

How to Measure Impedance of a Power Distribution Network of a DC-DC Converter



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ABSTRACT

This application note explains how to measure the Power Distribution Network (PDN) impedance of a DC-DC converter with a 2-port shunt-through measurement, suitable for measuring down to milliohm impedances at very high frequency. The method can be reproduced in a short amount of time using common instruments available in most laboratories.

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1 Introduction

Especially for DC-DC converters, meeting a low PDN Impedance is important to reduce the voltage variations due to strict load transient requirements. An ideal PDN design enables a DC-DC converter to supply a stable voltage to a load and maintain it within narrow margins. When designing a PDN, it is important to validate that the output impedance (or input impedance) of a DC-DC converter is meeting its target impedance and achieve low impedance value in the milliohm range. A PDN impedance analysis shows an overlay of the passive component impedances constituting the power network over frequency.

This application report describes a measurement method to evaluate the PDNs of a DC-DC converter, the 2-port shunt-through measurement. This method allows PDN designers to measure down to milliohm impedances while supporting measurement at very high frequencies.

2 2-Port Shunt-Through Measurement Theory

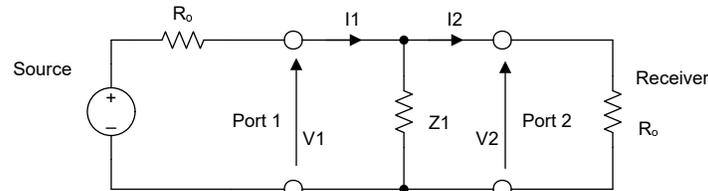


Figure 2-1. 2-Port Shunt-Through Circuit Configuration

Figure 2-1 shows the 2-Port Shunt-Through circuit configuration to measure Z_1 impedance. First of all, the S-parameter S_{21} is calculated to derive the Z_1 impedance value. As per definition, S_{21} is:

$$S_{21} = \frac{V_2 + I_2 R_0}{V_1 + I_1 R_0} = \frac{2 Z_1}{2 Z_1 + R_0} \quad (1)$$

Assuming that $R_0 = 50 \Omega$ and $S_{21} \ll 1$ (for very small impedance / resistances - $Z_1 \ll R_0$) when solving for Z_1 , the result is:

$$Z_1 = \frac{25 S_{21}}{1 - S_{21}} \sim 25 S_{21} \quad (2)$$

It is important to note that the measure of S_{21} is influenced by the VNA performance such as the dynamic range, the signal-to-noise ratio and the effective number of bits.

As all grounds in a VNA refer to the same point, an additional common mode current is created and affects measurement accuracy resulting in measurement errors. A Semi-floating differential amplifier is then used as a ground isolator to minimize ground loop currents.

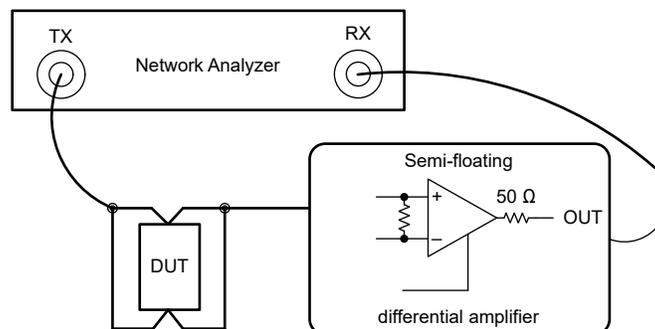


Figure 2-2. 2-Port Shunt-Through Circuit Configuration

Figure 2-2 shows a 2-port shunt-through measurement setup. The 2-port shunt-through measurement uses a vector network analyzer (VNA) to compute impedances at very high frequency and a semi-floating differential amplifier to measure impedances down to 1 mΩ. Selecting a semi-floating differential amplifier with a large

resistance to common mode current is paramount to improve the accuracy of the measurements especially at lower frequencies.

3 System Setup and Calibration Elements

Before performing the measurement, a Thru calibration of the VNA is required to avoid additional series resistor and impedance mismatches. At high frequency, mismatches commonly appear. The use of a SMA connector is favored to eliminate mismatch errors. An SMA connector also offers a small size, light weight and a high frequency capable connector, up to 18 GHz.

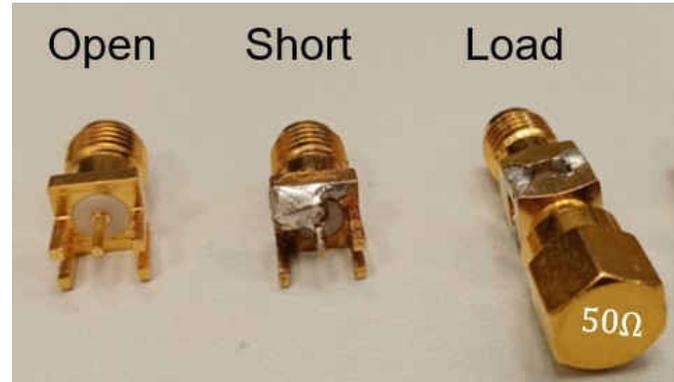


Figure 3-1. System Setup with T-Shaped Connector (left) and Calibration Elements (right)

The VNA and the semi-floating amplifier are connected by a SMA T-shaped connector as shown in [Figure 3-1](#) and the third hole is connected to a calibration element.

The calibration elements, as displayed in [Figure 3-1](#) are very convenient for mounting typical bypass capacitor sizes. The distance between the center pin and the GND pin must have a similar size than the DUT. In the case of a PDN evaluation, the pads of a buck converter output capacitor. The calibration elements generally used are open circuits, short circuits and 50 Ohm loads. It is possible to use other reference elements like a capacitor, an inductor or a 1mOhm resistor to verify the quality of the calibration of the VNA. These elements can be purchased or handmade starting from a female SMA connector [6].

To ensure reliability and reproducibility of the impedance measurement, it is very important to verify measurement parameters of the VNA. The operating frequency range might be by default narrower than the full frequency range thus can be extended to evaluate a wider frequency range. The frequency window can also be reduced to minimize computing time. To avoid saturation in measurements, it is recommended to adjust the attenuation level on the receiver channel.

The applied signal can be modulated based on DUT. In general, higher signal levels offer less signal-to-noise ratio (SNR) in measured values. Though, impedance value of passive components like ceramic capacitors tends to vary with measurement signal level. The user would then need to adapt signal level over frequency.

If the calibration is not well performed, the system is subject to higher SNR and inaccuracies. This would prevent to measure a very low impedances over the full frequency range.

After the Thru Calibration, the DUT is ready to be connected to the system to start the measurements.

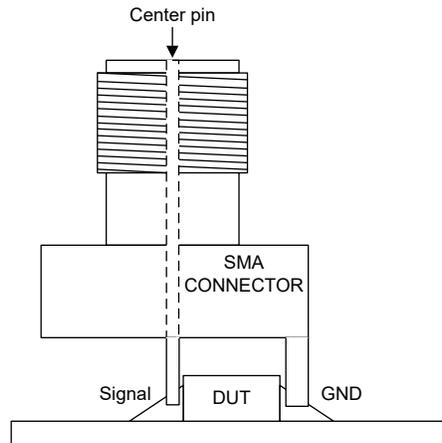


Figure 3-2. High-Frequency Probe Technique Using a Simple SMA Connector

By cutting off some of the SMA connector GND pins, an SMA connector can be modified, as shown in [Figure 3-2](#). An alternative method can be to use a SMA semi-rigid cable and cutting it short, stripping the center conductor and soldering a short pin to the outer conductor.

4 2-Port Shunt-Through Measurement of the TPS62A01 Output PDN

[Figure 4-1](#) shows an Application Circuit to perform a two-port shunt-through measurement, the [TPS62A01](#) Output PDN is evaluated.

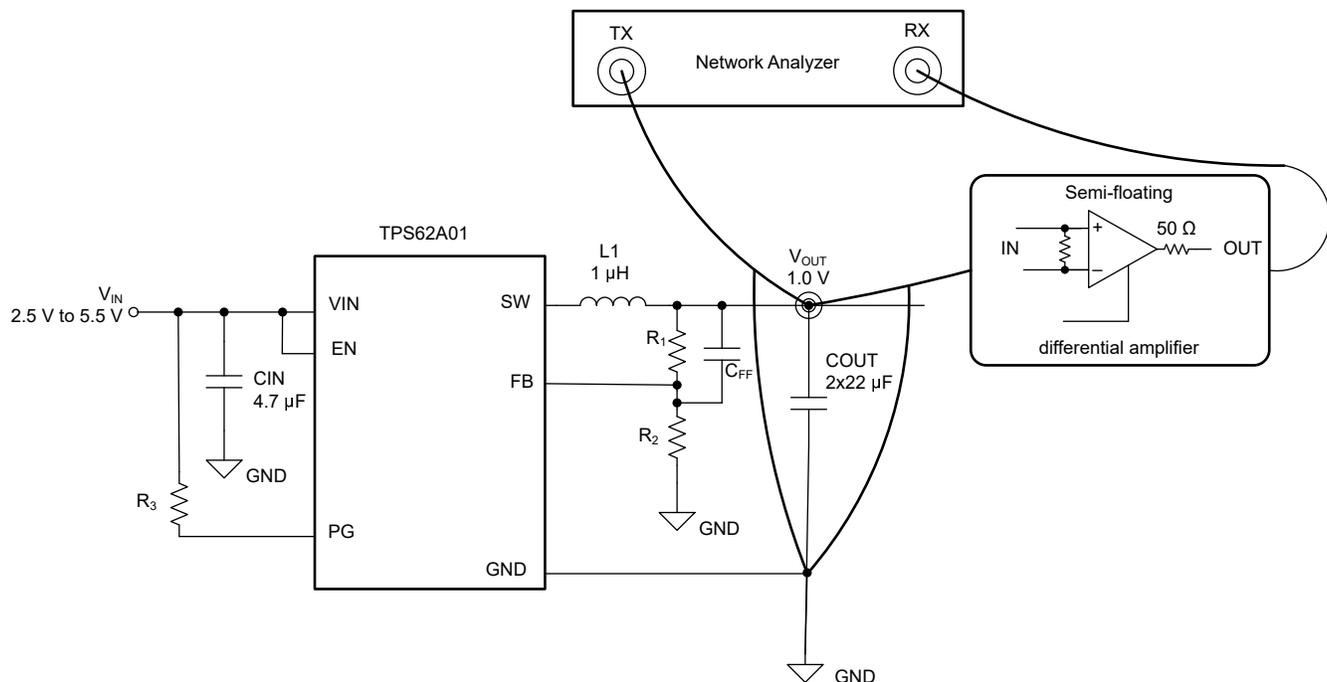


Figure 4-1. 2-Port Shunt-Through Measurement of the TPS62A01 Output PDN

The VNA Output (TX) is connected to the output PDN through a direct connection. The VNA Input (RX) is connected to the output of the PDN through a semi-floating differential amplifier on the VNA RX side.

Residual impedance will directly affect very low impedance measurements. Thus, making sure connections length are kept as short as possible will ensure a better fit to actual PDN behavior over frequency. Ensuring tight connections also helps reducing parasitic coupling effects and allow more accurate results.

5 PDN Impedance Measurement Example

Passive components can help lower the impedance at specific frequencies between power and ground planes. Using a congregate of different passive components on a PDN builds a filter to achieve a target impedance. Usually, on-board passive components lower impedances up to hundreds of MHz.

However, every passive component has parasitic elements influencing its impedance behavior. Analyzing the PDN impedance can help identify critical points of a PDN over frequency. For instance, when applying this to noise elimination, one can verify the effects of using a low impedance capacitor at a given frequency.

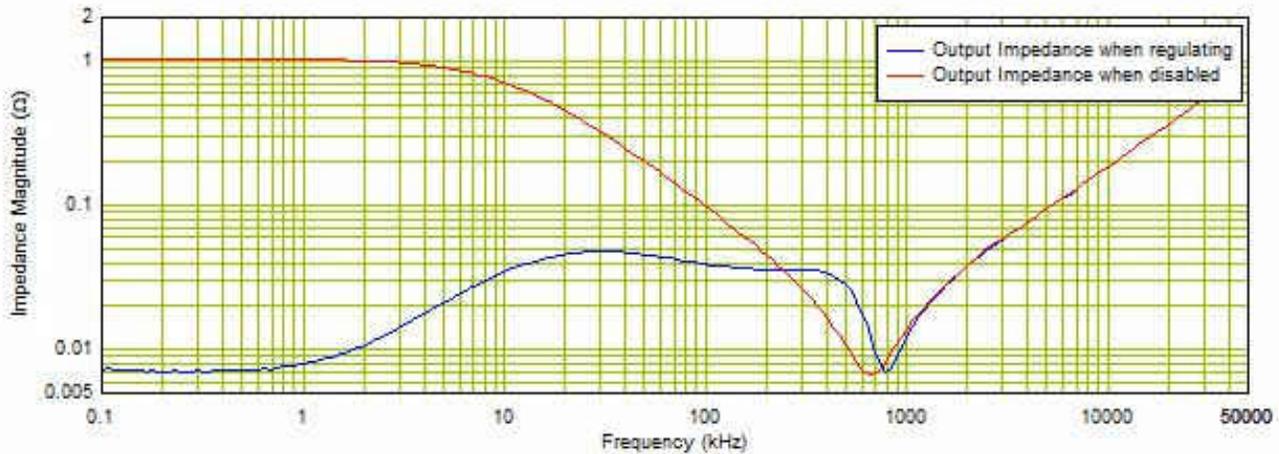


Figure 5-1. Output Impedance Measurements of the TPS62A01 Connected to a Resistive Load

Figure 5-1 shows the output impedance of the TPS62A01 when the converter is regulating (blue curve) and when the converter is disabled (red curve). In the middle section, the measured impedance tracks the impedance of the output capacitor bank, flattening out with its ESR value at 800 kHz. At high frequency, the impedance is dominated by the inductive behavior of the capacitance.

6 Summary

A 2-Port Shunt-Through measurement allows reliable measurement down to milliohm impedances while supporting measurement at very high frequencies. At high-current operation, PDN designers need to achieve very low impedance over frequency to meet load transient requirements. Therefore, a common challenge is to be able to measure very low impedance across all frequencies with an easy-to-use setup.

Further analysis can be conducted using a PDN impedance measurement. The useful data taken permits a DC-DC converter robustness assessment and stability check.

7 References

1. [The 2-Port Shunt-Through Measurement and the Inherent Ground Loop](#)
2. [Extending the Usable Range of the 2-Port Shunt Through Impedance Measurement](#)
3. [J2113A Semi-Floating Differential Amplifier – Ground Loop Breaker](#)
4. [3.5mm / SMA Vector Network Analyzer Components](#)
5. [Make Simple Fixtures from SMA Connectors](#)
6. [Homemade SMA Female Calibration Kit Measurements](#)
7. [Calibrating the E5071C Network Analyzers](#)
8. [2-Port Shunt-Through Impedance](#)

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