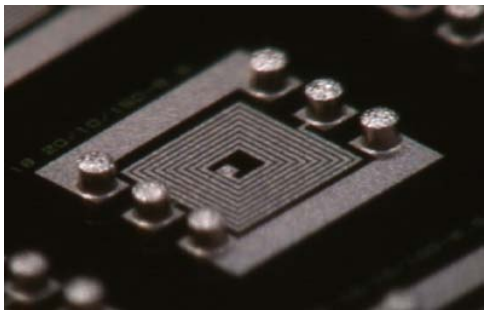
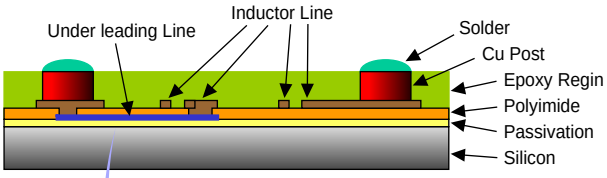
# Q-Factor Definition and Evaluation for Spiral Inductors Fabricated Using Wafer Level CSP Technology

***Abstract*** **-** A novel *Q*-factor definition and evaluation method are proposed for low-loss high-*Q* spiral inductors fabricated by using the wafer level chip size package (WLP) on silicon substrates, where the copper wiring technology with a polyimide isolation layer is used. A complex conjugate impedance matching condition is retained both at an input port and an output port of the inductor. The maximum available power gain ($G_{AMAX}$) is introduced to evaluate the energy loss in one cycle. This condition provides a unique insertion loss of passive devices.

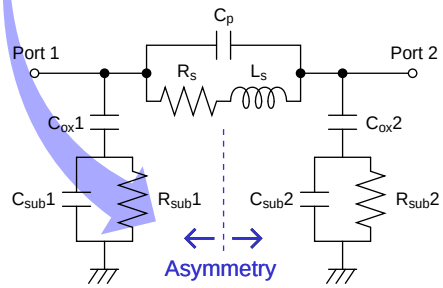
## High-Q spiral inductor fabricated by using wafer level CSP technology



High-Q spiral inductor fabricated on a Si substrate




Cross sectional view

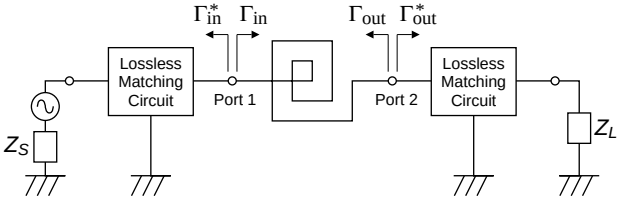



Equivalent circuit

## Novel Q-factor definition and evaluation for a spiral inductor

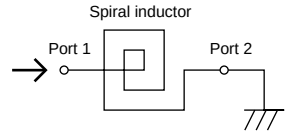
$$Q_{ind} = 2\pi \frac{\text{Peak magnetic energy} - \text{Peak electric energy}}{\text{Energy loss in one cycle}}$$

$$= \frac{2\pi}{T} \frac{2(\text{Time average magnetic energy} - \text{Time average electric energy})}{\text{Input energy} \times (1 - G_{AMAX})}$$

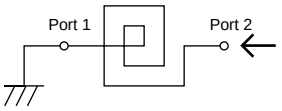



### Conventinal definitions

$$Q_{Port1} = -\frac{\mathrm{Im}\{Y_{11}\}}{\mathrm{Re}\{Y_{11}\}}$$




$$Q_{Port2} = -\frac{\mathrm{Im}\{Y_{22}\}}{\mathrm{Re}\{Y_{22}\}}$$



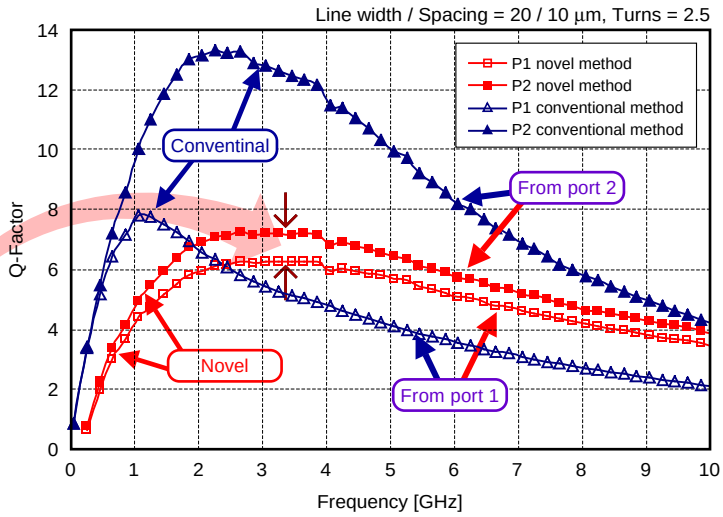

$$Q_{ind} = \frac{[2\,\mathrm{Im}\{S_{11}\}\,|1 - S_{22}\Gamma_L|^2 + 2\,\mathrm{Im}\{S_{22}\}\,|S_{21}\Gamma_L|^2 + 4\,\mathrm{Im}\{S_{21}\}\,\mathrm{Re}\{1 - S_{22}\Gamma_L S_{21}^* \Gamma_L^*\}]}{[1 - |S_{11}|^2 - |S_{21}|^2 + |\Gamma_L|^2 (|S_{22}|^2 - |\Delta|^2 + |S_{21}|^2) - 2\,\mathrm{Re}\{\Gamma_L (S_{22} - \Delta S_{11}^*)\}]}$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$

$$\Gamma_L = \Gamma_{out}^* = \left( S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} \right)^*$$

$$\Gamma_S = \Gamma_{in}^* = \left( S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right)^*$$

The difference is reduced !!




Measured Q-factors derived from novel and conventional methods