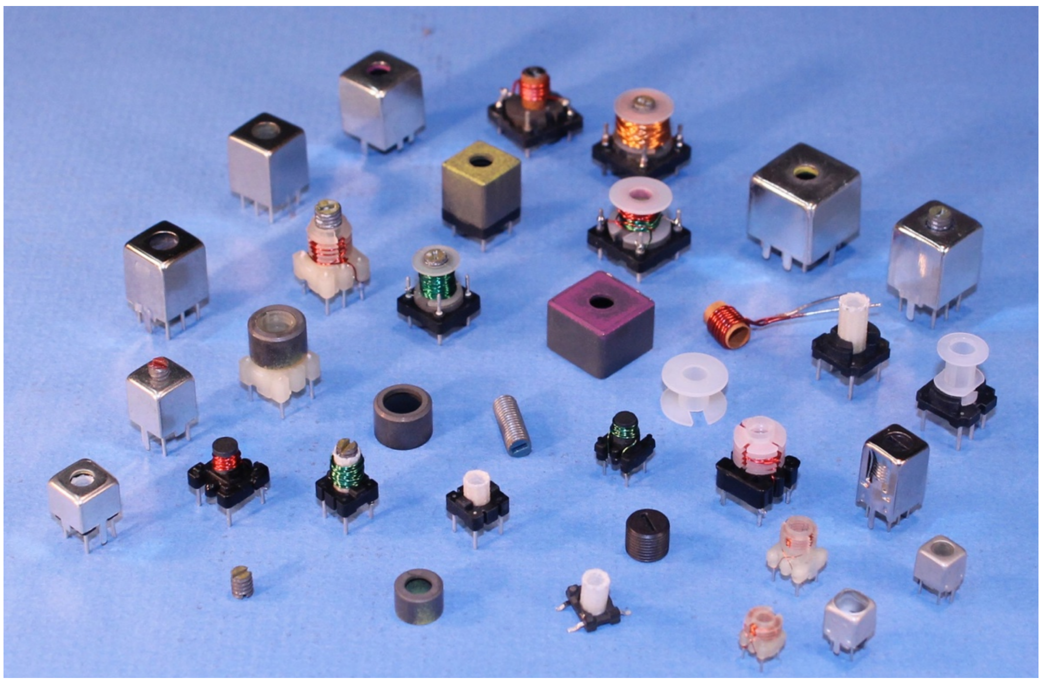
LODESTONE PACIFIC

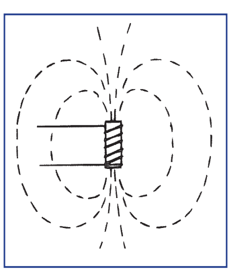
Shielded Coil Forms for High Q Tunable Inductors

Lodestone Pacific Shielded Coil Forms provide the assembly structure for High Q Variable or Tunable inductors common in RF applications like tuned circuits, antenna tuners, band-pass and band-stop filters, oscillators and amplifiers. High quality variable inductors balance inductance, frequency and resistance, matched to a capacitor, creating a LCR resonant circuit. (L=inductance, C=capacitance, R=Resistance). In most traditional analog radio transmitters, receivers, oscillators and filters, the LC resonant circuit is what defines the operating frequency and ensures selectivity.



Matching inductance and frequency, while reducing resistance, will maximize the Quality or "Q" of the variable inductor assembly. Q is a dimensionless parameter that measures the efficiency and performance of the variable inductor by indicating how well it stores energy relative to the energy it dissipates as losses, primarily due to resistance in the winding. In a resonant circuit common for tunable inductors, higher Q means sharper resonance, a narrow band-width, and lower losses.

The Q and characteristics of the magnetic field generated in a variable inductor is determined by the quality and shape of the magnetic core materials, and by the characteristics of the winding. A cylindrical iron powder tuning core or slug in the center of a spring wound wire coil form, activated by a current, will create a magnetic field with invisible lines of flux represented by Figure 1. The construction of the Shielded Coil Form traps and channels the magnetic lines of flux within a magnetic path-way created by the iron powder cup increasing the efficiency and performance of the assembly. The more complete the magnetic pathway along the magnetic lines of flux, the higher the inductance and Q of the assembly.



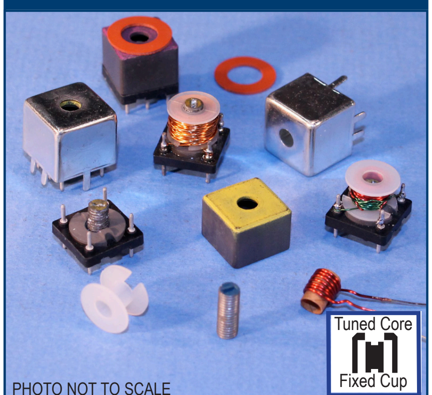
Higher Q for RF applications results in superior selectivity in filters and oscillators with minimal signal distortion. Lower Q tends to broadens bandwidth, but increases losses, which is a detriment to precision tuning.

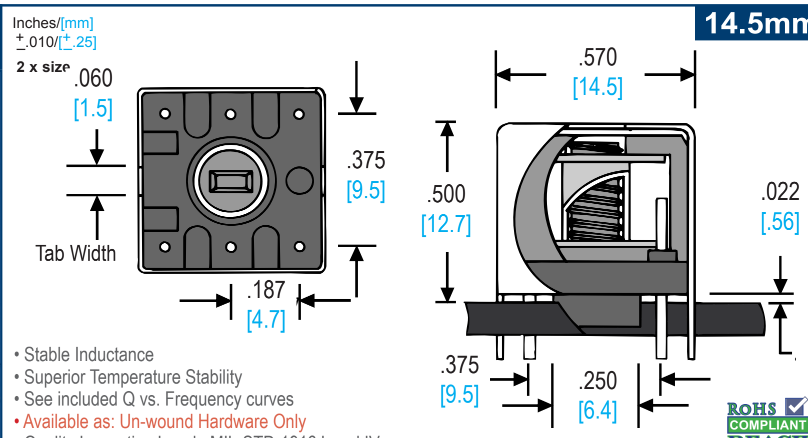
Lodestone Pacific Shielded Coil Forms use superior Micrometals carbonyl iron powder threaded tuning cores and cup cores to ensure very stable inductance with temperature and high Q in an optimized assembly. Lodestone Pacific offers shielded coil form (SCF) assemblies in 8mm, 11mm, 11.5mm and 14.5mm sizes. In addition to the core material, each assembly utilizes a DAP base with terminals molded-in that will tolerate up to 700˚F during soldering. Either a tubular or flanged bobbin winding form and a copper, 100% tin plated, shield can, (to isolate the variable inductor from adjacent components), is included in each assembly.

The Micrometals iron powder cores are formulated to maximize Q within a specific frequency range. For example, the Lodestone Pacific L57 assembly is available in three iron powder formulations depending on the operating frequency as shown on the included data sheet.

L57 SERIES

14.5mm





- Stable Inductance
- Superior Temperature Stability
- See included Q vs. Frequency curves
- Available as: Un-wound Hardware Only
- Quality Inspection Level: MIL-STD-1916 Level IV

RoHS COMPLIANT REACH

ASSEMBLY PART NO.	COLOR CODE	MAGNETIC MATERIAL (1)	FREQUENCY RANGE (2)	MATERIAL PERMEABILITY	ASSEMBLY A_L nH/turns² (3)	MAX µh 100 turns	MIN µh (4) 100 turns	TEMPERATURE STABILITY (5)
L57-2-PCT-B-4	RED	CARBONYL E	.25-10 Mhz	10.0	13.0	130	54	95 ppm/°C
L57-6-PCT-B-4	YELLOW	CARBONYL SF	10-50 Mhz	8.5	12.0	120	51	35 ppm/°C
L57-10-PCT-B-4	BLACK	CARBONYL W	10-100 Mhz	6.0	10.5	105	50	150 ppm/°C

1) The iron powder or ferrite materials are used in a portion of the base, the tuning core and cup core. Mix 3F is a combination of a ferrite tuning core and an iron powder cup core.
2) This represents the frequency range for Q optimization in tuned or resonant circuits. The inductive properties of the material is effective over a considerably wider frequency range.
3) Nanohenries (10^{-9} Henries) per turn squared.
4) The minimum inductance is measured in microhenries (10^{-6} Henries) per 100 turns with the tuning core tuned out of the winding area but still a part of the assembly.
5) The temperature stability is of the magnetic material, measured in parts per million per degree Celsius (ppm/°C) on a toroidal core and winding. This is only an indication of the temperature stability for a complete wound assembly.

Inductance of the variable assembly opposes changes in current via reactance. The inductance (L) of the assembly is listed in µH (micro-Henrys) for 100 turns for each assembly. Starting with the 100 turn inductance, listed in the data sheet, the number of turns of wire for a desired inductance can be calculated from the following formula.

$$\text{Required Turns} = 100\sqrt{\frac{\text{Desired L } (\mu H)}{\text{L } (\mu H) / \text{100 Turns}}}$$

The data sheet also provides a tuning range with expected max and min inductance base on 100 turns. Tuning the core to the center of the winding form will increase inductance; tuning the core out of the winding form will reduce inductance.

The inductance of each assembly is fairly flat with increasing frequency until after the peak of that assembly's Q. Above the peak Q frequency, apparent inductance will climb with frequency until the frequency when self resonance occurs.

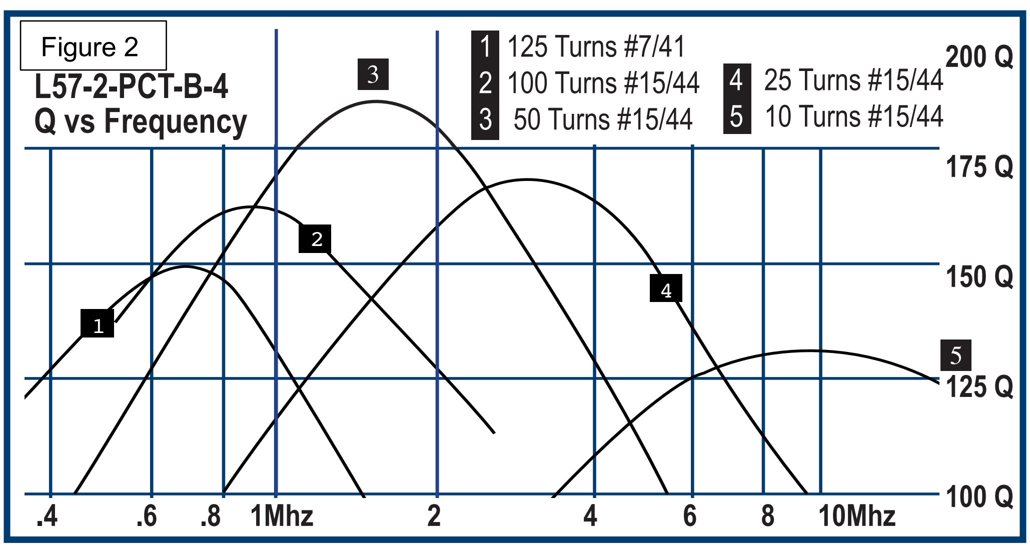
The assembly's contribution to superior Q is found in the core materials formulation, shape, inductance and frequency sensitivity. The key to optimising the Q of the assembly is selecting the proper core material, wire and winding characteristics for a particular frequency. The winding's contribution to Q is maximized by minimizing frequency specific wire losses in the winding. Q values are often shown as curves of Q value at particular frequencies. The shape and magnitude of these curves can be characterized by the following formula:

$$Q = \frac{2\pi fL}{R}$$

Where f is frequency in Mhz, L is inductance in µH and R is the effective series resistance due to both copper and core loss, in ohms. The Q vs frequency curves are plotted on a semi-log axis and were derived from actual testing of the assemblies in a parallel resonant circuit and reflect the expected Q readings with a specific inductance and winding. As the frequency is varied, the readings will trace a humped curve identifying the optimum inductance-frequency balance that produces the highest Q. Increasing inductance by adding turns of wire or tuning the core towards the maximum inductance position will create a new Q curve with a peak that will be shifted down in frequency. Conversely, reducing inductance by decreasing turns or de-tuning the assembly will shift the Q curve peak higher in frequency.

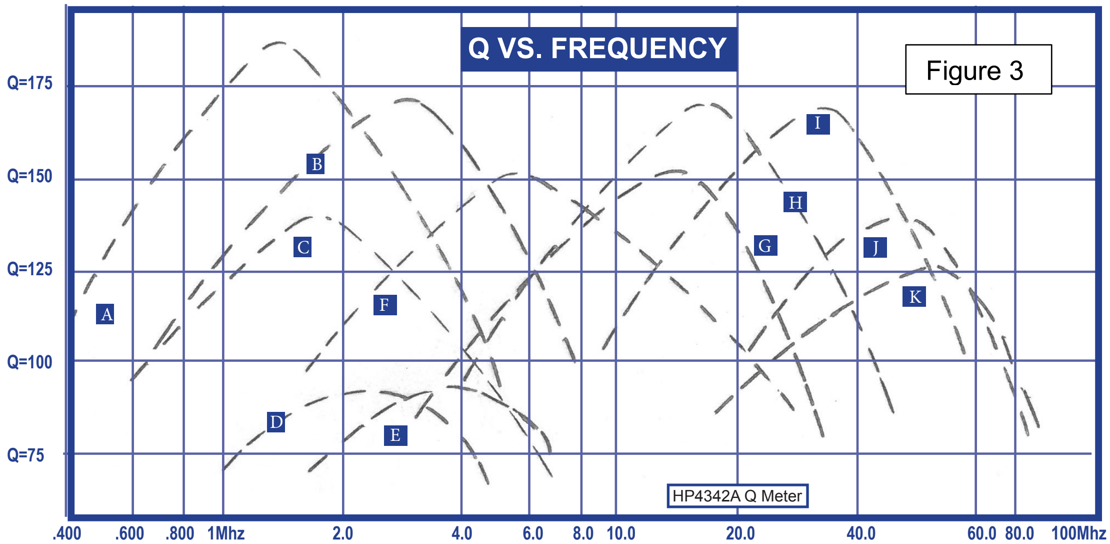
Figure 2 shows the L57-2-PCT-B-4 assembly wound with a decreasing number of turns on each assembly. The family of Q curves show the trend towards higher frequency Q curves as you reduce inductance by reducing turns. It also shows that the maximum value of each Q curve will diminish as the curve peaks move to the extremes of their recommended frequency ranges. There is an optimum frequency and inductance for a given assembly where the "peak of the peaks" will occur (at 1.5 Mhz in Figure 3). This is why applications requiring high Q are best engineered with the inductive portion of the tuned circuit optimised first, and the capacitor specified to support that optimum Q. Each Micrometals core material mix formulation will produce similar families of curves within their optimum frequency ranges.

Figure 2



Because Q is frequency specific, the Q curves are grouped by material within a frequency range. Mix-2 (Carbonyl E), material permeability of 10, 0.25 to 10 Mhz. Mix-6: Carbonyl SF, material permeability of 8.5, 10 to 50 Mhz. Mix-10: Carbonyl W, material permeability of 6.0, 20 to 100 Mhz. Once the frequency range of interest is determined, the assembly iron powder mix is selected to optimize Q in the range.

Figure 3 shows Q curve examples for four different sized Lodestone Shielded Coil Form assemblies. The amount of core material in the assembly will also improve Q. As an example, the L57-2-CT-B-4 wound with 25 turns of 15/44 Litz wire (curve B) will produce higher Qs than the L43-2-CT-B-4 and the L335-2-CT-F-4 with the same winding (curves F and D respectively). This is due to more iron powder in the larger L57 assembly.



A L57-2-PCT-B-4: 32uH, 50 Turns of #15/44
B L57-2-PCT-B-4: 8.2uH, 25 Turns of #15/44
C L57-2-PCT-B-4: 30uH, 50 Turns of #7/41
D L335-2-CT-F-4: 4.10uH, 25 turns of #15/44
E L335-2-CT-F-4: 2.16uH,18 turns of #15/44
F L43-2-CT-F-5: 6.10uH, 25 turns of #15/44
G L45-6-PCT-B-4: 1.77uH, 14 turns of #28
H L57-6-PCT-B-4: 0.98uH, 10 Turns of #26
I L57-10-PCT-B-4: 0.26uH, 5 Turns of #24
J L45-10-PCT-B-4: 0.16uH, 4 turns of #28
K L335-10-CT-F-4: 0.16uH,5 turns of #26

Winding Considerations

The type and size of the wire used in the winding is also frequency sensitive. As frequency is increased from 100 Khz to 1Mhz, the resistive eddie-current losses increase and the “skin effect” becomes significant. It is possible to minimize the “skin effect” by dividing the conductor into a bundle of interwoven insulated strands called Litzendraht or Litz wire. Depending on the frequency, the strand diameter is chosen so that the skin effect in the individual strands is negligible.

Litz wire is described as 7/41 (7 strands of 41 AWG), or 15/44 (15 strands of 44 AWG.) and will tend towards larger bundles of smaller strands as frequency is increased. Above 1 Mhz, the advantages of reduced resistance using Litz wire diminish as the capacitance of adjacent turns as well as the capacitance from the winding to the core becomes significant and stranded wire should be abandoned in favour of solid wire. Thus higher frequency windings will tend towards fewer well spaced turns of larger diameter enamel coated magnetic wire. The exact frequency is dependent on the application, but the practical transition is from 4 to 10 Mhz.

SHIELDED COIL FORM WINDING TABLE

WIRE SIZE AWG	20		22		24		26		28		30		32		34		36		38	
WIRE SIZE LITZ	100/43		60/43		40/43		10/40		10/42		15/45		9/45		6/45		5/47		4/48	
Single Layer | Full Winding	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F
L335							8	15	10	19	8	70	10	110	13	180	16	280	20	440
L43	4	8	6	12	8	16	10	20	13	52	17	102	21	126	27	216	34	404	42	588
L45	5	8	6	12	8	15	10	19	13	25	17	62	21	78	27	147	34	244	43	385
L57	5	10	6	24	8	32	10	60	13	104	17	170	21	252	27	432	34	680	43	1032

The winding table above shows the number of turns of Litz and solid magnetic wire of different gauges that will fit in each of the Shielded Coil Form’s winding area. These turns estimates are for indication only. The actual maximum number of turns will depend on insulation thickness and the winding technique.

Lodestone Pacific Shielded Coils Forms in Military Applications

Photo by Staff Sgt. Charles B. Johnson, courtesy of U.S. Army.

Figure 1. The SINCGARS radio from ITT provides secure tactical voice communications through frequency hopping.

Military radios use frequency-hopping technology to thwart enemy eavesdropping. While coded digital instructions are included in the transmission to coordinate the frequency hopping between radios, a clear and un-garbled voice signal still must be transmitted and received in a conventional sense. High Q is an important contributor to tuned circuits transmitting a sharp, clear signal while the frequency is changed several times a second.

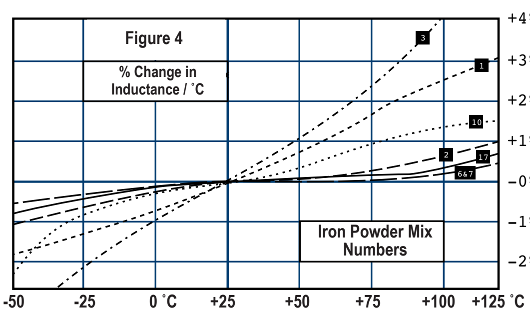
Maximizing the Q in tuned circuits is a bit of an art. Lodestone Pacific's variable shielded coil form product line has been an integral part of **J**oint **T**actical **R**adio **S**ystem (JTRS) and the ITT **SIN**gle **C**hannel **G**round and **A**irborne **R**adio **S**ystem (SINCGARS) for over 20 years. This tactical radio operates between 30 and 88 MHz with 2320 channels. The demands on the radio's LCR (L-inductor, C-capacitor, R-resistor) tuned circuits become more stringent as voice and data are switched between many frequencies per second in the heat, humidity, vibration and rigors of the combat environment.

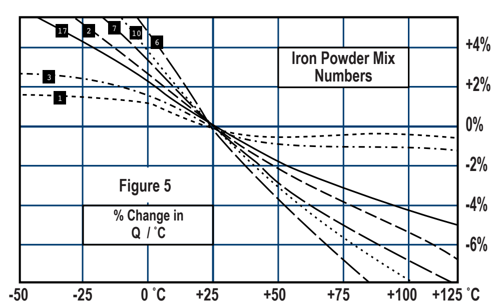
To maintain a .02% tight frequency tolerance in this demanding application, the Q, or quality of the tuned circuit is critical. The Q, factor, or Quality Factor, of a tuned LCR resonant circuit is a measure of the "sharpness of the response curve. The higher the Q value, the higher the energy at that specific frequency, and the sharper the response. The amount of Q in a radio's tuned circuits must carefully considered. If too high (and tight), some of the modulation's spectrum will be cut off. If the Q is too low, (with a wide peak), other signals and excessive noise will get through. It is best to use the highest Q inductors and capacitors available since a Q that is too high can be reduced by intentionally introducing resistance in the circuit, while circuit modification to improve the Q of a low quality inductor will add noise to the circuit.

Excerpt from Defense Electronics article:
Stable High-Q Inductors are Critical in Frequency Hopping Radios, by Rich Barden

Temperature Stability

An important characteristic of iron powder core materials is the outstanding temperature stability. The temperature stability information for each iron powder mix is listed in parts-per-million-per degree Celsius (ppm/°C) as seen in the L57 data sheet. As an example, the inductance of a 100ppm/°C material will change by 1% over a temperature change of 100 °C.





Figures 4 and 5 plot the temperature stability for iron powder materials as a percentage change in inductance and Q. Iron powder core materials have excellent temperature stability from -65°C (-150°F) up to 125°C (257°F). Ferrite materials are more sensitive to temperature and will exhibit changes in inductance and Q from 5 to 10 times greater than iron powder over the same temperature range.

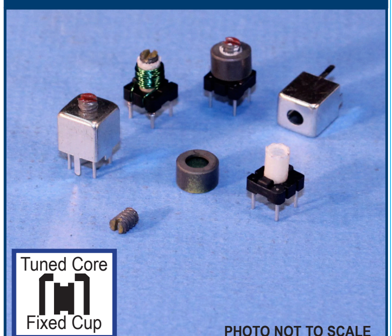
In an iron powder core, inductance will increase gradually as the core materials temperature increases from 25°C to over 100°C. With continuous operation above 100°C, (212˚F) inductance and Q will begin to degrade with time. The extent of this shift is dependent on time, temperature, and frequency. Iron powder cores tolerate temperatures down to -65°C with no permanent effects.

Extended periods of elevated temperature will result in a permanent shift in inductance and Q when the assembly is returned to ambient. For temperature sensitive applications up to 100°C, this shift can be stabilized by “aging” the core material at 100°C for a minimum of 48 hours. Temperature stability is an estimate base on temperature cycling on toroids of the same material.

In addition to the L57 Data sheet above, the smaller L335, L43, and L45 Shielded Coil Form data sheets are shown below.

L335 SERIES

8mm



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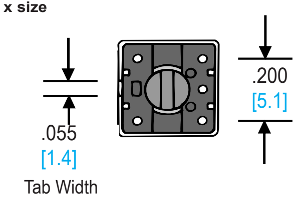

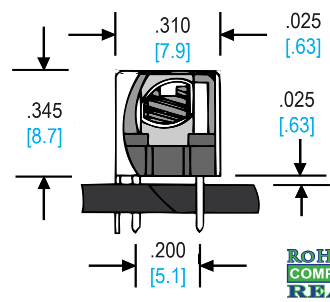

- Stable Inductance
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- See included Q vs. Frequency curves
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- Quality Inspection Level: MIL-STD-1916 Level IV

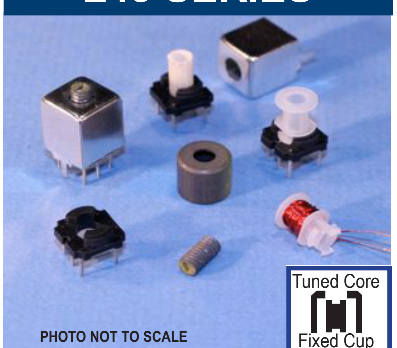
RoHS COMPLIANT REACH

ASSEMBLY PART NO.	COLOR CODE	MAGNETIC MATERIAL(1)	FREQUENCY RANGE (2)	MATERIAL PERMEABILITY	ASSEMBLY AL nH/turns² (3)	MAX µh 100 turns	MIN µh (4) 100 turns	TEMPERATURE STABILITY(5)
L335-2-CT-F-4	RED	CARBONYL E	.25-10 MHz	10.0	6.8	68	45	95 ppm/°C
L335-6-CT-F-4	YELLOW	CARBONYL SF	2.0-50 MHz	8.5	6.1	61	38	35 ppm/°C
L335-10-CT-F-4	BLACK	CARBONYL W	10-100 MHz	6.0	5.7	57	37	150 ppm/°C

1) The iron powder materials are used in the tuning core and cup core.
2) This represents the frequency range for Q optimization in tuned or resonant circuits. The inductive properties of the material is effective over a considerably wider frequency range.
3) Nanohenries (10^{-9} Henries) per turn squared.
4) The minimum inductance is measured in microhenries (10^{-6} Henries) per 100 turns with the tuning core tuned out of the winding area but still a part of the assembly.
5) The temperature stability is of the magnetic material, measured in parts per million per degree Celsius (ppm/°C) on a toroidal core and winding. This is only an indication of the temperature stability for a complete wound assembly.

L43 SERIES

11mm



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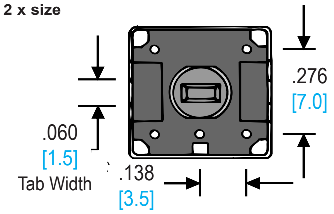

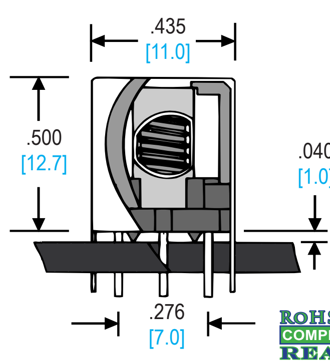

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L43-2-CT-F-5	RED	CARBONYL E	.25-10 MHz	10.0	9.8	98	48	95 ppm/°C
L43-6-CT-F-5	YELLOW	CARBONYL SF	2.0-50 MHz	8.5	8.5	85	44	35 ppm/°C
L43-10-CT-F-5	BLACK	CARBONYL W	10-100 MHz	6.0	7.2	72	43	150 ppm/°C

1) The iron powder or ferrite materials are used in the tuning core and cup core.
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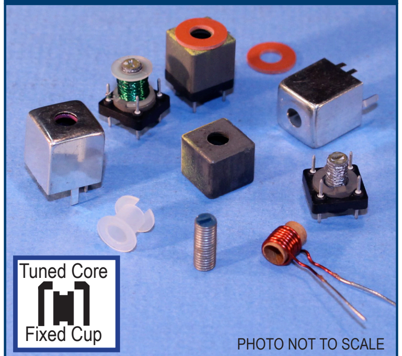
L45 SERIES

11.5mm



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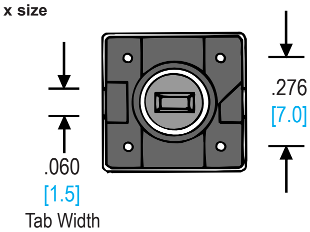

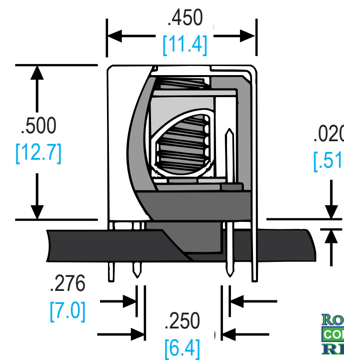

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L45-2-PCT-B-4	RED	CARBONYL E	.25-10 MHz	10.0	12.5	125	52	95 ppm/°C
L45-6-PCT-B-4	YELLOW	CARBONYL SF	2.0-50 MHz	8.5	11.5	115	47	35 ppm/°C
L45-10-PCT-B-4	BLACK	CARBONYL W	10-100 MHz	6.0	10	100	46	150 ppm/°C

1) The iron powder or ferrite materials are used in a portion of the base, the tuning core and cup core.
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Each Lodestone Pacific Shielded Coil Form assembly includes a Shield Can, Cup Core, Winding Form or Bobbin, Threaded Tuning Core, and a thermoset plastic (DAP) Base with terminals moulded-in. Assemblies are sold unassembled and unwound. We can recommend coil winder with experience in maximizing Q in variable inductors. Solderability to MIL-STD-202, Method 208.

https://lodestonepacific.com/shielded-coil-forms/

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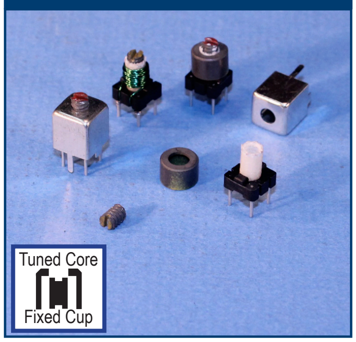
Lodestone PACIFIC 35 Years

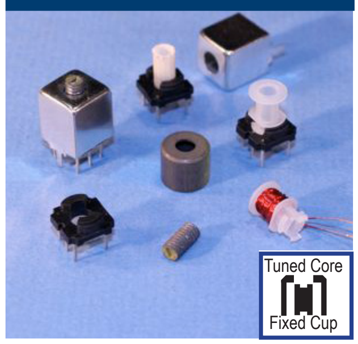
LODESTONE GROUP

Reed-Rex • Lodestone Pacific • Digilant
Bantam Clean Power • Neo Crucible

L335 SERIES



L43 SERIES



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