From March 2010 *High Frequency Electronics*

Minimizing Electromagnetic Interference When Powering Wireless Systems

By Afshin Odabaee
Linear Technology Corporation

This article discusses EMI issues for DC/DC switching regulators, showing how emissions control can be simplified by using a regulator module designed to exceed EMI standards

EMI can be a difficult and frustrating problem for all electronic systems. If you walk into an RF laboratory and say, “I don’t know whether this DC/DC regulator’s EMI will disrupt or fail the operation of my system, but I have to design it now and test it later,” you’ll get sympathetic looks from your colleagues. Some will silently pray for you.

RF systems designers are savvy engineers and, in many ways, masters in techniques to reduce conducted and radiated noise. They are intensely motivated and focused on eliminating potential sources of system noise, much as an angry bull focuses on the red cape in a bullfighting ring. Yet, the red cape sneaks up on you in mysterious ways in DC/DC switching regulators.

Systems incorporating sophisticated high frequency functionality are consuming more power and are increasingly assembled on denser circuit boards. Higher power consumption and close proximity of components increase the risk of a point-of-load switching regulator’s electromagnetic energy interfering with RF circuitry.

The noise from switching DC/DC regulators encompasses both conducted and radiated noise. The conducted noise travels over printed circuit board (PCB) traces and can be attenuated with filters and proper layout. Experienced system designers attack this issue by adding input and output filters such as ferrite beads (pi-filters) and by careful layout of the PCB. Often a linear post regulator is used after a switching regulator’s output to filter some of this energy. This is a common practice when powering RF power amplifiers, for example.

The radiated noise, is electromagnetic energy which travels through air (space) and is often more difficult to tame. This radiation must be stopped at the source, and that source can be as obvious as multigigabit transceivers or as elusive as DDR memory—or the overlooked DC/DC switching regulator.

Raise Some Noise

Switching DC/DC regulators, by nature, dissipate energy. It is the strongest at the switching frequency of the regulator, where, for example, large currents are switched by a MOSFET. Depending on the frequency, the harmonics or the strength of the energy being switched, a DC/DC switching regulator can disrupt data integrity or prevent a system from passing EMI standards such as EN55022 or CISPR22 class B or A.

Often, RF systems engineers who have experienced the intense urgency of fixing previous last minute EMI issues, decide to overfilter a regulator’s circuit. The fear of not passing a test due to EMI noise is far greater than the cost or wasted PCB area. And no one can blame them. But there are many other tools available to the designer.

Here are several common methods to alleviate noise:

1) **Bypassing**
Bypassing is used to reduce the flow of high switching current especially in high impedance PCB traces. It is most often accomplished by shunting the path with a capacitor.

2) **Decoupling**
Decoupling in a power supply circuit refers to the isolation of two circuits on a common line. As was mentioned before, low pass filters such as common ferrite bead/capacitor pi-filters are very effective.

3) **di/dt**
Know the sources of fast derivative (fast rise/fall time) current sinks or sources and determine their return paths. Make sure to bypass all of them.

4) **Layout**
Make sure your small signal, ground and power planes are properly placed. Keep small signals and power planes separated from one another. Minimize inductance in your traces.

5) **Shields**
To contain and reduce emanated energy from a DC/DC regulator (if it's "noisy"), you may need to add metallic shields around the circuit. Use shielded inductors.

6) **Adjust the frequency**
Does the switching regulator have an adjust pin, PLL (phase lock loop) or SYNC pin to set the switching frequency to a desired value? It's a good idea to choose a switching regulator with PLL capability. It may come in handy later on during final testing of your board.

7) **Spread Spectrum Frequency Modulation**
Some modern switching regulators come with an on-board SSFM feature. Or you could buy a SSFM clock generator if the regulator lacks this function. With SSFM you can reduce the energy level by spreading it across a wider frequency range, thus preventing a strong level concentrated at a particular frequency value. Be sure that the switching regulator has SYNC or PLL capability.

8) **Let someone else worry about it**
If the switching regulator circuit is designed cleverly, its layout optimized and, most importantly, already tested under strict industry EMI standards, then someone else has already done the job. These products do exist.

There are many categories of EMI. An engineer has to worry about both susceptibility and emissions. Susceptibility refers to the amount of noise that can be thrown at the design without malfunction or destruction, including such things as ESD spikes, AC riding on a DC line and even the induced energy of nearby lightning strikes. Emissions refer to the amount of noise that the design throws out at other products.

In general, a designer worries most about emissions. With few exceptions, most systems operate in an environment where the emissions of each product are required to not exceed some predefined level. In theory, if each product complies with these emission levels, the noise level running throughout the system is low enough that no one has to worry about susceptibility.

We Failed the EMI Test

There are three little words that design engineers dread: "We failed EMI." There are four little words that are even worse: "We failed EMI again." Many a seasoned engineer is scarred with dark memories of long days and nights in an EMI lab, struggling with aluminum foil, copper tape, clamp-on filter beads and finger cuts to fix a design that just won't quiet down.

There are two types of emissions: conducted and radiated. Conducted emissions ride on the wires and traces that connect up to a product. Since the noise is localized to a specific terminal or connector in the design, compliance with conducted emissions requirements can often be assured relatively early in the development process with a good layout or filter design.

Radiated emissions are another story. Everything on the board that carries current radiates an electromagnetic field. Every trace on the board is an antenna, and every copper plane is a resonator. Anything other than a pure sine wave or DC voltage generates noise all over the signal spectrum. Even with careful design, no one really knows exactly how bad the radiated emissions are until the system gets tested—and radiated emissions testing cannot be formally performed until the design is essentially complete.

So what is a design engineer to do? One approach is to use parts that are pre-tested and known to have low emissions. Using these "verified and certified" parts greatly increases design success.

In the United States, radiated emissions and EMI testing are regulated by the Federal Communications Commission. The most commonly encountered specification is the Federal Code of Regulation (CFR) FCC Part 15. CFR FCC Part 15 regulates all radio frequency devices, whether or not they are intentional emitters. It defines two classifications of unintentional radiating digital devices, A and B. Class B is stricter, defining limits around 10 dB lower than class A.

Don't get confused by the term "digital device." In the FCC's eyes, a digital device is anything that generates and uses timing signals of frequency greater than 9 kHz. Today, that covers a lot of products, including most switching power supplies.

Class A devices are used in commercial, industrial or

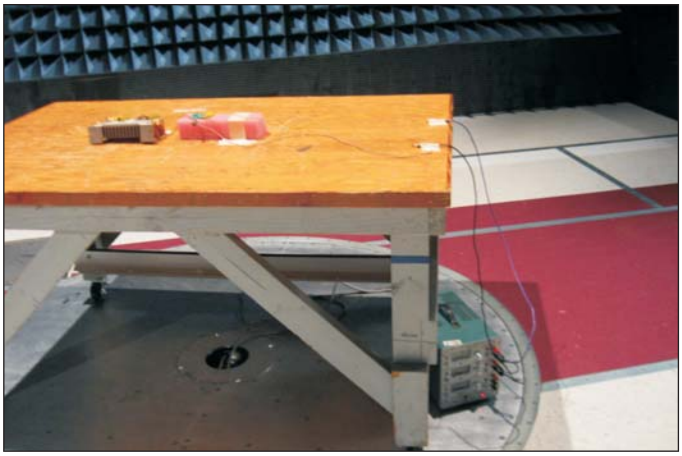

Figure 1 · The test setup. The power source, a linear lab grade power supply, is on the floor.

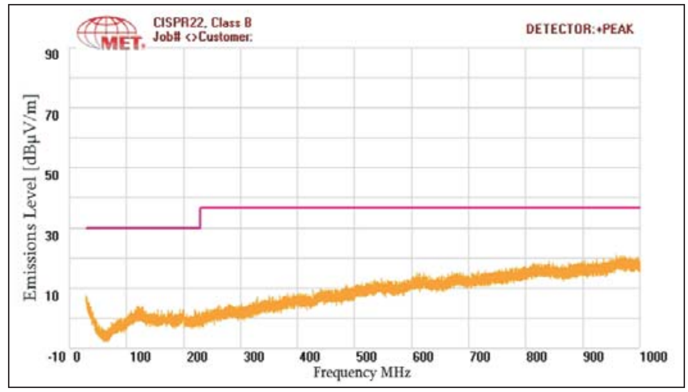

Figure 2 · LTM8032 EMI test baseline: Ambient noise in the 5 meter chamber, with no devices operating.

office environments. Class B devices are intended for residential use. An example of a class A device is a mainframe computer, seldom seen in a home. A monitor, while certainly used in offices, is also used in private homes, so it is a class B device.

In order to be useful in a class B device, a component should radiate less noise than the specified limit. How much less is dependent on the other components in the system. If the device emits more than the class B limit, some means must be devised to reduce the noise, such as shielding or slew rate limiting.

Meeting EMI Regulatory Standards

In Europe, allowable electromagnetic emissions are generally defined by EN55022. Another commonly encountered specification is CISPR 22, which comes from the international agency Comite International Special des Perturbations Radioelectriques (International Special Committee on Radio Interference). These two specifications are similar to FCC part 15, defining similar (but not identical) limits and dividing them into the two A and B emissions classes.

In today's modern designs, switching power supplies can make a significant contribution to the radiated noise coming from a system. To date, there are three products that have radiated EMI emissions compliant with CISPR 22 class B: LTM8020, LTM8021 and the LTM8032 µModule® DC/DC regulator.

Each of these units was tested at the MET Labs facility in Santa Clara, California. MET Labs is accredited by numerous agencies, including NIST and A2LA for EMI testing. A complete listing of the lab's credentials is provided on their Web site: http://www.metlabs.com/pages/emcaccred.html

Radiated emissions testing is highly regulated, and the test method specifications are very detailed. There is no means by which a design engineer can influence the measurement technique or method. When asking a lab to perform radiated emissions testing, an engineer chooses only the test specification; the lab handles the rest and the design engineer is not invited to participate in the measurement process. In the case of the LTM8000 series µModule devices listed above, the chosen test specification is CISPR 22 class B.

Of the three products under discussion, the LTM8032 is built specifically for low EMI. It is rated for up to 36 V_{IN}, and 10 V_{OUT} at 2 amps. It was tested in MET Labs' 5 meter chamber set up as shown in Figure 1. The LTM8032 is mounted on a circuit board with no bulk capacitance installed. The input and output capacitance are ceramic devices with the minimum values specified in the data sheet for proper operation.

The assembled unit is placed atop an all-wooden table. The all-wood construction ensures that the test setup does not shield or shadow noise emanating from the device under test (DUT). The power source, a linear lab grade power supply, is on the floor. The load for the LTM8032, with its heatsink, is also on the table top.

Measuring EMI from the LTM8032

Before measuring the emissions from the LTM8032, a baseline measurement is taken to establish the amount of ambient noise in the room. Figure 2 shows the noise spectrum in the chamber without any devices running. This may be used to determine the actual noise produced by the DUT. You may ignore the red lines in the Figure 2 graph, as they are not relevant to this discussion.

Figures 3a and 3b show the LTM8032 emissions plots whe operating with maximum power out: 10V at 2A, for 24V and 36V inputs, respectively. There is a slight discrepancy to note between the spectrum plots and the CISPR 22 class B limits. The CISPR 22 class B limits shown in Figures 3 through 7 are for quasi-peak measurements, which take the peak noise emissions and cal-

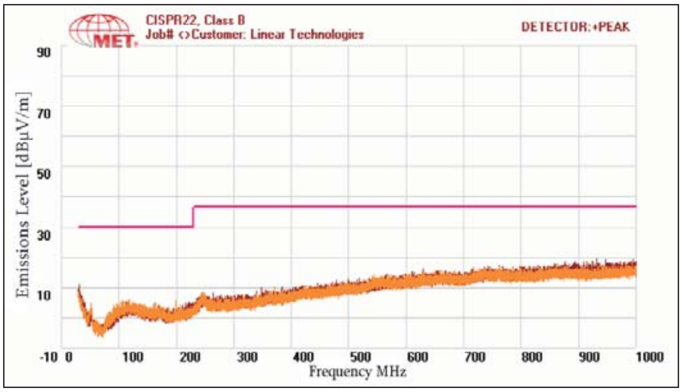

Figure 3a · LTM8032 emissions for 20 watts out, 24V_{IN}.

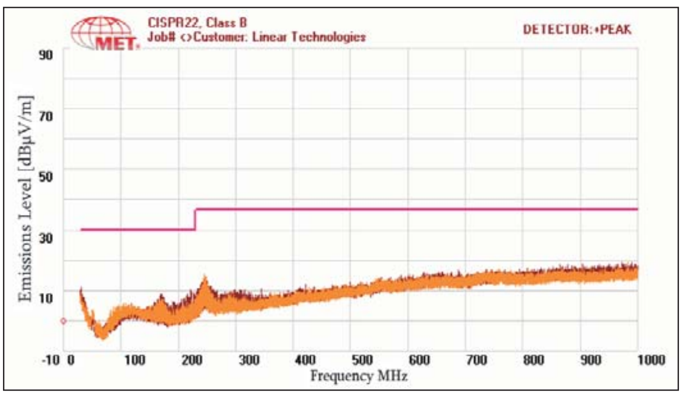

Figure 3b · LTM8032 emissions for 20 watts out, 36V_{IN}.

culate the integral average of the noise signals over time. The time of the averaging is based on the frequency at which the noise is detected. The noise measurements in Figures 2 through 6, however, are simply peak measurements, as indicated in the upper right corner of the spectrum plot, so the design margin indicated in the plots is even greater than what is graphically indicated. A copy of this report is available on www.linear.com/umodule.

There are two traces in the plot, one each for the vertical and horizontal orientations of the test lab receiver's

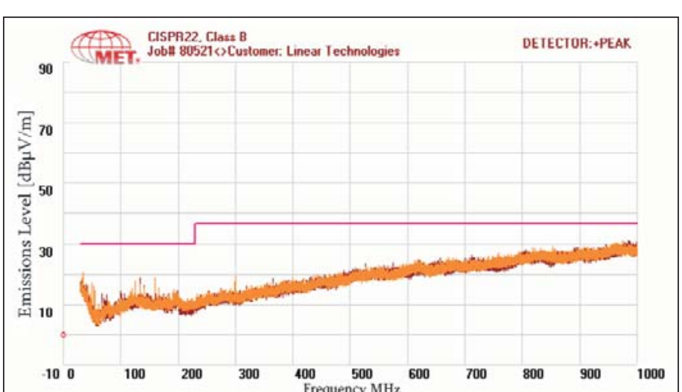

Figure 5 · LTM8020 emissions for 12 V_{IN}, 5 V_{OUT} at 200 mA.

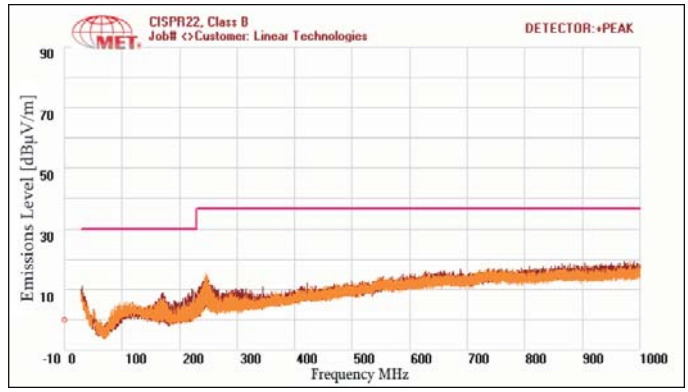

Figure 4 · LTM8032 emissions for 10 watts out, 12V_{IN}.

antenna. You can see that the LTM8032 easily meets the CISPR 22 class B limits, by a wide margin.

Figure 4 shows the emissions with the LTM8032 operating at 10 watts out: 5 V at 2 A, with V_{IN} of 12 V. Once again, the emissions are very low.

Two other parts are also CISPR 22 class B compliant, the LTM8020 and LTM8021. The LTM8020 is rated for up to 36 V_{IN} and up to 5 V_{OUT} at 200 mA, while the LTM8021 is rated for 36 V_{IN}, 5 V_{OUT} at 500 mA. These two devices were tested in MET Labs' 10 meter chamber. This chamber is a bit noisier than the 5 meter chamber. The higher noise floor is evident when comparing the plots of Figures 5 and 6 to Figures 2 through 4. As in the case of the LTM8032, the red lines in these plots are the quasi-peak limits, while the spectrum plot displays the peak measurements. Thus, the actual noise margin is greater than what is shown.

The DUT configuration is similar to the LMT8032. They are assembled on circuit cards with no bulk capacitors and only the minimum required ceramic capacitors. They are mounted on a wooden tabletop, along with the load, and the power source is on the floor.

The emissions spectrum for the LTM8020 is given in Figure 5 for an input voltage of 12 V (data for 24 V and

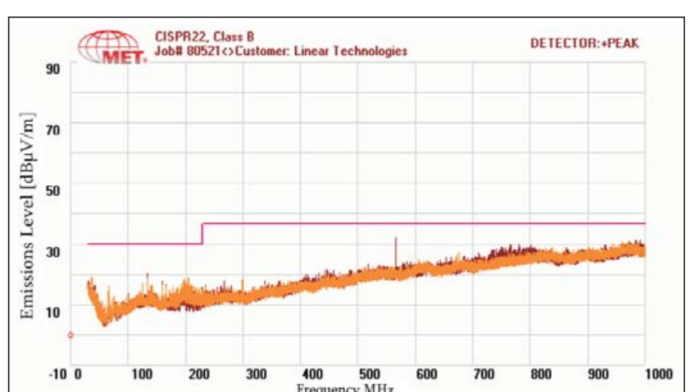

Figure 6 · LTM8021 emissions for 12 V_{IN}, 5 V_{OUT} at 500 mA.

36 V inputs are available at www.linear.com). The output power is 1 W, 5 V at 200 mA.

The emissions spectrum of the LTM8021 is shown in Figure 6 for input voltage of 12 V. The output power is 2.5 W, 5 V at 500 mA.

Summary: Ultralow EMI, Low Heat Dissipation and Compact DC/DC Systems-in-a-Package Solve EMI Issues in RF Systems

An innovative family of DC/DC µModule regulators has been designed for noise sensitive electronic systems, such as RF systems, where EMI is a concern. These devices have been tested by a certified test lab, to evaluate EMI performance relative to CISPR 22 class B emission limits.

These µModule regulators provide ultralow noise performance with high efficiency, compact package and a simple design similar to a linear regulator because of:

· Shielded inductors
· Careful layout
· On-board filters
· Controlled MOSFET gate drive
· Low input and output ripple
· Complete DC/DC circuit in a surface-mount package

This family of DC/DC µModule regulators brings peace-of-mind to all system designers concerned with noise. The LTM8020, LTM8021 and LTM8032 are quiet and provide complete power supply solutions for wireless systems.

Author's Comments

The author humbly confesses to the complexity of this topic, and the years of experience and education required to understand and alleviate circuit problems related to noise. There are PhDs, scientists and brilliant minds who describe noise in thicker volumes than Tolstoy did in *War and Peace.* The aim of this article is to provide some pointers and to demonstrate that the solution to a DC/DC switching regulator's EMI can be achieved.

Author Information

Afshin Odabaee is product marketing manager for Linear Technology's uModule DC/DC converters, joining the company in 1995. He received his BSEE from Santa Clara University. Afshin is a budding photographer in his leisure time. He can be reached by e-mail at: aodabaee@linear.com