APPLICATION NOTE

Using Coaxial Line Elements as Inductors

Introduction

Coaxial line elements can be used below resonance to simulate high Quality factor (Q), temperature-stable, compact inductors. More precisely, shorted coaxial lines exhibit an inductive reactance when used below quarter-wave resonance, and approximate the behavior of an ideal inductance or coil over a limited frequency range. As the operating frequency approaches the Self-Resonant Frequency (SRF) of the coaxial line element, the approximation is less valid.

An exact equivalent circuit is complex and includes parasitic elements resulting from a transition from the printed wiring board to the interior of the coaxial line. In this Application Note, a first-order model includes only the ceramic coaxial line and an estimate of the inductance due to the physical length of the center conductor tab. The tab inductance appears in series with the coaxial line's input impedance. An ideal, loss-less transmission line is assumed to simplify the calculations. Minor corrections to part length may be evident from prototype circuit performance.

Let the preferred inductive reactance at the design frequency (f_0) be approximated by:

$$Z_{input} = Z_0 \tan(\Theta) \qquad \textbf{(1)}$$

Where:

Z_{input} = Impedance at the coaxial line terminals (Ω).
Z_0 = Coaxial line characteristic impedance (Ω).
$\Theta = \dfrac{2\ell}{\lambda_g}$ Coaxial electrical length (radians).

The characteristic impedance (Z_0) is established by the coaxial dimensions and the material dielectric constant (ε_r), as shown in Table 1. The cross-section width (W) and hole diameter (d) differ from final catalog part sizes by an allowance of 0.001 inches for conductor metallization thickness.

Table 1. Coaxial Lines Properties vs Profile and Material

Profile	1000 (10.5 ± 0.5)	2000 (20.6 ± 1.0)	8800 (39.0 ± 1.5)	9000 (90 ± 3)	Tab Inductors
HP	25.3 Ω	18.1 Ω	13.1 Ω	8.6 Ω	1.8 nH
EP	22.5 Ω	16.1 Ω	11.7 Ω	7.7 Ω	1.0 nH
SP	18.3 Ω	13.1 Ω	9.5 Ω	6.3 Ω	1.0 nH
LS	18.4 Ω	13.1 Ω	9.5 Ω	6.3 Ω	0.9 nH
LP	27.4 Ω	19.6 Ω	14.2 Ω	9.4 Ω	1.0 nH
SP	25.7 Ω	18.4 Ω	13.3 Ω	8.8 Ω	0.6 nH
SM	18.4 Ω	13.1 Ω	9.5 Ω	6.3 Ω	0.6 nH

The Z_0 values in Table 1 were computed from the following approximation from H. Riblet's *An Accurate Approximation of the Impedance of a Circular Cylinder Concentric with an External Square Tube*, IEEE Transactions on Microwave Theory and Techniques, Volume MTT-31, October 1983, pp. 841–844.

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(1.079 \frac{W}{d}\right) \qquad \textbf{(2)}$$

Z_0 = Coaxial line characteristic impedance (Ω).
ℓn = Coaxial line physical length (inches).
ε_r = Material dielectric constant.
W = Cross-section width (inches).
d = Hole diameter (inches).

The wavelength in the dielectric (λ_g) can be calculated from the expression in Table 2, with f_0 as the design frequency in MHz.

Table 2. Wavelength (lg) in Dielectric

Material	ε_r	Wavelength Formula for λ_g (Inches)
1000	10.5 ± 0.5	3642/f_0
2000	20.6 ± 1.0	2601/f_0
8800	39.0 ± 1.5	1890/f_0
9000	90 ± 3	1244/f_0

$$\iota = \frac{\lambda_g}{2\pi} \tan^{-1}\left(\frac{Z_{input}}{Z_0}\right) \qquad \textbf{(3)}$$

ι = Length of part (inches).
λ_g = Wavelength in the dielectric at f_0 (inches).
Z_{input} = Impedance at the coaxial line terminals (Ω).
Z_0 = Coaxial line characteristic impedance (Ω).

Note: *The shorted transmission line model requires the constant of the material filling the coaxial line.*

Inductance-per-unit/length formulas are useful only when the line is very short compared to a wavelength, and are inaccurate as the f_0 approaches the SRF. The equation for input impedance can be rearranged to determine the part length for a preferred inductive reactance.

Phone [301] 695-9400 • Fax [301] 695-7065 • trans.tech@skyworksinc.com • www. trans-techinc.com

The SRF must lie within the recommended frequency range for the same profile and material when used as a coaxial resonator. This restriction places constraints upon the range of inductive reactance that can be realized by this technique, although arbitrarily high reactance values can be achieved close to the SRF. The designer should carefully analyze the circuit response when the f_0 is near the SRF.

The SRF can be calculated from previously-determined values. The center conductor tab presents a small additional series inductance that may be included in the total preferred inductive reactance. Although the tab influence has not been measured, the suggested approximate values are given in Table 1.

The SRF can be calculated from:

$$\mathrm{SRF} = \frac{\lambda_g f_o}{4} \times \frac{1}{\ell} \tag{4}$$

Where:

λ_g = Wavelength in the dielectric at f_0 (inches).
f_0 = Design frequency (MHz).
ℓ = Coaxial physical length (inches).