



APPLICATION NOTE 986

Input and Output Noise in Buck Converters Explained

: Input and output noise in buck (step-down) converters can be a cause of concern to the system designer. This application note attempts to provide a theoretical explanation of the individual contributions of conducted noise on the input and output sides of buck converters. These equations will hopefully allow the power supply design optimize components for noise immunity.

Introduction

The goal of this application note is to give a brief explanation of the individual contributions of conducted noise on the input and output sides of buck (step-down) converters. Equations are listed to help calculate the peak-to-peak noise contributions of each noise source. These equations will hopefully allow the designer of buck converters to pick components that will help them meet their design objectives.

Assumptions

The equations listed in this application note are appropriate for any buck converter, independent of the control scheme, as long as they meet the following limitations:

1) The equations assume continuous conduction above 0A.

This assumption describes the current flow in the inductor. Depending on the components used, the load and the topology of the buck converter, the current flow through the inductor can look like that shown in **Figure 1**. The middle graph of Figure 1 shows discontinuous current flow. Discontinuous current flow occurs when the current through the inductor tries to go negative (current flows out of the output capacitor and into ground), but gets clamped at zero. Discontinuous conduction typically, but not always, occurs under light load conditions.

The bottom graph of Figure 1 shows an example of continuous conduction where the current through the inductor drops below 0A. In order for the current to drop below 0A, the converter needs to have synchronous rectification and be designed to allow for such operation. With such a converter the current will typically, but not always, go below 0A under light load conditions.

Independent of whether the converter is synchronously rectified or not, continuous conduction above 0A will tend to happen at higher loads as shown in the top graph in Figure 1. Thus, the equations listed in this application note should be appropriate when the converter is operating close to maximum loading.

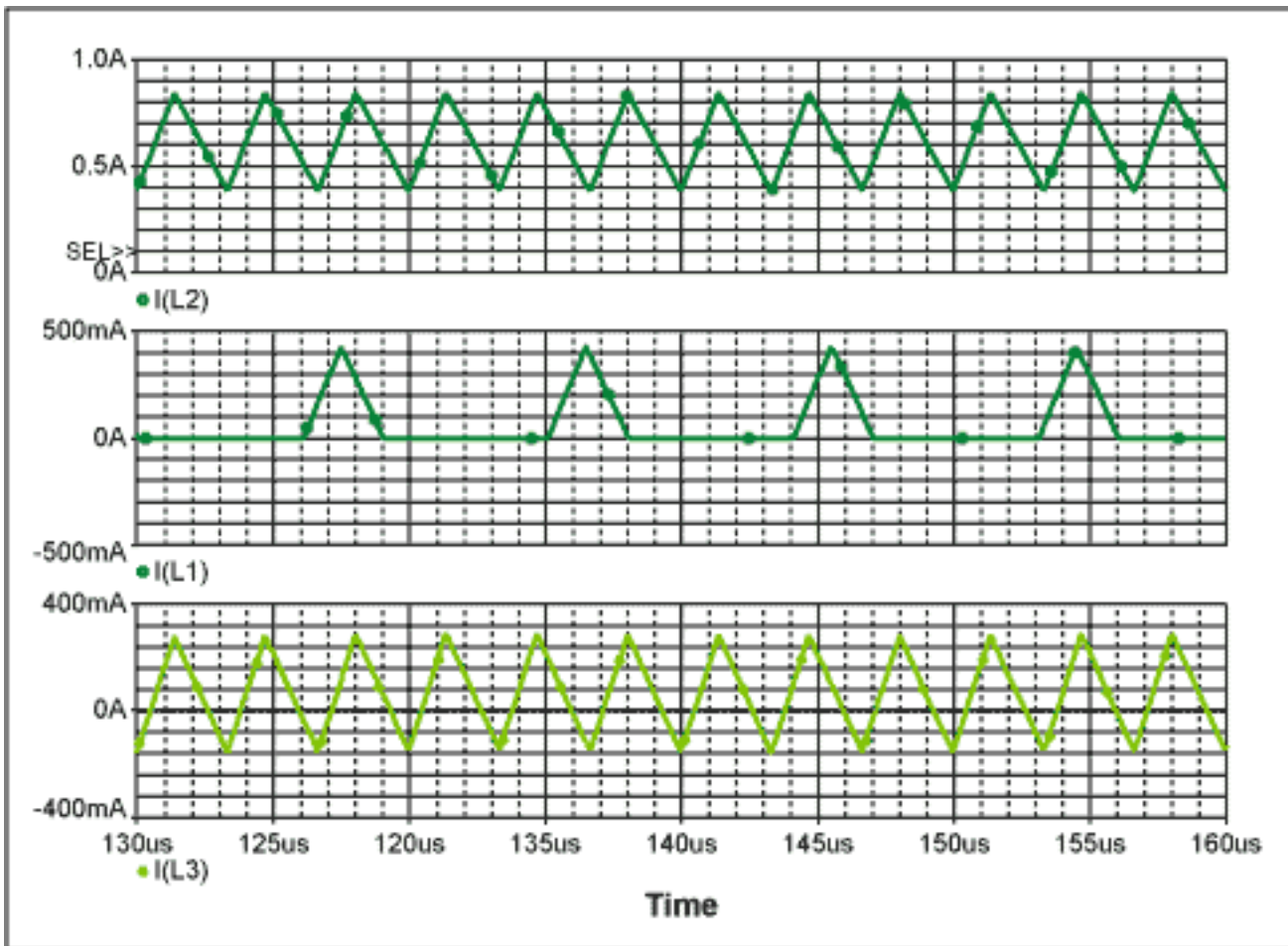


Figure 1. Shows three possible waveforms for the current flowing through the inductor in a buck converter. The top graph shows continuous conduction operation where the current never drops below 0A. The middle graph shows discontinuous conduction. The bottom graph shows continuous conduction where the current drops below 0A.

Use the equation listed below to test a particular design. If this inequality is met, the converter is operating in continuous conduction above 0A, and this first assumption will be satisfied.

$$\left(i_{\text{out}} - \frac{1}{2 \cdot f \cdot L} \cdot \frac{V_{\text{out}}}{V_{\text{in}}} \cdot (V_{\text{in}} - V_{\text{out}}) \right) > 0$$

V_{in} = the input voltage

V_{out} = the output voltage

f = the frequency at which the buck regulator is switching

L = the value of the inductor

i_{out} = the output current

Equation 1. When this equation is met, an ideal buck converter will be operating in continuous conduction with the current through the inductor never going below ground.

2) The load is a constant DC load

This assumption needs to be made for practical reasons. While assumption #1 is a reasonable assumption for most applications, this assumption is most likely not true. In a typical buck converter application the current draw of the load will fluctuate. This fluctuation will cause noise, due to the finite response time of the converter,

and the equivalent series resistance (ESR) of the output capacitor (explained later), among other things. In order to calculate the output noise due to this fluctuation, the characteristics of the load need to be known. For the purposes of this application note, this is, of course, impossible.

3) The converter is 100% efficient

This again is a practical consideration. The equations would be unwieldy if this assumption was not made. Most modern buck converters have excellent efficiency and the amount of error this assumption introduces is minimal.

Background

Some of the noise sources in buck converters come from the non-ideal properties of the components used. To better understand these noise sources, a brief discussion of the non-ideal aspects of components are discussed below. To keep this discussion simple, only the non-idea properties relative to buck converters are discussed.

Model for MOSFETs

For the purposes of a buck converter, a first-order model for a MOSFET is a switch in series with a resistance, as shown in **Figure 2**. In this model, the MOSFET has a finite resistance between its drain and its source when the MOSFET is turned on. Typical on resistances can vary widely depending on the MOSFET and the application. As a point of reference, the IRF7303 used on the MAX1653EVM has a typical on-resistance of $.08\ \Omega$ ($V_{gs} = 4.5V$).

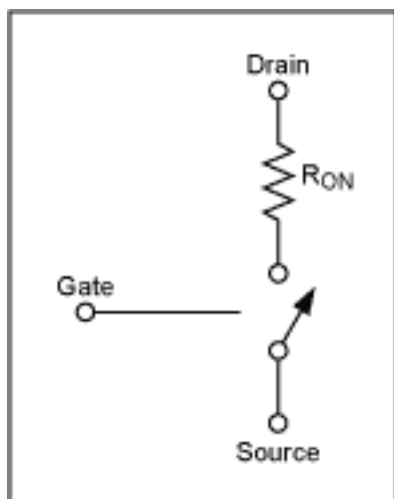


Figure 2. A first-order model of a MOSFET used in a buck converter.

A more complete model for a MOSFET is shown in **Figure 3**.

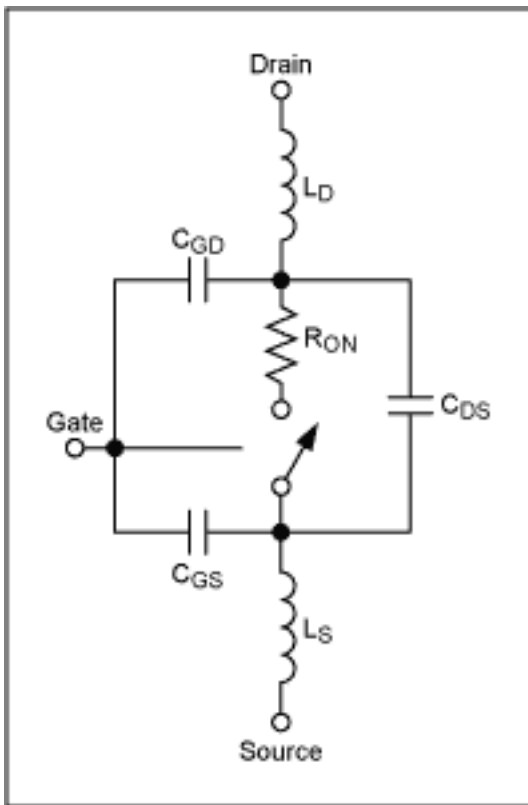


Figure 3. A more detailed model of a MOSFET used in a buck converter.

This model adds inductances and capacitances to the first-order model in Figure 2. The three capacitors shown are:

- C_{gd} = Capacitance from the gate to the drain
- C_{gs} = Capacitance from the gate to the source
- C_{ds} = Capacitance from the drain to the source

Again, using the IRF7303 as an example, typical values for these capacitances are listed below ($V_{ds} = 8V$).

- $C_{gd} = 120pF$
- $C_{gs} = 470pF$
- $C_{ds} = 180pF$

In addition to these capacitances, both the drain and the source of the MOSFET have equivalent inductances in series with them. In the case of the IRF7303, these are both listed in the data sheet of the IRF7303 as 4nH and 6nH for the drain and source respectively.

Model for Capacitors

The model for a capacitor is shown in **Figure 4**.

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