WIRE-WOUND RF CHIP INDUCTORS

Application Notes

Pulse
A TECHNITROL COMPANY

The Basics of Wire-Wound Chip Inductors

Pulse currently supplies high quality magnetic products to companies such as 3COM, Cisco, Ericsson, Intel, Marconi, Nokia and Nortel and has been active in the field of RF engineering, since the launch of its first wire-wound 1008 chip product in 1982. Pulse now offers five ranges of wire-wound chip from 0402 to 1210 (see table 1.0 below): the "CD Range" with 100% compatibility to other market leaders, and the "CM and CQ ranges" with improved electrical performance with a Ceramic core construction; the FD and FT series with a Ferrite core construction.

In recent years, Pulse has leveraged its strength within the Telecoms and Networking industry to extend its product range to encompass RF products for the Cable Modem, CATV, MMDS and TETRA markets. Pulse now also offers Wide Bandwidth RF Transformers, Splitter Combiners, Couplers, Diplexers, Low Pass Filters and High Power Impedance Matching Transformers. To explore the complete range of RF products, visit the Pulse website: **http://www.pulseeng.com./Products/finder/rf_hfc_cable.htm for cable products** *and* **http://www.pulseeng.com/scripts/finder/rfind/mcis.cfm for RF chip inductors.**

Pulse Part No.	Inductance Range (nH)	Number of Values	Tolerance Range	Availability
PE-0402CD	1.0 ~ 120	28	5 & 10%	In Mass Production
PE-0603CD	1.8 ~ 390	32	2, 5, 10 & 20%	In Mass Production
PE-0805CD	3.3 ~ 1500	32	1, 2, 5, 10 & 20%	In Mass Production
PE-0805CM	3.3 ~ 680	25	1, 2, 5, & 10%	In Mass Production
PE-0805FT	1000 ~ 68000	12	5 & 10%	In Mass Production
PE-1008CD	4.7 ~ 5600	39	2, 5 & 10%	In Mass Production
PE-1008CM	4.7 ~ 4700	40	1, 2, 5, 10 & 20%	In Mass Production
PE-1008CQ	3.0 ~ 220	13	5 & 10%	In Mass Production
PE-1008FD	150 ~ 10000	15	5 & 10%	In Mass Production
PE-1210FT	10 ~ 12000	38	5 & 10%	In Mass Production
PE-1206CD	3.3 ~ 1200	28	5 & 10%	In Mass Production

Table 1.0 Pulse Chip Inductor Product Range

Competing Chip Inductor Types

Capacitor and resistors are available in a wide variety of sizes and component values and it is possible to purchase almost any value, tolerance or other rating. Inductors, on the other hand, are not so readily available and engineers may find it necessary to wind their own inductors to get a specific value of inductance.

There are mainly 3 varieties of inductor in common use today and they are wire-wound, multi-layer and drum core chip inductors. The primary differences between these competing types are the core material used to enhance the inductance of coil and the construction method. Wire is wound around a ceramic or ferrite bobbin or in the case of multi-layer the coil is formed by interconnecting layers of conductive material printed on a ceramic substrate.

Table 2.0 indicates that the performance merits of wire-wound inductors versus the alternative multi-layer and drum core platforms. If price were the only consideration then, of course, there would be no market available for wire-wound chip inductors. But price is not the only consideration, since RF engineers must also consider the needs of the application in terms of Q factor, Idc (maximum current carrying capacity). Rdc (resistance at dc), Tolerance and SRF (self-resonant or series resonant frequency.

SMT	Technology	Material Substrate	Q Factor	SRF	Idc	Tolerance
Chip Inductor	Wire-wound	Ceramic	High	High	High	Good
Chip Inductor	Wire-wound	Ferrite	Low	Low	High	Poor
Multi-layer	Printed	Ceramic	Low	Low	Low	Poor
Drum Core	Wire-wound	Ferrite	Low	Low	Low	Poor

Table 2.0 Summary of Chip Inductor Relative Performance

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The Inductor Basics

An inductor is formed by winding a wire around a ceramic or ferrite core to increase the magnetic flux linkage between the turns of the coil. The majority of high frequency inductors above 50MHz are formed on a ceramic bobbin or substrate. Nonmagnetic cores (ceramic cores) have the opposite effect to a magnetic core in that they reduce instead of increase the inductance of the coil. Ceramic cores are mainly used to reduce the RF core losses as the high frequency currents mainly flow near the surface of the conductor. The resistance that a conductor offers to the high frequency alternating current is much greater than the resistance of the same conductor to direct current (dc) and is known as the skin effect. The skin effect is a characteristic of conductors that carry alternating current and is much more pronounced in coils than in straight conductors.

Skin effect causes the current in the conductor to be much denser near the surface of the conductor than at its centre. Consequentially, as the instantaneous value of the alternating current changes the inductance of a conductor in its interior is much greater than the instantaneous inductance near its surface. The result is more current flows near the surface or "skin" of the conductor than at its centre. Since the inductance of the coil increases proportionally to the increasing frequency, the skin effect also increases as the frequency is increased.

Another source of loss is the dielectric material used to form the body of the inductor. There is no perfect insulator and so dielectric losses can not be avoided at very high frequencies. Dielectric losses, like skin effect also tend to increase the effective resistance of a coil at high frequencies.

Whilst there is no perfect component compared to a resistor or capacitor, inductors are probably the component most prone to changing its performance over frequency. Figure 1.0 illustrates what a real world inductor looks like at RF frequencies and the resultant equivalent circuit.

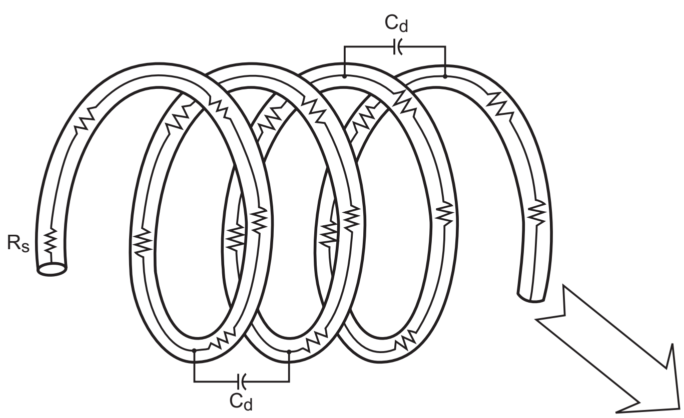

Fig. 1.0 A
Distributed Capacitance and
Series Resistance in an Inductor

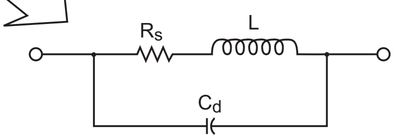

Fig. 1.0 B
Equivalent Circuit
of an Inductor

Fig. 1.0 A shows how capacitive coupling (Cd) can occur between two wires, when the wires are placed in close proximity to one another and only separated by a dielectric. The resistance (Rs) is a representation of the wire resistance that exists in a wire. **Fig. 1.0 B** shows a representation of the lumped resistive, capacitive and inductive component elements of an inductor.

The Inductor Basics *(continued)*

The effect of Cd can have a dramatic effect upon the impedance of the inductor as illustrated in Fig 2.0, because "fringe" effects become dominant at high frequencies. At low frequencies the inductor's reactance parallels that of an ideal inductor. With increasing frequency the reactance of the inductor departs from the ideal curve and increases at a much faster rate until it reaches a peak value at the inductor's parallel resonant frequency (Fr). Above Fr the inductor's reactance begins to decrease with increasing frequency and thus the inductor begins to look like a capacitor. The series resistance (Rs) of the coil prevents the impedance of the inductor from reaching infinity at resonance (Fr). Another effect of Rs is to broaden the resonant peak of the impedance curve at Fr.

Comparisons made between inductors at near to Fr will produce an inaccurate representation of the inductor's performance. This can lead to problems in the end application since the performance of one inductor to another may vary quite markedly since the performance of the inductor is dominated by the parasitic content (distributed capacitance Cd) of the inductor.

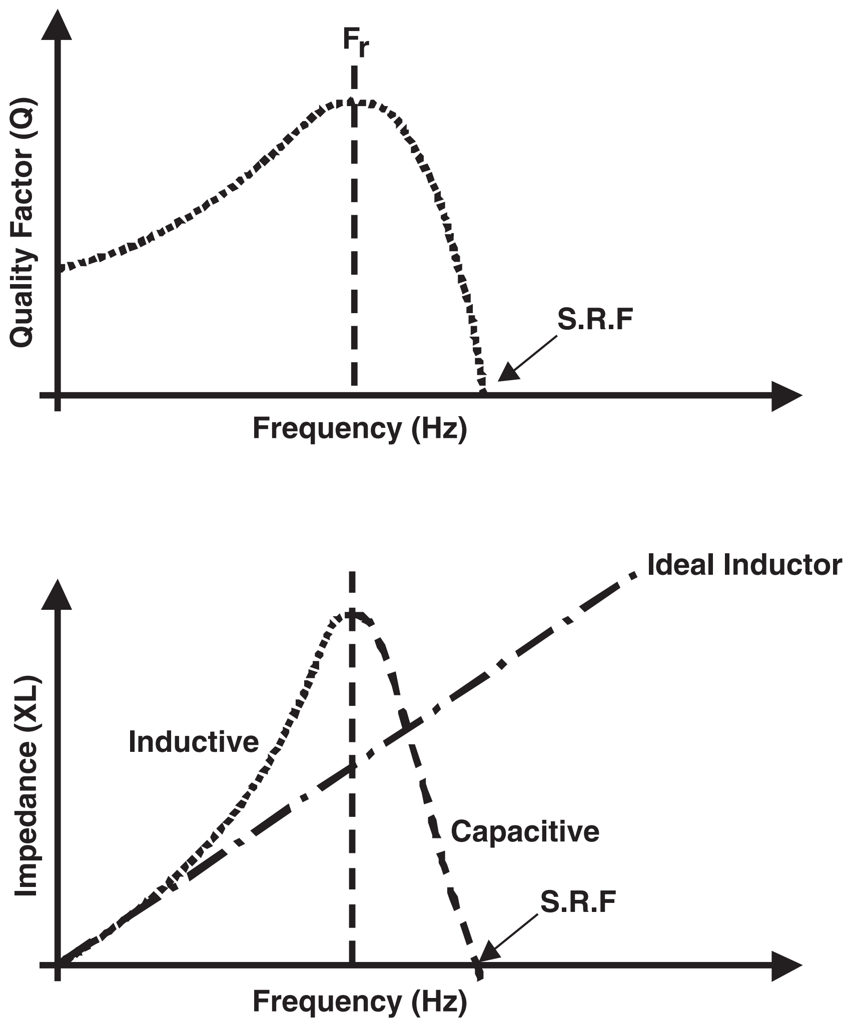

Fig. 2.0 Impedance and Inductance Characteristic of a Real World Inductor

Q factor / SRF

The ratio of an inductor's reactance (XL) to its series resistance (Rs) is often used as measure of the quality factor of the inductor. The larger the ratio, the better the inductor. The quality factor of an inductor is often referred to as the Q of the inductor. If the inductor were constructed from a perfect conductor (zero loss), its Q would be infinite. Of course this is impossible, and so the Q of an inductor will always have some finite value.

The Q factor, Fr and SRF of an inductor are directly linked to one another. If the test frequency is near Fr or SRF, the inductor results may be misleading by very wide margins, since the result is dominated by distributed capacitance reactance. To overcome this problem, the test frequency of the inductor is normally located at a point on the inductor's curve where the reactance of the inductor approaches that of an ideal inductor, so that component to component variations are kept to a minimum since the parasitic contribution is also at a minimum. To overcome this problem, RF engineers should select an inductor with the highest test frequency possible to guarantee the quality of the inductor.

At low frequencies, the Q of an inductor is very good because the only resistance in the winding is the dc resistance of the wire which is very small (Fig. 2.0). As mentioned earlier, as the frequency increases, the skin effect increases to degrade the Q of the inductor. At low frequencies, the Q increases directly inline with the reactance (XL) since the skin effect has not become noticeable. The Q continues to rise, but as the frequency approaches Fr, the skin effect starts to become a dominant, reducing the rate of increase. At Fr, the series resistance and reactance are increasing at the same rate. Above Fr, the distributed capacitance Cd and skin effect of the winding combine together to decrease the Q of the inductor to zero at SRF.

Understanding Inductor Curves

RF design engineers require inductors to meet the following requirements:

1. Low cost
2. Compatibility to the competition
   Q, SRF and useable frequency range => competition
3. Component to component variation small
4. Performance approachs that of an ideal inductor
   High Q (low series resistance)
   High SRF (low distributed capacitance)

	Ideal Inductor		Real World Inductor	
Distributed Capacitance	Cd = 0	Infinite SRF	Cd = Min	High SRF High Fr
Series resistor	Rs = 0	Infinite Q	Rs = Min	High Q High Fr

3.0 Characteristics of a Real World Inductor Vs Ideal Inductor

Determining the Inductor Equivalent Circuit

To determine the inductor equivalent circuit, an RF engineer must deduce the value of Rs and Cd from the curves supplied by the inductor manufacturer. To do this, the following equations can be used. Of course, the values deduced only apply at one specific frequency. The recommended frequency at which the inductor is used within the application should be an order of magnitude (÷ 10) below the SRF, and preferably not near than ½ Fr.

Equation 1: $Fc < \frac{SRF}{10}$ and/or $< \frac{FR}{2}$

Equation 2: $Rs = \frac{XL}{Q} = \frac{2 * \pi * Fc * L}{Q}$

Equation 3: $Cd = \frac{1}{(2 * \pi * SRF)2 * L}$

Where:
Fc = Centre frequency of application / intended operation
SRF = Series resonant or self resonant frequency of the inductor
π = 3.14159
L = Inductor value

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