Ripple and Noise Measurements
with DC/DC Switch-Mode Power Supplies

As switching frequency and switching speeds continue to increase, special care should be taken to ensure accurate measurement of input and output voltage ripple in switch mode DC/DC power supplies (SMPSs). There is no industry standard to measure ripple and noise in DC/DC converters. Test set-up and methodologies vary from vendor to vendor, which can cause significant confusion. The techniques described in this application note provide reproducible results and require no special laboratory set-up beyond a high frequency voltage probe and oscilloscope.

This application note will summarize the set-up, methodology, and practical measurement guidelines to accurately measure input and output voltage ripple (or switching noise). These measurement techniques are equally suitable to all SMPS DC/DC topologies, as well as charge pump (switched capacitor) regulators. Other techniques are recommended for the low noise levels typical found with non-switching low dropout linear regulators (LDOs). The measurement examples will focus on SMPS buck (step-down) low voltage regulators.

Ripple and Noise
Ripple and noise voltage refers to the AC coupled voltage signal appearing on the DC input and output capacitors of a DC/DC regulator.

SMPS output noise can be categorized as having ripple and noise content. For the purposes of this discussion, ripple is the output voltage fluctuation associated with charge and discharge events of the SMPS. This noise has a low peak-to-average ratio, occurs at the fundamental switching frequency, and is often referred to as RMS noise. The ripple waveform represents the charging and discharging of the input and output capacitance and, as a result, is greatest at maximum load. The ripple voltage can be reduced with increased input and/or output capacitance.

High frequency noise spikes occur at the SMPSs turn-ON and turn-OFF events. This can be accurately measured with an oscilloscope (see Figure 1) assuming good bench set-up. Although the noise repetition frequency is determined by the switching frequency of the SMPS, the frequency content of the noise spikes is generally much higher than the switching frequency. The amplitude is highly dependent on SMPS topology, circuit parasitics, and PCB layout. Since it occurs at a high frequency, the noise spikes are highly susceptible to probe and laboratory set-up.

![Figure 1: Typical AC Coupled Ripple and Noise Voltage.](image)

Oscilloscope Probe Setup
Ripple and noise voltage appears at the input and output of SMPS DC/DC converters. The total noise is the sum of the ripple and noise components. Simple steps should be taken to assure minimum oscilloscope pickup to the high frequency events, which can be magnified by the large ground loop formed by oscilloscope probe ground. This means that even a few inches of ground wire on the oscilloscope probe may result in hundreds of millivolts of noise spikes when improperly routed or terminated. The following two methods show the incorrect method (Figure 2) and the correct method (Figure 3) of measurement in the oscilloscope and the measurement location.
RMS noise levels are dominated by the charge and discharge of the input and output capacitor. Peak-to-peak noise results from the ringing of parasitic inductance, capacitance, and resistance occurring at the SMPS switching events.

**Incorrect Method**

![Incorrect Method Diagram]

*Figure 2: Incorrect Method of Using Probe to Measure Ripple and Noise.*

Figure 2 shows an incorrect method because the clip-on ground wire of the probe picks up radiated noise. Also, the greatest source of error usually comes from the clip-on ground wire because of its unshielded portion of the oscilloscope probe. The loop created between the signal terminal and the clip-on ground wire of the oscilloscope probe works like an antenna. Voltage errors induced by magnetic radiation in the loop appear on the oscilloscope. The bigger the area of the loop is, the greater the noise picked up from the switching events.

**Correct Method**

![Correct Method Diagram]

*Figure 3: Correct Method of Using Probe to Measure Output Ripple and Noise.*
The best way to minimize this effect is to use very short and direct connections to the oscilloscope probe. To reduce measurement errors, the position of the probe should be placed directly across the output capacitor, as shown in Figure 3. The total loop area in the signal and ground connections is now as small as possible. Noise can be eliminated or reduced as suggested below:

1. Remove the clip-on ground wire and the probe clip-on adapter from the oscilloscope probe, providing access to the metal ground conductor.

2. Wrap the oscilloscope probe lead (unshielded ground portion) several times around with large diameter (20 AWG) tinned copper wire. Solder the end of the tinned copper wire to the ground terminal of the output capacitor.

3. Connect the probe tip of the oscilloscope probe to the output terminal (V_OUT) of the output capacitor. In this case, the tip is in contact with the output node of the DC/DC converter. As a result, the total loop area of the output signal and the ground connections becomes very small.

**Conclusion**

![Diagram](image)

**Figure 4: The Difference Between Two Measurements.**

Figure 4 illustrates the two V_OUT traces using two methods of probing techniques. The circuit is an SMPS buck (AAT1121 step-down) converter operating at 1.5MHz. The output voltage is regulated to 1.8V with 250mA load and measured in full bandwidth. It is noticeable that trace (2) in green shows significant high frequency noise and ringing coincident with each switching event. However, trace (3) in red shows no noise pick-up. Therefore, the set-up and methodologies are very important to ensure accurate measurements.
Figure 5: The Actual Measurement (Zoom-In).

Figure 5 shows the snapshot captured with 20MHz bandwidth filtering built into many oscilloscopes to reject the unwanted common mode noise due to the passive probe being used. The AAT1121 buck converter exhibits less than 10mVp-p ripple and negligible noise. This is due to the low output noise inherent in SMPS buck (step-down) converters, good PCB layout, and proper probing technique.