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A Novel Inductance Evaluation Method for Clip-Type Inductors and Meander Inductors Under the Impedance Matched Condition

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1. Introduction

Increasing demands of developments for high performance inductors used in the analog/microwave integrated circuits require appropriate evaluation methods for inductor characterizations. Inductors are usually evaluated under a short-circuited load condition, since the condition provides the largest inductor current, causing the largest magnetic fluxes due to the Ampere's law. However, this load condition is not practical, since these inductors are often used as impedance matching elements, where the complex conjugate impedance matching condition is retained. Since Q factor values and inductance values are strong functions of the load conditions, a development of appropriate evaluation methods for the inductors has been required. Thus, Q factor evaluation method under the impedance matched condition has been proposed by the present authors [1].

This paper is focusing on a novel evaluation method for inductance values for inductors. By using newly derived formulas, inductance values for a fabricated CSP (Chip Scale Packaging) clip inductor and a fabricated meander inductor are evaluated. The method represents an inherent nature of inductor devices under test including circuit parasitic elements.

2. Definition and Evaluation Formulas for Inductors

Inductance is defined as the stored reactive energy divided by the angular frequency, where the stored reactive energy means the stored magnetic energy minus the stored electric energy. According to the definition, the inductance values can be evaluated for various kinds of load conditions. Conventionally, the short-circuited load condition is used, where the inductance is represented as follows.

$$L_{conv} = \frac{\mathrm{Im}\{1/Y_{11}\}}{2\pi f} \tag{1}$$

Meanwhile, form the two-ports S parameters of the inductor under test, the complex conjugated impedance matching load and source condition, as described in Fig.1, is mathematically obtained [1]. Under the condition, the stored reactive energy can be calculated. Thus, the inductance is represented as:

$$L_{nov} = Z_0 \left(\frac{2\,\mathrm{Im}(S_{11})\left|1 - S_{22}\Gamma_L\right|^2 + 2\,\mathrm{Im}(S_{22})\left|S_{21}\Gamma_L\right|^2}{2\pi f\left(\left|1 - S_{22}\Gamma_L\right|^2\left|1 - \Gamma_{in}\right|^2\right)} + \frac{4\,\mathrm{Im}(S_{21})\mathrm{Re}\left(S_{21}^*\Gamma_L^* - S_{22}\Gamma_L S_{21}^*\Gamma_L^*\right)}{2\pi f\left(\left|1 - S_{22}\Gamma_L\right|^2\left|1 - \Gamma_{in}\right|^2\right)} \right) \tag{2}$$

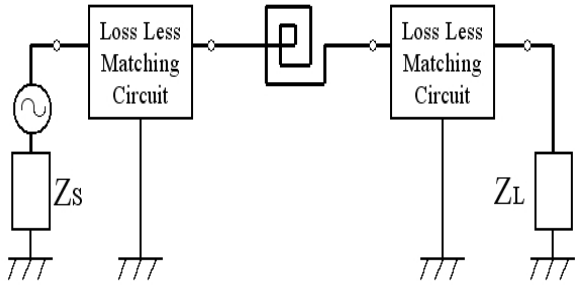
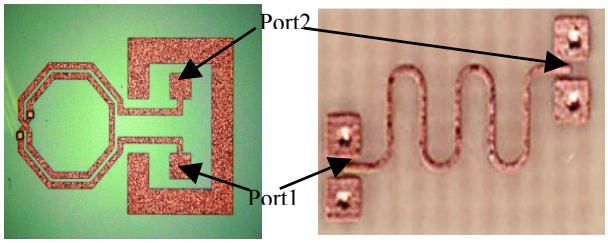


Fig.1 Inductance evaluation under impedance matched conditions.



(A) (B)

Fig.2 Clip-type inductor fabricated using CSP technology(A) and meander inductor fabricated on PCB (B).

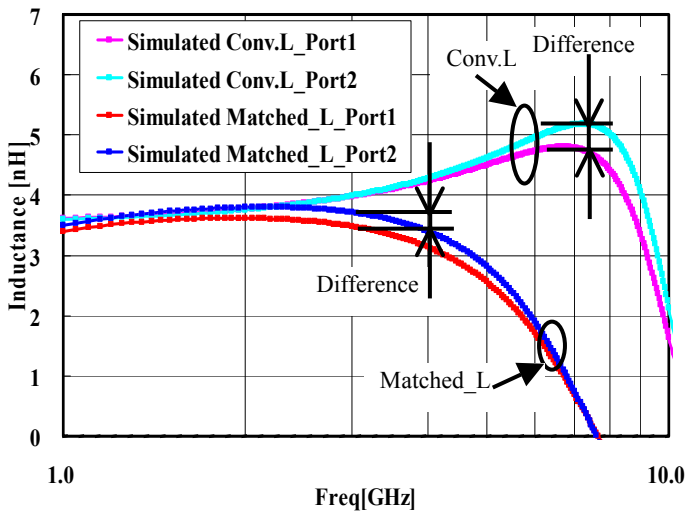


Fig.3 Simulated inductance values for clip-type inductor. Number of turns are 2, Line width / space =30/20 um.

$$\Gamma_{in} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L} \quad (3)$$

Where, Γ_L is the reflection coefficient looking toward the load.

3. Evaluated Inductance Values

Fig.2 shows photographs for the fabricated CSP clip-type inductor [2] and the fabricated meander inductor.

Fig. 3 and Fig. 4 show simulated and measured inductance values for the clip-type inductor with 2 turns evaluated both from the conventional evaluation method and from the proposed impedance matched evaluation method from 1 GHz to 10 GHz range. The moment method solver for the electro-magnetic fields was used for the simulations. On wafer measurements were performed. At the low frequency regions below 2GHz, these two methods provide almost the same inductance values. However, the peaky inductance values due to the resonance are seen in the conventional evaluation method at the high frequency regions. Meanwhile, smooth and natural characteristics are observed in the proposed method for the whole frequency range. Differences in the inductance values between the port 1 side evaluation and the port 2 side evaluation are relatively small in the proposed method.

Fig. 5 and Fig. 6 shows simulated and measured inductance values for the meander inductor evaluated from the conventional evaluation method and the proposed the matched evaluation method from 1 GHz to 5 GHz. The most interesting feature for the meander inductor, where the current flow direction at the adjacent segment is always opposite (canceling magnetic fields), is retaining negative inductance values even at low frequency ranges. This result comes from high impedance levels at the complex conjugate matched condition for the meander inductors, where the signal voltage is large and the signal current is low at the terminals. This condition enhances the stored reactive energy due to parasitic capacitors and decreases the stored reactive energy caused by the intrinsic inductor. Scattering for measured data in Fig.6 is due to the S parameter determinant calculations for the fabricated meander inductors with low insertion loss.

4. Conclusion

The impedance matched evaluation method for inductance values has been proposed and demonstrated. By using newly derived formulas, inductance values for the fabricated CSP clip-type inductor and the fabricated meander inductor are evaluated. The method represents the inherent nature of inductor devices under test including circuit parasitic elements.

References

[1] Y. Aoki，K. Honjo, "*Q*-Factor Definition and Evaluation for Spiral Inductors Fabricated Using Wafer-Level CSP Technology," *IEEE Trans. Microw. Theory Tech.*, vol.53, no.10, pp. 3178-3184, Oct. 2005.

[2] Y. Aoki，S.Shimizu，K. Honjo，"Novel Symmetric High Q Indctors Fabricated Using Wafer-Level CSP Technology," EUMW, December 2007.

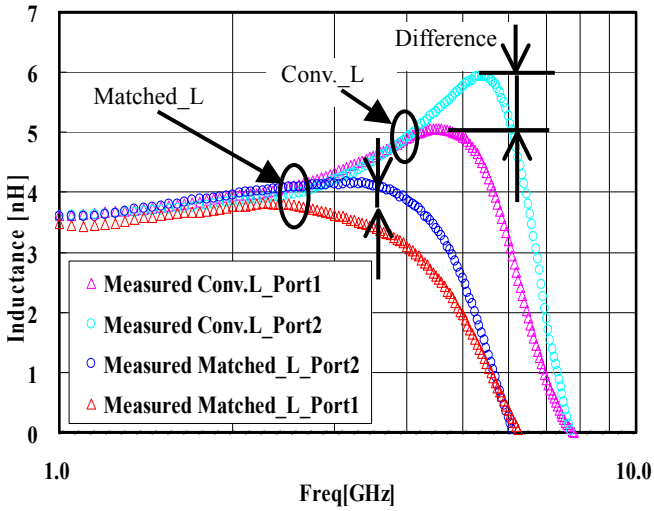


Fig.4 Measured inductance values for clip-type inductor. Number of turns are 2, Line width / space =30/20 um.

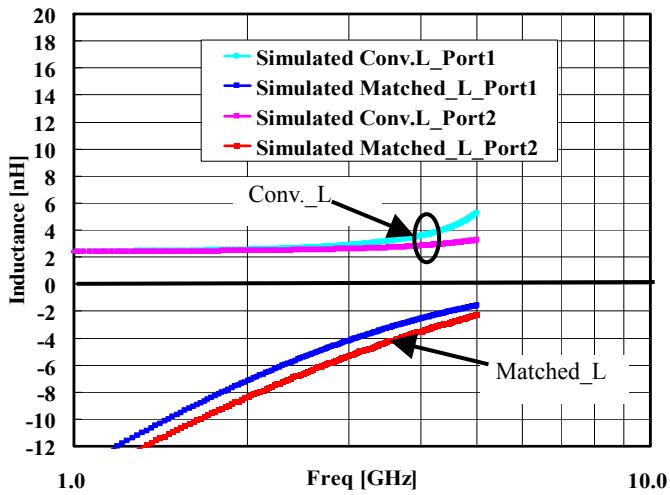


Fig.5 Simulated inductance values for meander inductor. Line width =100um

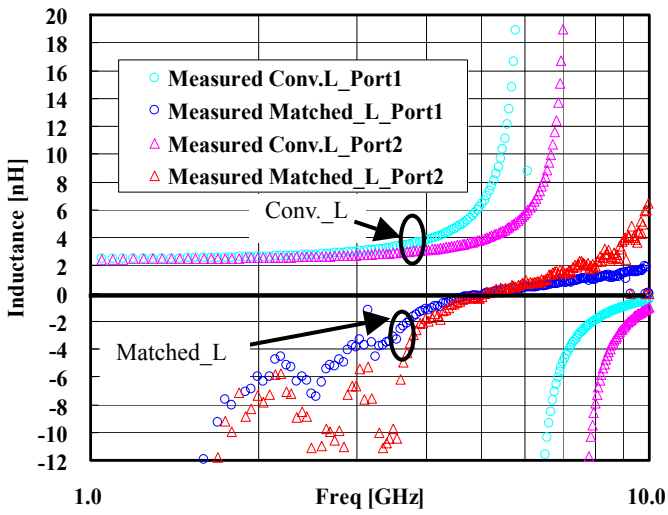


Fig.6 Measured inductance values for meander inductor. Line width =100 um.