MMIC Design and Technology
Passive Elements 2

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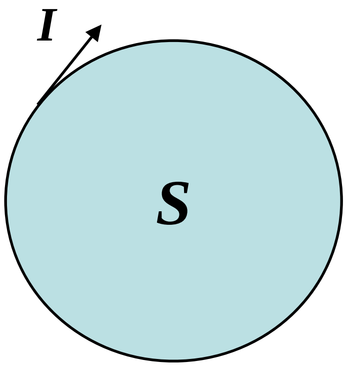
Topics

- Inductance Calculations
- Lumped Element Lines
- Impedance Matching

Inductance

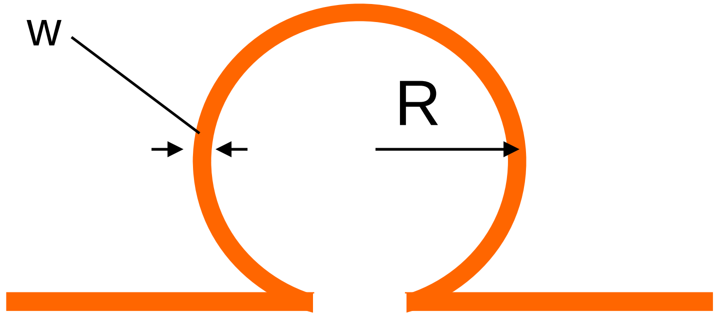
$$L = \frac{1}{I} \iint B \bullet dS$$



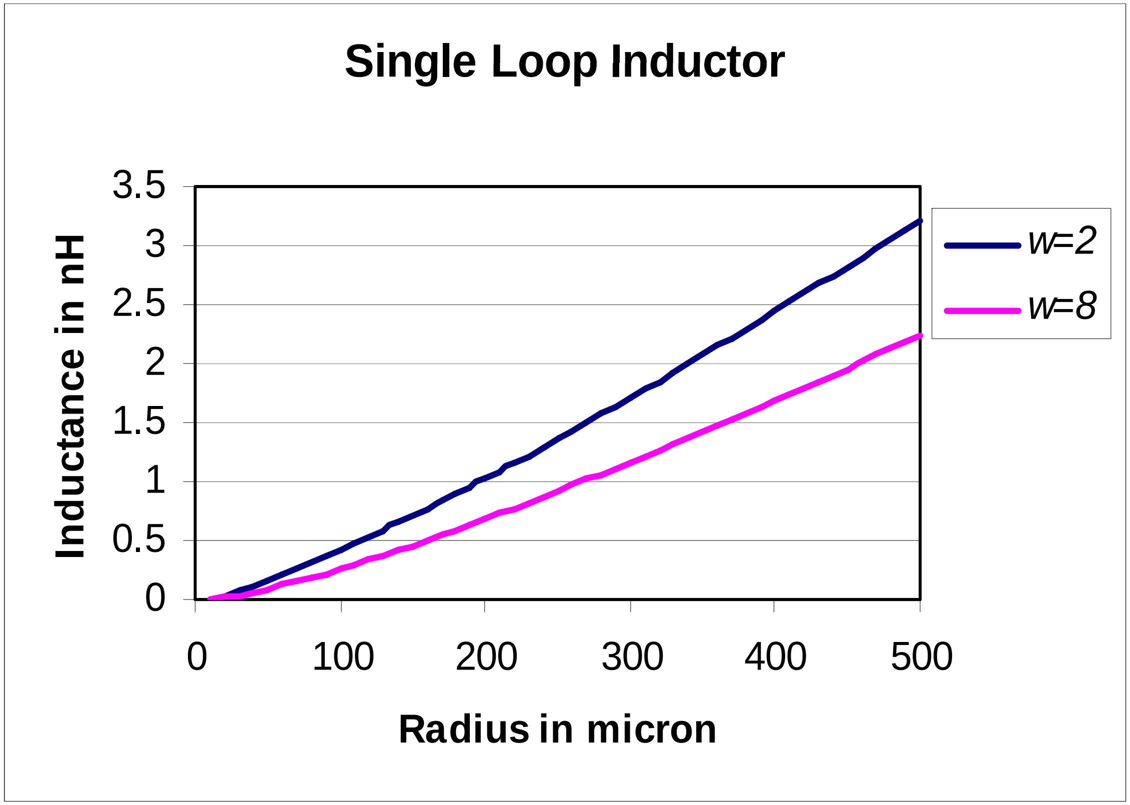
Single Loop

$$L = \mu R\left[\ln\left(\frac{R}{w+t}\right) + 0.078\right]K_g$$

$$K_g = 0.57 - 0.145\ln\left(\frac{w}{h}\right)$$

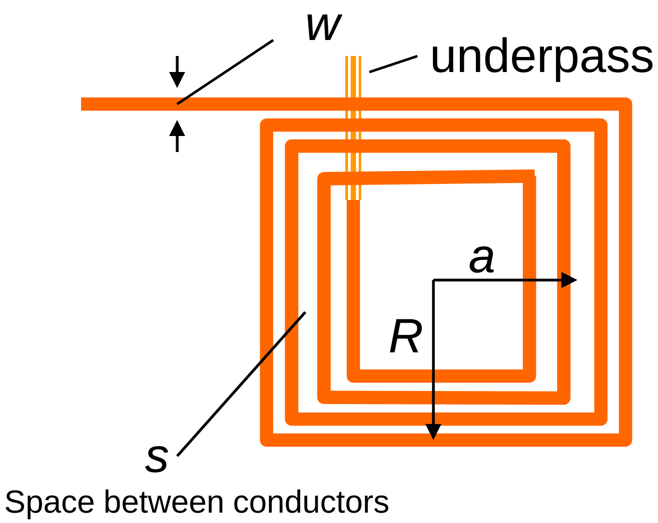


Inductance of Single Loop



h=0.1mm

Spiral Inductor



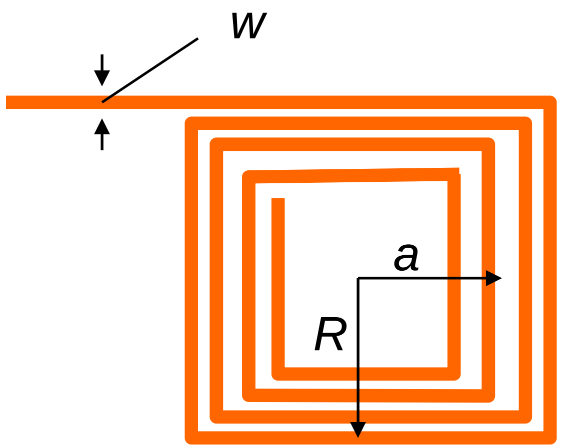
Square Spiral Inductor
Overall radius *R*
Mean radius *a*
Number of turns *N*
Conductor width *w*
Substrate thickness *h*
Conductor thickness *t*

Zero order estimate $$L_{est} = \mu N^2 R$$

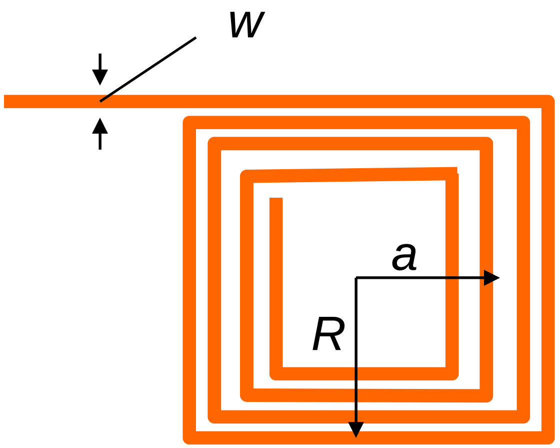
L= 3 nH for N=4 and R=.15mm

Inductance of Spiral

- Positive inductance produced by mutual inductance of windings with current flowing in same direction
  - Minimize spacing to produce large inductance
- Windings with current flowing in opposite directions have negative mutual inductance and reduce total inductance
  - Increase open space in center to reduce negative mutual inductance



Calculation



Detailed calculations of spiral inductors is found at:

H.M. Greenhouse, "Design of Planar Rectangular Microelectronic Inductor," IEEE Transactions on Parts, Hybrids, and Packaging, VPHP-10, no.2, June, 1974, pp 101-9.

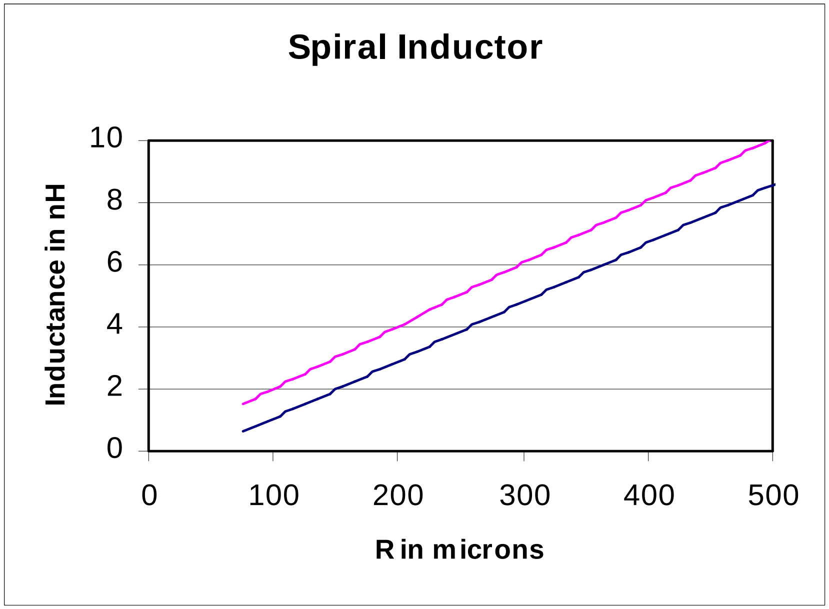
$$L = \frac{37.5\mu N^2 a^2}{22R + 14a}$$

Here is an approximation

Estimate good to about 5%

Inductance of Spiral

$$L = \frac{37.5\mu N^2 a^2}{22R + 14a} K_g$$

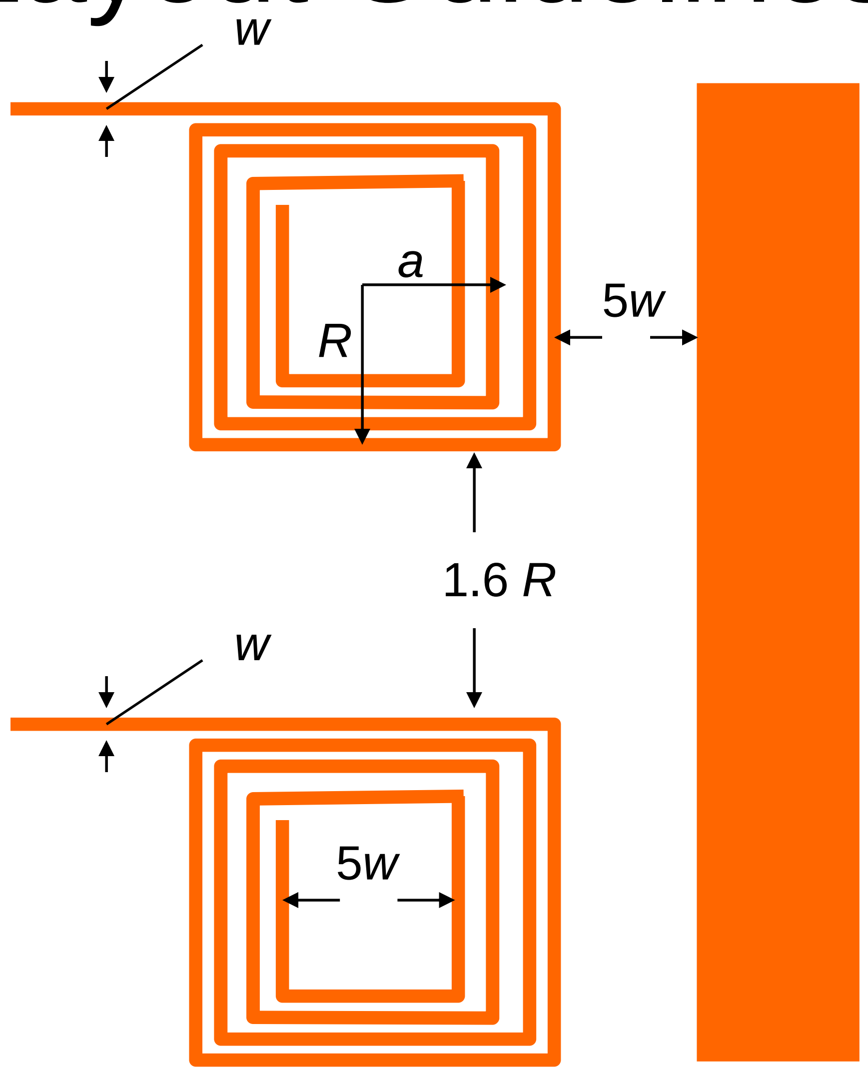


$$K_g = 0.57 - 0.145 \ln\left(\frac{w}{h}\right)$$

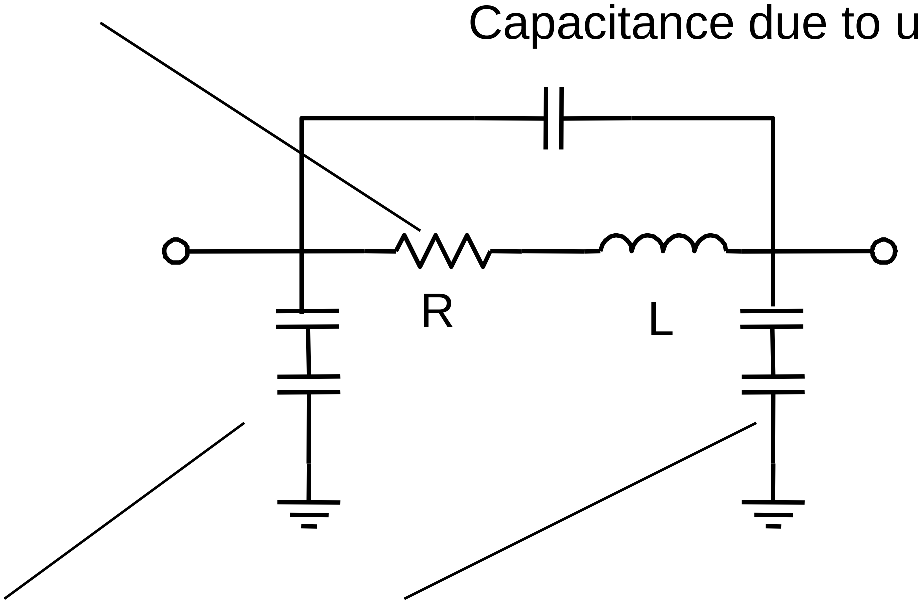
N=4, w=10μm
H=100μm
s=10μm

Account for ground plane

Layout Guidelines



Spiral Inductor Equivalent Circuit



Resistance of conductors

Capacitance due to underpass

Capacitance due to dielectric coating and GaAs Substrate

Best Practices

- Use top layer metal (thickest)
  - lowest resistive losses
- Minimize space between windings *s*
  - *Largest coupling between windings*
- Keep center open
  - Inner turns contribute little to L but still add to R and C

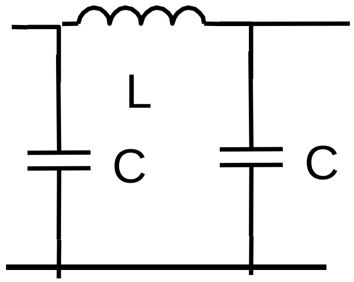
Lumped Element Transmission Lines

Replaces a ¼ wave length line with characteristic impedance Zo

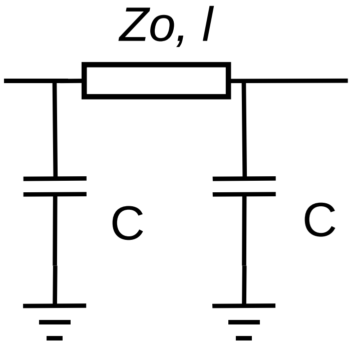
When:

$$L = \frac{Z_0}{2\pi f}$$

$$C = \frac{1}{2\pi f Z_0}$$



Lumped –Distributed Transmission Line



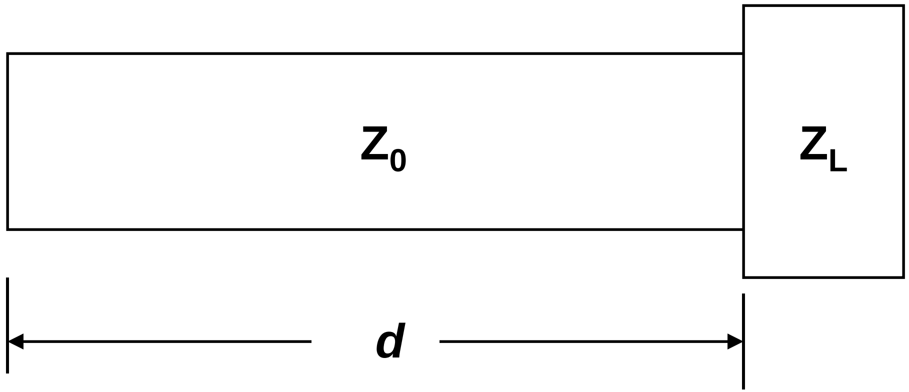
Replaces a ¼ wavelength line of $Z_{\lambda/4}$

With a reduced line length = *l*

And impedance Z_0

$$Z_0 = \frac{Z_{\lambda/4}}{\sin(\frac{2\pi l}{\lambda})} \qquad C = \frac{\cos(\frac{2\pi l}{\lambda})}{2\pi f Z_{\lambda/4}}$$

Impedance Matching



$$\rho_d = \rho_L e^{-j2\beta d}$$

$$\rho_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

For lossless line $\beta = \dfrac{2\pi}{\lambda_g}$

$$Z_{in}(d) = Z_0 \left[\frac{Z_L + jZ_0 \tan(\beta d)}{Z_0 + jZ_L \tan(\beta d)} \right]$$

Special Cases

$$Z_{in}(d) = Z_0 \left[\frac{Z_L + jZ_0 \tan(\beta d)}{Z_0 + jZ_L \tan(\beta d)} \right]$$

$$d = \frac{\lambda_g}{4} \qquad \tan(\beta d) = \tan(\frac{\pi}{2}) = \infty \qquad Z_{in} = \frac{Z_0^2}{Z_L}$$

$$d = \frac{\lambda_g}{2} \qquad \tan(\beta d) = \tan(\pi) = 0 \qquad Z_{in} = Z_L$$

Examples

- Match 50Ω source to 100Ω load
  - Design in micro-strip at 10GHz
    - What is the length
  - Design in lumped line at 10GHz
    - What are the values of L and C
    - What are the physical dimensions of L and C
  - Design in distributed-lumped line at 10GHz
    - What is the reduced line length and impedance
    - What is the value of C
    - What are the physical dimensions