

## *An Accurate Method For Measuring Capacitor ESL*

*by Steve Sandler, Picotest, Phoenix, Ariz.*

The equivalent series inductance (ESL) of chip capacitors is becoming an increasingly important parameter as bandwidths and switching frequencies rise in many high-performance systems. The stability and high-frequency dynamic performance of these systems is dependent, in part, on capacitor ESL. For their part, manufacturers of ceramic and tantalum capacitors have been working hard to reduce the ESL of their components. However, system designers cannot simply rely on the capacitor vendors' published data for ESL, which is limited at best. It's important that designers be able to make their own ESL measurements.

With ESL values typically in the range of 1 nH to 5 nH, measuring the ESL of chip capacitors is not a trivial task. At present, some designers try to measure ESL by measuring the resonant frequency of the capacitor, and calculating inductance from that reading. Unfortunately, such measurements are often inaccurate because of the parasitic inductance in the test set-ups or lack of probe and adapter calibration. Perhaps it's no wonder that most designers simply don't bother to measure ESL at all.

What's needed is an accurate ESL measurement method such as the one described here using a network analyzer in combination with an impedance adapter to measure the device impedance over frequency. This approach specifically addresses the issue of test-fixture parasitics, accurately measuring both the capacitance and inductance of the device under test.

The procedure presented here for measuring ESL uses OMICRON Lab's Bode 100 network analyzer and B-SMC impedance adapter (Fig. 1.) The Bode 100 is particularly well suited for this measurement because of its very low noise floor. Although this is a difficult measurement and well outside of the published specification range of the B-SMC impedance adapter, we accepted the challenge to measure a 1.2-nH chip inductor. The test results confirm that the adapter is suitable for such low-inductance measurements. After demonstrating the validity of the measurement setup and method, we present ESL measurement results for an actual chip capacitor.

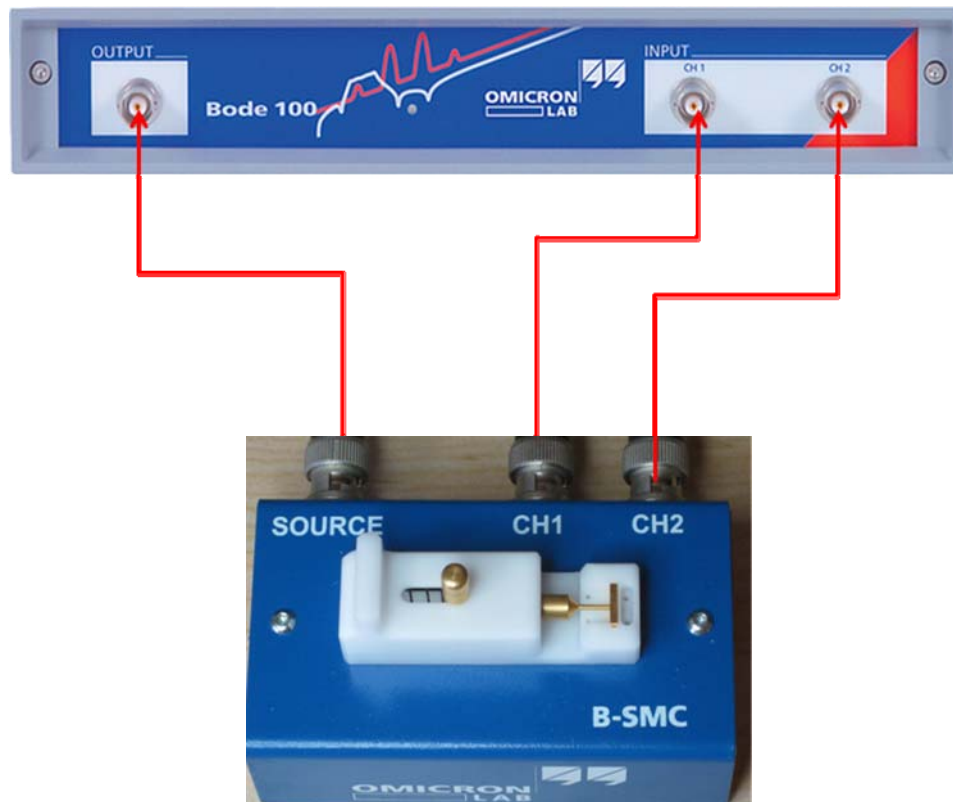


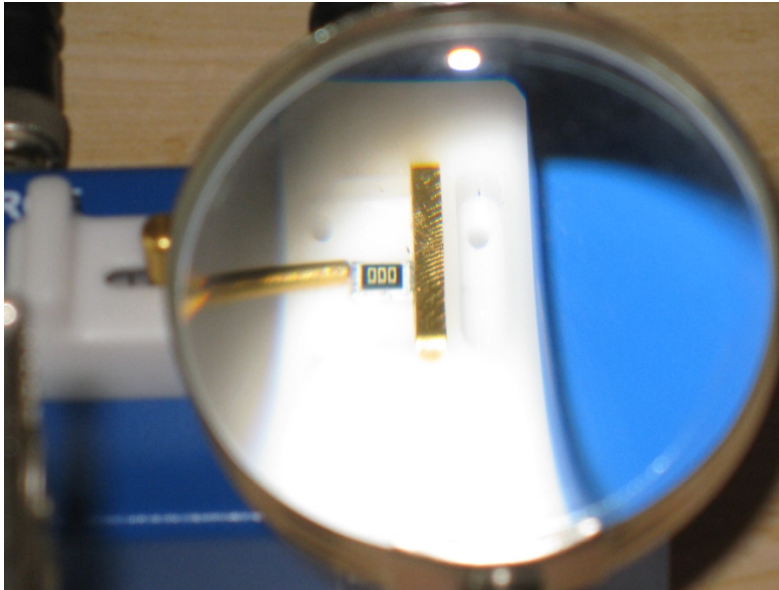
Fig. 1. Connection of the Bode 100 and B-SMC impedance adapter.

### *Calibrating the Measurement*

One of the most critical aspects of the measurement is calibrating out the parasitics from the cables and the adapter.

*Due to the critical nature of the measurement it is essential that the physical size of the open, load, and short devices are the same physical size as the inductor being measured (Fig 2).*

For this example, we purchased 0- $\Omega$  resistors (jumpers), 49.9- $\Omega$  resistors and 20-M $\Omega$  resistors, all in the same package as the inductor we wished to measure. In this case, these devices are all 0805 case size. A standard "Open, Short, Load" calibration technique, in accordance with the Bode-100 Users Manual, should be implemented to ensure measurement accuracy.



*Fig. 2. A 0805-sized "short" device installed in the B-SMC impedance adapter.*

First, we insert the 0- $\Omega$  resistor and perform a "short" calibration. Next, we insert the 20-M $\Omega$  resistor and perform the "open" calibration. Finally, we install a 49.9- $\Omega$  resistor and perform the "load" calibration. **Be sure to enter the 49.9- $\Omega$  value in the "advanced" section of the dialog box** (Fig 3.) We selected a 49.9- $\Omega$  resistor as we had those available in a tight tolerance (0.1%). The most critical calibration is the Short Delay Time, which accounts for the delay time through the "short." This was determined by making adjustments until three different valued precision inductors all measured the proper values.

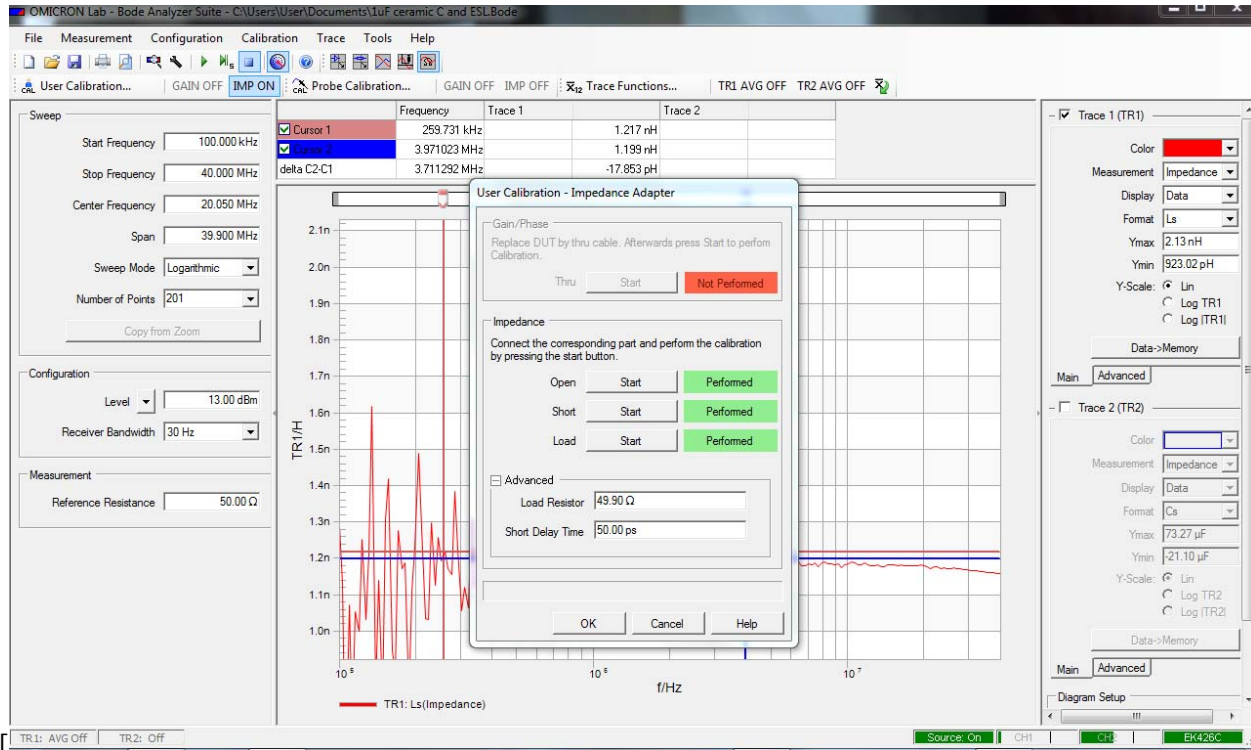


Fig. 3. The graphical user interface for the Bode 100 network analyzer showing the dialog box for calibration of the impedance adapter.

### Making the Measurement

Once the setup has been fully calibrated, we can measure the impedance of the 1.2-nH inductor. Fig. 4 shows the impedance of the device. The DC impedance is approximately -34 dB or approximately 20 mΩ and the inductive region is clearly visible above 2 MHz,

We can determine the inductance as  $L=Z/\omega=Z/(2\pi f)$  or we can measure L directly as in Fig. 5.

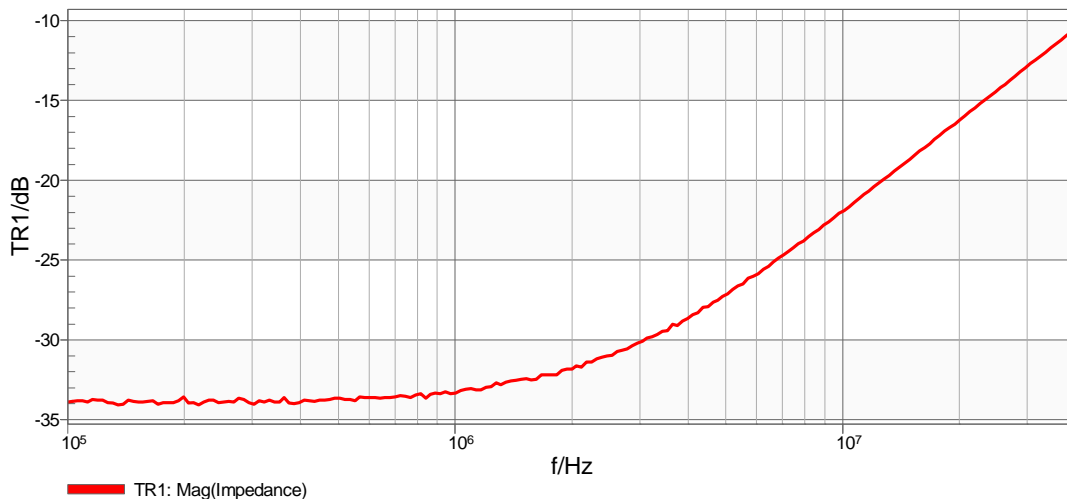


Fig. 4. Impedance of a TDK 1.2-nH chip inductor.

From the series inductance (Ls) display in Fig. 5, we can see that while this is a very sensitive measurement resulting in a noisy low frequency region, we can reasonably measure the 1.2-nH inductance for frequencies

above 1 MHz. This frequency limit is based primarily on the total impedance of the device, which is approximately 21 mΩ at this frequency.

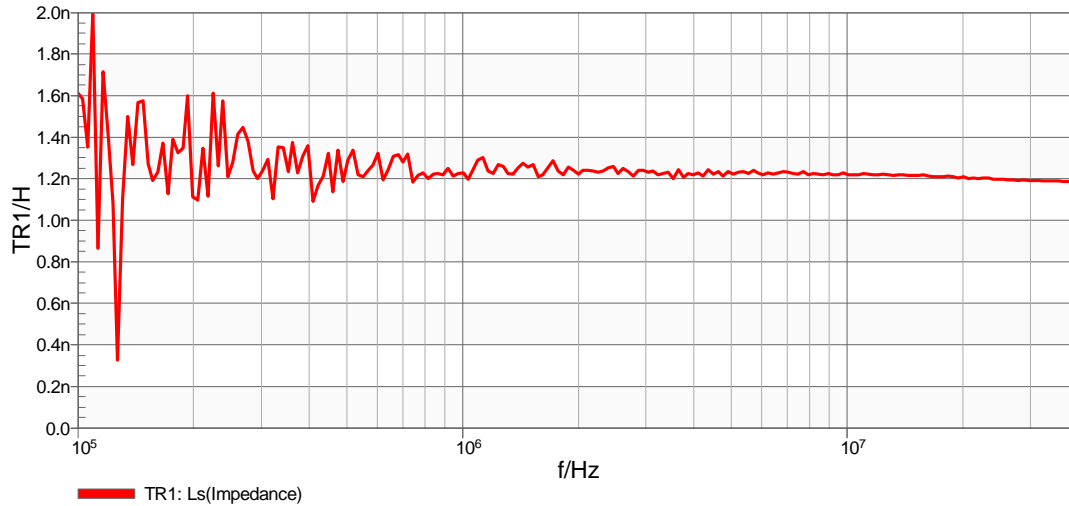


Fig. 5. Measurement of the series inductance of the 1.2-nH 0805 chip inductor.

Fig. 6 shows the measurement of series inductance for a nominal 1-μF ceramic capacitor. The ESL of this 0805 sized device is found to be 730 pH. Note that the resonant frequency of this device is approximately 6 MHz. Fig. 7 confirms that it is possible to measure actual inductances in this range. Here, we are measuring the impedance of two 1.2-nH chip inductors connected in parallel.

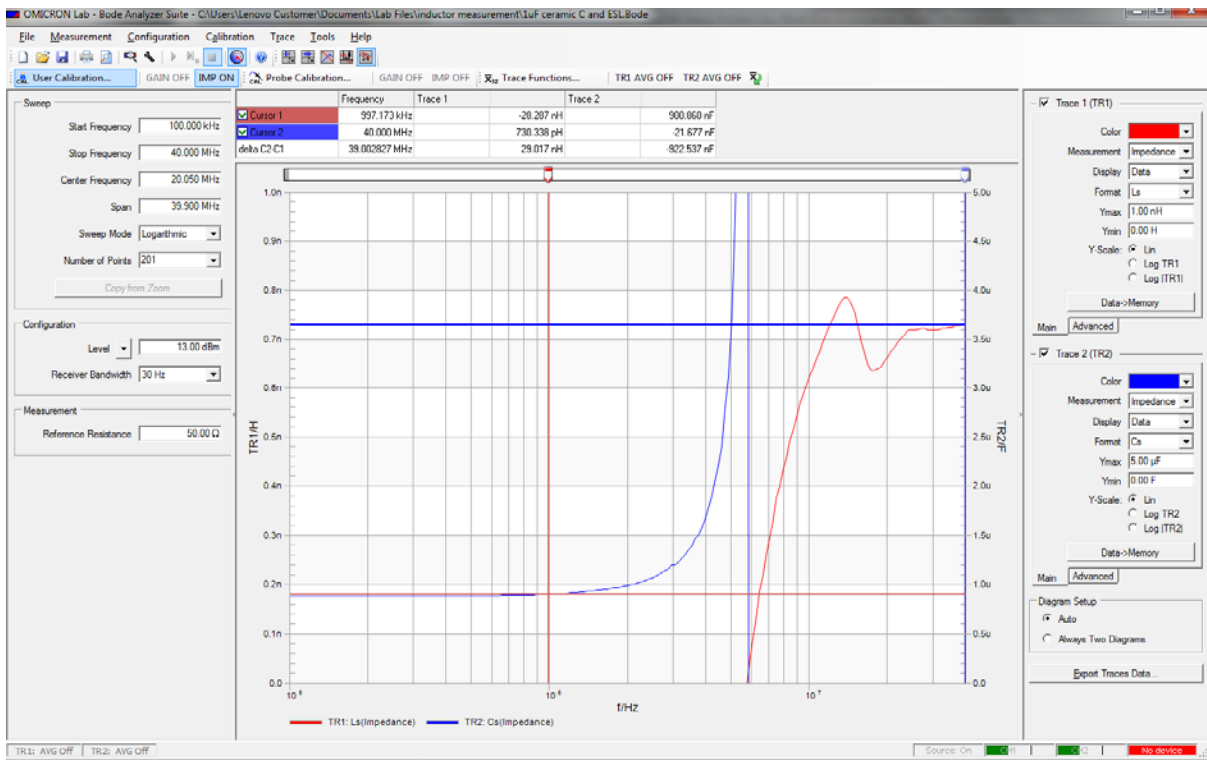


Fig. 6. Measurement of series inductance (red trace) and capacitance (blue trace) of a nominal 1-μF ceramic chip capacitor. The ESL of this device is 730 pH or 0.730 nH above the 6-MHz resonant frequency and the capacitance is 901 nF below the 6-MHz resonant frequency.

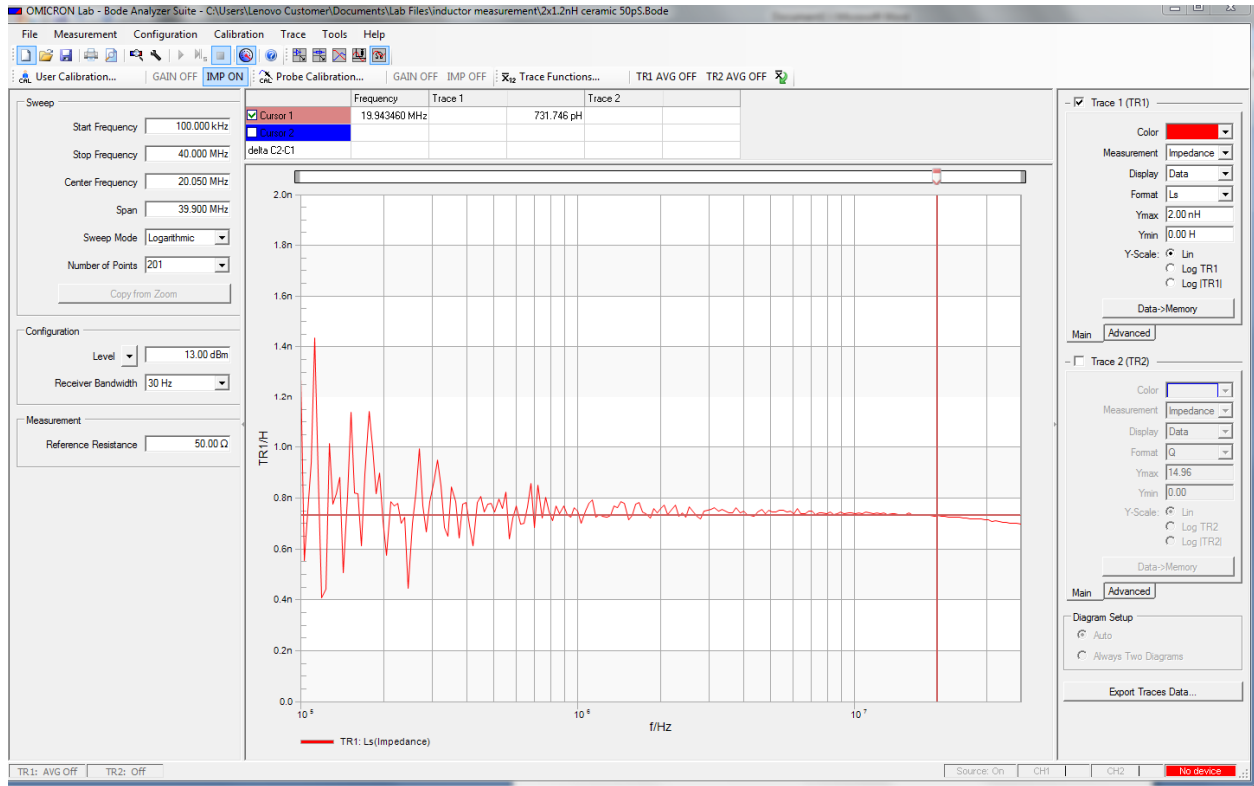


Fig. 7. Measurement of series inductance of two 1.2-nH chip inductors connected in parallel. The measured value is 731.7. Ideally, this value should be closer to 600 pH. However, the device under test consisted of two stacked 0805 chips, which have a different physical structure than the devices used to calibrate the test setup. Theoretically, we could come closer to a 600-pH measurement if we stacked two 0805 “shorts” for the calibration or adjusted the delay time for the two stacked devices.

## Conclusion

The Bode100 Vector Network Analyzer, combined with the B-SMC impedance adapter, allows measurement of very low values of inductance, such as the ESL of high performance ceramic and tantalum capacitors.

## About The Authors



Steve Sandler is the managing director of Picotest, a Phoenix company that specializes in precision test and measurement equipment. Sandler is also the founder and chief engineer of AEI Systems, where he leads development of high-fidelity simulation models for all types of simulators, as well as the design and analysis of both power and RF systems. Sandler has over 30 years of experience in engineering and is a recognized author, educator and entrepreneur in the areas of power, RF and instrumentation.