DIGI-KEY ELECTRONICS

ACADEMIC COMPONENT REFERENCE GUIDE

FIXED INDUCTORS

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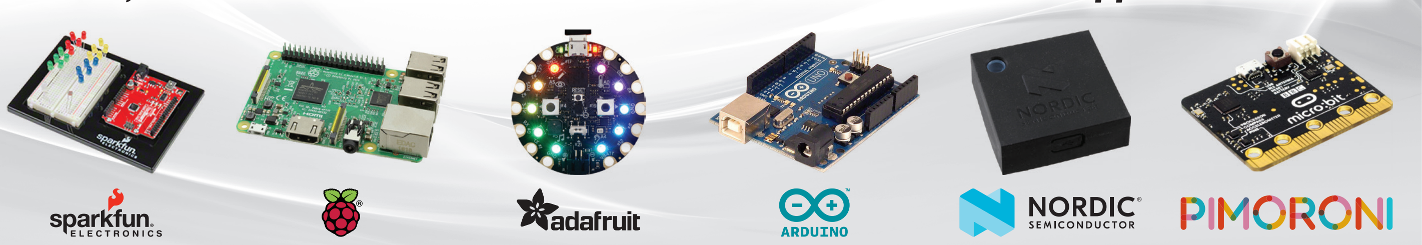
Digi-Key®
ELECTRONICS



FIXED INDUCTORS

Type

The "type" attribute as applied to fixed inductors is a reference to the general construction method used for a given part. It is significant in that different construction methods lead to different trade-offs in terms of non-ideal behaviors, cost, and other factors.

The different values available are not perfectly orthogonal in what they represent, in the sense that some parts could reasonably be described using more than one of the available terms.

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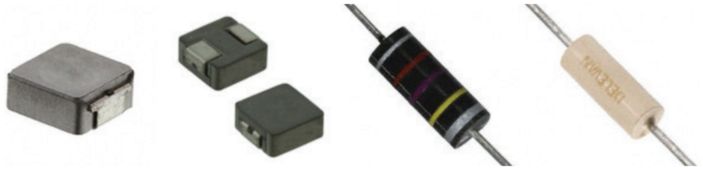
Here, as elsewhere, a hyphen or "dash" (also called "null") as a parametric value indicates that the referenced parameter is either not applicable to the part in question or that data has yet to be entered for a given part. At the time of writing, roughly 20% of the fixed inductors available from Digi-Key list a dash for the Type parameter. Due to the significant portion of product that has a null type value, it's recommended to include the dash when making initial type selections in order to avoid exclusion of potentially useful results.

The bulk of the parts with a null type value at the time of writing would likely be classified as wirewound. However, parts best classified as some other type can be found amid the mix.

Molded

The "molded" type value was originally intended to specifically reference a patented construction method in which an inductor's core is formed around its windings using powder processes, rather than the windings being formed around a core as in traditional construction methods. Such an approach can provide performance advantages relative to traditional construction methods, and devices produced in this way are classified as being of "molded" type.

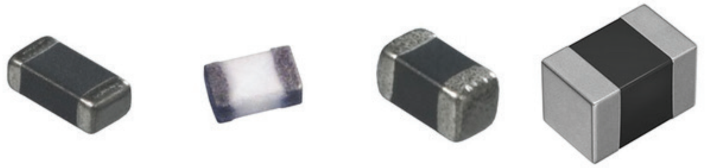
Not all devices currently categorized as "molded" however, are produced in this fashion as many products undergo a molding process using plastic, ceramic, or other materials simply to encapsulate the product, rather than to form an active part of the device. Given that most such devices are formed by wrapping wire around a core rather than one of the other methods, "wirewound" would likely be the more correct type value for such products.



Multilayer

Multilayer type inductors are constructed using techniques and methods similar to those used for multilayer ceramic capacitors in which ceramic and conductive materials are combined in layers and patterns to produce the desired internal conductor geometry, and then subjected to a co-firing process which fuses the product into a solid whole.

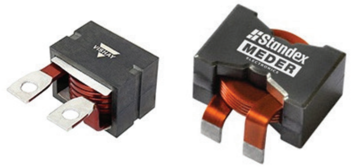
Inductors formed using this process may exhibit a wide range of Q values and self-resonant frequencies, but the nature of the process lends itself to the production of physically small parts with relatively high current ratings for their size, rendering multilayer inductors well suited to filtering and miniaturized power conversion applications. Among the other chip-scale inductor types (including thin and thick film) the multilayer devices tend to offer lower precision and higher ratings in terms of inductance and current capacity.



Planar

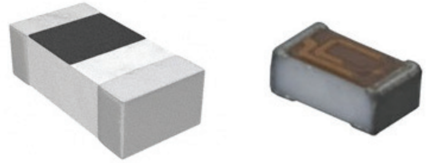
The Planar inductor type, in Digi-Key parlance, refers to devices in which the windings have a rectangular, rather than circular cross section. Such devices typically have a limited number of turns, and are designed to carry large amounts of current for products of their size.

Products of this type should not be confused with the concept of "planar magnetics", a design technique in which a magnetic core is placed around a set of windings formed using printed circuit board traces in order to obtain an inductor with a very low profile.



Thick Film

Thick film inductors are produced using processes similar to those used to manufacture thick film resistors, the essence of which is the use of screen printing techniques to form a device's internal conductors on a ceramic substrate. Among the chip-scale inductors it is a process that is generally of higher precision than multilayer products and lower precision than thin film products. Though capable of sufficient precision as to be useful for RF applications, a much larger selection of thin film inductors is available at the time of writing, suggesting broader market acceptance of that technology for high-precision inductors.

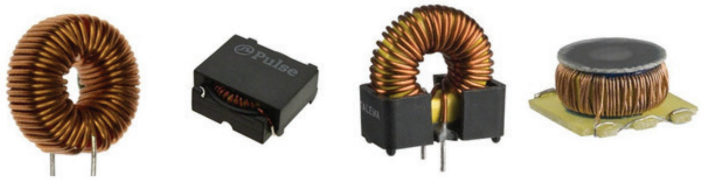


Thin Film

Thin film inductors are manufactured using processes familiar to the semiconductor fabrication industry, which allow a very high degree of precision in the production process exceeding that of the other types listed here. Accordingly, they are the current techonology of choice for RF and similar applications where high-precision discrete inductors are required.

Toroidal

The defining characteristic of toroidal type inductors is their core shape, which is not surprisingly a toroid or "doughnut" shape. The symmetry and closed magnetic circuit offered by such a core shape result in minimal magnetic flux leakage from the device to an extent that toroidal inductors are sometimes considered shielded and described as such, even in the absence of any outer shielding material. Toroidal inductors are frequently produced with a variety of additional furniture to facilitate mounting, and while clearly formed by winding wire around a core, they are not classified as "wirewound" due to the distinguishing characteristics associated with their core shape. Due to practical difficulties associated with winding wire around a toroidal core, the cost of toroidal inductors and other magnetic components is their primary disadvantage.



Wirewound

Wirewound inductors are those formed by wrapping wire around a magnetic core of some type, and which have no distinguishing feature which would cause them to be categorized otherwise. The bulk of the general-purpose inductors available are of this type. They are relatively inexpensive and easy to produce, and as such are favored where large inductance values or current handling capability are called for, a high degree of precision isn't particularly important, and cost is a factor.

Material - Core

An inductor's core carries the magnetic flux produced when current flows through its windings, for which it also often provides mechanical support. The properties of the materials used have a significant influence on the resulting behavior of the device, including the amount of inductance that can be obtained, stability of that inductance value over temperature and DC bias, saturation behaviors, efficiency, and most other characteristics of interest.

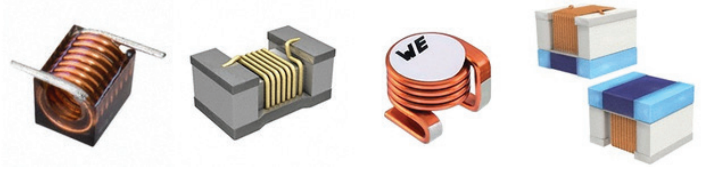
The core material designations listed here reflect information provided by the product manufacturers. The various terms are not mutually exclusive as a result, and exhibit varying degrees of specificity and overlap among each other. In addition, approximately 1/5th of the products listed at the time of writing did not have values entered for this parameter. For these reasons, a high degree of care should be used when making selections from this column, and inclusion of the null (dash) value is also recommended to avoid omission of potentially useful search results.

Non-Magnetic Materials

Non-magnetic materials are those which do not appreciably affect a magnetic field in which they are placed. When used as inductor cores, they primarily provide mechanical support for the windings rather than participating in the device's magnetic circuit. Lack of a magnetic core restricts the amount of inductance that can be achieved in a given physical space but avoids core losses and saturation, so devices based on non-magnetic core materials are mostly low inductance (<1uH) devices with comparably good Q factors, high-frequency performance, linearity, and stability. They commonly find use in RF and signal applications where minimizing non-ideal behaviors is of more importance than the ability to store large amounts of energy.

Air

Some devices labeled described as having an air core actually are just a self-supporting coil of wire (perhaps with some non-magnetic furniture attached to facilitate handling and assembly) while the term "air core" is also occasionally used as a generic reference to devices with non-magnetic cores, given the negligible difference between actual air and other non-magnetic materials.

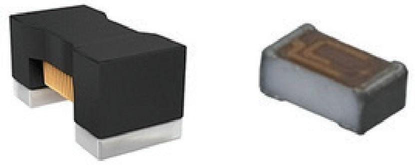


Alumina

Also known as aluminum oxide and having a chemical formula Al2O3, alumina is a widely-used ceramic material in the electronics industry and elsewhere. It's hard and has high temperature resistance with relatively good thermal conductivity, which can be useful for aiding extraction of heat from an inductor's windings.

Non-Magnetic

Products described as having a non-magnetic core are those where the manufacturer's data indicates as much, but provides no further detail.

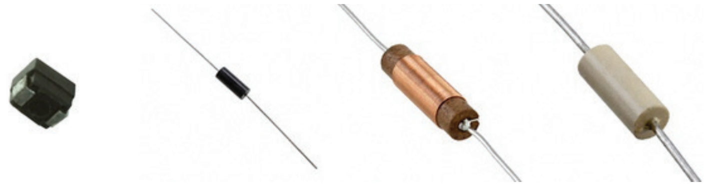


Polymer

While "polymer" is a very non-specific term, those that would seem likely candidates for use as an inductor core are likely to be non-magnetic, less robust to elevated temperatures, and less thermally conductive than alumina, though less costly by volume and with greater ease of manufacture. Parts thus described at the time of writing are currently limited to a small smattering of obsolete part series.

Phenolic

Slightly less general a term than "polymer" is "phenolic," which implies a thermosetting (doesn't re-melt with application of heat) polymer based on a phenol. It's non-magnetic, which is the chief item of interest so far as inductor cores are concerned.



Ceramic

The term "ceramic" in this context is not particularly helpful, insofar as materials that can be classified as ceramic may have wildly varying magnetic properties—ferrites are considered a ceramic and are highly magnetic, whereas aluminum oxide ("alumina") is also considered a ceramic material and is non-magnetic. The general implication of the term "ceramic" seems to lean more toward the latter (non-magnetic) sense however, and the low-inductance/high-frequency characteristics of the bulk of the products thus labeled suggest that the majority of these "ceramic" cores are indeed of a non-magnetic character.

Magnetic Materials

Magnetic materials are to inductors what dielectric materials are to capacitors: they allow a higher inductance value to be achieved for a given set of windings than would be achieved by using a non-magnetic material at the expense of introducing new loss mechanisms and operational limitations.

More thorough explanations are available from other resources, but a few key concepts merit brief description here:

(Relative) Permeability: Loosely speaking, a magnetic material's relative permeability characterizes the factor by which it increases the inductance of a given coil when used as a core material, relative to the same coil's inductance with a non-magnetic core. Higher permeability is generally better when the associated trade-offs aren't unbearable because it allows use of fewer windings to achieve a desired inductance value. For brevity, the "relative" portion is commonly dropped in casual discussion.

Saturation Flux Density: Loosely speaking, a magnetic material's saturation flux density characterizes the amount of magnetism it can carry before it becomes 'full' and its magnetic properties rapidly deteriorate. Higher saturation flux densities allow use of physically smaller cores to achieve a given inductance value, making higher values preferable when the associated trade-offs are acceptable. It's commonly specified in units of Teslas (T) or gauss, with 1T=10x10^3 gauss.

Powdered Metal Materials

Powdered-metal fabrication processes are a family of manufacturing techniques based on molding finely-divided powders of a metal or alloy into a desired shape, usually followed by a sintering or bonding process to provide mechanical strength. Characteristic of such techniques is a high degree of control over the chemical composition of the materials used, and the ability to achieve highly uniform material properties throughout a finished part.

Powder processes offer unique benefits for making inductor (or transformer) cores in that the electrical and magnetic properties of the resulting materials can be altered relative to a contiguous, bulk mass of the same basic stuff. Through tweaks to variables like powder grain size, the amount of porosity (or amount of binder material used) in the part, and any coatings or oxide layers present on the powder grains, the saturation, permeability, and loss characteristics of materials can be adjusted, allowing the use of materials, geometries, and operational parameters that would otherwise be impractical using solid/bulk materials. Powdered metal materials typically find use at frequencies up to a few hundred kHz, beyond which ferrite materials tend to become preferred.

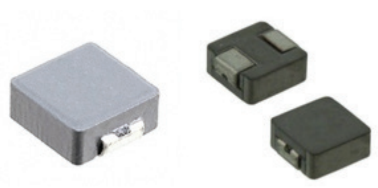
Due to the influence of processing and construction techniques on material properties along with variations in exact material content, the following represent general classifications, more so than references to specific materials with specific, fixed properties.

Powdered Iron

Powdered iron cores are the low-cost/high-loss option among the common metal powder core materials, though they do offer relatively high saturation flux densities in the region of 1.2~1.5T, and relatively stable characteristics with temperature. Where size is not of great importance, the low material cost allows some of the loss characteristics to be offset through the use of a larger core cross section than might otherwise be chosen.

Carbonyl Powder

Though "carbonyl powder" is a rather inexact term from a chemical perspective, in the context of magnetic core materials it's understood to refer to carbonyl iron powder, which is a high-purity iron powder obtained through a chemical process that also can impart a unique microstructure that gives improved loss characteristics compared to iron powders prepared by other means.



Sendust

Sendust, also known by the trade name Kool mu®, is a powdered-metal alloy consisting of iron, silicon, and aluminum in roughly 85/9/6 proportions, respectively. Variations on the basic concept exist, though sendust materials generally saturate in the neighborhood of 1T, which is a figure slightly less but comparable with that expected of iron powders. In terms of both cost and loss characteristics, sendust offers a middle ground between iron powder and nickel-iron materials.

Nickel Iron

Though the term does not necessarily imply any particular ratio, a combination of nickel and iron in roughly equal proportions (often called "high flux") offers a saturation flux density of around 1.5T, which is equal to or better than iron powder but with greatly reduced loss characteristics. Due to the high proportion of nickel content it is relatively costly, but the high saturation flux density and low loss characteristics make it useful in applications where minimal core size is of interest.

Molybdenum Permalloy (MPP)

MPP is a nickel-based alloy with iron and a dash of molybdenum, with approximate proportions of 81/15/4 of Ni/Fe/Mb, respectively, though different sources cite ratios that vary by a few percent. MPP generally exhibits the lowest loss characteristics of the powdered metal core materials, favorable parameter stability with application variables, saturation flux density around 0.8T, and the highest cost of the common powder metal materials.

Ferrites

Ferrites are a class of magnetic ceramic materials based on iron oxide which have very high electrical resistivity compared to other magnetic materials. The flavors used as inductor cores are usually a “soft” type, meaning they retain little magnetization after a magnetizing force is removed (“Hard” ferrites are used to make permanent magnets). The high electrical resistance of ferrite materials allows for minimal eddy current losses in the core, making ferrites generally more useful than powdered metal materials at frequencies above a few hundred kHz. The major tradeoff for this is that ferrite materials tend to saturate at much lower flux densities (on the order of 0.2~0.5T) than powdered metal materials, necessitating use of core geometries with larger cross sections.

Ferrite

Ferrite materials are available with a wide variety of characteristics, so the description of a core material as being simply "ferrite" does not communicate much beyond those characteristics which the soft ferrite types hold in common.

Manganese Zinc Ferrite

Manganese zinc ferrites have a higher permeability and lower resistivity than nickel zinc ferrites and are used at lower frequencies, typically in a range of a few hundred kHz to a few MHz.

Nickel Zinc Ferrite

Nickel-Zinc ferrites have higher resistivity than manganese zinc ferrites and lower permeability, and are typically used at frequencies above a few MHz.

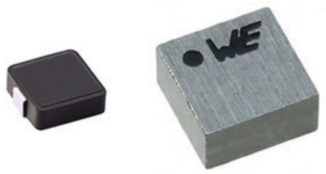
Other/Ill-Specified Materials

Iron

Devices described as having an “iron” core may or may not be produced using powder processes—the term doesn’t specify much beyond basic chemical composition. Cores made from solid slugs of iron tend to become lossy at rather low frequencies, making the use of powder processes for "iron core" inductors likely for most inductors designed for modern electronics purposes.

Iron Alloy

Insofar as a great many of the commonly used magnetic materials are alloys of iron, this term is resplendently non-specific for this context. Beyond the implication of being a material of magnetic nature and the likely use of a powder metal process, little additional information can be safely inferred.



Metal

This remarkably non-specific term doesn’t indicate much other than the core material is metallic. Whether it’s even a magnetic metal or not is not specified. Generally speaking, however, “metal” core inductors are likely to be magnetic in nature.

Metal Composite

Another very non-specific term, “metal composite” is likely a vague reference to a powdered metal core of some form, though little additional information can be inferred.

Inductance

Inductance characterizes opposition to changes in electrical current flow through a device. Folks who are shopping for inductors generally have some familiarity with this concept, so an extended description will be left for the electronics textbooks.

The inductance values for each part shown represent a nominal value, measured under manufacturer-defined test conditions, using a test signal of a specific frequency that is reflected under the Frequency - Test parameter. Actual device inductance under the standard test conditions may vary within the indicated Tolerance limits for the part, and may be observed to exceed these limits when evaluated under test conditions that differ from those specified by the manufacturer.

Current Rating

An inductor's current rating usually characterizes device limitations that arise from resistive heating caused by current flowing through the non-zero resistance of a device's windings. Methods may differ, but a common practice for establishing a device's current rating is to determine the amount of DC current flow that produces an increase in device temperature of some specified amount, often in the range of 20~40°C. It should be noted that such a test method does not account for device heating due to core losses, which contribute to the heating of devices with magnetic cores when the current through an inductor has AC content. For this reason and because of the square-law relationship between current flow and resistive heating, selecting inductors with a current rating at least 10% in excess of the RMS value that the application will impose is suggested.

Note also that some manufacturers may combine information on thermal- and saturation-derived device limitations, and specify a single current rating based on whichever phenomenon becomes limiting first.

Current - Saturation

An inductor's saturation current rating characterizes device limitations that arise from the magnetic constraints of a device's core. It is commonly determined as the amount of DC current flow through an inductor that causes the measured inductance to decrease by some proportion (often 20~30%) from it's initial value under the manufacturer's standard test conditions. While saturation is something to be avoided in most applications, the consequences of so doing can vary significantly depending on circuit design, making it difficult to recommend a standard de-rating factor that is broadly suitable.

Note carefully that devices with non-magnetic cores are generally immune to saturation effects, and often do not list a saturation current value as a result. Specifying a non-null value or range of values for this attribute will therefore eliminate ALL such devices from search results.

Shielding

In the context of inductors, shielding refers to the containment of magnetic flux resulting from current flow through a device's windings in order to reduce unwanted coupling with nearby circuits. **Shielded** devices provide a complete (or very nearly complete) magnetic circuit through and around their windings, resulting in very good flux containment and minimum unwanted coupling, generally at higher cost than other devices. **Unshielded** devices do not provide a complete magnetic circuit through and around their windings, resulting in relatively high flux linkage and coupling to adjacent circuits, although at relatively low cost. **Semi-shielded** devices offer a measure of compromise between the two, typically through the application of an epoxy or similar material containing a magnetic substance to the regions of an unshielded inductor from which flux leakage would otherwise occur. Such an approach offers a balance between the cost and flux containment/coupling avoidance characteristics of shielded and unshielded types. A hyphen or "dash" in this parametric column indicates that the information was not provided by the manufacturer or has not yet been entered into the product database.

Note that inductors with non-magnetic core materials are predominantly of an unshielded type.

DC Resistance (DCR)

Until room-temperature superconducting materials become available, the windings of all fixed inductors will possess some amount of electrical resistance. The values reflected here typically represent a limiting maximum value quoted by the manufacturer, measured using a DC test signal at the manufacturer's standard test temperature.

Q @ Freq

An inductor's Q factor is a measure of how closely a device approaches an ideal, pure inductance. More precisely, it is the ratio of the complex part of a device's impedance to its real part, which can also be understood as the amount of energy an inductor is capable of storing divided by the amount of energy lost in the process. Ideally, energy losses would be zero, resulting in a Q value of infinity. Because all practical inductors currently have some amount of DC resistance, this isn't possible. Additionally, the use of magnetic core materials can introduce additional losses, though this can be offset by reductions in the length of the windings required to achieve a given inductance value.

The Q values shown are in most cases "typical" values provided by the manufacturer, which are not guaranteed but are representative of the bulk of parts produced. The associated frequency value indicates the frequency at which the indicated Q value is measured, which may or may not be the same as the value shown under the Frequency-Test attribute for a part. The frequency qualification provided for Q values is particularly pertinent to devices which incorporate magnetic core materials since the behaviors of these materials (and the resulting Q factor) is frequency dependent as a general rule. Other factors including temperature and mechanical stress can influence the behavior of magnetic materials, all of which combine to make observed Q values in magnetic-core inductors a relatively variable and application-dependent quantity.

Frequency – Self Resonant

Real-world inductors invariably exhibit some amount of parasitic capacitance, which is effectively in parallel with the desired inductance between the device's terminals. As the frequency of an applied signal increases, the influence of this parasitic capacitance increases until it becomes dominant, and the inductor no longer behaves as an inductor. The point at which this transition occurs is known as an inductor's self-resonant frequency, and represents the maximum frequency for which an inductor is useful as such. Subject to other considerations, (inductance, current ratings, size, cost, etc.) typical applications are best served by devices with as high a self-resonant frequency as possible.

Ratings

In this context, the "ratings" attribute is used solely to indicate whether or not a part is qualified to AEC-Q200 standards. The AEC (Automotive Electronics Council) is an industry organization which promotes standards of quality, reliability, and durability for electronic components used in automotive applications. Further information regarding these standards may be found at http://aecouncil.com/AECDocuments.html.

Frequency - Test

This attribute indicates the frequency of the test signal used by a manufacturer to determine a device's Inductance value. It may or may not be the same frequency at which a device's Q value is characterized. Device characteristics may differ from those listed when operated at other frequencies, particularly for devices that incorporate magnetic core materials. For this reason, selection of devices with a test frequency in the same ballpark as the intended frequency of operation is suggested as a means of aiding more rapid identification of components likely to be of use.

Features

This attribute is used to indicate product characteristics of particular note. At the time of writing, soft terminations are the only such feature enumerated in this context. Soft terminations refer to the use of materials and construction techniques in ceramic-bodied devices that allow for limited mechanical flexure to occur between a device's ceramic body and its electrical contacts in order to reduce the risk of failure from mechanical fracture. This is a feature much more commonly found in ceramic capacitors and resistors, however, a handful of inductive products are now being produced with such features as well.