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CHARACTERIZING CONDUCTED EMI SOURCES WITH A 1/50/500-OHM MEASUREMENT

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EXECUTIVE SUMMARY

A new test procedure for characterizing conducted EMI sources using a 1/50/500-ohm measurement is investigated in this report. Applying Thevenin's theorem, the unknown source is characterized by its open circuit voltage and complex source impedance. The procedure outlined in this report, uses three voltage measurements to determine the following three unknown quantities: open circuit voltage, source resistance and the magnitude of the source impedance.

Preliminary results validate the procedure, but also indicate that results can be highly susceptible to measurement errors. Possible solutions are to make more than three measurements or make a measurement with a controlled reactive load. Work on this project is continuing.

I. THEVENIN EQUIVALENT SOURCE MODEL

Several test procedures have been proposed to measure the conducted noise coupling from integrated circuits as describe in the IEC 61967 standards. However, each of these measurements loads the outputs of the device-under-test with an impedance that may or may not represent the load impedance that the device will see in a real application. As fully characterizing an unknown source isn't possible by just a single voltage or current measurement, more information is required if we want to know how much conducted noise will be generated in different situations [1]. According to Thevenin's theorem, a circuit source can be fully characterized by two measurements; an open-circuit voltage measurement and a short-circuit current measurement. A Thevenin equivalent source model can be built using these impedance measurements. In general, two methods can be used to determine the Thevenin impedance as illustrated in Figure 1. One is to measure the source voltage under different load conditions. Another is to turn the source off and measure the impedance looking into the source terminals with a network/impedance analyzer.

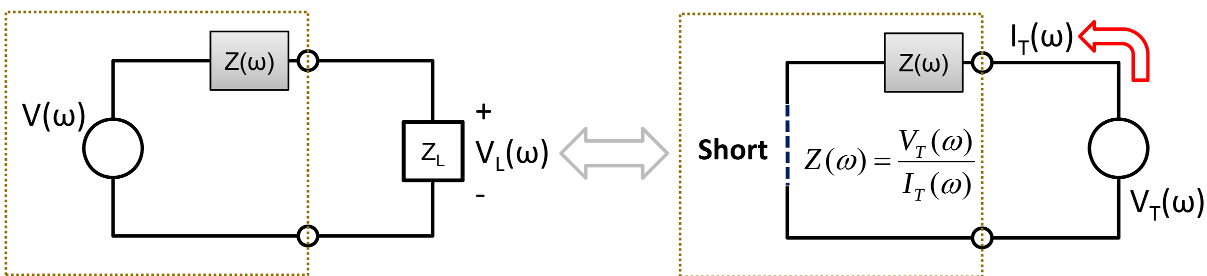


Fig. 1. Two approaches to get the Thevenin impedance.

As shown on the left in Figure 1, the first method is generally easier to implement and characterizes the source under normal operating conditions. The second method, illustrated on the right in Figure 1, permits a swept-frequency characterization of the Thevenin impedance, which facilitates a more accurate characterization of this impedance with lumped circuit elements.

II. 1/50/500-OHM MEASUREMENT

A. Measured voltage variation by load value

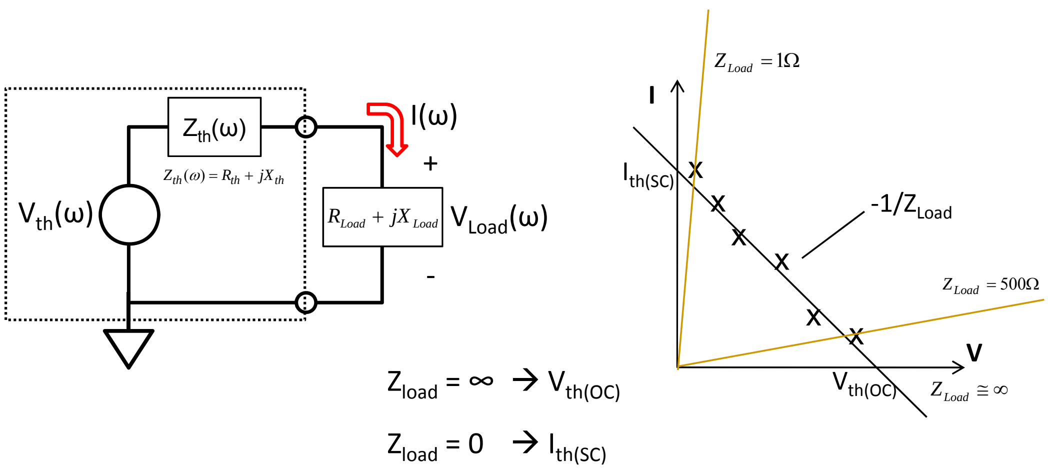


Fig. 2. Thevenin equivalent circuit and the V-I curve of circuits with 1Ω and 500 Ω loads.

At higher frequencies, it can be difficult to measure the Thevenin open-circuit voltage, V_{oc}, and short-circuit current, I_{sc}, directly. However, we can estimate V_{oc} and I_{sc} with adequately high and low valued load impedances as indicated on the right in Figure 2. If the reactance of the load could be controlled at high frequencies, we could use three values of load impedances to solve for the three unknown factors: Thevenin resistance, R_{th}, Thevenin reactance, X_{th}, and Thevenin voltage, V_{th}, in the Thevenin equivalent source model as illustrated on the left in Figure 2. In practice, attaching a reactive load in series with a reactive source impedance and accurately measuring the voltage across the reactive load is very difficult. Since we are usually not interested in the sign of the source reactance, measurement of the magnitude of the voltage induced across three real-valued load resistances is sufficient. For our measurements, the load resistances were chosen to be 1, 50 and 500Ω. Fixtures were built to terminate the source with the appropriate resistance and connect to a 50-ohm oscilloscope or spectrum analyzer as shown in Figure 3.

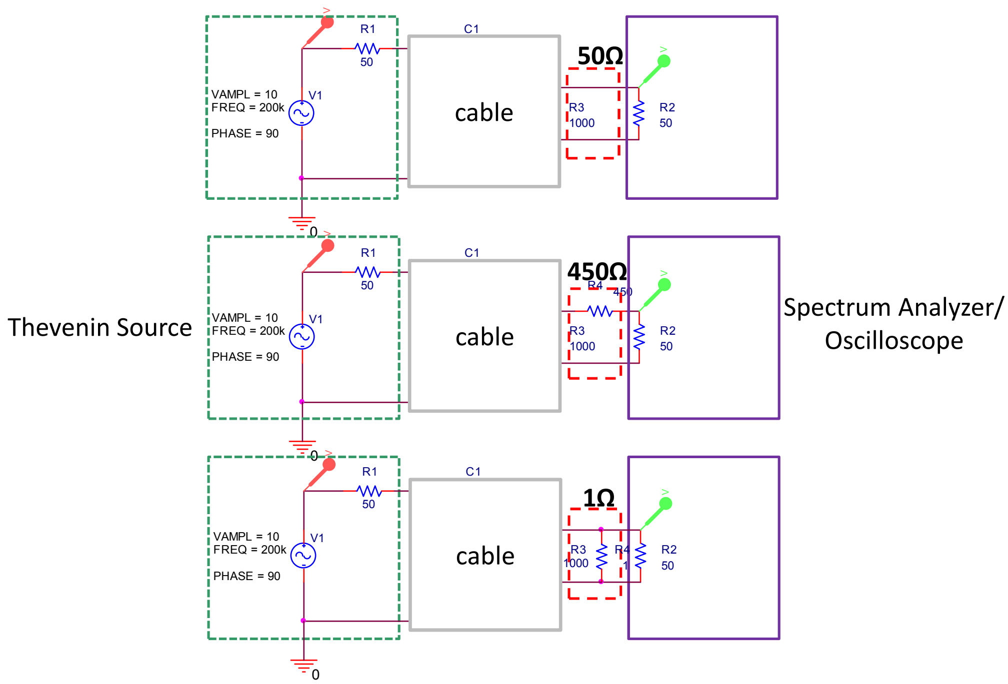


Fig. 3. Three load conditions for characterizing conducted EMI sources.

B. Estimation of Thevenin equivalent circuit

Equations (1) – (3) express the expected value of the measured voltage for the three load conditions as a function of the source parameters, V_{th} and Z_{th};

$$\left|V_{50\Omega\_Measurement}\right| = \left|V_{th}\right| \left|\frac{Z_{50\Omega}}{Z_{50\Omega} + Z_{th}}\right| \tag{1}$$

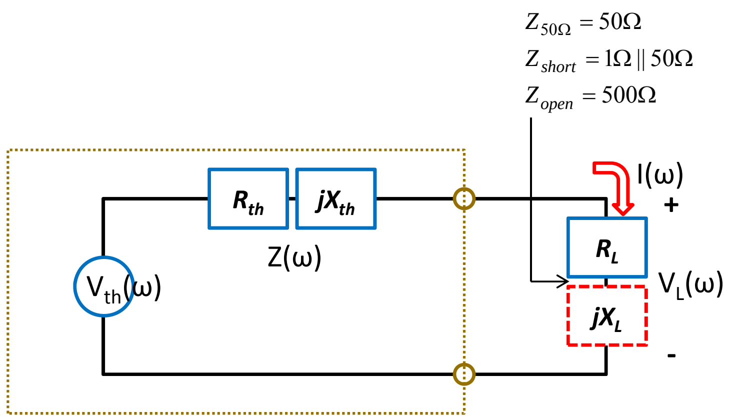
$$\left|V_{short\_Measurement}\right| = \left|V_{th}\right| \left|\frac{Z_{short}}{Z_{short} + Z_{th}}\right| \tag{2}$$

$$\left|V_{open\_Measurement}\right| = \left|V_{th}\right| \left|\frac{Z_{open}}{Z_{open} + Z_{th}}\right| \tag{3}$$

where,

$$Z_{th} = R_{th} + jX_{th} \tag{4}$$

Figure 4 illustrates the three load conditions and the corresponding calculation for the measured voltages across the load.



$$V_L(\omega) = \left|\frac{R_L}{R_L + Z_{th}(\omega)}\right| \left|V_{th}(\omega)\right|$$
$$\Rightarrow \left|\frac{R_L + jX_L}{(R_L + R_{th}) + j(X_L + X_{th})}\right| \left|V_{th}(\omega)\right|$$
$$= I(\omega)Z_L = I(\omega)(R_L + jX_L)$$

Fig. 4. Voltage equation for Thevenin equivalent circuit.

Equations (1) – (4) can be algebraically manipulated to express the source parameters V_{th}, R_{th} and $|X_{th}|$ as a function of the measured voltages,

$$V_{th} = \sqrt{\frac{\left(\left(R_{1\Omega} \,||\, R_{50\Omega}\right) - R_{50\Omega}\right)}{2\left[[A]-[B]\right]}} \tag{5}$$

$$R_{th} = \left|V_{th}\right|^2 [B] - \frac{\left(R_{450\Omega} + 2R_{50\Omega}\right)}{2} \tag{6}$$

$$\left|X_{th}\right| = \sqrt{\frac{\left|V_{th}\right|^2 \left(R_{50\Omega}\right)^2}{\left|V_{50\Omega\_Measurement}\right|^2} - (R_{50\Omega} + R_{th})^2}\ . \tag{7}$$

C. Test Procedure

Equations (5) to (7) can potentially be used to calculate the Thevenin source parameters for a variety of sources, including switch mode power supplies and integrated circuits using the following basic test procedure.

1. Set up the test configuration with an ICM (Impedance conversion module, 1/50/500 ohm), the product/IC under test, an LISN (Line Impedance Stabilization Network), and a spectrum analyzer as illustrated in Fig. 3.

2. Measure the voltage, $V_N(f)$ with the three different impedance configurations (1Ω, 50Ω, 500Ω) using the spectrum analyzer.

3. The measured voltage is used to estimate the Thevenin source model parameters using (5) to (7).

Figure 5 illustrates how ICs and powered electronic devices can be characterized using the 1/50/500 ohm measurement.

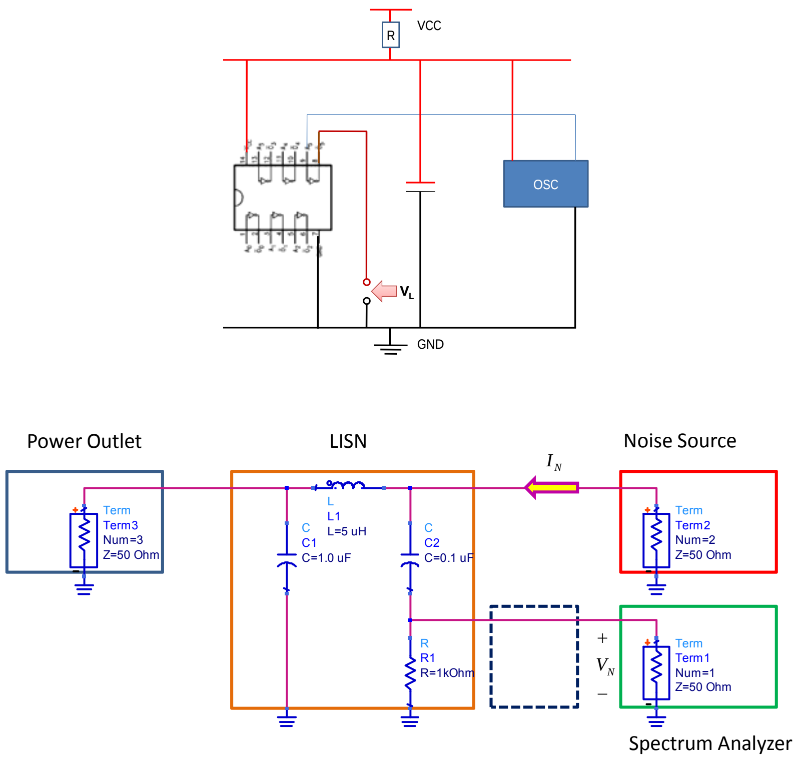


Fig. 5. Measurement examples for Thevenin equivalent source model; IC, SMPS

IV. FUTURE WORK

This project is still in its early stages. Preliminary measurements and simulations indicate that for some sources, measurement errors of a few percent can result in much larger errors in the estimation of the Thevenin impedance. This is particularly true for sources with very low or very high source impedances. Alternate formulations and adjustments to the test procedure are being evaluated. Possible solutions involve making more than three measurements to do a "best fit" calculation, using known physical information about the source to further constrain the calculations, or using a controlled reactive load for one of the measurements. The ultimate goal of this project is to develop a reliable and accurate method for fully characterizing conducted EMI sources and producing source-models that can be used in system-level simulations.

REFERENCES

[1] Todd Hubing, "Building IC Models Based on Measurement and Using these Models Productively," *EMCCompo 2007, 6th International Workshop on Electromagnetic Compatibility of Integrated Circuits*, Torino, Nov. 2007

[2] IEC 61967-1 Integrated circuits - Measurement of electromagnetic emissions, 150 kHz to 1 GHz - Part 1: General conditions and definitions, International Electrotechnical Commission, Geneva, Switzerland, March 2002.

[3] IEC 61967-4 Integrated circuits - Measurement of electromagnetic emissions, 150 kHz to 1 GHz - Part 4: 1Ω/150Ω direct coupling method, International Electrotechnical Commission, Geneva, Switzerland, April 2002.