

Reducing Noise Generated By Switching Regulators

by Frederik Dostal, Analog Devices, Munich, Germany

Switched-mode power supplies generate noise. In many applications this noise needs to be limited so that analog data integrity is not compromised and also to pass certain EMI requirements. This article will introduce different types of noise we find in switched-mode power supplies (SMPSs), discuss different noise-coupling mechanisms and ultimately present solutions to reduce the generation of noise and to filter remaining disturbances with the best strategies.

While the concepts discussed here are generally applicable to all SMPS designs, the focus here is mainly on the type of nonisolated, dc-dc converters or *point-of-load converters* (POLs) that are used to generate the various low-voltage supply rails in electronic systems. Nowadays, nonisolated dc-dc conversion at the board level is typically accomplished using switched-mode techniques. So, the components that perform this function are generally referred to as switching regulators.

However, note that terms such as “dc-dc converters,” “point-of-load converters” and “switching regulators” are often used more-or-less interchangeably throughout the industry. Although sometimes power IC and module vendors make distinctions among these terms based on the different levels of functional integration that the devices offer. Nevertheless, most of the board-level dc-dc converters are in fact switching regulators. But nonisolated dc-dc conversion can also be performed by another class of voltage regulators—linear regulators. However, these are mainly used as filter components for noise-sensitive loads. Otherwise, the high power-conversion efficiency of switching regulators is appreciated in most applications.

Switching regulators are very noisy by definition. They switch high currents on and off in short transition times. This combination is bound to generate a lot of noise. While the basic principle of switched-mode power supplies cannot be changed, there are certainly ways to reduce the generated noise and to filter the remaining noise with different approaches. These various methods enable an application to pass EMI tests but also to prevent power supply noise from coupling into other, sensitive analog circuitry in a given system.

Different Types Of Noise

There are many different types of noise a switching regulator generates. The most important ones are switching noise from the switching frequency, high-frequency noise resulting from the switching transitions, ringing after switching transitions, ringing in discontinuous current conduction mode and beat frequencies caused by multiple switching regulators running in one system.

Switching Frequency Noise

Switching noise from the switching frequency can be very dominant. Today, it is typically located in the frequency band between 500 kHz and 3 MHz for non-isolated dc-dc converters. The beauty of switching frequency noise is that the switching frequency can be adjusted with high accuracy using an external clock signal. When this is done, filtering this noise can be relatively simple.

This noise is generating the output ripple voltage and it can be filtered with an LC filter. Also, a linear regulator can be used to reduce the ripple voltage seen by a sensitive load. In Fig. 1, the top waveform is the output ripple voltage produced by a buck regulator. Such a waveform is characteristic when ceramic output capacitors with very low equivalent series resistance (ESR) are used. The bottom waveform in Fig. 1 shows how this signal is attenuated by an additional LC filter or linear regulator that is placed on the switching regulator’s output.

To help designers calculate the right values of filter components for specific designs, semiconductor manufacturers offer calculation tools on their website. Analog Devices offers ADIsimPower for circuit calculation and ADIsimPE for simulation.

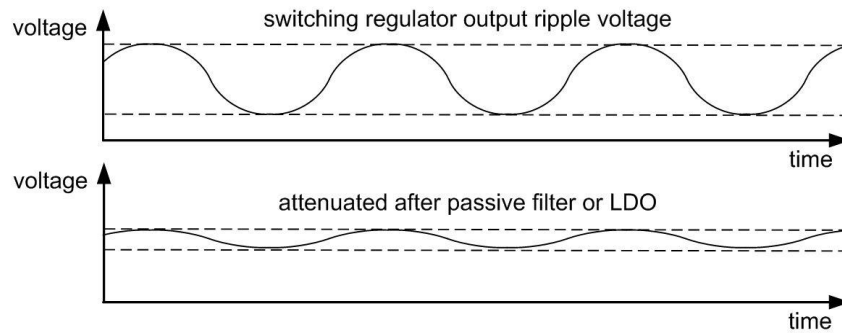


Fig. 1. Output ripple voltage based on the switching frequency of a switched-mode power supply.

Switching Transition Noise

High-frequency noise produced by the switching transitions is often the most difficult noise to deal with. This noise is a function of the parasitic inductances in the current path including inductances associated with board traces, IC pins, vias and bonding wires.

As an example, if we have one inch of PCB trace, as a rule of thumb we assume that such a trace has about 20 nH of parasitic inductance. Assuming a switching transition speed of 30 ns in a typical switching regulator design and a required 5 A of output current, we can calculate the voltage offset this one inch of trace generates. We simply use the basic formula for inductance: $V = L * di/dt$. Entering the values in our example gives us a total voltage offset of 3.3 V.

This is a very large offset resulting from only one inch of trace length due to our fast changing currents. This generated ac voltage offset will couple through the design and will result in unwanted coupled noise. Fig. 2 shows a switching transition of a buck regulator.

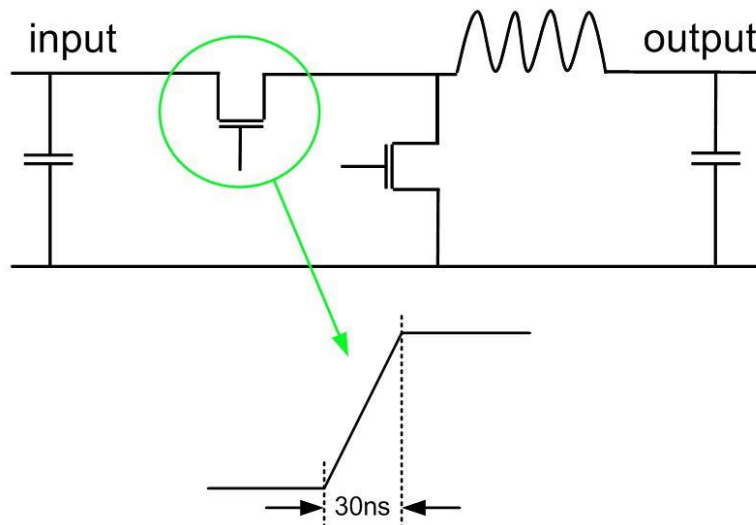


Fig. 2. Fast switching transitions in a buck regulator.

The key to reducing this noise is to minimize the parasitic inductance. The "di" in the formula above cannot be reduced, since a certain load will require a certain current. In the future, this current is even likely to increase, as shrinking IC process geometry calls for lower voltages and assuming constant power, we will see even higher currents. Similarly, the "dt" needs to be small. Fast transition times reduce switching losses, thus allowing higher switching frequencies that enable the use of small and low cost inductors and output capacitors.

In the old days, before the year 2000, most switching regulators used bipolar switching transistors as power switches. These delivered relatively slow transition times of about 100 ns or longer. They had higher switching losses and were demanding lower switching frequencies. However, they caused much lower voltage offsets across parasitic inductances.

Today, we see switching transition speeds of only a few nanoseconds. In the future, transition times are likely to decrease even further with silicon carbide, gallium nitride and other very high-speed power switching technologies. They will enable lower switching losses, thus higher switching frequencies will be possible, allowing for very compact and low-cost power supplies. But the only thing we can do to reduce the generated switching transition noise is to reduce the parasitic inductances corresponding to 'L' in the formula above.

Fig. 3 shows the critical ac current traces in a switched-mode buck regulator in the bottom schematic in red. It is quite simple to find these critical traces in any switched-mode power supply. As a first step, we indicate the current flow during the on-time. This is done in the top schematic and the current flow is shown in blue. Then we indicate the current flow during the off-time. The schematic in the center shows this current path in green. In the third schematic, we highlight all traces, where there is a difference in current flow between the top and the center schematic. These are the traces in which we change current flow from full current to no current within a few nanoseconds.

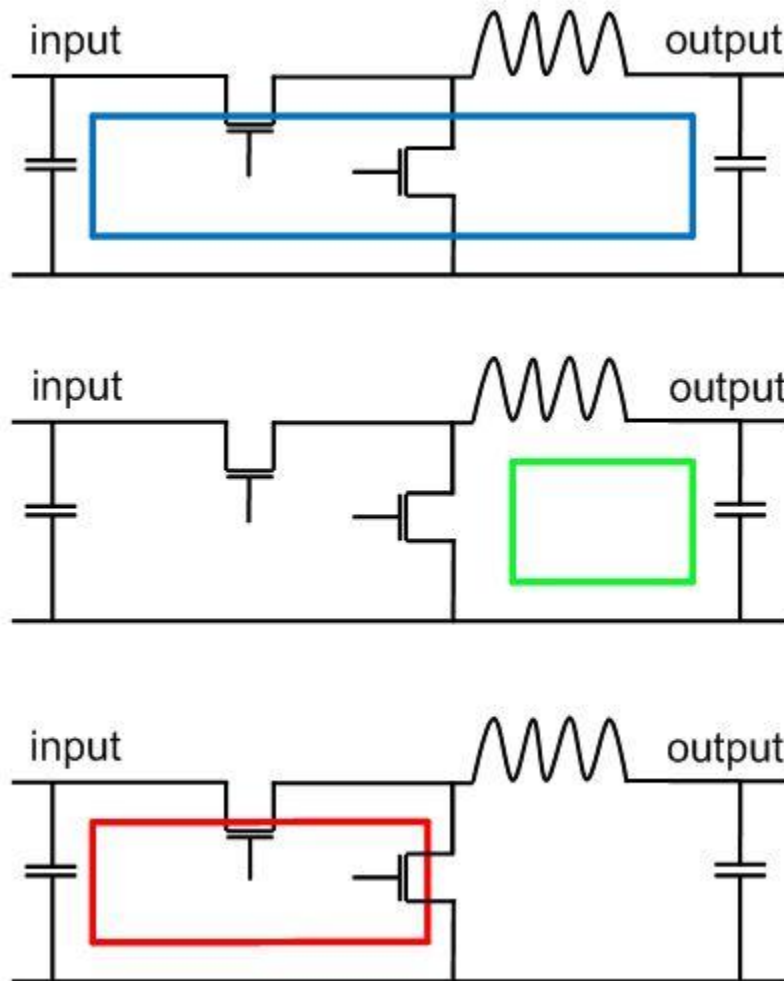


Fig. 3. Finding ac current traces in a switched-mode power supply.

These are the traces we need to keep as short as absolutely possible. This will reduce our parasitic inductance L and thus reduce the generated voltage offsets after such switching transitions.

In the buck regulator example, this means that the input capacitor needs to be very close to the high-side switch and also close to the ground connection of the low-side switch. This shows us, that critical ac current traces can also be ground traces. Such return currents should never be routed through a ground plane. If they are, they will cause the ground plane to see voltage offsets based on the parasitic inductance of the return trace.

Fig. 4 shows how an ac ground current return path should be handled. It needs to be locally routed. Vias should not be used in this local ground path, since they add inductance, increasing voltage offsets and as a result, generate even more noise. Certainly, this local ac current ground return trace needs to be at ground potential, so we attach this trace to the ground plane at one point using a via. This will keep the noisy ac return currents local.

The via connection from the ground current return path to the ground plane helps to decouple the silent ground plane voltage from the noisy local ac current return trace.

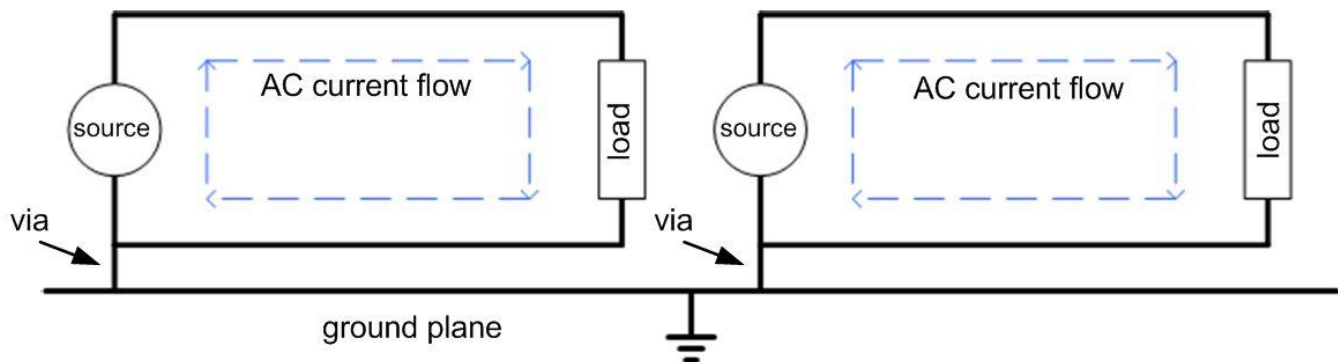


Fig. 4. Keep ac current traces local and do not route them through a ground plane.

Breaking this rule and dumping ac return currents of a switching regulator into a ground plane will make the whole ground plane bounce and cause all kinds of trouble. Ground planes are supposed to give an accurate ground reference potential to different subcircuits in the system and they are supposed to shield RF noise. If ideally no currents are carried by the ground plane, it will be silent and have the same voltage all across it.

Switching transition noise is typically in the range of 10 MHz to 300 MHz. It is much higher in frequency than the switching frequency of a switching regulator. For attenuation of this noise on the output of the power supply, an LC filter, commonly used to reduce the output ripple voltage, may not be the right choice. Ferrite beads are much better suited to attenuate such high frequencies.

Ringling After Switching Transitions

Voltage ringing on the switch node after a switching transition can be seen in Fig. 5. It has multiple causes. The main one is mostly parasitic influences and the fact that current flow cannot change instantaneously, but requires some time to ramp up through parasitic inductances.

Such noise can be reduced by snubbers or active clamp circuitry. Passive snubbers will dissipate the energy of this ringing into a resistor ultimately generating heat. Active clamp circuitry is feeding the energy of the ringing partially back into the circuit, increasing the overall efficiency of the power supply.

Often, in simple nonisolated dc-dc converters, snubbers are not used, since most of the time, the energy in the switch-node ringing is not very high, causing only small disturbances. In transformer-based switched-mode

power supplies, primary and secondary-side snubbers or active-clamp circuitry is required more often to reduce noise.

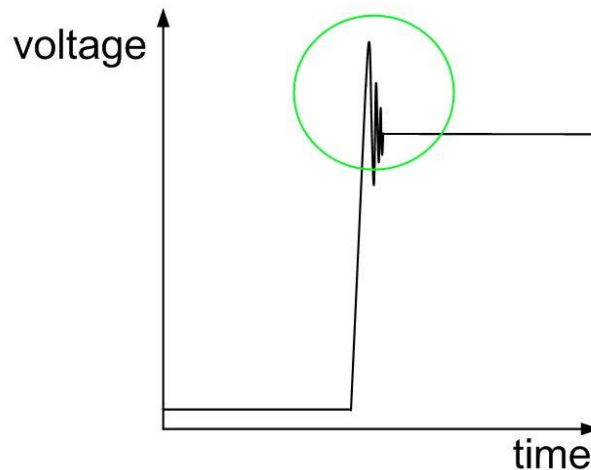


Fig. 5. Switch-node-voltage ringing after a switch transition.

Ringing In Discontinuous Current Conduction Mode

In discontinuous current conduction mode (DCM), some lower-frequency ringing can be observed on the switch node. It can be seen in nonsynchronous buck regulators where the low-side switch is implemented with a freewheeling Schottky diode. Synchronous buck regulators also show this behavior in a light-load power saving mode, when the low-side switch is not actively being turned on and off and the MOSFET’s body diode is carrying the off-time current instead.

The resulting ringing is depicted in Fig. 6. It is caused by charge swinging back and forth on the temporarily high-impedance switch node when the inductor current is zero and both switches are turned off.

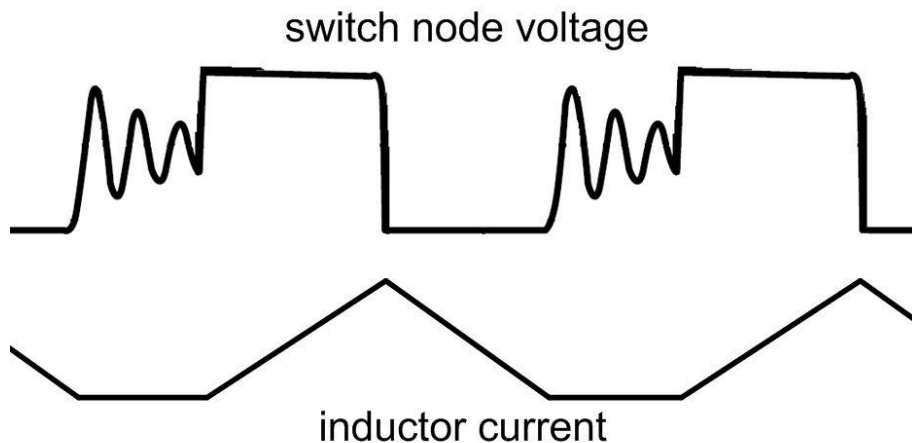


Fig. 6. DCM ringing in a nonsynchronous buck regulator.

In general, when designing a switching regulator for lowest noise, the regulator should not be configured to operate in DCM. For the same output power, DCM causes much higher peak currents compared to continuous current conduction mode (CCM). These peak currents are likely to cause excessive noise in the system. However, every CCM design will also run in DCM during a light-load condition.

So, if a given design needs to operate with lowest noise under both full load and partial load conditions, snubbers can be used to reduce the DCM ringing. However, as this ringing is generally very low power ringing on the temporarily high-impedance switch node, in most of the cases a snubber is not needed.

Beat Frequencies

Beat frequencies are low frequencies that are generated due to the overlapping of two different switching frequencies in a given system. Most modern electronic systems require multiple voltage rails. Processor cores, I/O interfaces, FPGAs as well as analog circuitry usually require different supply voltages.

For the generation of these voltages, switching regulators are commonly used. If simple buck-type dc-dc converters with a fixed switching frequency are selected, they do not all switch at exactly the same switching frequency. The typical switching frequency might be 1 MHz, but in reality, if you look into the electrical characteristics in the datasheet of the regulator, you will find that the 1-MHz switching frequency can vary from a minimum to a maximum value. So instead of both switching regulators switching at 1 MHz, one might switch at 900 kHz and the other at 1.1 MHz.

Fig. 7 shows an example with two switching regulators in one system. While both switchers are of the same type with a typical switching frequency of 1 MHz, the top regulator switches at 1.1 MHz while the bottom one switches at 900 kHz. On the output of the top switcher, one certainly will see 1.1-MHz ripple voltage but additional effects of 900-KHz switching are also seen. This is the input switching noise of the bottom regulator, coupling through the top regulator onto the 2.5-V output voltage.

Whenever we have overlapping frequencies like this, every now and then both peaks fall on top of each other and by this an additional lower frequency is generated. This frequency can couple into our system and often it is not so easy to filter out this low frequency. It can even be an audible frequency causing the system to make unwanted sounds.

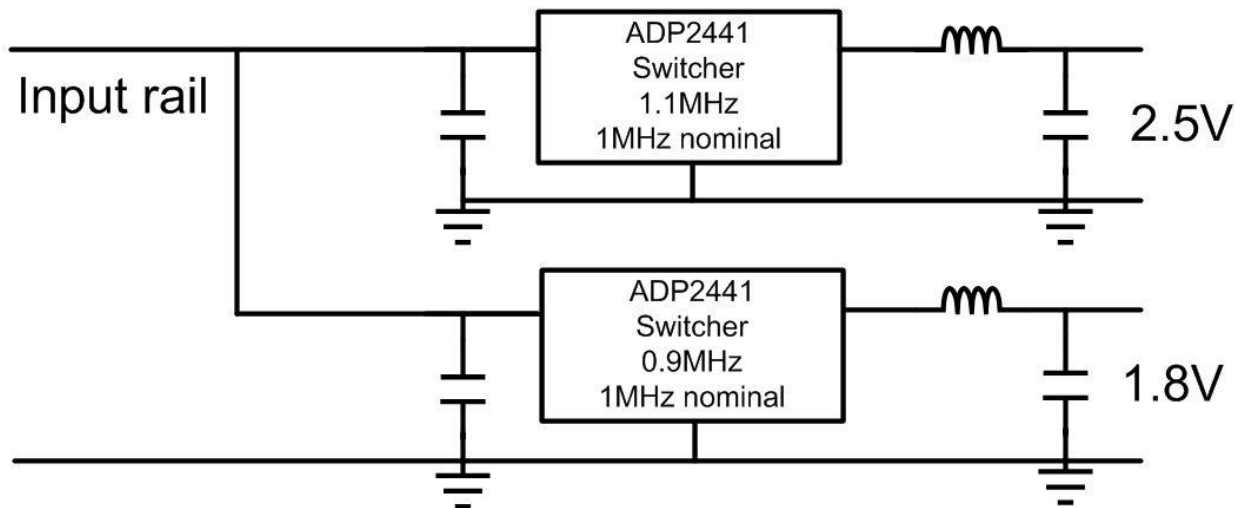


Fig. 7. Multiple switching regulators in a system and the generation of beat frequencies.

The best way of dealing with this effect is to synchronize all switching regulators in a system to the same switching frequency. This way, beat frequencies are not generated. While doing this, it can be a very good idea to also phase shift the start of each switching regulator. This means that they both share the same switching frequency but start turning on their high-side switch at different times. This results in a situation where multiple switching regulators start pulling current from the source at different times. The positive effect is to lower noise on the input line of the buck regulators and reduce the number of input bypass capacitors needed, saving board space and money.

A way to achieve this *interleaving* of regulators is to use a power management unit with multiple switching regulators all integrated in one chip such as Analog Devices' ADP5135. Then the circuit designer does not have to worry about synchronizing and phase shifting the different switchers. It is done automatically and beat frequencies do not appear.

Input Filtering In A Buck Regulator

Often, when a buck regulator is used in a system and there is a noise issue, engineers intuitively decide to filter the regulator output. Since the output is what is ultimately connects to the noise-sensitive load, it's the output that needs to be filtered—or so the thinking goes. But the reality is that the output produced by a buck regulator is generally low noise.

Fig. 8 shows the low-noise and high-noise sides of a stepdown converter. The output side is low noise since there is an inductor in series with the output. Inductor current is ramping up during the on-time and ramping down during the off-time. In contrast, the input side of the buck converter is very high noise. During the on-time, maximum current is flowing through the input trace and during the off-time, no current is flowing into the topology. This is why the input line is considered to be an ac current line.

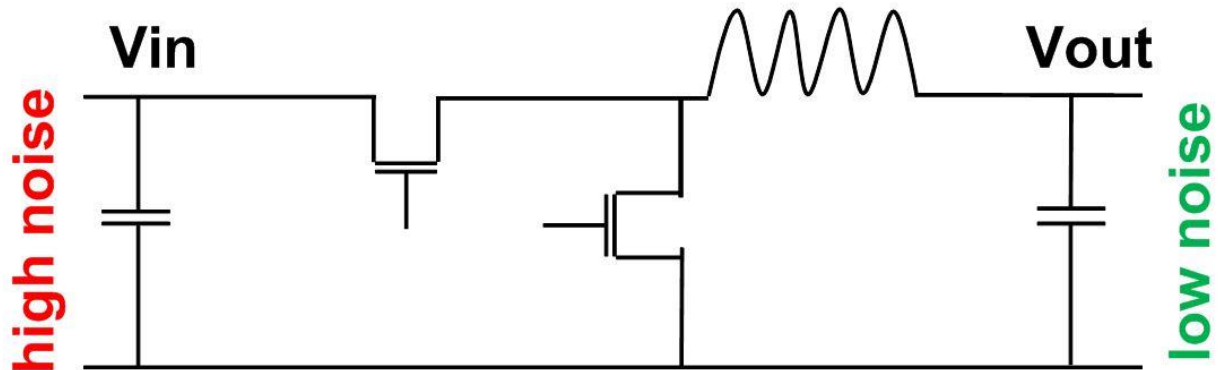


Fig. 8. The input side of a buck regulator is actually the noisy side.

The input capacitor does help to average the source current slightly, but it is not able to completely generate a constant dc input current. Therefore, designers are advised to keep in mind that very often, when there is a noise problem in a system with a buck regulator, it is not actually the output of the buck that is the problem, but rather the input. It is noisy and often has a long trace on a given PCB. To solve this issue, input filtering can help.

This article has explained the most common sources of noise in nonisolated dc-dc converters and outlined the remedies for attenuating or eliminating these noise sources. However, these discussions are only an introduction to the topic of switched-mode power supply noise and there is a wealth of literature available on this subject. The references provided below offer a starting point for further reading. In addition, more information can be found in the How2Power Design Guide, as noted below.

References

1. "[Printed Circuit Board Layout Guidelines for Step-Down Regulators, Optimizing for Low Noise Design with Dual Channel Switching Controllers](#)" by Scott Zheng, Analog Devices' application note AN-1119.
2. "[Measuring Output Ripple and Switching Transients in Switching Regulators](#)," by Aldrick S. Limjoco, Analog Devices' application note AN-1144.
3. "[Noise Reduction Network for Adjustable Low Dropout Regulators](#)" by Glenn Morita, Analog Devices' application note AN-1329.

4. "[Noise Sources in Low Dropout \(LDO\) Regulators](#)" by Glenn Morita, Analog Devices' application note AN-1120.
5. "[How to Apply DC-to-DC Step-Down/Step-Up \(Buck/Boost\) Regulators](#)" by Ken Marasco, Analog Devices' application note AN-1149.

About The Author



Frederik Dostal joined Analog Devices in 2009 and currently works as the power management technical marketing engineer for Europe. Dostal began working in the power management field in 2001. Since this time he has been active in various power management applications positions including four years in Phoenix, Arizona where he worked on switched-mode power supplies. Dostal studied microelectronics at the University of Erlangen, Germany.

For further reading on switching regulator noise, see the How2Power [Design Guide](#), locate the "Design Area" category, and click on the link for "Noise Performance" Also, see the link for "EMI and EMC."