Advanced Energy

Ripple & Noise Measurements

Abstract: Switching regulators inherently generate some noise during their operation due to the non-linear nature of the voltage and current waveforms. Some of this noise will appear on the output voltage terminals and will ultimately be 'seen' by the load. Understanding how much noise can be critical for some applications, so when a vendor states the maximum values for these on their datasheet, we need to know how this is quantified. Being able to measure this is key, and this paper looks the various methods that can be used to measure ripple and noise on a power supply and how these can affect the perceived measured values.

1.0 Introduction:

There are two distinct components to the output noise. These are commonly referred to as 'ripple' and 'noise'. Defining what these are, how they occur, and how to measure each of them accurately will allow us to interpret correctly how we expect any given power supply to perform when integrated into a system.

2.0 Ripple and Noise

The ripple exists because, during a portion of the converter's operating cycle, energy is transferred to the secondary from the primary and the output voltage increases slightly. During the time interval when there is no energy transfer to the secondary, the load current is supplied by stored energy in the output capacitance and inductance of the converter, and the output voltage decreases slightly as this energy is depleted. Ripple is a low frequency component and will be occur at the same as the converter operating frequency, or some multiple thereof.

Noise is much more variable and harder to predict than ripple. It is caused by ringing in parasitic inductances due to the large values of di/dt that occur internally in a switching converter. The noise is much higher frequency than the ripple and can be up into the MHz range. Noise occurs in the form of "bursts" at the time of switching activity in the converter, so therefore appears to be superimposed upon the peaks and valleys of the ripple waveform as shown in Fig 1.

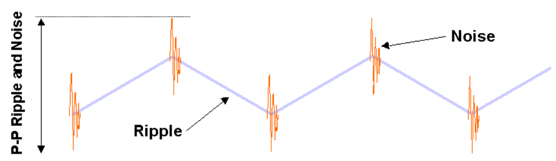

Fig 1: Output Ripple & Noise

Knowing how to measure these items, is not complicated, but it does require an understanding of what you are measuring. You must also ensure that your measurement techniques are accurate,

repeatable, and that you correctly interpret what you are seeing once you take these measurements.
In fact, measuring any low-level signals in a power supply is not without its challenges. Often it is notoriously difficult to correlate measurement values; they are highly dependant on setup, measurement equipment and point of measurement. This is particularly true when it comes to measuring the output ripple and noise of a power supply.

3.0 Taking accurate measurements

Any voltage probing suffers potential errors:

The loop formed by the probe's signal and ground, acts as an unshielded loop antenna and will pick up noise from its surrounding environment. On top of this most garden-variety scopes have very poor common mode rejection. It can sometimes be hard to know whether what you are measuring is the signal you are probing, or induced coupling from a nearby circuit. High frequency common mode currents flowing through the parasitic inductance of the probe ground lead (typically about 250nH) will induce a significant voltage.

However, there are several steps that can be taken to eliminate this from your measurement.

3.1 Limit the bandwidth on the measurement:

Output Ripple and Noise is usually specified with a 20MHz Bandwidth. This reduces the high frequency noise components. Most scopes will have this available internally. If in doubt about its performance, it can be calibrated with a signal generator.

3.2 Eliminate Common mode noise picked as a result of the measurement technique:

An effective and easy way to implement this would be to wind the scope lead through a toroid a few times. This will reduce high frequency common mode currents that have been picked up by the measurement technique.

3.3 'Tip and Barrel method'

The next method that eliminates pick up on the earth lead, is not to use the earth lead at all. Instead the ground sheath of the probe is used to earth the scope directly. If you consider that the average probe ground lead has an inductance of approx 250nH. Typical oscilloscopes have an input capacitance of 15pF. These can form a tuned circuit resonating around 80MHz.

Note that the comments above are only about the ground lead of the probe. The earth lead of the oscilloscope must not be disconnected under any circumstances. This would be a dangerous practice to engage in and it is also totally ineffective at reducing high frequency CM currents. They would continue to flow through the large capacitance from the chassis of the oscilloscope to earth.

3.4 Minimize reflections:

Let us consider the various impedances when placing a scope lead on the output of the power supply

- The output impedance of the power supply will be very low (a few mOhms).
- The line impedance will be 50 Ohms
- A termination of 1MOhm (input impedance of the scope).

With this level of mismatching, the resulting reflections and ringing could give a false measurement on the actual noise measured. In particular, the peak measurements could be noticeably different. This can be addressed by placing a 50 Ohm resistor in series with the 50 Ohm line at the power supply end. Another 50 Ohm resistor in parallel at the scope end will properly terminate the line. To stop this 50Ohm taking DC load current from the power supply, place a capacitor in series with the 50 Ohm resistor at the power supply end. Of course, because of the two 50 Ohm resistors you have now a resistor divider effect. So, the measured amplitude must be multiplied by two to get the actual value.

4.0 Comparing Output Ripple and Noise specifications:

The amount of noise that a power supply will generate varies with load and temperature. So, it is important to note the conditions under which these values are published. Look carefully at the vendor's notes for details of any external components used or test measurements set-up. In many cases vendors will also publish required PCB layouts.

However, with the low noise performance of the Xgen series, no such reading between the lines is required. Simply attach a scope probe on the output pins, apply any load and the noise will be within the specified limits of either 1% or 100mV (whichever is the higher). A sample of these are shown in Section 5.

5.0 Ripple and noise variations with temperature.

Ripple and noise measurements taken on an Xg3 are shown below. All of these are taken under full load conditions, using the same measurement techniques, with the only variable in the setup being operating ambient conditions. These were taken at low temperature (-20°C), nominal ambient (25°C) and high temperature (50°C).

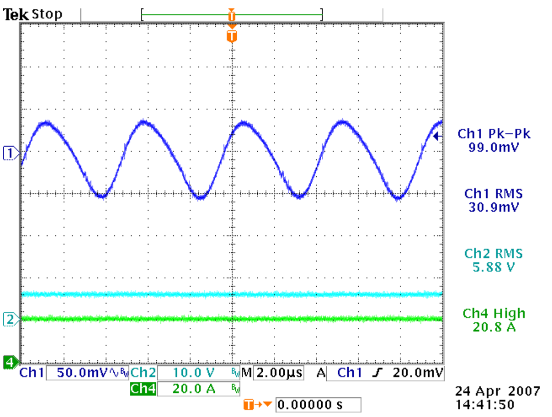

Fig X: Ripple and Noise measured on an Xg3 under full load conditions Ambient =+ 25°C

CH1 = V_{OAC}
CH2 = V_{ODC} =6V
CH4 = I_O =20A(Electronic Load)
Measured: 99mV Pk-Pk

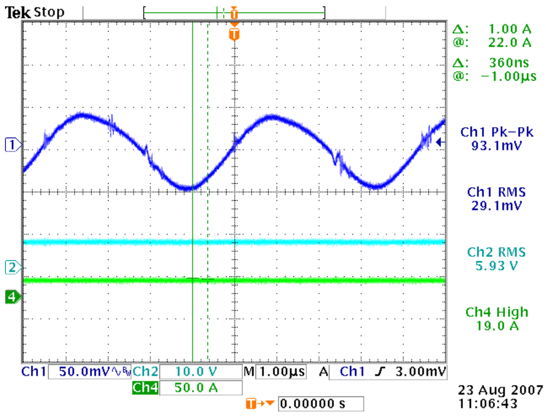

Fig X: Ripple and Noise measured on an Xg3 under full load conditions Ambient = -20°C

CH1 = V_{OAC}
CH2 = V_{ODC} =6V
CH4 = I_O =20A(Electronic Load)
Measured: 93mV Pk-Pk

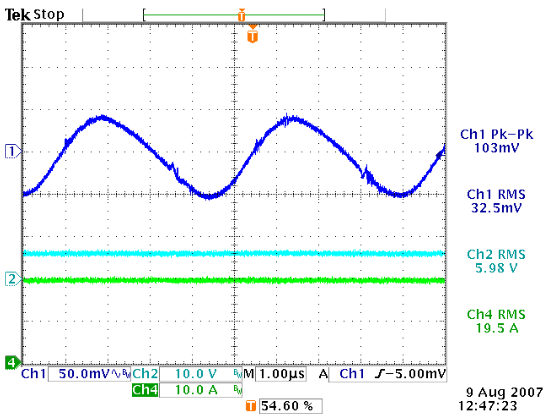

Fig X: Ripple and Noise measured on an Xg3 under full load conditions Ambient = +50°C

CH1 = V_{OAC}
CH2 = V_{ODC} =6V
CH4 = I_O =20A(Electronic Load)
Measured: 103mV Pk-Pk

You will observe that over a 70°C ambient difference we can see a 20mV difference in the peak to peak measurements. This is as expected due to the characteristics of the output capacitors, and output choke that will vary with temperature. This has a direct bearing on the amount of ripple we now see on the output. With this in mind, it is key to understand how the ripple and noise on any given design will vary with temperature.

6.0 How to reduce these figures further:

In a nutshell, you can reduce ripple voltage by adding a low-pass filter. In the simplest case, you use a capacitor. In a more complex case, you could use an LC filter, making the peak voltage smaller. The specifics are dependent on the power and performance requirements. One item to note is that if you place an LC on the output, **AND** you bring out the remote sense leads on a power supply, you now have in your control loop an LC in series with an LC which may inadvertently create an oscillator ! Keep the inductance small and capacitors on the larger side to reduce the possibility of this occurring.

7.0 Summary:

Switching regulators will introduce some noise into the application due to the non-linear nature of their voltage and current waveforms. If your application is sensitive to this event then ,firstly, understand what you are trying to measure, and secondly to ensure that the right technique is employed in taking these measurements. You should also look at the small print, and work with your vendor to understand how these features will change over the entire operating range of the power supply. In doing so you will ensure that you do not encounter any issues later during your design stage.

About Advanced Energy

Advanced Energy (AE) has devoted more than three decades to perfecting power for its global customers. AE designs and manufactures highly engineered, precision power conversion, measurement and control solutions for mission-critical applications and processes.

AE's power solutions enable customer innovation in complex semiconductor and industrial thin film plasma manufacturing processes, demanding high and low voltage applications, and temperature-critical thermal processes.

With deep applications know-how and responsive service and support across the globe, AE builds collaborative partnerships to meet rapid technological developments, propel growth for its customers and power the future of technology.

For further information on our products, please visit www.advancedenergy.com.