ALL POWER-SUPPLY COMPONENTS, INCLUDING VOLTAGE REGULATORS, INDUCTORS, AND TRANSFORMERS, AND THEIR LAYOUT DETERMINE THE AMOUNT OF EMI A SUPPLY GENERATES. AN OVERVIEW COVERS THE MECHANISMS AND PHYSICAL PRINCIPLES GOVERNING THE GENERATION AND PROPAGATION OF POWER-SUPPLY ELECTRICAL NOISE.

Proper layout and component selection control power-supply EMI

Most portable devices include a regulator or other form of power supply, and the lower supply voltages associated with smaller-lithography ICs have mandated these power circuits in many nonportable devices as well. Although many designers don’t fully understand the trade-offs, these trade-offs can have a major effect on battery life, compliance with EMI/EMC regulations, and the basic operation of a product under design. Some knowledge of regulator types, circuit topologies, associated components, and layout is critical to controlling power-supply EMI.

REVIEWING THE REGULATORS

The most common power converter is the voltage regulator. It accepts a voltage that varies over a given range and generates an output voltage that does not vary. Regulators come in two main categories: switching types and all others, mainly the linear and shunt types. Unlike switching regulators, one limitation of linear and shunt types is that the output voltage must remain less than the input voltage. Also, the efficiency of most switching regulators is better than that of an equivalent linear or shunt regulator. Yet the low noise and simplicity of linear and shunt types make them attractive alternatives to switching regulators.

The simplest type of voltage regulator is a shunt regulator, which adjusts current through a resistor...
to drop the input voltage to a regulated output level. Zener diodes also function this way. However, power dissipation in a zener diode is high, and its load regulation—the change in output voltage with a change in load current—is poor. Some shunt regulators let you set the regulation voltage with a voltage divider, but those types of regulators usually appear as building blocks in more complex regulators or power supplies. In general, shunt regulators are appropriate for low-power systems in which the variation of load current is small. You can expand this narrow application range by adding an active pass element, usually a bipolar transistor, that transforms the shunt into a linear regulator.

Linear voltage regulators use an active bipolar or MOSFET pass element to drop the input voltage down to the regulated output voltage. Among these devices, the LDO (low-dropout) types have become popular in the last decade. “Dropout” refers to the minimum difference between the input and output voltage that sustains regulation. Some so-called LDOs have dropout voltages as high as 1V, but more typical LDO values range from 100 to 300 mV.

Because a linear regulator’s input current is approximately equal to its output current, its efficiency—the output power divided by input power—is a function of the output-to-input voltage ratio. Thus, dropout is important because lower dropout means higher efficiency. If the input voltage is much higher than the output voltage or if the input varies widely, then the maximum efficiency is difficult to achieve. LDO regulators also serve as a barrier to the noise that a switching regulator generates. In this role, the LDO regulator’s LDO characteristic improves the circuit’s overall efficiency.

REGULATORS CONDUCT OR RADIATE NOISE

If the performance of a linear or shunt regulator is inadequate for the application, then the designer must turn to a switching regulator. Along with improved performance come the drawbacks of larger size and cost, a greater sensitivity to and higher generation of electrical noise, and a general increase in complexity.

A switching regulator or switching power supply produces noise that can emerge through conduction or radiation. Conducted emissions can take the form of voltage or current, and you can further characterize each of these emissions as common- or differential-mode conduction. To complicate matters, the finite impedance of connecting wires enables voltage conduction to cause current conduction and vice versa; in addition, differential-mode conduction can cause common-mode conduction and vice versa.

In general, however, you can optimize a circuit to reduce one or more of these emissions. Conducted emission usually poses a greater problem for fixed systems than for portable systems. Because portable devices operate from batteries, their load and source have no
external connections for conducting emissions.

To understand the source of noise in a switching regulator, you must first understand its operation. Descriptions of the many types of switching regulators are beyond the scope of this article. But, in general, a switching regulator converts the source voltage or current to load voltage or current by employing active elements, such as transistors and diodes, to shuttle current through storage elements, such as inductors and capacitors.

**SWITCHING REGULATORS SHUTTLE CURRENT**

To illustrate the operation of a switching regulator, consider a typical synchronous-rectified step-down converter (Figure 1). During normal operation, the circuit conducts current from input to output when the high-side switch, $Q_1$, is on and continues conducting through the inductor when $Q_1$ is off and the synchronous rectifier, $Q_2$, is on. First-order approximations of the current and voltage waveforms (Figure 2) make a flawed assumption that all the components are ideal, but this article covers the parasitic effects of these components later.

Because $Q_1$ is on only part-time, the input source and input capacitor, $C_{IN}$, see discontinuous currents. $C_{IN}$ supplies the excess current ($I_{LOAD} - I_{DUTY}$) while $Q_1$ is on, and it stores charge from the input current while $Q_1$ is off. If $C_{IN}$ were of infinite value, with zero ESR (equivalent series resistance) and zero ESL (equivalent series inductance), the voltage across it would remain constant during these partial charge and discharge cycles. Actual voltage fluctuates over each cycle. The current pulses divide between $C_{IN}$ and the input source based on the relative conductances at or above the converter’s switching frequency.

One way to eliminate these conducted emissions is a brute-force approach: Connect low-impedance bypass capacitors at the input. A more subtle approach, however, can save cost and board area: Add impedance between the source and converter, making sure the necessary dc current can pass. The best device is an inductor, but you should make sure the converter’s input impedance remains low between dc and the loop-crossover frequency. The loop crossover for most dc/dc switching converters is from 10 to 100 kHz. Otherwise, input-voltage fluctuations can destabilize the output voltage.

Current ripple on the output capacitor, $C_{OUT}$, is much less than on $C_{IN}$. The amplitude of the current is lower, and unlike the input capacitor, the current is continuous and, therefore, has less harmonic content. Normally, each turn of the coil is covered with wire insulation that forms a small capacitor between each pair of turns. Adding these parasitic capacitors in series forms a small equivalent capacitor in parallel with the inductor, which provides a path for conduction of current impulses to $C_{OUT}$ and the load. Thus, the discontinuous edges of the voltage waveform at the switching node, $I_x$, conduct high-frequency current to $C_{OUT}$ and the load. The usual results are spikes on the output voltage, with energy ranging from 20 to 50 MHz.

Often, the load for this type of converter is some form of microelectronics that is susceptible to conducted noise, and, fortunately, the converter’s conducted noise is easier to control at the output than at the input. As is true for the input, low-impedance bypassing or secondary filtering can control output-conducted noise. You should be cautious of secondary filtering, or postfiltering, however. Output voltage is a regulated variable in the control loop, so an output filter adds delay, phase, or both to the loop gain, possibly destabilizing the circuit. If you place a high-Q LC postfilter after the feedback point, the inductor’s resistance degrades the load regulation fixed for high-Q LC filters, and transient load currents may cause ringing.

**SHARING STEP-DOWN PROBLEMS**

Other switching-converter topologies have problems similar to those of step-down converters. A step-up converter, for example (Figure 3), has the basic structure of a step-down converter but with inputs and outputs swapped. (You should note that the rectifier acts as a switch and turns on when the power switch is off.) Thus, problems at the input of a step-down converter apply to the output of a step-up converter.

Step-down converters are limited because their output voltage must be less than the input voltage. Similarly, a step-up converter’s output voltage must be greater than its input voltage. This requirement is problematic when the output voltage falls within the input-voltage range. The flyback converter is one topology that solves this problem (Figure 4).

Because currents at the input and output are discontinuous, which makes conducted emissions more difficult to control, noise from this converter is gen-
generally worse than that of a step-up or -down type. Another problem with this converter is that current in each transformer winding is discontinuous, and these discontinuities act with the transformer’s leakage inductance to produce high-frequency spikes, which can conduct to other circuits. Physical separation of the primary and secondary windings causes this leakage inductance. Thus, magnetic fields in the air cause the leakage inductance because fields in the core couple both the primary and secondary windings. Spikes due to the leakage inductance, therefore, cause magnetic-field radiation.

The SEPIC (single-ended primary-inductance converter) also solves the problem of overlapping input and output voltages. Similar to a flyback circuit, the SEPIC connects a capacitor between the transformer primary and secondary windings (Figure 5). This capacitor provides a path for current in the primary and secondary windings so that flyback currents are off and improves the flyback circuit by making the primary and secondary currents continuous. On the other hand, adding input or output capacitance to a flyback circuit can sufficiently improve its emissions to make that topology as acceptable as the SEPIC. If you expect conducted and radiated noise to be problems, you may prefer the SEPIC circuit to the flyback converter.

FILTERING HIGH-FREQUENCY NOISE

For some applications that require the minimum possible output noise, the efficiency deficit of using a linear regulator is unacceptable. A switching regulator followed by a linear postregulator may be suitable in these cases. The postregulator attenuates high-frequency noise that the switching regulator generates, resulting in noise performance approaching that of a lone linear regulator. Because most voltage conversion occurs in the switching regulator, the efficiency penalty is much smaller than a penalty for a lone linear regulator.

This scheme can also replace flyback converters and SEPICs in applications for which the input and output voltages overlap. The step-up converter operates when the input is less than the output, and the linear regulator operates when the input is greater than the output. Some ICs combine a step-up converter and LDO.

FILTERS ATTENUATE COMMON-MODE NOISE

By definition, common-mode conduction is in phase on both connections of the input or output. Typically, this conduction poses a problem only for fixed systems that have a path to earth ground. In a typical offline power supply with common-mode filters (Figure 6), the main source of common-mode noise is the MOSFET. The MOSFET is usually a major power-dissipating element in the circuit and requires a heat sink.
For a TO-220 device, the heat-sink tab connects to the MOSFET drain, and in most cases, the heat sink conducts current to earth ground. Even though the MOSFET is electrically isolated from the heat sink, some capacitance between the MOSFET and earth ground exists because the chassis must connect to ground for safety. As it switches on and off, the rapidly changing drain voltage drives current through the parasitic capacitance (CP_{2A} and CP_{2B}) between the isolated primary and secondary windings. Thus, noise can conduct to the output as well as the input.

In Figure 6, common-mode lowpass filters attenuate the common-mode conducted noise that exists between the noise source—the power supply—and the input or output. You or the manufacturer generally wind common-mode chokes (CML_{1} and CML_{2}) on a single core with the polarity shown in Figure 6. Load current and the line current driving the power supply are both differential-mode currents; that is, current flowing in one line flows out the other. By winding the common-mode chokes on one core, the fields cancel due to differential-mode currents, allowing you to use a smaller core because it stores very little energy.

Many of the common-mode chokes designed for offline power supplies have a physical separation between the windings. This construction adds differential-mode inductance, which also helps to reduce the conducted differential-mode noise. Because the core links both windings, fields that stem from differential-mode current and differential-mode inductance are in the air rather than in the core. The result may be radiated emissions.

Common-mode noise that generates in the power supply's load may be conducted through the power supply to the ac line via parasitic capacitance (CP_{2A} and CP_{2B}) in the transformer. A Faraday shield in the transformer—a ground plane between the primary and secondary winding—can reduce this noise (Figure 7). The shield forms capacitors from the primary and secondary winding to ground, and these capacitors shunt common-mode currents to ground rather than allowing them to pass through the transformer.

**Electric Fields**

Just as conducted emissions can be in the form of voltage or current, radiated emissions can be in the form of electric or magnetic fields. Because fields exist in space rather than in conductors, there is no distinction between differential- and common-mode fields. An electric field exists in the space between two potentials, and a magnetic field exists around a current traveling through space. Both fields can exist in a circuit because capacitors store energy in electric fields and inductors, and transformers store and couple energy in magnetic fields.

Because an electric field exists between two surfaces or volumes with different potentials, it is relatively easy to contain the electric-field noise that a device generates by surrounding the device with a ground shield. Such shielding is common practice in the construction of CRTs, oscilloscopes, switching power supplies, and other devices with fluctuating high voltages. Another common practice is the use of ground planes on pc boards. Electric fields are proportional to the potential difference between surfaces and inversely proportional to the distance between them. They exist, for instance, between a source and any nearby ground plane. Therefore, multilayer pc boards let you shield circuitry or traces by placing a ground plane between them and any large potential.

You should be cautious, however, of capacitive loading on high-voltage lines when you use ground planes. Capacitors store energy in electric fields, so placing the ground plane near a conductor forms a capacitor between the conductor and ground. A large dV/dt signal on the conductor can cause large conducted currents to ground, thereby degrading the conducted emissions while controlling the radiated emissions.

If electric-field emissions are present, the likely culprit is the highest potential in the system. In power supplies and switching regulators, you should beware of the switching transistors and rectifiers, because they normally have high potentials and may also have large surface areas due to heat sinking. Surface-mount devices may have this problem, too, because they often require large amounts of pc-board copper for heat sinking. In that case, you should also beware of capacitance between any large-area heat-sink plane and the ground plane or a power-supply plane.

Electric fields are relatively easy to contain, but magnetic fields are a different proposition. Enclosing a circuit in high-μ material can provide an effective shield, but that approach is difficult and costly. Usually the best way to control magnetic-field emissions is to minimize them at the source. In general, this approach requires that you choose inductors and transformers designed to minimize radiated magnetic fields. You should also configure the pc-board layout and interconnect wiring to minimize the size of current loops, especially in high-current paths. High-current loops not only radiate magnetic fields, but also increase the inductance of conductors, which can cause voltage spikes on lines that carry high-frequency current.

Circuit designers inexperienced in...
transformer or inductor design are likely to choose off-the-shelf transformers and inductors. Even so, designers who are knowledgeable in magnetics can choose the optimal components for an application.

The key to reducing inductor emissions is in the use of high-μ material for keeping the field in the core and out of the surrounding space. Magnetic fields have a proportionally higher density in higher μ material. This condition is similar to parallel conductances: a 1S (s=siemens) conductance (1fΩ resistor) in parallel with a 1-mS conductor (1 kΩ resistor) has 1000 times the current of the 1-mS conductor. A magnetic-field density divides in a ratio of 1000-to-1 between a 1000μ, 1-in.² core and a 1μ, 1-in.² core. High-μ materials cannot store a lot of energy, so for compact inductors you must use a high-μ core with an air gap (Figure 8).

The B field (Y-axis) is proportional to \( V \times t/N \), where \( N \) is the number of turns. The H field (X-axis) is proportional to \( N \times t \). Thus, the slope of the curve (proportional to \( \mu \)) is also proportional to the inductance (\( L=V/(dl/dt) \)). Adding a gap to this ferrite (or any other high-μ core) reduces the slope, thereby lowering the effective μ and, consequently, the inductance. Inductance decreases by the change in slope, maximum current increases by the change in slope, and the saturation B field remains the same. Therefore, the maximum energy (\( V^2/LF \)) stored in the inductor increases. You can also illustrate this increase by applying a voltage to the inductor and noting the amount of time to reach saturation, or \( B_{sat} \). Energy stored in the core is the integral of \( (V \times L)dt \). Because the current associated with a gapped core is higher for the same voltage and time, the corresponding level of stored energy is higher.

Adding a gap to the core, however, increases magnetic-field radiation in the space around the inductor. For this reason, most designers avoid the use of bobbin cores in some noise-sensitive applications because the large air gap makes them notorious generators of magnetic-field radiation. The bobbin core, which is simply a bobbin-shaped piece of ferrite, is one of the simplest and cheapest types of gapped ferrite core. Winding wire around the center post makes an inductor. Costs are low because you or the manufacturer can wind the wire directly around the core with no extra work other than terminating the wire. In some cases, the wires terminate on a metallized area at the bottom of the core, which allows surface-mounting of the inductor. In other surface-mounted components, the inductor mounts on a ceramic or plastic header where the wires terminate.

Some manufacturers put ferrite shields around the bobbin core to help reduce field emissions. This measure helps, but it also reduces the gap and, therefore, reduces the energy that the core can store. Because the ferrite itself can store very little energy, manufacturers often leave a small gap between the shield and the core, which allows some unwanted radiation of magnetic fields in this type of inductor. Depending on the level of acceptable emissions, the bobbin core may be a good compromise between cost and EMI.

Application requirements determine whether other core shapes should include gaps. Pot cores, E-I cores, and E-E cores, for example, have center legs or posts that can include gaps (Figure 9). Adding a gap to the center of the core, which the coil surrounds, helps reduce the radiated emissions that the air gap causes. These inductors are usually more expensive because you or the manufacturer must wind the coil separately from the core and then assemble the core parts around the coil. For easy design and assembly, you can purchase cores with a pregapped center leg.

Perhaps the best core for reducing radiated emissions is the distributed-gap toroid. This core comprises a mixture of filler and high-μ metal powder pressed into the doughnut shape of a toroid. The grains of metal powder, separated by nonmagnetic filler, have small air gaps between them that create an overall “air gap” that is evenly distributed throughout the core. The coil winds through the center and around the outside of the core, which makes the field travel in a circle along the middle of the coil. As long as the coil winds around the whole circumference of the toroid, this type of core shields the outside by completely surrounding the magnetic field.

The loss in a typical distributed-gap toroidal core is sometimes higher than for gapped ferrites because metal grains in the toroid are susceptible to eddy currents that generate heat and reduce power-supply efficiency. Toroids are also expensive to wind because wire must feed through the center of the core. Machines can wind the wire, but they are slower and more expensive than traditional coil-winding machines.

Some ferrite toroidal cores have a discrete air gap. The resulting magnetic-field emissions are higher than those of distributed-gap cores, but typical gapped toroids have lower losses because they contain the field better than other dis-
cretely gapped ferrite cores. The coil reduces emission by shielding the gap, and the toroidal shape helps keep the field inside the core.

**INDUCTORLIKE LIMITATIONS**

Transformers have many limitations in common with inductors because they are wound on the same cores. Some issues are unique to transformers, however. The performance of actual transformers can approach that of an ideal transformer, which couples voltage from the primary to secondary winding with a ratio proportional to the turns ratio in each winding.

The equivalent circuit of a transformer models the interwinding capacitance as $C_{wa}$ and $C_{wb}$ (Figure 10). These parameters pose the problem of common-mode emissions in isolated power supplies. Winding capacitances $C_p$ and $C_s$ are small and usually negligible at the operating frequencies of switching power supplies and regulators. The magnetizing inductance, $L_{1p}$, is important, because too much magnetizing current can cause the transformer to saturate. As for inductors, saturation increases the magnetic-field emission from transformers. Saturation also causes higher core loss, higher temperature with the possibility of thermal runaway, and a degradation of coupling between the windings.

A magnetic field that links only one winding causes leakage inductance. Although some coupled inductors and transformers, such as common-mode chokes, are designed for a high level of this parameter, leakage inductances $L_{1p}$ and $L_{1s}$ are the most problematic parasitic elements in a switching power supply. Magnetic flux that links two windings couples those windings together. Both transformer windings are around the core, so any leakage inductance is outside the core and in the air where it can cause magnetic-field emissions.

Another problem with leakage inductance is the large generated voltage that appears when the current changes quickly, as it does in the transformer of most switching power supplies. Such voltage can overstress the switching transistor or rectifier. Dissipative snubbers, which usually comprise a series resistor and capacitor, are common elements for controlling this voltage by dissipating the energy of the voltage spike. On the other hand, the design of some switching devices enables them to withstand repetitive avalanche breakdowns, and these devices can dissipate the energy without external snubbers.

You can determine the leakage inductance of a transformer by shorting the secondary winding and measuring the inductance at the primary winding. This measurement includes any secondary leakage inductance that couples through the transformer, but in practice, you must account for such leakage because it adds to the primary voltage spike. You calculate the corresponding spike energy as $E = \frac{1}{2}Lf$, so power lost to the leakage inductance is the energy of each spike multiplied by the switching frequency. Consequently, $P = \frac{1}{2}LI^2f$.

Transformer requirements depend on power-supply topology. Topologies that directly couple energy across the transformer, such as half-bridge, full-bridge, push-pull, or forward converters, require a high-magnetizing inductance to prevent saturation. The transformer primary and secondary windings simultaneously conduct current in these circuits, directly coupling the energy through the transformer. Because the core stores little energy, the transformer can be smaller. These transformers typically comprise windings on an ungapped core of ferrite or other high-$\mu$ material.

Other power-supply topologies require the transformer core to store energy. The transformer in a flyback circuit stores energy via the primary winding in the first half of the switching cycle. In the second half of the cycle, the circuit retrieves this energy and feeds it to the output via the secondary winding. As is true for inductors, an ungapped high-$\mu$ core is unsuitable for storing energy in a transformer. Instead, the core must be discretely gapped or have a distributed gap. The resulting component is larger than a component with an equivalent ungapped core, but it may save an extra inductor as well as cost and space.

**AVOIDING COMPATIBILITY PROBLEMS**

Component selection is important in controlling EMI, but the pc-board layout and interconnects are equally important. Layout and component placement are critical to the circuit’s proper operation and interaction, especially for the high-density, multilayer pc boards common in switching power supplies. The power switching can cause large dV/dt and dl/dt signals in the pc-board traces, which can result in compatibility problems when coupling to other traces. You can avoid compatibility problems and expensive pc-board revisions by taking extra care in the layout of critical paths.
Radiated and conducted emissions are distinct in a system, except in the pc board and wiring. Adjacent traces that couple electric fields also conduct currents via an ac voltage across parasitic capacitance. Magnetic-field coupled traces act somewhat like transformers. You can describe these interactions using lumped components or through field theory, and the approach you take depends on which method more accurately describes the interaction.

MINIMIZING CROSSTALK

Two or more conductors in close proximity are capacitively coupled, so large voltage changes on one conductor couples currents to the other. If the conductor’s impedance is low, the coupled currents generate only small voltages. Capacitance is inversely proportional to the distance between the conductors and proportional to the area of the conductors, so you can minimize the conducted noise by keeping the area of the adjacent conductors small and their separation large.

Another method for reducing the coupling between conductors is to add a ground plane or shield. A ground trace, or in some cases a power-supply bus or other low-impedance dc node, between conductors can prevent their interaction by capacitively coupling them to ground instead of to each other. But you should exercise caution. Traces carrying fast dV/dt changes positioned close to a plane with high-impedance interconnect to ground can couple these changes to the ground plane. In turn, the ground plane can couple the signals to sensitive lines, thereby exacerbating the noise problem. If the ground plane doesn’t carry large currents, it may be tempting to connect it to ground through a small wire. The high inductance of a small wire, however, can cause the ground plane to appear as a high impedance in the presence of fast-changing voltages.

You must take care to ensure that a ground plane does not inject noise into sensitive parts of a circuit. Input and output bypass capacitors, for example, often pass current through a ground plane, and the high-frequency current components can affect sensitive circuitry. To prevent this problem, pc boards often include separate planes for the power and signal grounds. Connecting the planes at one point minimizes the noise injected into signal ground from the power ground. This practice is similar to that of a star ground in which all components connect to ground at one point and all traces leave that point in a “star” pattern. The star ground has the same effect as separate power- and signal-ground planes, but it isn’t practical for large, complex pc boards that include many grounded components.

If you know that a node is sensitive to injected noise, then you should route traces and wires that connect to this node away from nodes with high-voltage changes. If this routing is impossible, add a good ground or a shield. Good capacitive bypassing of the node can also decrease its susceptibility to crosstalk but may degrade the high-frequency operation of that node. Where appropriate, a small capacitor connected between the node and ground or between the node and a power-supply bus forms a suitable bypass.

When choosing the bypass capacitor, make sure it has a low impedance over the range of frequencies that are potentially problematic. ESR and ESL may cause the impedance to be higher than expected at high frequencies, so the low ESR and ESL of ceramic capacitors are attractive for bypass applications. The ceramic dielectric has a large effect on performance as well. Higher capacitance dielectrics, such as Y5V, may allow large changes in capacitance over voltage and temperature. At the maximum rated voltage, capacitors made of these ceramics may exhibit as little as 15% of their unbiased capacitance. In many cases, a smaller capacitance value with a better dielectric yields crosstalk attenuation that is less dependent on bias and temperature and provides better and more consistent bypassing.

The placement of bypass capacitors is also critical. To attenuate high-frequency noise, you must route the signals in question through the bypass capacitor. In Figure 11a, the length of trace in series with the capacitor adds to its ESR and ESL, increasing the impedance at high frequencies and reducing the capacitor’s effectiveness as a high-frequency bypass. A better layout routes the traces through the capacitor, so the trace’s stray ESR and ESL aid the bypass capacitor’s filter action rather than degrade it (Figure 11b).

Some nodes should not include bypassing because bypassing changes their frequency characteristics. One example is the feedback–resistor divider. In most switching power supplies, a resistive-feedback divider drops the output voltage down to a level acceptable to the error amplifier. Adding a large bypass capacitor to this feedback node forms a pole with the resistance of that node. Because the divider is part of the control loop, this pole becomes part of the loop characteristic. If the pole frequency is less than one decade above the crossover frequency, its phase or gain effects can adversely affect loop stability.

DEALING WITH STRAY INDUCTANCE

Some currents in a switching power supply switch on and off quickly. Stray inductance in those current paths can induce large noise voltages that couple into sensitive circuitry and stress the components. Lines carrying dc currents seldom cause problems because dc does not cause voltage spikes or couple ac to oth-
er traces. A line in series with an inductor, for example, is not a problem because the stray inductance is much smaller than the inductor value. The large series inductance also prevents discontinuities in the current.

If a circuit produces discontinuous currents, you should try to prevent the current from traveling in large loops. These loops produce larger values of inductance, thereby increasing any consequent magnetic-field radiation. This caveat applies to component placements as well because current usually switches between active devices, such as transistors and diodes.

Consider the step-down converter of Figure 1. When the high-side MOSFET switch, Q1, is on, current travels via the input, Q1, the inductor, and the load. After Q1 turns off, the diode D conducts current until the synchronous rectifier, Q2, turns on. Current then flows through Q2 until it turns off; then the diode carries current until the cycle starts again. Note that currents through the inductor and output capacitor are continuous and, therefore, should not be major contributors to noise. If you place Q1, Q2, and D some distance from one another, the surrounding fields must shift quickly in response to the rapid current changes between the components. Because the generated voltage is proportional to the change in magnetic field with time (dΨ/dt), these rapid field fluctuations can generate large voltage spikes.

Note that the input source and output load carry high-frequency currents. These currents should pass through the input and output bypass capacitors; otherwise, they conduct through the input or output lines or both. The impedance of input and output bypass capacitors is important. The capacitors should be large enough to keep the impedance low at input and output, but larger capacitors, such as tantalum or electrolytic types, have higher ESR and ESL than smaller ceramic types. Therefore, you must ensure that the impedance of the capacitors is sufficiently low at the frequencies of concern.

One alternative is to parallel a ceramic capacitor with an electrolytic or tantalum capacitor, because the ceramic has lower impedance at high frequencies. In most cases, that arrangement is no better than multiple electrolytic or tantalum capacitors in parallel to reduce ESR and ESL or than multiple ceramic capacitors in parallel to increase the total capacitance.

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