DATA SHEET

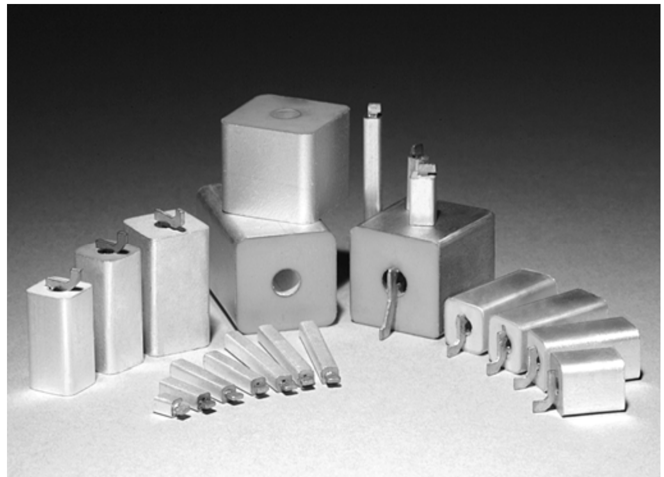
Introduction and Applications for Coaxial Resonators and Inductors (300 MHz to 6.0 GHz)

Applications

- Low phase noise VCOs
- DROs
- Narrow band filters
- Nationwide pagers
- Duplexers
- GPS
- UHF-tuned potential amplifiers
- Wireless communications
- Tuned oscillators

Features

- Frequency tuned to 0.5% and 1.0%
- High dielectric constant
- Rugged construction
- Low-loss silver
- Acts as a parallel resonant circuit or high quality inductor
- 2 mm to 20 mm designs available
- Circuit miniaturization
- Eliminates microphonics
- Repeatability of design
- Negligible aging effects
- Excellent solderability
- Improved circuit Q
- High resonant impedance
- Automation compatible



Introduction

Skyworks, through its wholly-owned subsidiary Trans Tech, offers ceramic coaxial line elements in seven sizes and four dielectric constants that span applications from 300 MHz to 6 GHz. The Very High Frequency (VHF)/Ultra High Frequency (UHF) bands are traditionally “awkward” for realizing discrete inductors and capacitors. Metallized ceramics provide an attractive alternative, as the wireless communication market now forces a continuous trade-off between performance and miniaturization.

Our ceramic solution offers advantages of a high Quality Factor (Q), reduced size, better shielding, and temperature performance that are superior to that which is obtainable from conventional L-C circuits or microstrip construction.

Two types of coaxial resonators are offered: a quarter-wave short (λ/4) and a half-wave open (λ/2). The quarter-wave has a thick-film silver applied to one end. The half-wave has both ends unmetallized.

Our four dielectric materials are shown in Figure 1, along with the recommended frequencies of use. Table 1 provides the material properties chart that can be used to determine the optimum material necessary for an application.

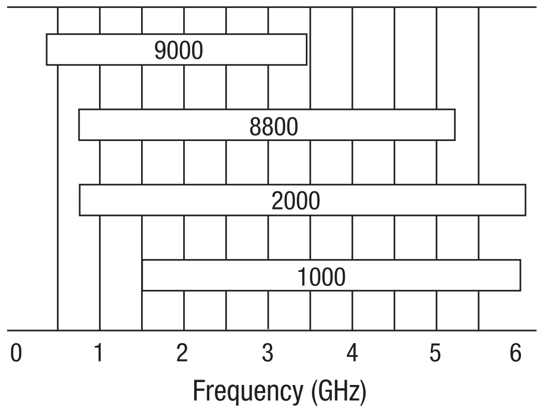


Figure 1. Material Selection Chart

Table 1. Material Properties

Item	Material Type			
	1000	2000	8800	9000
Dielectric constant	10.5 ± 0.5	20.6 ± 1.0	39.0 ± 1.5	90 ± 3
Temperature coefficient of resonant frequency τf (ppm °C)	0 ± 10	0 ± 10	4 ± 2	0 ± 10

The properties given for the ceramic materials used to produce the coaxial line elements are measured for internal quality control purposes. The electrical quality factor (Q) of the coaxial line elements is determined primarily by the metallization. Typical properties of the coaxial line elements are listed in Tables 2 through 5.

Quality Factor (Q) Specifications

1000 and 2000

Figures 2 through 5 show the quality factor charts for various resonator profiles. The resonators are grouped by:

- Wavelength type = λ/4 and λ/2
- Material = 1000 and 2000
- Profile = High Profile (HP), Enhanced Q Profile (EP), Standard Profile (SP), Large diameter (LS) profile, Miniature Profile (MP), and Sub-Miniature (SM) profile

The listed Q value on each curve is the value guaranteed for the lowest operating frequency of each component type. The Q increases approximately as the square root of increasing frequency. Typical Qs are 10% to 15% higher.

1000 Series Q Curves

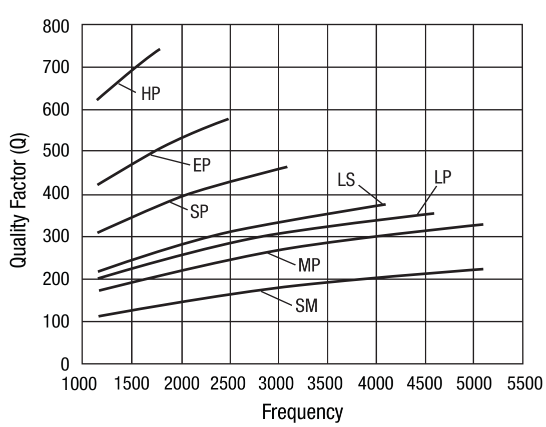


Figure 2. D1000 Quarter-Wave Q Curves

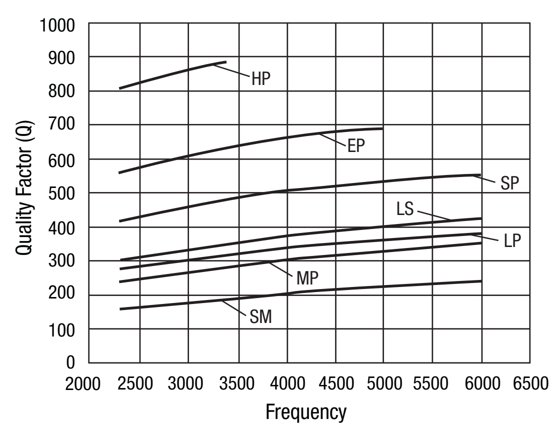


Figure 3. D1000 Half-Wave Q Curves

2000 Series Q Curves

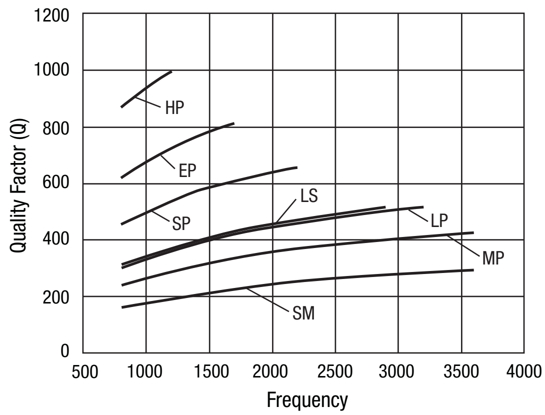


Figure 4. D2000 Quarter-Wave Q Curves

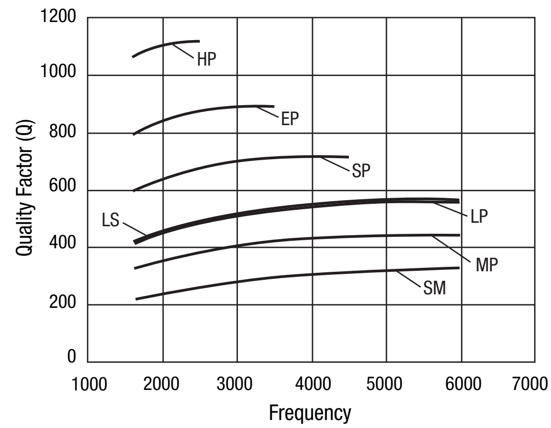


Figure 5. D2000 Half-Wave Q Curves

8800 and 9000

Figures 6 through 9 show the specified quality factor charts of the various offered resonator components. The resonators are grouped by:

- Wavelength type = λ/4 and λ/2
- Material = 8800 and 9000
- Profile = HP, EP, SP, Low Profile (LP), LS, MP, and SM

The listed Q value on each curve is the minimum value for the lowest operating frequency of each component type. The Q increases approximately as the square root of increasing frequency. Typical Qs are 10% to 15% higher.

8800 Series Q Curves

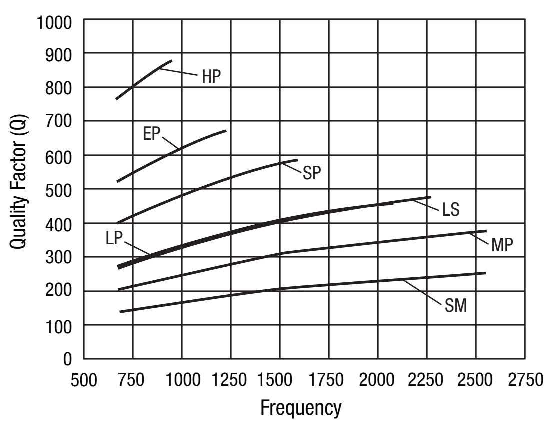


Figure 6. D8800 Quarter-Wave Q Curves

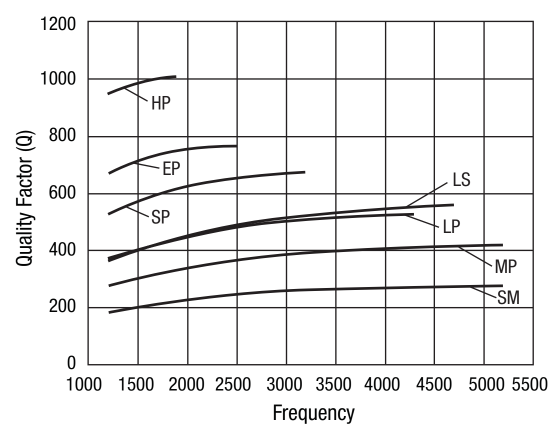


Figure 7. D8800 Half-Wave Q Curves

9000 Series Q Curves

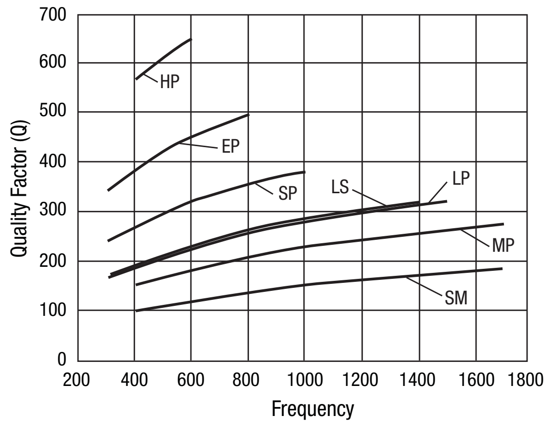


Figure 8. D9000 Quarter-Wave Q Curves

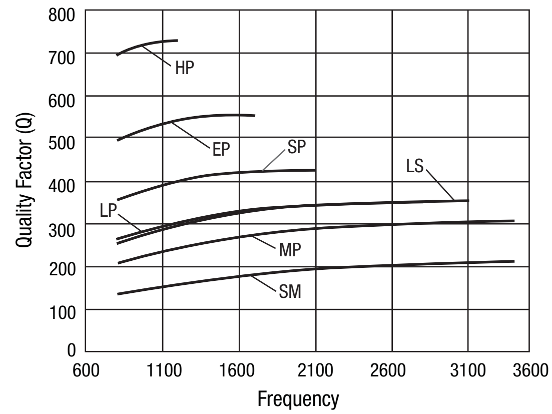


Figure 9. D9000 Half-Wave Q Curves

Dimensions and Configurations

The coaxial resonator components are available in the frequency range of 300 MHz to 6 GHz. Seven mechanical profiles are offered to give the designer the greatest flexibility in selecting the electrical quality factor (Q). There are three large profiles:

- HP = Highest Q and size
- EP = High Q and wide frequency
- SP = A compromise of electrical Q and size (should be considered the component of choice for most applications)

Four smaller profiles are available space is restricted:

- LP
- LS
- MP
- SM

The LP and LS profiles both have the same outer physical dimensions, but differ in the dimension of the inner diameter. This difference allows for different characteristic impedances, and increases the options available to designers. Overall comparisons can be determined from the given Q curves or by using the our COAX program.

These components are available in square configurations with the dimensions shown in Figures 10 through 16.

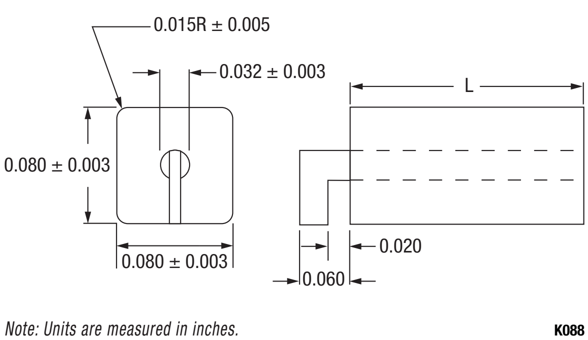


Figure 10. SM (2 mm)

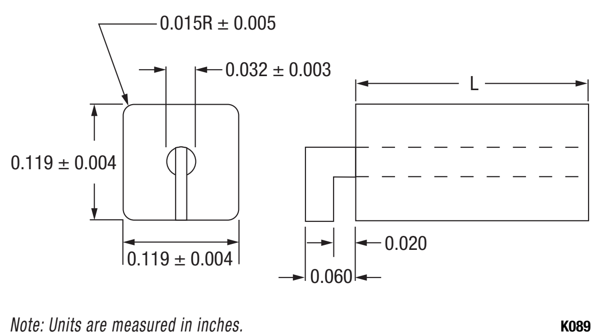
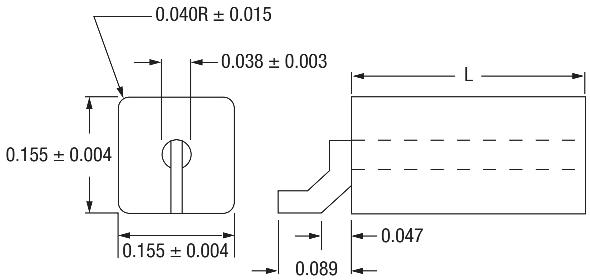
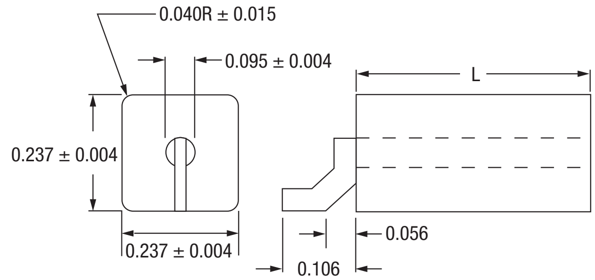


Figure 11. MP (3 mm)



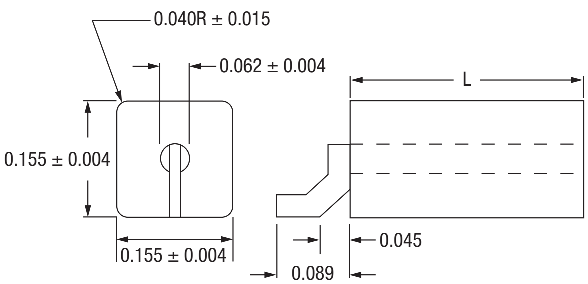
Note: Units are measured in inches. K090

Figure 12. LP (4 mm)



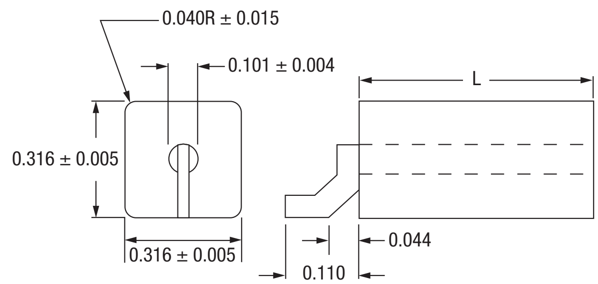
Note: Units are measured in inches. K092

Figure 14. SP (6 mm)



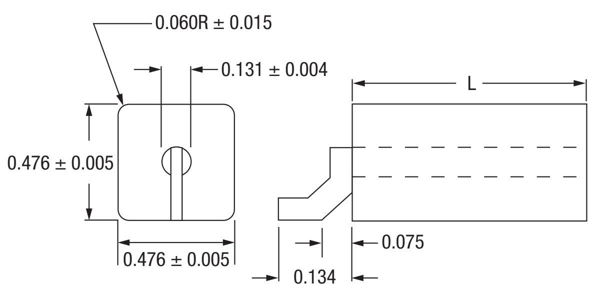
Note: Units are measured in inches. K091

Figure 13. LS (4 mm)



Note: Units are measured in inches. K093

Figure 15. EP (8 mm)



Note: Units are measured in inches. K094

Figure 16. HP (12 mm)

Ceramic Coaxial Resonators

Tables 2 through 5 summarize the various profiles, materials, and types available for coaxial Transverse Electro-Magnetic (TEM) mode resonators. We provide two types, four materials, and seven profiles. This range of component variables should meet most circuit design requirements. While the component is manufactured to a frequency, a formula is given to determine the approximate length. The selected resonant frequency is available with two standard frequency tolerances of ±0.5% and ±1.0%. The minimum tolerance is ±2 MHz.

Note: *The ordered value of f_0 is set according to our measurement procedure. The f_0 in your circuit may vary due to stray reactance. This offset can be corrected by changing the ordered value of f_0.*

Table 2. Recommended Frequencies for 1000 Series (ε_R = 11.5 ± 0.5)

Type	Profile	Recommended Range f_0 (MHz)	Nominal Length (Inches) ±0.030 Inches	Nominal Length Range (Inches)	Characteristic Impedance (Ω)
λ/4 Quarter-Wave Length	HP	1100– 1720	L = 870/f_0 (MHz)	0.506–0.792	24.1
	EP	1100– 2390		0.364–0.792	21.5
	SP	1100– 2960		0.294–0.792	17.5
	LS	1100–4400		0.198–0.792	17.5
	LP	1100– 3920		0.222–0.792	26.2
	MP	1100– 4860		0.179–0.792	24.5
	SM	1100– 4860		0.179–0.792	17.5
λ/2 Half Wave Length	HP	2200–3240	L = 1740/f_0 (MHz)	0.536–0.792	24.1
	EP	2200–4780		0.364–0.792	21.5
	SP	2200–5725		0.304–0.792	17.5
	LS	2200–5725		0.304–0.792	17.5
	LP	2200–5725		0.304–0.792	26.2
	MP	2200–5725		0.304–0.792	24.5
	SM	2200–5725		0.304–0.792	24.5

Table 3. Recommended Frequencies for 2000 Series (ε_R = 21.5 ± 1.0)

Type	Profile	Recommended Range f_0 (MHz)	Nominal Length (Inches) ±0.030 Inches	Nominal Length Range (Inches)	Characteristic Impedance (Ω)
λ/4 Quarter-Wave Length	HP	800–1200	L = 635/f_0 (MHz)	0.542–0.813	18.1
	EP	800–1700		0.382–0.813	16.1
	SP	800–2200		0.296–0.813	13.1
	LS	800–3200		0.203–0.813	13.1
	LP	800–2900		0.224–0.813	19.6
	MP	800–3600		0.181–0.813	18.4
	SM	800–3600		0.181–0.813	13.1
λ/2 Half Wave Length	HP	1600–2500	L = 1270/f_0 (MHz)	0.520–0.813	18.1
	EP	1600–3500		0.372–0.813	16.1
	SP	1600–4500		0.289–0.813	13.1
	LS	1600–6000		0.217–0.813	13.1
	LP	1600–6000		0.217–0.813	19.6
	MP	1600–6000		0.217–0.813	18.4
	SM	1600–6000		0.217–0.813	13.1

Table 4. Recommended Frequencies for 8800 Series (ε_R = 39.5 ± 1.0)

Type	Profile	Recommended Range f_0 (MHz)	Nominal Length (Inches) ±0.030 Inches	Nominal Length Range (Inches)	Characteristic Impedance (Ω)
λ/4 Quarter-Wave Length	HP	600–900	L = 469/f_0 (MHz)	0.525–0.787	13.1
	EP	600–1200		0.394–0.787	11.7
	SP	600–1600		0.295–0.787	9.5
	LS	600–2300		0.205–0.787	9.5
	LP	600–2100		0.225–0.787	14.2
	MP	600–2600		0.182–0.787	13.3
	SM	600–2600		0.182–0.787	9.5
λ/2 Half Wave Length	HP	1200–1900	L = 938/f_0 (MHz)	0.497–0.787	13.1
	EP	1200–2500		0.378–0.787	11.7
	SP	1200–3200		0.295–0.787	9.5
	LS	1200–4700		0.201–0.787	9.5
	LP	1200–4300		0.220–0.787	14.2
	MP	1200–5200		0.182–0.787	13.3
	SM	1200–5200		0.182–0.787	9.5

Table 5. Recommended Frequencies for 9000 Series (ε_R = 93 ± 2)

Type	Profile	Recommended Range f_0 (MHz)	Nominal Length (Inches) ±0.030 Inches	Nominal Length Range (Inches)	Characteristic Impedance (Ω)
λ/4 Quarter-Wave Length	HP	400–600	L = 306/f_0 (MHz)	0.518–0.778	8.5
	EP	300–800		0.389–1.037	7.6
	SP	300–1000		0.311–1.037	6.2
	LS	300–1500		0.207–1.037	6.2
	LP	300–1400		0.222–1.037	9.2
	MP	400–1700		0.183–0.778	8.6
	SM	400–1700		0.183–0.778	6.2
λ/2 Half Wave Length	HP	800–1200	L = 612/f_0 (MHz)	0.518–0.778	8.5
	EP	800–1700		0.366–0.778	7.6
	SP	800–2100		0.296–0.778	6.2
	LS	800–3100		0.201–0.778	6.2
	LP	800–2800		0.222–0.778	9.2
	MP	800–3400		0.183–0.778	8.6
	SM	800–3400		0.183–0.778	6.2

Coaxial Resonator Order Information

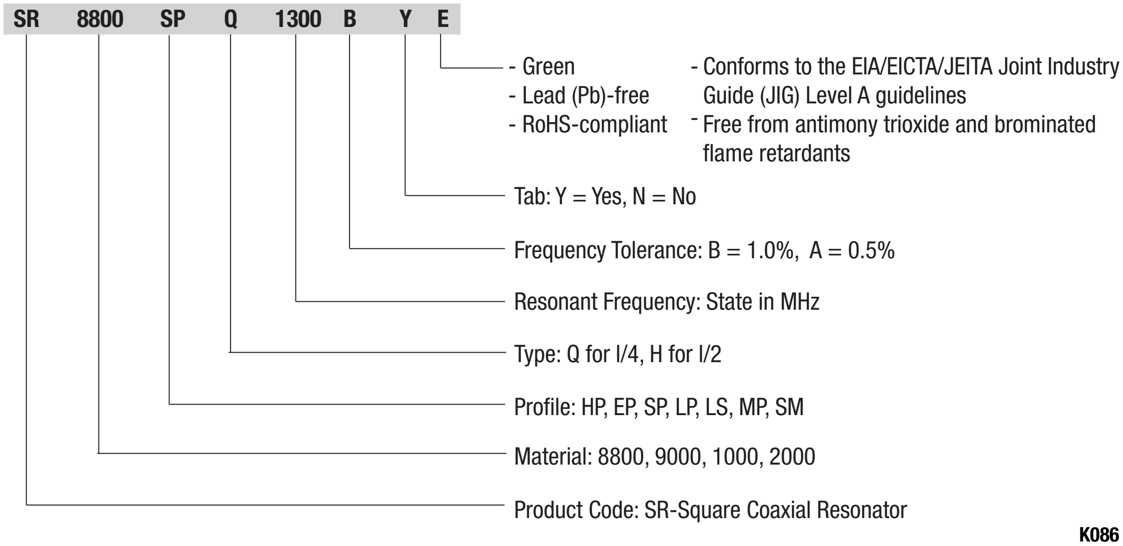


Figure 17. Coaxial Resonator Order Example

Ceramic Coaxial Inductors

Our coaxial inductors are most frequently used in the resonant circuit of Voltage-Controlled Oscillators (VCOs), where a varactor provides the tuning capability. The designer is usually confronted with trade-offs between high-Q for best phase noise and component size versus circuit board real estate. An algorithm for selecting the correct part follows. In addition, our COAX program can provide valuable assistance for determining the correct part. For sample circuits, basic principles, and some helpful hints, refer to the following Application Notes:

- *Coaxial Resonators for VCO Applications* (document number 202664)
- *Computer Simulation of Coaxial Resonators* (document number 202721)

While there is no physical distinction between a coaxial resonator and a coaxial inductor, the selection of an inductor for a VCO begins by first knowing (from analysis or experiment) the equivalent inductance that the active circuit, including the varactor, must see. In general, the VCO active circuit loads the resonator, lowering the resonator's Self-Resonant Frequency (SRF). The situation is analogous to externally capacitively loading a discrete parallel resonant L-C circuit.

While there is an approximate equivalent L-C circuit for the coaxial resonator close to the resonance, this model has limited application.

The coaxial resonators and inductors are more accurately modeled as a transmission line. For more details, refer to the two Application Notes referenced above.

Values of inductance that can be achieved depend upon the separation between the VCO frequency and the SRF of the coaxial line element. Values less than 1 nH are not practical as the metal connection tab has an equivalent inductance of this order.

In our experience, equivalent inductances in the range of 3 nH through 20 nH have been popular among designers of VCOs for wireless equipment.

To order a part or check on part availability, contact us or refer to Figures 17 and 19.

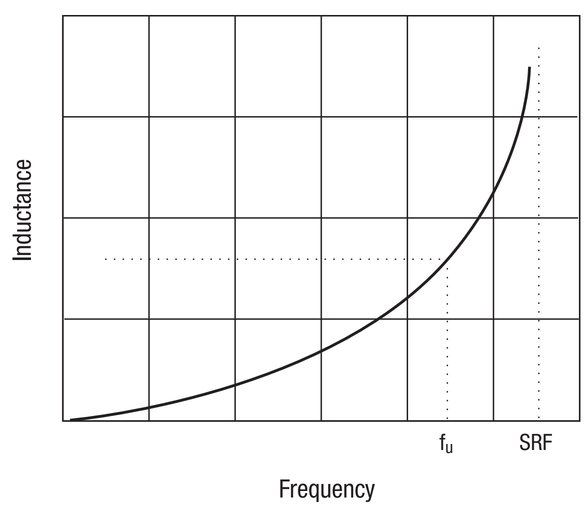


Figure 18. Frequency of Use vs Inductance

Coaxial Inductor Order Information

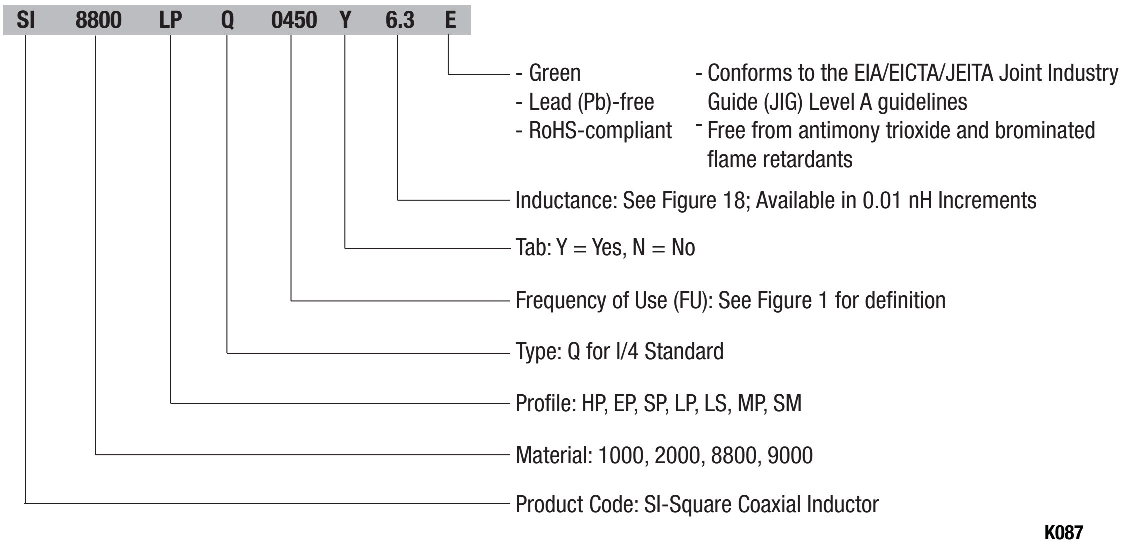


Figure 19. Coaxial Inductor Order Example

Table 6. Coaxial Line Properties vs Profile and Material

Profile	Material Type 1000	2000	8800	9000	Tab Inductors
HP	24.1 Ω	18.1 Ω	13.1 Ω	8.5 Ω	1.8 nH
EP	21.5 Ω	16.1 Ω	11.7 Ω	7.6 Ω	1.0 nH
SP	17.5 Ω	13.1 Ω	9.5 Ω	6.2 Ω	1.0 nH
LS	17.5 Ω	13.1 Ω	9.5 Ω	6.2 Ω	0.9 nH
LP	26.2 Ω	19.6 Ω	14.2 Ω	9.2 Ω	1.0 nH
SP	24.5 Ω	18.4 Ω	13.3 Ω	8.6 Ω	0.6 nH
SM	17.5 Ω	13.1 Ω	9.5 Ω	6.2 Ω	0.6 nH

Table 7. Wavelength (λg) in Dielectric

Material	ε_R	Wavelength Formula for λ_G (Inches)
1000	11.5 ± 0.5	$3480/f_0$
2000	21.5 ± 1.0	$2540/f_0$
8800	39.5 ± 1.0	$1876/f_0$
9000	93 ± 2	$1224/f_0$

Inductor Selection Guide

1. Select one of the four dielectric materials.
2. Determine the VCOs operating frequency (f_{VCO}).
3. Determine the preferred inductance or circuit impedance (Z_{IN}). Use the following formula to convert the inductances to impedances:

   $Z_{IN} = 2*\pi* f_{VCO} * L_{IN}\ \Omega$
4. Calculate the effect of the tab. Tab inductances are given in Table 2 in the Application Note *Optimizing DROs for Low Phase Noise* (document number 202727). Use the following formula to convert the tab inductances to impedances:

   $Z_{IN} = 2*\pi*f_{VCO}*L_{TAB}\ \Omega$
5. Determine the input impedance by subtracting the effect of the tab using the following formula:

   $Z_{INPUT} = Z_{IN} – Z_{TAB}$
6. Calculate the wavelength (λ_G) of the part in the dielectric (see Table 7 for the appropriate formula).
7. Determine the characteristic impedance (Z_O) of the part (see Table 8).
8. Calculate the physical length of the part using the following formula:

   $l = (\lambda_G/2*\pi) \tan^{-1} (Z_{INPUT}/Z_O)$ inches
9. Determine the SRF of this part using the following formula:

   $SRF = (\lambda_G*f_{VCO})/(4*l)$
10. Check the recommended frequency in Tables 2 through 5 for the appropriate material to ensure a valid part.

Measurement Description of Q, f_0, and L

The evaluation of Q (quality factor) and f_0 (resonant frequency) of coaxial components is made with a one-port reflection measurement on a network analyzer. The probe is moved into the Inner Diameter (ID) of the device until the input resistance of the device matches the terminal resistance of the network analyzer. This input resistance is indicated by a 50 Ω circle on the Smith Chart display, and is known as "critical" coupling. The point on this circle where the response is purely resistive (capacitance reactance equals inductive reactance) is the point of resonance and is defined by a complex impedance of Z = 50 + j Ω. The Q is computed by observing the frequency span between the Voltage Standing-Wave Ratio (VSWR) minus 2.616 ($Z = 50 \pm j50\ \Omega$) on either side of f_0. The Q is defined as $f_0/\Delta f$.

The inductance parameter (L) is measured with an Analog Power Control (APC) 7 mm connector that is mounted flush with a conducting plane, and a full one-port calibration (open, short, broadband 50 Ω load) is performed. The inductor is then clamped into place with the tab touching the inner conductor and metallized body touching the grounding plane. The inductance (L) is measured at the frequency of use. The impedance vector on the Smith Chart of a network analyzer gives the necessary information where $Z = R + jwL$.

Characteristic Impedance

As shown in Table 8, the characteristic impedance (Z_0) of the coaxial TEM mode components is a function of the profile dimensions and dielectric constant of the material. The Z_0 value is reduced over its air line value by the square root of the dielectric constant of the material. At a one-eighth wavelength, the short-circuit line exhibits an inductive reactance, while the open-circuit line exhibits a capacitive reactance equal in magnitude to Z_0.

$$Z_0 = \text{character impedance} = \frac{60}{\sqrt{\varepsilon_R}} \ln\left(1.079 \frac{W}{d}\right)$$

Where:

- w = width of resonator
- d = diameter of inner conductor
- ε_R = dielectric constant

Table 8. Characteristic Impedance

	Material Type			
Profile	**1000**	**2000**	**8800**	**9000**
HP	24.1 Ω	18.1 Ω	13.1 Ω	8.5 Ω
EP	21.5 Ω	16.1 Ω	11.7 Ω	7.6 Ω
SP	17.5 Ω	13.1 Ω	9.5 Ω	6.2 Ω
LS	17.5 Ω	13.1 Ω	9.5 Ω	6.2 Ω
LP	26.2 Ω	19.6 Ω	14.2 Ω	9.2 Ω
SP	24.5 Ω	18.4 Ω	13.3 Ω	8.6 Ω
SM	17.5 Ω	13.1 Ω	9.5 Ω	6.2 Ω

Ceramic Coaxial Inductor Soldering Conditions

TTI coaxial components are compatible with standard surface mount reflow and wave soldering methods. The HP components may require mechanical support mounting because of the larger size. Contact us for details.

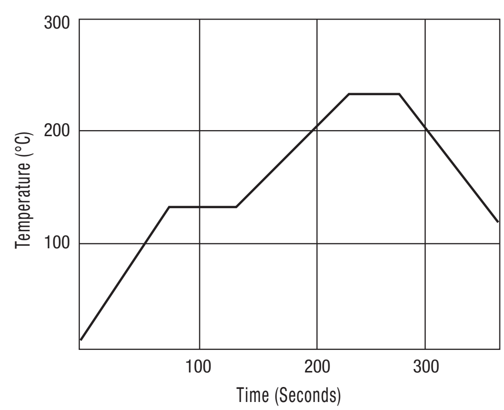
Solders *must* contain silver. Non-silver bearing solders leach silver from the resonator during reflow.

Tabs that are:

- Non-RoHS are Sn/Pb plated.
- RoHS compliant are gold-plated with a nickel underlayer or an unplated nickel silver alloy.

Additional attaching methods include a hot air gun, an infrared source, a soldering iron, a hot plate, a vapor phase, etc. The coaxial component body is ceramic and subject to thermal shock if heated or cooled too rapidly.

We recommend Figure 20 as the soldering profile. For further information, refer to the *Coax Resonators Reflow Process Compatibility for Lead (Pb)-Free and RoHS-Compliant* document on our website. Repeatable results can be best achieved with air cooling only, not quenching.



Note: *The maximum temperature depends on the solder type.*

Figure 20. Soldering Profile

Figure 21 indicates the maximum tolerance of the component planarity with respect to the datum plane.

Equation (1) Input Impedance f0

$$Z_{INPUT} = f Z_0 \tan\left(\frac{2\pi f_0}{4\ SRF}\right)$$

Where: f0 = Resonant frequency

Equation (2) Resonant Frequency

$$\iota = \frac{c}{4\ SRF\ \sqrt{\varepsilon_R}}$$

Where: c = Speed of light

ε_R = 39.5 (8800 material)
ε_R = 93 (9000 material)
ε_R = 11.5 (1000 material)
ε_R = 21.5 (2000 material)

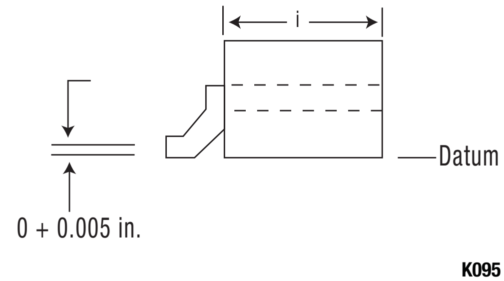
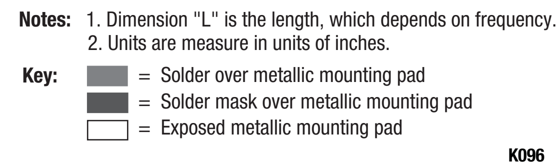


Figure 21. Surface Mount Tolerance for Components with Tabs

Packaging for Ceramic Coaxial Inductors

Tape and reel packaging is available. Contact us for details.



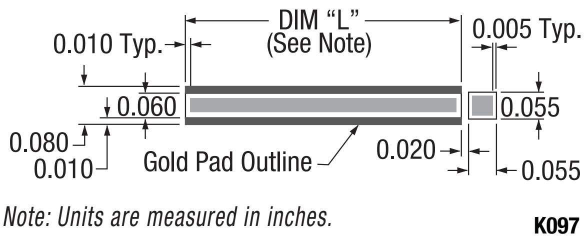


Figure 22. 2 mm (SM) Coaxial Resonator Footpad Dimensions

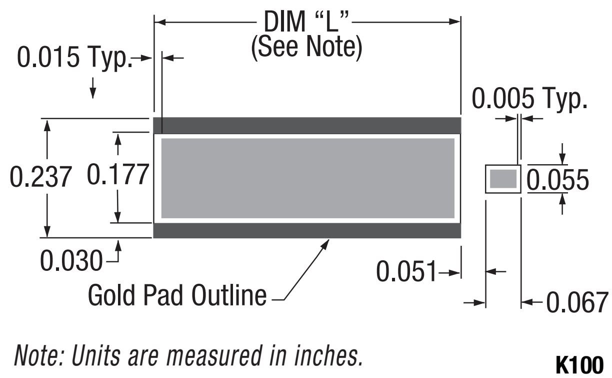


Figure 25. 6 mm (SP) Coaxial Resonator Footpad Dimensions

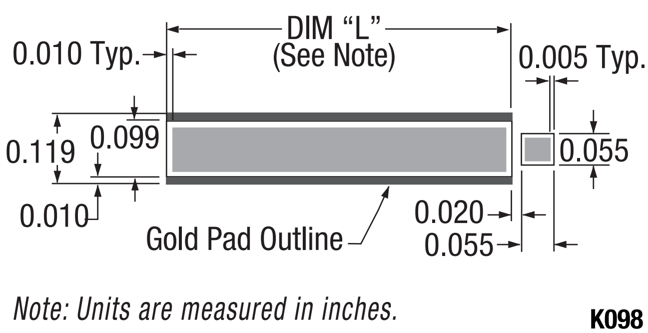


Figure 23. 3 mm (MP) Coaxial Resonator Footpad Dimensions

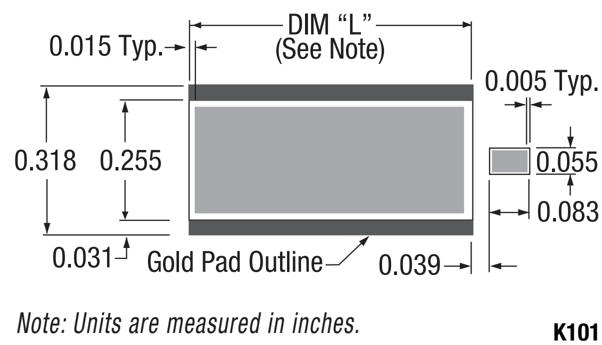


Figure 26. 8 mm (EP) Coaxial Resonator Footpad Dimensions

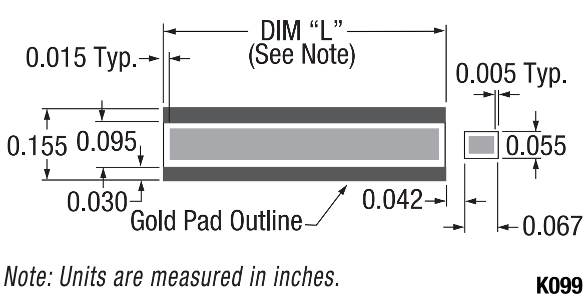


Figure 24. 4 mm (LP/LS) Coaxial Resonator Footpad Dimensions

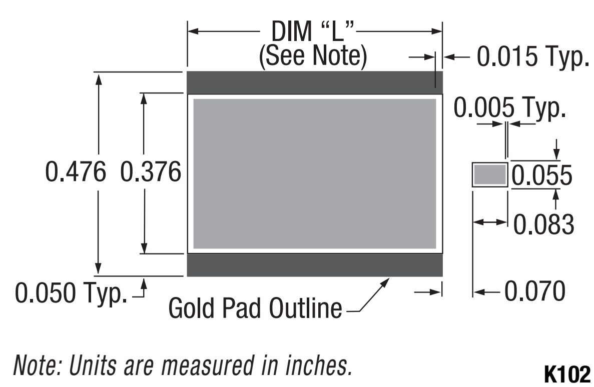


Figure 27. 12 mm (HP) Coaxial Resonator Footpad Dimensions