conducted EMI specification

Frequency range MHz	Limits dB (µV)	
	Quasi-peak	Average
0.15 to 0.50	66 to 56	56 to 46
0.50 to 5	56	46
5 to 30	60	50

Table 2. CISPR 22 Class A conducted EMI specification

Frequency range MHz	Limits dB (µV)	
	Quasi-peak	Average
0.15 to 0.50	79	66
0.5 to 30	73	60

Table 3. CISPR 22 Class B radiated EMI specification

Frequency range MHz	Quasi-peak limits dB (µV/m)
30 to 230	30
230 to 1,000	37

Table 4. CISPR 22 Class A radiated EMI

Frequency range MHz	Quasi-peak limits dB (µV/m)
30 to 230	40
230 to 1,000	47

Table 5. Extended Testing Upper Range with DUT Internal Oscillator Frequency

Testing Upper Range	DUT Maximum Internal Oscillator Frequency
1GHz 2GHz	108MHz 500MHz
5GHz	1GHz
6GHz	Higher than 1GHz

Switching Power Supplies: Where are the Noise Sources?

Switching power supplies can generate electromagnetic energy and noise as well as be affected by electromagnetic noise from external aggressors. Noise generated by a switching power supply can be in the form of conducted or radiated emissions. Conducted emissions can take the form of voltage or current, and each of these can be categorized as common-mode or differential-mode. Also, the finite impedance of connecting wires enables voltage conduction to cause current conduction, and vice versa, and differential-mode conduction to cause common-mode conduction, and vice versa.

For a closer look at noise sources in a switching power supply, **Figure 1** shows a simplified buck regulator schematic.

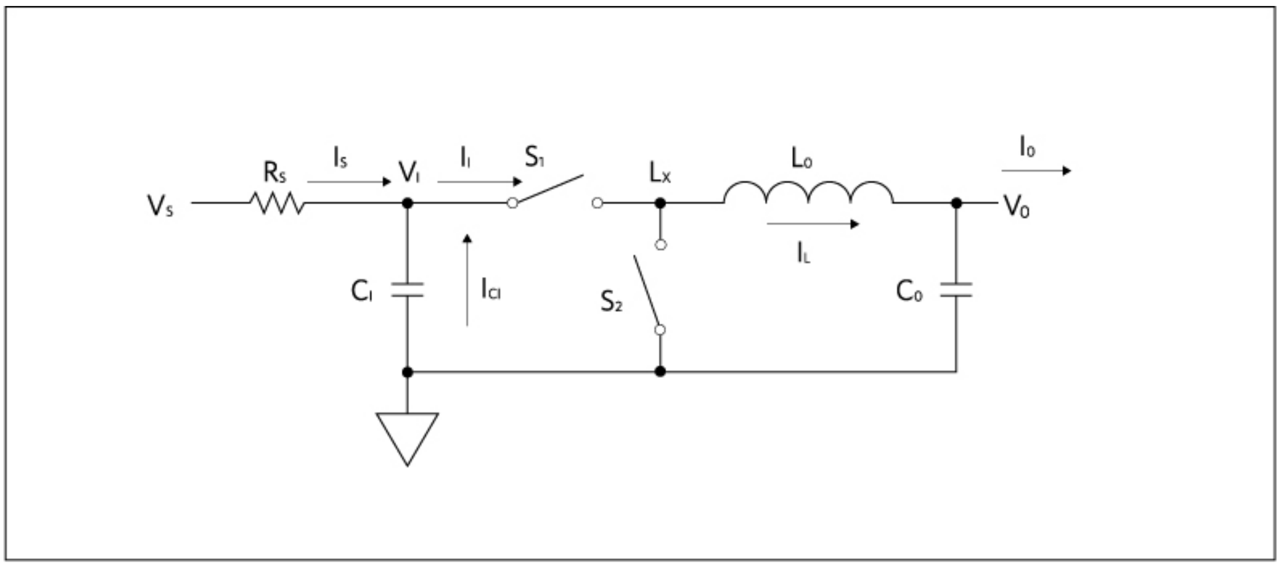

Figure 1. Simplified buck regulator schematic.

Conducted EMI

As shown in Figure 1, the input current (I_I) of the buck regulator is a pulsing waveform, which is the main source of conducted, differential EMI injecting back into the power source (V_S). Conducted emissions are primarily driven by fast-changing current shapes at the input of the converter (di/dt). The value of conducted emissions is measured as voltage at the input of the converter (V_S) using a line impedance stabilization network (LISN). The input capacitor (C_I) filters out the AC (pulsing) component. The net current (I_S) is the difference between I_I and I_{CI}. I_S must be DC or as smooth as possible. If C_I is an ideal capacitor with infinite capacitance, it would keep V_I constant and effectively filter out all the AC components of I_1, leaving a constant (DC) current flowing from the source V_S and a constant DC voltage drop across the source impedance (R_S). In this case, the conducted EMI is zero since I_S is a DC current. In practice, use a π-filter between the input source and the converter to contain conducted EMI within the regulatory limit.

Conducted emission usually poses a greater problem for fixed systems than for portable systems. Because the portable device operates from batteries, the load and source have no external connections for conducting emissions.

Radiated EMI

Radiated EMI are fast-changing magnetic fields that have a high-frequency content of 30MHz and above. Magnetic fields are generated by the circuit's current loops. Changes in these fields, if not properly filtered or shielded, can couple into other nearby circuitry and/or equipment and cause radiated EMI effects.

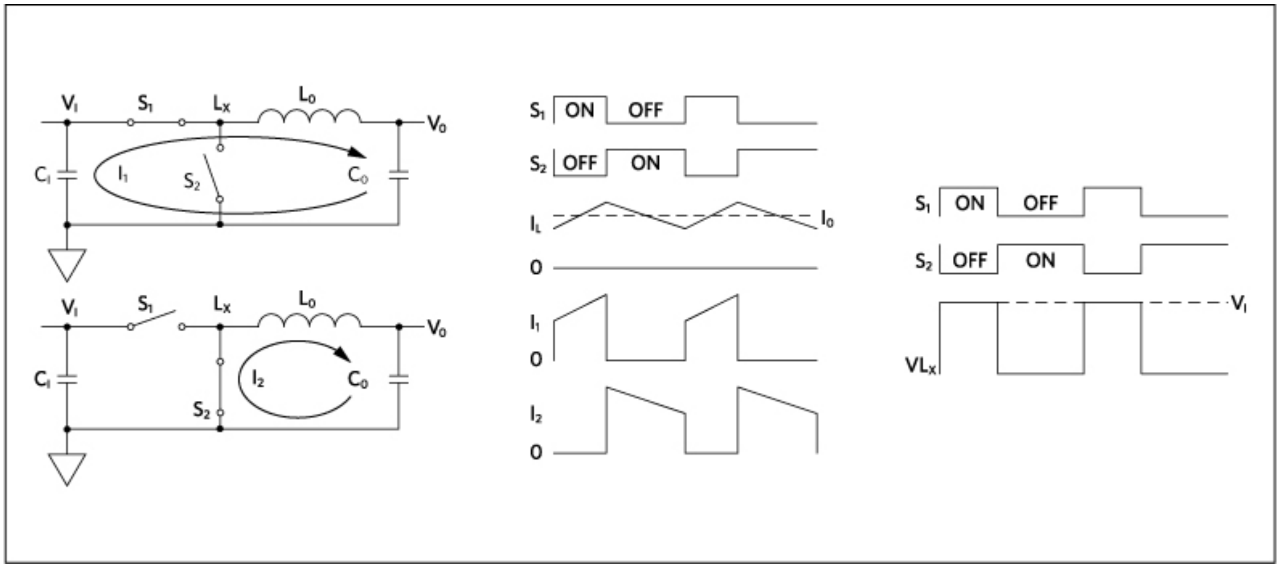

Figure 2. Simplified buck regulator schematic and its fast di/dt current loops.

Figure 2 shows a buck converter with fast di/dt current loops I_1 and I_2. The current loop I_1 conducts during the on-time when S_1 is on and S_2 is off. The current loop I_2 conducts during the off-time when S_1 is off and S_2 is on. The pulsating nature of the current loops I_1 and I_2 causes change in the magnetic fields with a field strength that is proportional to the change of the current magnitude and the area of the conducting loop. Fast di/dt current edges generate high-frequency harmonics and EMI in the regulatory radiated range. Keeping the area of these current loops small minimizes the field strength. Slowing down these edges reduces the high-frequency harmonic content of the switching regulator, but slow transitions impact the regulator efficiency due to wasted energy. This application note describes techniques that minimize the EMI radiation without impacting efficiency.

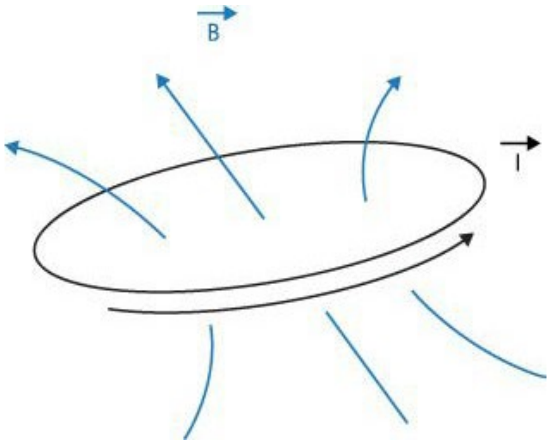

Figure 3. Magnetic field generated by a current loop.

The voltage node LX (also called other names such as SW by some vendors) is a rectangular wave (ignore the parasitic ringing for now) that is connected to the inductor. Fast LX's dv/dt voltage discontinuous edges couple the high-frequency current to CO and the load through the output inductor's parasitic capacitance, which can in turn generate EMI noise. Minimizing the output inductor's parasitic capacitance can reduce this noise-coupling issue. LX also has high-frequency parasitic ringing, which can be reduced by using an RC snubber network from LX to GND.

The same principle of the EMI noise sources described above applies to other switching-converter topologies as well. However, the severity of the noise depends on the current and voltage wave shapes of a specific topology. Consider a boost converter running in continuous conduction mode. In this scenario, the converter has a less conducted EMI component at its input, since the input current is more continuous compared to that of a buck converter.

Designing and planning for EMI compliance upfront in the design process is essential for project success. Doing so late in the game makes the process challenging, time consuming, and costly. Line filtering, power-supply design, proper PCB layout, and shielding are some common techniques to minimize EMI.

Designing EMI Line Filtering

A π-filter placed between the input source and power converter reduces conducted emissions from a power converter. Select the filter components by performing the steps, as follows:

1. Determine the input impedance R_{IN}. The worst-case closed-loop input impedance of a buck converter is $R_{IN} = R_O/D^2$ for all frequency where R_O is the output load, and D is the operating duty cycle. The minimum input impedance occurs when the converter is operating at minimum input supply voltage.

> Example: Consider one of Maxim's Himalaya SiP power modules, MAXM17575, a $4.5V_{IN}$ to $60V_{IN}$, $0.9V_{OUT}$ to $54V_{OUT}$ that supplies up to 1.5A. Using the MAXM17575 Evaluation Kit (EV kit) as an example, the minimum input voltage is 7.5V. The output load is Ro = Vo/Io = 5V/1.5A = 3.3 . The maximum operating duty cycle is $D = Vo/V_{INmin}$ = 5V/7.5V = 0.66. So, the least possible input impedance is $R_{IN} = Ro/D^2 = 3.3$ $/0.66^2 = 7.6$.

2. Design the EMI filter with output impedance 10db lower than R_{IN}. The addition of the input filter can affect the performance of the DC-DC converter. To minimize the effect, the output impedance of the filter must always be less than the input impedance of the power converter for all frequencies up to the converter's crossover frequency.

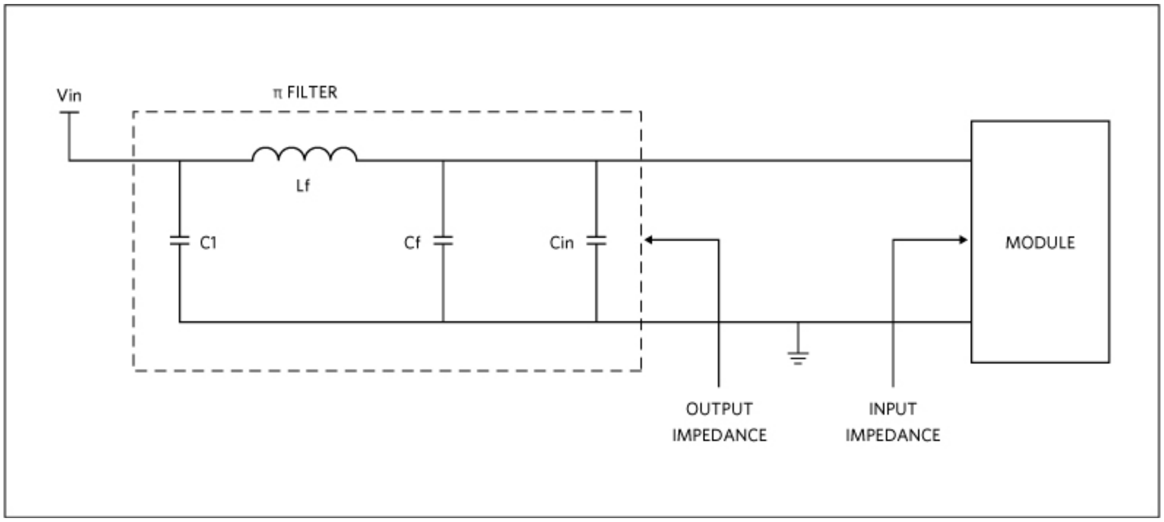

Figure 4. Conducted EMI input filter, inserted between input and a power module.

The output impedance of the LC filter at its resonance frequency, which is the highest value, is as follows:

The effective impedance of the filter is 10dB less than the input impedance of the buck converter, which is approximately equal to one-third of the input impedance. For the MAXM17575 example, the required Zo is $R_{IN}/3$ = 7.6/3 = 2.5 for all frequencies up to the MAXM17575 circuit's crossover frequency, which is 45kHz.

Designing a PCB Layout for EMI Compliance

The PCB layout has a significant effect on the EMI compliance. A bad PCB layout can ruin a power converter with perfect electrical design. Based on the same buck converter example, here are some of the best practices for PCB layout to minimize EMI noise sources:

1. Minimize high di/dt current loops.
    a. Properly place Lo, Co, and S_2 close together to minimize the I_2 current loop.
    b. Place this entire group of components close to S_1 and C_1 to also minimize the I_1 current loop.

    When using a buck regulator IC (i.e., a buck controller with integrated power switches S_1 and S_2), it is important to select ICs that have good pinouts to allow this minimization. The same consideration applies to using power modules.

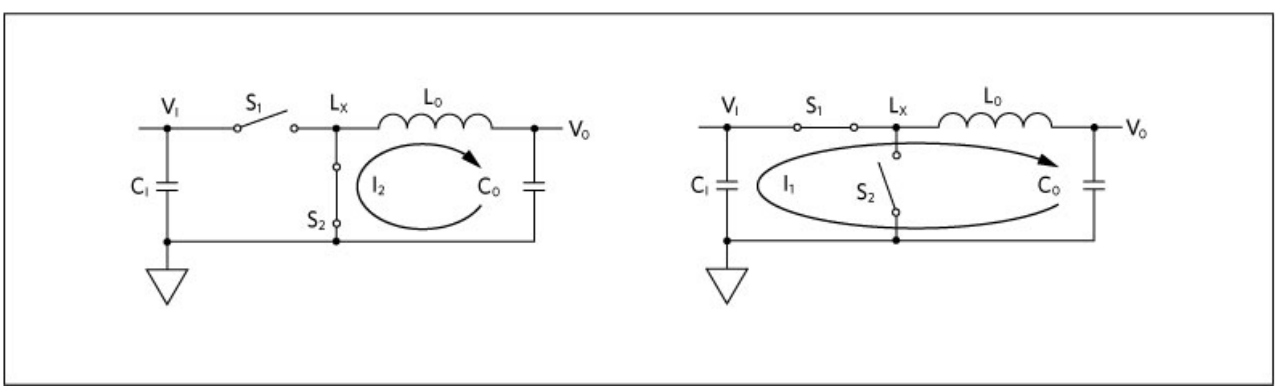

Figure 5. Buck converter's high di/dt current loops.

2. Use a Faraday shield. A Faraday shield or cage is an enclosure used to block electromagnetic fields. There are two common ways to implement a Faraday shield in a power system.
    a. A cage made of conductive material (such as copper) that encloses the entire power system or equipment. The electromagnetic field is contained inside the cage. However, this approach is usually expensive because of the cost of the cage material and additional assembly labor.
    b. A layout with shielding ground planes on both the top and bottom of the PCB connected by a via to mimic a Faraday cage. All high di/dt loops are placed in the inner layers of the PCB so that our Faraday cage shields the magnetic field from radiating outward. This method, depicted in **Figure 6**, is at a lower cost and usually adequate to contain EMI.

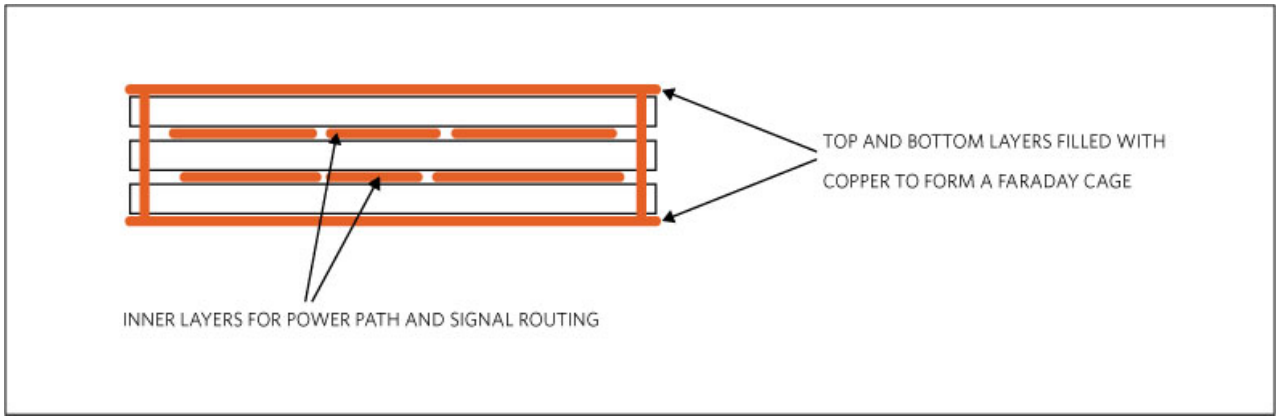

Figure 6. Faraday shield applied on a multi-layer PCB board.

Following these PCB layout best practices provides a reasonable way to achieve EMI regulatory compliance without compromising power converter efficiency by otherwise slowing down the switching edges.

Consider Maxim's Himalaya wide input IC, MAX17502, which operates at 4.5V_{IN} to 60V_{IN}, 0.9V_{OUT} to 54V_{OUT} supplying 1A current.

supplying 1A current. The following is the MAX17502 EMI EV kit PCB layout, using the Faraday shield technique (b). **Figure 7a** shows the top and bottom layers used as the Faraday shield. **Figure 7b** shows the second and third inner layers for routing. The second layer is used as an extra shield, but it can also be used to route traces. In this layout, the high di/dt current loops I_1 and I_2 are routed on the third layer, which is completely enclosed in our Faraday shield.

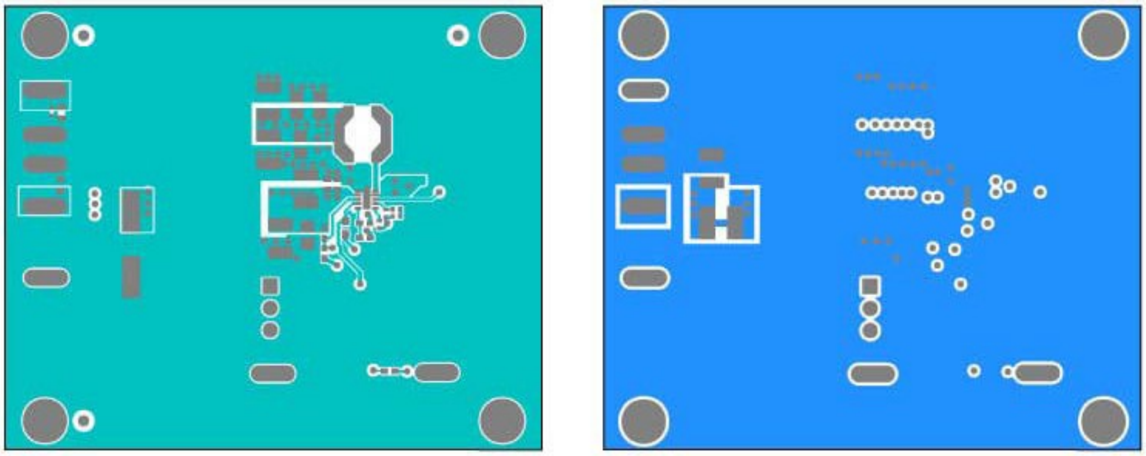

Figure 7a. Top layer and bottom layer used as Faraday shield.

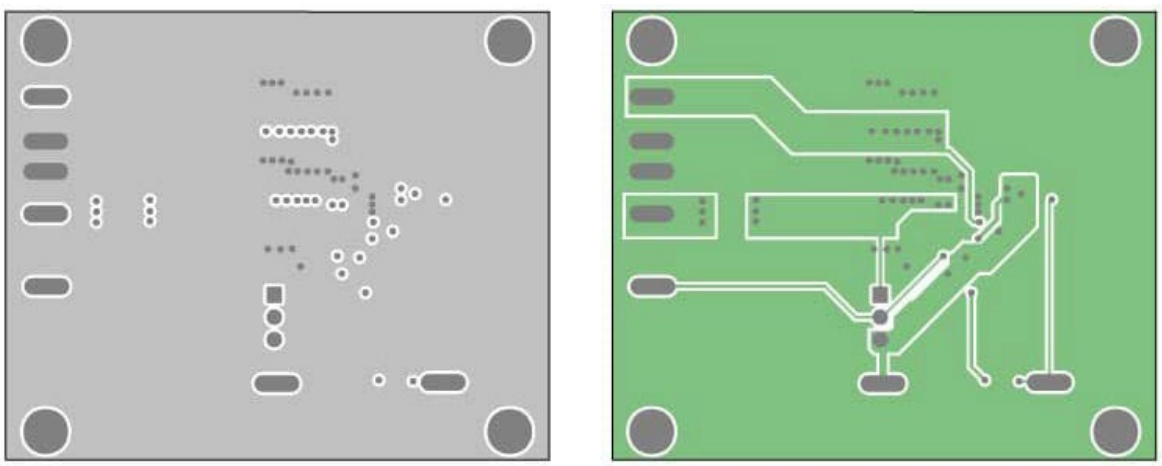

Figure 7b. Second and third (inner) layers, with high di/dt loops routed on the third layer.

Figure 8 and **Figure 9** show the EMI test results of this MAX17502 EMI EV kit, which passes CISPR 22 Class B with good margin.

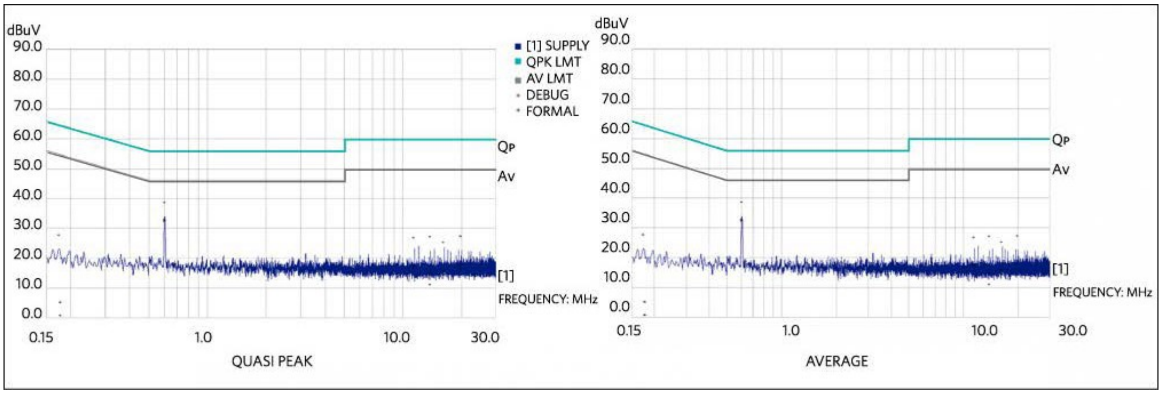

Figure 8. MAX17502 EMI EV kit conducted EMI test result. Left: quasi peak, right: average.

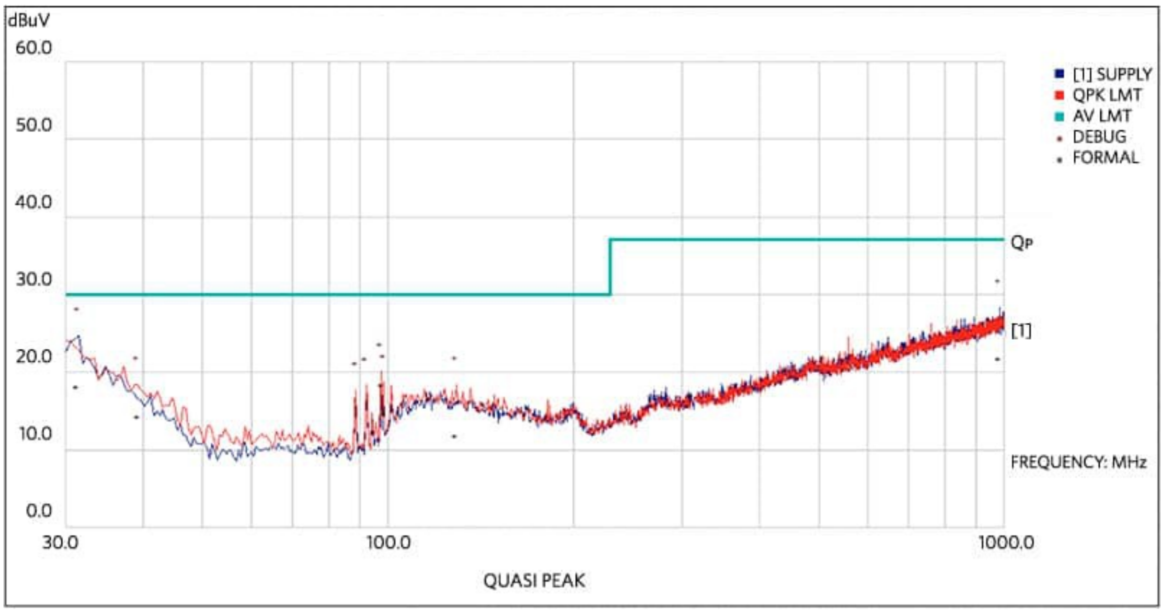

Figure 9. MAX17502 EMI EV kit radiated EMI test result.

Power Components with Low EMI

Since the magnetic field from the output inductor can also radiate and cause EMI issues, using a low EMI inductor reduces radiated EMI. Shielded inductors are recommended, as the magnetic field is shielded and contained within the inductor structure. Avoid inductor types where the magnetic energy can radiate freely. Power modules using shielded inductors and employing good PCB layout practices exhibit good EMI performance.

Low EMI Power Regulators and Modules

Maxim's Himalaya regulator and power module families employ low EMI power inductors and good PCB layout practices and provide inherently low EMI power solutions. Using the Himalaya solutions means you do not need to worry about compliance, unlike with other simplistic switchers in the market. Maxim has done all the work with the ICs, modules, and example reference layouts so that you can pass CISPR 22 (EN 55022) at optimal cost. The following displays EMI test results of an example, MAXM17575, together with input EMI filter information:

Table 6. EMI Test Results of MAXM17575

Test Article (EUT)	MAXM17575	Result	PASS-EN55022 (CISPR 22) CLASS B
		EUT Revision	REV-P1
Input Voltage	24V-Positive	Output Voltage	5.0V
Switching Frequency	900KHz	Output Current	1.5A

EMI Filter Configuration − Conducted EMI Test

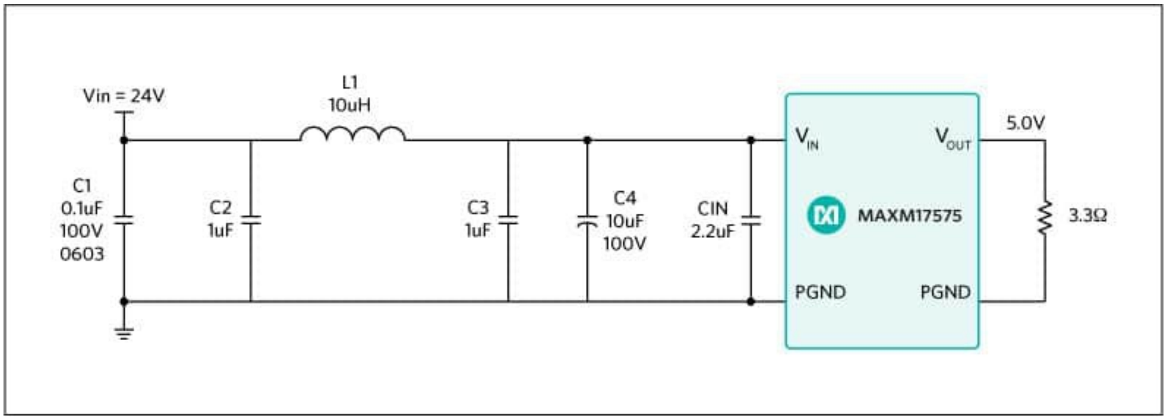

Figure 10. MAXM17575 EV kit EMI filter configuration for conducted EMI test.

Table 7. Filter Component for Conducted Test Results

Filter Component	Value	Part Number	Manufacturer
Inductor-L1	10μH	PA4332.103NLT	Pulse Electronics
Capacitor-C1	0.1μF	GRM188R72A104KA35	Murata
Capacitor-C2, C3	1μF	GRM32CR72A105KA35	Murata
Capacitor-C4	10μF	EEE-TG2A100P	Panasonic
Capacitor-CIN	2.2μF	GRM32ER72A225KA35	Murata

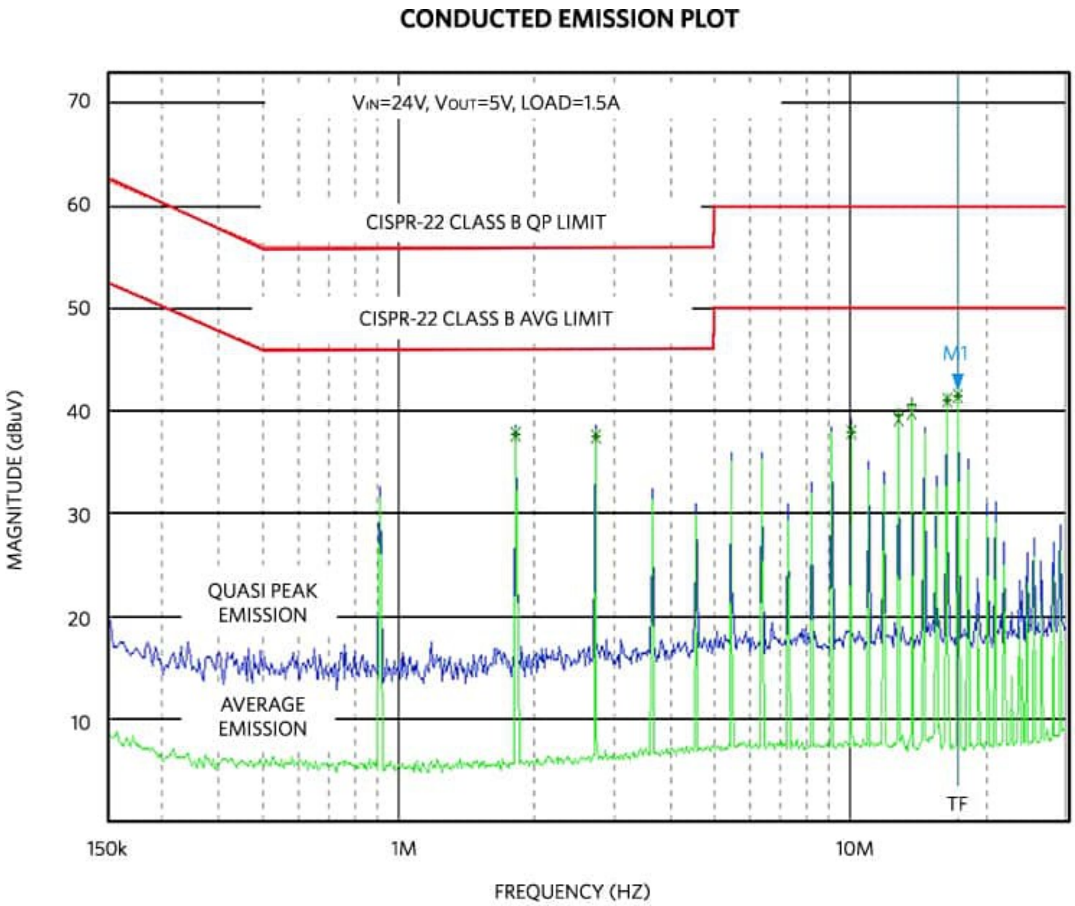

Figure 11. MAXM17575 EV kit conducted EMI test result. Blue: quasi peak, Green: average.

EMI Filter Configuration − Radiated EMI test

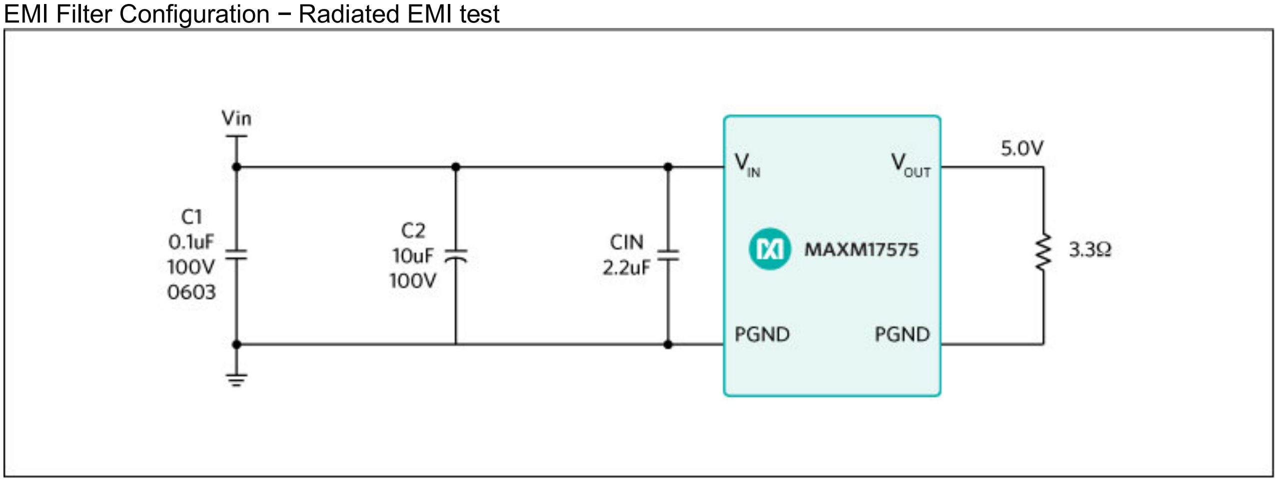

Figure 12. MAXM17575 EV kit EMI filter configuration for radiated EMI test.

MAXM17575 has inherently very low radiated EMI. The input filter shown for the conducted EMI test is not needed and is not used for the radiated test. Using the input filter provides additional passing margin for the radiated test result.

Table 8. Filter Component for Radiated Test Results

Filter Component	Value	Part Number	Manufacturer
Capacitor-C1	0.1µF	GRM188R72A104KA35	Murata
Capacitor-C2	10µF	EEE-TG2A100P	Panasonic
Capacitor-CIN	2.2µF	GRM32ER72A225KA35	Murata

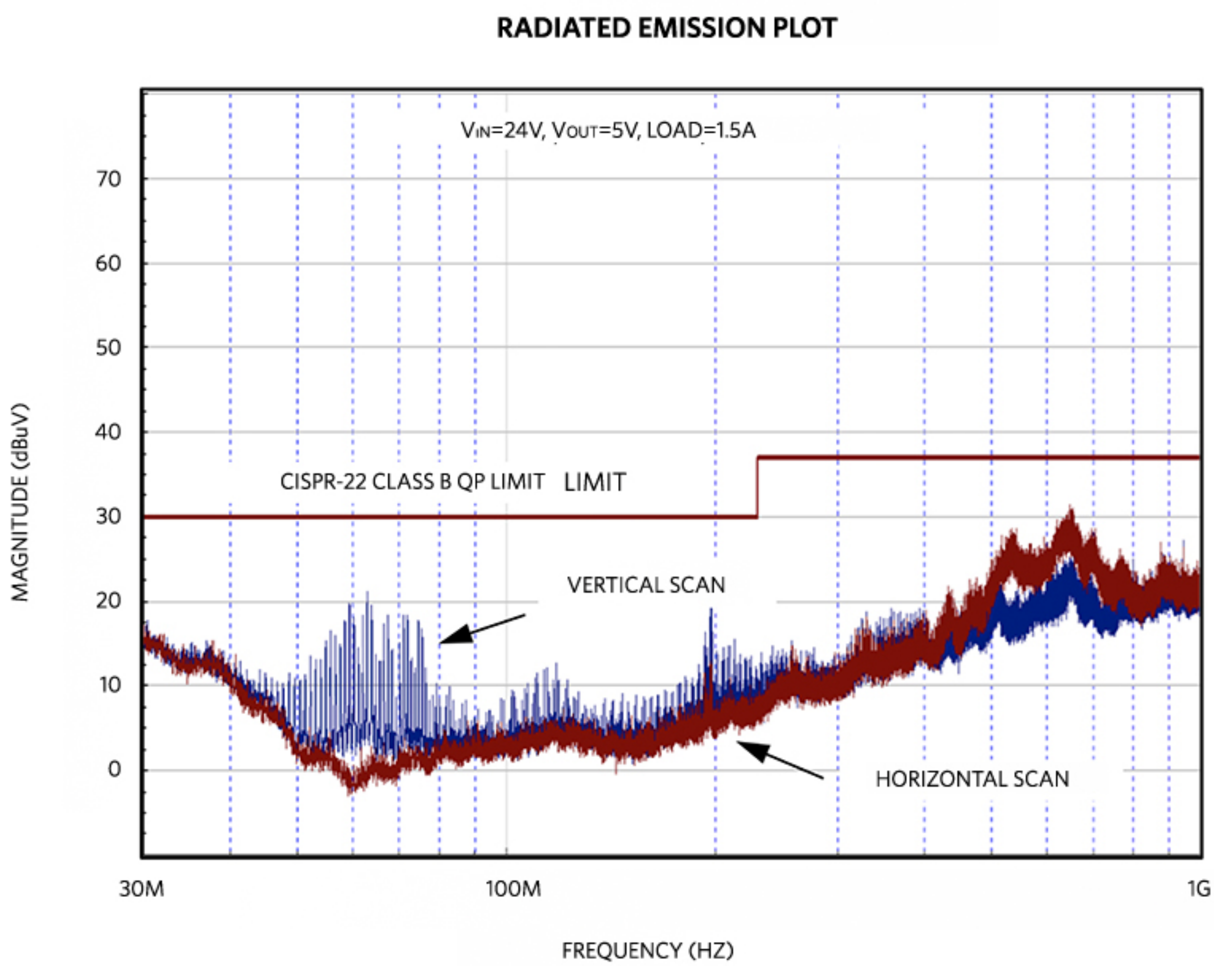

Figure 13. MAXM17575 EV kit radiated EMI test result.

Conclusion

Addressing the EMI compliance of your design at the earliest phases of the design cycle is critical for project success. This application note covers common techniques for minimizing EMI, as well as guidelines and examples for line filtering design, good PCB layout, and shielding practices. Applying a well-planned design using a proper filter (low EMI PMICs, components, and/or power modules) and good PCB layout techniques and shielding can put you on the right track toward first-pass success.

Wi-Fi is a registered certification mark of Wi-Fi Alliance Corporation.

Related Parts		
MAX17502	60V, 1A, Ultra-Small, High-Efficiency, Synchronous Step-Down DC-DC Converter	Free Samples
MAXM17575	4.5V to 60V, 1.5A High-Efficiency, DC-DC Step-Down Power Module with Integrated Inductor	Free Samples

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