TECHNICAL PAPER

Inductance Measurements for Multi-Terminal Devices

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Abstract

New innovations in both the telecommunication industry as well as the computer industry have mandated a need for using low inductance capacitive devices in power supply decoupling applications. With this being the case, different concepts for the construction of these devices have recently been the key to the success of reaching inductances of less than 50pH. There is, however, a significant bottleneck to the new innovation process due to measurement techniques. Most of the newer devices are using techniques such as multi-path current flow, short length, and equal and opposite current injection techniques to achieve low inductance levels. Also, coupled with these new designs is the need for higher energy storage capabilities and thus more capacitance. All of these effects are presenting more complex tasks in the measurement process. This paper gives both a generic approach for measurement as well as an exact approach specifically for the Interdigitated (IDC) type devices.

IINDUCTANCE MEASUREMENTS FOR MULTI-TERMINAL DEVICES

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I. Previous Techniques and Their Implications

In the past, the approach was to use impedance analyzers to find the resonance point and low frequency capacitance to calculate the inductance by using Equation 1. This method is very accurate for normal ceramic packages and is extensively detailed in “Parasitic Inductance of Multilayer Ceramic Capacitors” by Dr. Jeff Cain. Significant complications, however, arise in using this approach for multi-terminal devices. Essentially, the ability to recreate the true effects of multiple connections is impossible with the standard fixtures available. Also, the calibration kits are not conducive to accurate measurement of a multitude of circuit configurations. The impedance analyzer has preset electrical lengths that only characterize the parasitics of the generic fixtures made by the manufacturer. Simply put, the need for specialized test fixtures is imperative in recreating the actual working environment seen.

Equation 1: Equation for Resonance

$$\omega = \frac{1}{\sqrt{C \cdot L}}$$

II. Specialized Fixtures

As noted earlier, specialized fixtures must be used so that the parasitics can be extracted properly. Figure 1A and 1B are illustrations of an actual fixture used for multi-terminal measurement particularly for the 6 terminal IDC. The optimal via connections and current distribution paths are shown in this view. In order to obtain the principles of current cancellation, the fixture must be designed such that the current is evenly dispersed in a multi-planar configuration. By doing this, equal and opposite current injection is obtained which ultimately provides inductance cancellation. This method is the optimum method of connectivity that will achieve the lowest inductance values. This particular fixture is used for both the open circuit calibration and part measurement. The actual difficulty arises in constructing a short circuit representation that will provide an accurate phase reference position. The phase reference must be shifted to the actual point of contact of the part.

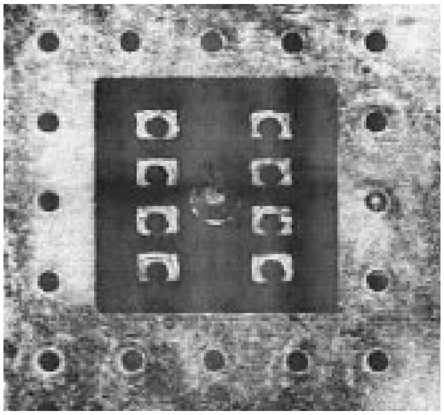

Figure 1A: Component Layer

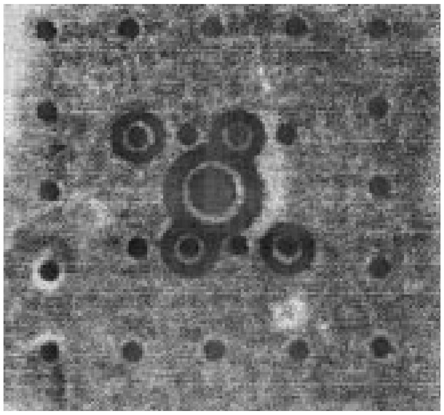

Figure 1B: Signal Injection Layer 1

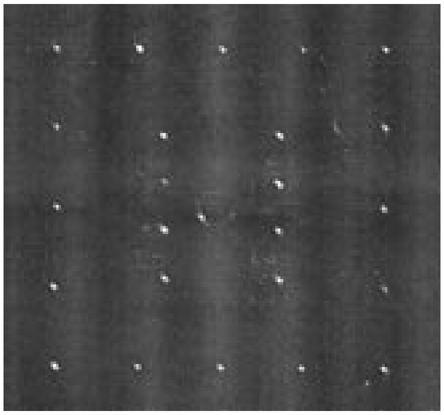

Figure 2: Short Circuit Standard

If the phase reference is not correct both high and low amounts of inductance are given. Figure 2 displays the short circuit calibration standard for this configuration. As can be seen, the phase reference position will be shifted to the exact point where the part will be placed thus providing the correct measurement of inductance. Special care must be taken, however, in insuring that all of the fixtures have very little loss. Therefore, high conductivity metals as well as low loss dielectrics must be used in the fixture's construction.

III. Calibration

Once again, the measurement is directly dependent on both calibration techniques as well as fixture construction. If optimal parameters are used for the construction of the fixture then we can proceed to the concept of calibration. The HP 4291 impedance analyzer with its combination of bandwidth and resolution capability is the instrument of choice for this particular measurement. After an appropriate construction of the test vehicle is obtained, electrical lengths for calibration must be established. The process should be as follows:

1. Calibrate to the port test head (low impedance in most cases) with the systems standards and using the factory presets. Use the short, open, load, and low-loss capacitor for the standards. Make sure that the fixture selection function is set to none before doing so.
2. Connect the appropriate adapter to the APC-7, which, in this case, is an APC-7 to SMA straight plug.
3. Connect the short circuit fixture to the end and set the machine to measure the reflection coefficient on the Smith Chart.
4. Use the port extension function in the calibrate menu to determine the electrical length of the short circuit.
5. Turn off the port extension and select the user fixture under the fixture menu.
6. Enter in the exact electrical length that was determined for the short standard as the electrical length for the fixture.
7. Proceed to the calibrate menu and look at the compensation kit. Make sure that the kit is zeroed out. Correct design of the fixture provides very little conductance, capacitance, and loss.
8. Use the fixture compensation menu to perform both the open circuit and short circuit calibration.

After this process is performed, the correct phase reference and impedance values are given by the analyzer. A load compensation is not used because the load inductance will be calibrated out and will shift the reference plane to an inappropriate point.

IV. Data Interpretation and Inductance Calculation

As noted earlier, the low frequency capacitance value and the resonant frequency can be used to determine the inductance for low dielectric constant materials. This, however, is not the case for newer materials because the dielectric has some properties that can not be characterized with this simple formula. Also, the impedance bridge has internal software that makes calculations based on the half power points and resonance to determine the inductance values. Caution must be taken when using these values as well. The calculations are based on a fit to the series RLC model, which may not explain the phenomenon correctly because the equations are based on exact resonance. The newer materials often have higher dielectric constants which ultimately make the material much more dependent on the frequency of the AC field that is applied. The actual permitivity will decrease with frequency, which ultimately lowers the capacitance and shifts the actual resonant frequency to a higher value. With these particular materials, the inductance must be drawn from the impedance value at very high frequencies. The inductance values must be calculated when the voltage leads the current by 90 degrees. At this point the reactance is primarily inductive which enables the correct amount of inductance to be extracted. Given in the table below are the values of various inductance for both the measurements and simulations.

Device Type	**Simulated Inductance**	**Measured Inductance**
1206 NP0 IDC	174pH	172pH
1206 Low K X7R IDC	174pH	178pH
1206 High K X7R IDC	174pH	178pH
1206 High K X7R Nickel IDC	174pH	178pH

Table 1

V. Conclusion

It is quite clear that the procedure for correct measurement of these new multi-terminal low inductance devices can prove to be quite arduous. It is imperative that the process of designing the calibration standards as well as the measurement fixture must be very well controlled in order to obtain the correct numbers. Also, the functions and limitations of the impedance analyzer must be properly understood before choosing the right type of fixture and what numbers are within range. Table 1 gives the measured values as well as the simulated values for the six terminal IDC. The simulation was performed on a quasi-static Method of Moments EM simulator for verification of the design concept. As can be seen, both measurement and simulation corroborate the method presented above.

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