Don't Forget to Terminate Cables

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We know that in high-speed signal-integrity measurements one of the first rules is to properly terminate traces and cables. However, many of our PDN measurements may be limited to lower frequencies, such as measuring the switching ripple of a DC-DC converter. Do we really need to terminate our measurement cables if the signal we want to measure is the switching ripple of a converter running at 1 MHz? We may think that in this case termination is not needed or does not matter. We may be up to some surprises…

Let us look at the output ripple of the LTM4604 converter [1], which was our Device Under Test in an earlier column [2]. The converter is powered from a 4.5V battery pack, it's output voltage is set to 1.2V. An approximate 1A DC load is created by a small incandescent bulb. The output ripple is measured by a Tektronix TDS540B oscilloscope that I recently bought on E-Bay. The 1 Gs/s maximum real-time sampling rate and 500 MHz analog bandwidth, together with a maximum 1 mV/div vertical sensitivity makes this category of oscilloscopes very useful for many PDN measurements even today. The setup is shown in *Figure 1*.

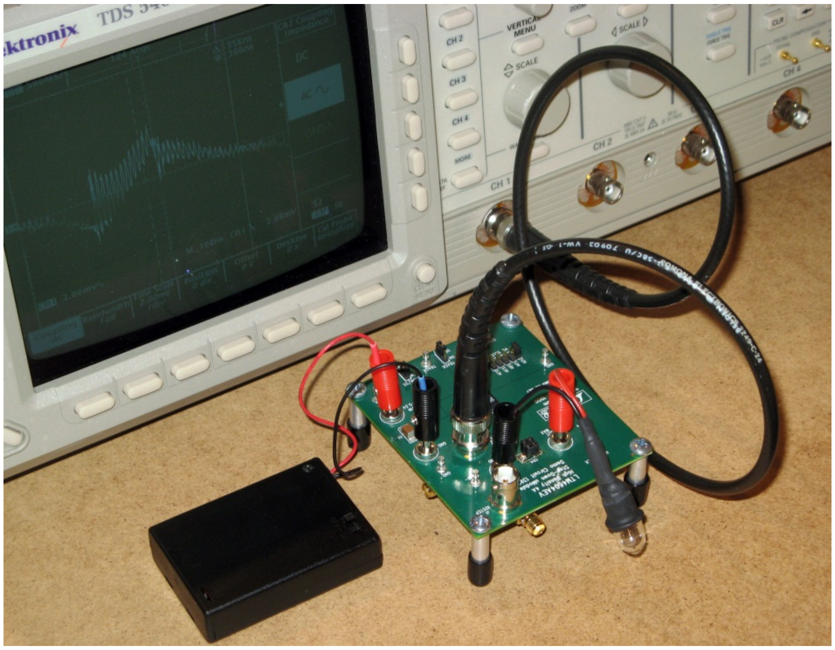

***Figure 1**: LTM4604AEV DC-DC converter evaluation module (courtesy of Linear Technologies), connected to CH1 of a Tektronix TDS540B oscilloscope through a coaxial cable.*

When we connect the output BNC socket to CH1 of the oscilloscope with a coaxial cable, we get a waveform shown in *Figure 2*.

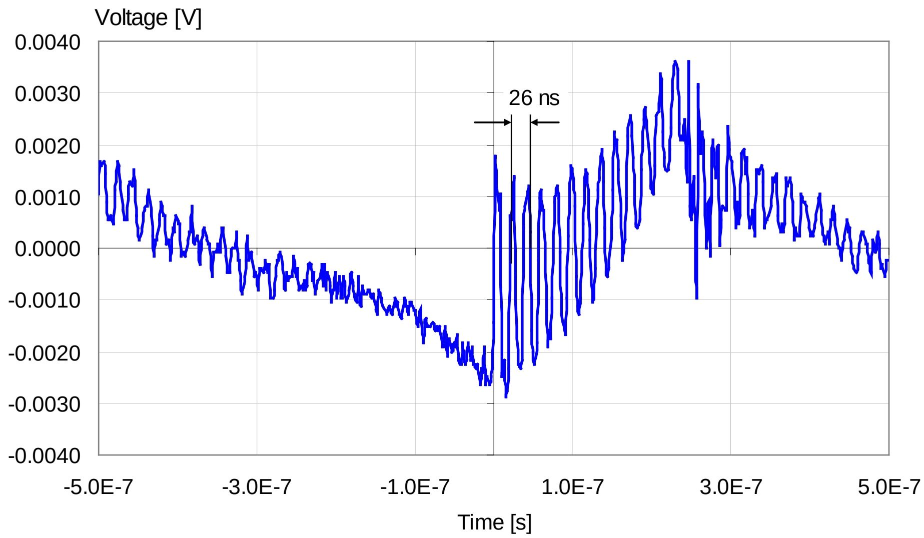

Figure 2: *Output ripple of the DC-DC converter shown in Figure 1.*

The figure shows approximately one full cycle of the converter, with the trigger point aligned to time zero. The ON time, shown by the positive ramp, is approximately 0.3 μs. The peak-to-peak ripple is below 10 mV, so everything makes sense, except we see a strong oscillation during the ON time with a 26 ns period. When we check the oscilloscope settings, we notice that –in order to show the small AC contents on top of the 1.2V DC- the Autoscale feature uses AC coupling on the oscilloscope input. Checking further, we will notice that the input impedance is set to 1 MOhm. This 38 MHz ringing is caused by the reflections on the 0ne-meter long connecting cable; a Belden RG 58C/U coaxial cable. The coaxial cable has almost full reflections at both ends: an approximately +1 voltage reflection coefficient at the oscilloscope input and an approximately -1 voltage reflection coefficient at the DC-DC converter output. These conditions create a quarter-wave resonator with a resonance period of four times the one-way propagation delay. The unloaded propagation delay is 5.1 ns/m; with the load reactances at the input and output of the cable we may get a delay of 6.5ns, which results in a 38 MHz ringing frequency. We will notice by using different cables that the ringing frequency changes proportionally with the cable delay.

Unfortunately the 38 MHz ringing frequency is not high enough so that we could count on eliminating it by switching on the customary 20 MHz BW limit option. The proper way to eliminate this ringing is to use a 50-Ohm termination at the oscilloscope input. We can use either an external 50-Ohm termination at the end of the cable and then we can keep the 1 MOhm input setting on the oscilloscope, or switch the oscilloscope input to 50 Ohms. When we switch the oscilloscope input to 50 Ohms (and leave the AC coupling setting), we get a warning reminding us that the 50 Ohm input impedance together with the series capacitor providing the AC coupling will result in an increased high-pass cut-off frequency. Since in this case our lowest frequency component of interest is the 1MHz fundamental wave of the switching ripple, this will not degrade our measurement.

Using the 50-Ohm termination setting on CH1 input, we get a ringing-free switching waveform as shown in *Figure 3*.

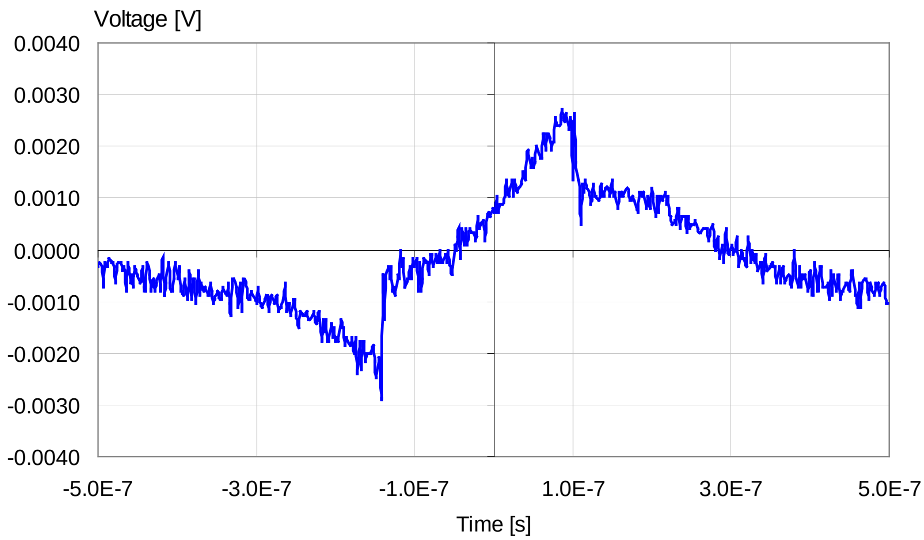

Figure 3: *Output switching ripple measured with 50-Ohm termination at the oscilloscope input.*

This waveform is much cleaner and it now allows us to hunt for finer details. For instance, as shown in *Figure 4*, if we zoom on a switching transition, we will notice a high-frequency ringing; this time on the other hand it is ‘real’; it is generated by the DUT.

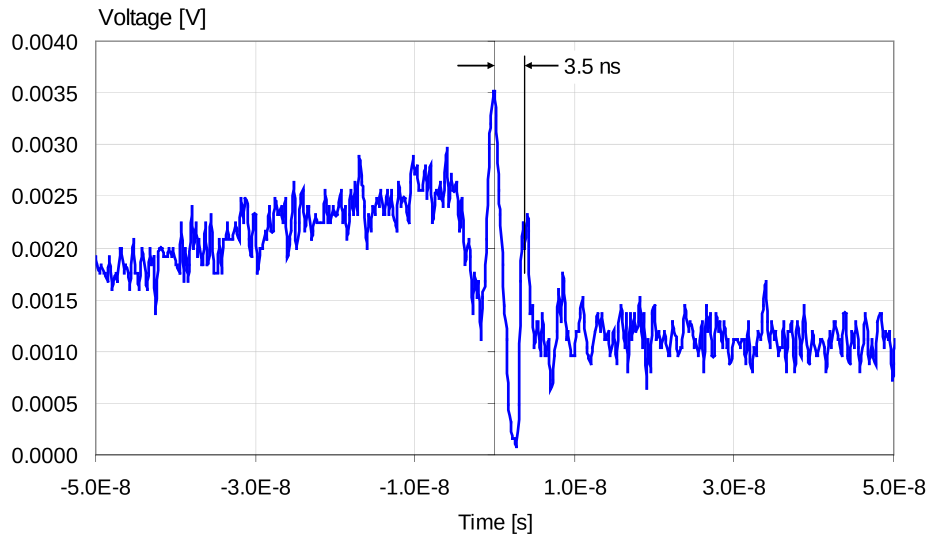

Figure 4*: Same waveform as in Figure 3, except zoomed around the end of the ON period.*

This high-frequency ringing now has a 3.5 ns period, corresponding to a 286 MHz frequency. As opposed to the 38 MHz ringing we had before, this ringing does not change as we change cables. By looking at the switch-node waveform, we can convince ourselves that this ringing is the parasitic ringing originated inside the DC-DC converter module and is the result of the fast switching edge exciting the parasitic inductances and capacitances associated with the switching elements.

References:

[1] Linear Technologies LTM4604AEV evaluation module. http://www.linear.com
[2] "Do Not Measure Across Capacitors!" QuietPower column, http://www.electrical-integrity.com/