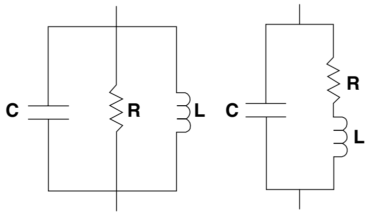
Circuit Simulation of Surface Mount Inductors and Impedance Beads

INTRODUCTION

With the advent of higher component densities, smaller components, and reduced design to market times, many of today's complex circuits are designed using a computer and circuit simulation software rather actual physical bread boarding.

Inductors can be one of the most difficult passive components to accurately simulate, due to their inherent parasitic capacitive and resistive elements. These parasitic elements are the result of the resistance and turn-to-turn capacitance of the current conductor, which will affect the characteristic impedance of the inductor, particularly at higher frequencies. Figure 1 illustrates the equivalent circuit model for a real inductor with parasitic elements.



Circuit A Circuit B

Figure 1. Equivalent Circuit for a Real Inductor

SIMULATING THE PERFORMANCE OF AN INDUCTOR

In many computer based circuit simulators, if a single element inductor is placed in the circuit, it will be represented as an ideal inductor. This may be acceptable if the simulation is at a frequency well below the series resonant frequency (SRF) of the inductor, as the impedance curve for the ideal and the real inductors are identical over frequency until a point that is about 20 % of the inductor's SRF. At this point, the impedance curves diverge due to the effects of the parasitic elements.

However, the accuracy of the ideal inductor model will begin to increase beyond 20 % of the inductor's SRF.

Figure 2 is a graph of the impedance versus frequency characteristics of a real and ideal inductor.

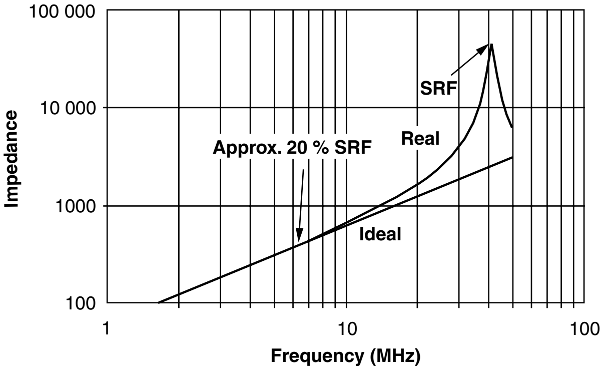


Figure 2. Impedance/Frequency Curves of Real and Ideal 10 µH Inductor

Most inductors can be represented with an acceptable degree of accuracy by one of the circuits shown in Figure 1. Circuit A typically represents an inductor that uses a magnetic core material such as ferrite or powdered iron. Circuit B will accurately represent most nonmagnetic core inductors commonly referred to as "air cores." If the equivalent circuit values of the parasitic capacitance and resistance are known along with the effective inductance, the inductor model can be inserted in the circuit simulator and provide an accurate representation of the inductor's true performance in the A circuit.

Vishay Dale has generated the equivalent circuit values for many of its surface mount product lines. A table illustrating the equivalent circuit values for each of the current Vishay Dale product lines follows this discussion.

LIMITATIONS OF INDUCTOR MODELS

Most inductors are used well below their series resonant frequency (SRF) and these basic, three element inductor models will be very accurate under these simulation conditions. The SRF of the inductor occurs when the inductivereactance (X_L) is equal to the capacitive reactance (X_C) of the conductor. The impedance of the inductor is at its maximum and would be infinite if there were no core loss or if the resistance of the conductor were zero. Above the SRF, the X_C exceeds X_L and the inductor behaves like a capacitor. As the frequency increases above the SRF point, the inductor will go through several more resonant phases as a result of secondary parasitic elements which require a more complex equivalent circuit. For this reason, the typical useful range for the three element inductor models is the SRF of the inductor plus about 25 %.

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	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (nH)	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (nH)
1.2	B	75.790	2.12680	0.896
1.5	B	50.568	1.48730	1.254
1.8	B	69.254	1.32050	1.469
2.2	B	72.762	0.91637	2.115
2.7	B	79.357	0.82001	2.356
3.3	B	87.174	0.66923	2.929
3.9	B	86.272	0.57138	3.452
4.7	B	123.660	0.47681	4.150
5.6	B	143.730	0.38200	5.255
6.8	B	171.930	0.31975	6.376
8.2	B	230.000	0.28377	7.329
10.0	B	213.970	0.23723	8.904
12.0	B	312.950	0.19187	11.175
18.0	B	554.440	0.13639	16.818
33.0	B	792.650	0.08367	30.769
39.0	B	1.059	0.07628	35.933
47.0	B	1.832	0.06090	45.300
56.0	B	1.987	0.05267	54.122

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	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (nH)	CIRCUIT	RESISTANCE (mΩ)	CAPACITANCE (pF)	INDUCTANCE (nH)
1.5	B	0.0319	0.0000	1.34
1.8	B	0.0485	0.0000	1.65
2.2	B	0.0557	0.0000	1.98
2.7	B	0.0554	0.0125	2.52
3.3	B	0.0374	0.0118	3.15
3.9	B	0.0541	0.0232	3.68
4.7	B	0.0834	0.0362	4.40
5.6	B	0.1197	0.0439	5.46
6.8	B	0.1209	0.0486	6.54
8.2	B	0.1256	0.0515	7.82
10.0	B	0.1806	0.0555	9.64
12.0	B	0.2173	0.0620	11.55
15.0	B	0.2812	0.0630	14.64
18.0	B	0.3140	0.0647	17.45
22.0	B	0.3322	0.0698	21.26
27.0	B	0.4009	0.0683	25.98
33.0	B	0.5273	0.0740	31.95
39.0	B	0.5809	0.0694	37.29
47.0	B	0.7227	0.0723	45.30
56.0	B	0.9117	0.0667	53.70
68.0	B	1.0948	0.0717	63.19
82.0	B	1.4347	0.0684	76.62
100.0	B	1.5531	0.0709	93.26

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	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (nH)	**CIRCUIT**	**RESISTANCE (É^1)**	**CAPACITANCE (pF)**	**INDUCTANCE (nH)**
3.9	B	0.0884	0.0075	4.3
4.7	B	0.0958	0.0061	4.6
5.6	B	0.1053	0.0325	5.5
6.8	B	0.1297	0.0320	5.2
8.2	B	0.1472	0.0398	8.1
10	B	0.1468	0.1445	11.2
12	B	0.1749	0.0598	12.6
15	B	0.1861	0.0836	16.4
18	B	0.2194	0.0698	18.8
22	B	0.2420	0.0837	22.4
27	B	0.2638	0.0921	27.4
33	B	0.2814	0.1046	33.4
39	B	0.3282	0.0924	39.0
47	B	0.3432	0.0975	45.3
56	B	0.4023	0.0927	55.7
68	B	0.4356	0.0936	67.9
82	B	0.4880	0.1503	79.8
100	B	0.5968	0.0968	94.4
120	B	0.7235	0.1994	97.7
150	B	1.1647	0.1295	132.9
180	B	1.2414	0.1698	150.2
220	B	1.3983	0.1719	194.2
270	A	17.7k	0.4812	230.6
330	A	16.4k	0.5637	274.2
390	A	12.6k	0.8714	331.9
470	A	10.5k	1.5701	425.7
560	A	10.9k	1.2488	491.0
680	A	12.1k	1.3662	592.1
820	A	13.5k	1.1962	737.5
1000	A	12.5k	1.4749	859.1

IMC-1210

	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (µH)	**CIRCUIT**	**RESISTANCE (Ω)**	**CAPACITANCE (pF)**	**INDUCTANCE (H)**
0.010	B	89.79 m	0.0984	6.83 n
0.012	B	107.98 m	0.0965	9.09 n
0.015	B	119.35 m	0.1285	11.09 n
0.018	B	138.90 m	0.1390	14.62 n
0.022	B	135.92 m	0.1827	18.48 n
0.027	B	172.43 m	0.2258	22.37 n
0.033	B	218.71 m	0.1876	30.59 n
0.039	B	209.12 m	0.2440	35.42 n
0.047	B	215.71 m	0.2882	37.57 n
0.056	B	308.05 m	0.3251	46.38 n
0.068	B	224.86 m	0.3369	54.42 n
0.082	B	359.50 m	0.2936	63.2 n

IMC-1210

	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (µH)	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (H)
0.100	B	353.36 m	0.3709	80.52 n
0.120	B	363.80 m	0.5019	103.4 n
0.150	B	229.68 m	0.6020	139.55 n
0.180	B	312.54 m	0.6353	159.31 n
0.220	B	269.10 m	0.7814	205.23 n
0.270	A	5.98 k	0.6474	253.82 n
0.330	A	4.11 k	0.6869	309.87 n
0.390	A	4.59 k	0.7050	375.18 n
0.470	A	7.48 k	0.7929	439.72 n
0.560	A	9.09 k	0.9563	523.33 n
0.680	A	10.66 k	0.8764	646.61 n
0.820	A	11.24 k	0.7070	751.05 n
1.0	A	14.21 k	1.2100	0.99 µ
1.2	A	13.73 k	0.9900	1.15 µ
1.5	A	15.51 k	1.5800	1.46 µ
1.8	A	18.89 k	1.4300	1.72 µ
2.2	A	20.98 k	1.1200	2.11 µ
2.7	A	25.90 k	0.9800	2.66 µ
3.3	A	24.65 k	1.5200	3.16 µ
3.9	A	27.80 k	1.6900	3.67 µ
4.7	A	26.43 k	1.4100	4.5 µ
5.6	A	35.52 k	1.3400	5.28 µ
6.8	A	38.26 k	1.5700	6.32 µ
5.2	A	37.93 k	1.3500	7.52 µ
10.0	A	46.21 k	1.5200	9.43 µ

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	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (µH)	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (H)
0.010	B	64.1	0.1357	9.9 n
0.012	B	88.7	0.1463	11.8 n
0.015	B	130.7	0.1746	14.6 n
0.018	B	143.7	0.1926	17.4 n
0.022	B	200.2	0.1892	21.3 n
0.027	B	156.7	0.2227	29.2 n
0.033	B	273.4	0.1597	38.4 n
0.039	B	197.6	0.2976	34.0 n
0.047	B	212.7	0.2630	44.2 n
0.056	B	277.6	0.3289	48.1 n
0.068	B	314.1	0.2958	61.8 n
0.082	B	325.6	0.2483	84.9 n
0.100	B	412.8	0.3469	84.9 n
0.10	A	11.46	0.5351	0.0935 µ
0.12	A	13.69	0.4697	0.1177 µ
0.15	A	13.69	0.4757	0.1424 µ
0.18	A	18.45	0.5231	0.1623 µ
0.22	A	28.14	0.4544	0.2012 µ
0.27	A	45.62	0.4926	0.2408 µ

For technical questions, contact: magnetics@vishay.com

IMC-1812

	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE (µH)	CIRCUIT	RESISTANCE (kΩ)	CAPACITANCE (pF)	INDUCTANCE (µH)
0.33	A	28.00	0.5365	0.2957
0.39	A	29.24	0.5127	0.3429
0.47	A	29.47	0.5427	0.4508
0.56	A	41.36	0.4498	0.5104
0.68	A	32.51	0.4792	0.6067
0.82	A	32.76	0.4674	0.7412
1.00	A	12.40	1.6920	0.9513
1.20	A	12.33	1.6740	1.1640
1.50	A	14.92	1.6930	1.4020
1.80	A	18.89	1.4410	1.7370
2.20	A	23.51	1.6220	2.1300

ILBB-0603

	EQUIVALENT CIRCUIT DATA			
NOMINAL IMPEDANCE	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (µH)
40	A	65	0.900	0.0952
60	A	80	0.900	0.1533
68	A	100	0.900	0.1779
80	A	118	1.000	0.1993
120	A	157	1.200	0.3356
220	A	315	0.900	0.6037
300	A	420	0.800	0.7954
450	A	545	0.800	1.1186
600	A	690	0.800	1.4531
750	A	810	0.900	2.0182
1000	A	1.1k	0.658	2.4001

ILBB-0805

	EQUIVALENT CIRCUIT DATA			
NOMINAL IMPEDANCE	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (µH)
11	A	18	0.90	0.0273
32	A	50	0.85	0.1053
60	A	82	0.70	0.2114
90	A	125	1.00	0.2836
120	A	165	1.00	0.2969
150	A	208	1.00	0.4437
300	A	350	1.00	0.8621
400	A	510	0.90	1.3274
600	A	636	1.20	1.3454
1000	A	975	1.00	2.7573
1500	A	1600	1.00	4.7412
2000	A	2500	0.90	7.4365

ILB-1206

	EQUIVALENT CIRCUIT DATA			
NOMINAL IMPEDANCE	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (H)
19	A	27	0.9	63.51 n
26	A	37	0.8	75.00 n
50	A	75	0.4	109.60 n
31	A	37	1.0	73.34 n
70	A	95	0.2	174.12 n
120	A	150	1.5	352.33 n
150	A	180	0.9	492.76 n
300	A	330	1.8	1.05 µ
500	A	485	2.1	1.69 µ
600	A	610	2.0	2.49 µ

ISC-1210 0.10 µH - 1 µH

	EQUIVALENT CIRCUIT DATA			
NOMINAL INDUCTANCE	CIRCUIT	RESISTANCE (Ω)	CAPACITANCE (pF)	INDUCTANCE (µH)
0.010	A	1.04	0.1003	0.00741
0.012	A	1.21	0.1051	0.00782
0.015	A	1.80	0.2178	0.01284
0.018	A	2.50	0.2487	0.01564
0.022	A	2.35	0.2434	0.01889
0.027	A	3.00	0.2279	0.02466
0.033	A	3.07	0.1983	0.03188
0.039	A	3.63	0.4437	0.03427
0.047	A	4.39	0.2873	0.03947
0.056	A	5.47	0.4233	0.04478
0.068	A	4.74	0.3259	0.06028
0.082	A	10.12	0.3506	0.07696
0.100	A	7.50	0.4130	0.08288
0.120	A	2.39	0.5536	0.12007
0.150	A	3.37	0.5382	0.14700
0.180	A	3.20	0.6848	0.16420
0.220	A	3.99	0.6573	0.22131
0.270	A	4.27	0.6229	0.25678
0.330	A	4.75	0.6377	0.31673
0.390	A	3.00	0.9118	0.39058
0.470	A	7.49	1.1016	0.44061
0.560	A	6.19	0.9598	0.50199
0.680	A	7.79	0.7370	0.62592
0.820	A	6.85	1.0187	0.80402
1.000	A	10.40	1.3400	0.98740

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Contact Factory for Current Data

FREQUENTLY ASKED QUESTIONS

Why is the equivalent circuit inductance less than the nominal value of the inductor? For instance, the equivalent circuit inductance listed for an IMC-1210 0.82 µH inductor is only 0.74 µH.

The effective inductance of a component can be adversely affected by the parasitic elements. Capacitance cancels out some of the inductive reactance and reduces the effective inductance of the device. Throughout a family of inductors, wire size, core size, core material and number of turns will be varied to achieve the proper inductance. The most efficient inductors (with smallest parasitic element) have the lowest number of turns, the largest wire and the optimum core dimensions.

Since it is not economically feasible to have ideal core and wire sizes for each inductance value in a series, some values will have more significant parasitic elements that affect the performance of the inductor. For example, one core and wire size may be used for as many as 5 adjacent values in an inductor series. The number of turns is varied to achieve the higher inductance values. An inductor with more turns will have more inter-winding capacitance so the highest inductor with the same core and wire size will typically be more affected by the winding capacitance than the lower values.

I would like to perform a Monte Carlo analysis that will examine my circuit over the tolerance range of all my components. How much can I expect the parasitic elements to change due to manufacturing tolerances?

This is a tough question to answer.

Vishay Dale and other inductor manufacturers sell inductors based on four major specifications:

Inductance ± a percentage tolerance

Minimum Q at a specified frequency

Maximum DCR of the winding or conductor

Minimum SRF

In order to achieve these specifications, core size and material, wire size, and number of turns can be varied. Due to manufacturing tolerances on all of the inductor components, wire size and/or number of turns may vary on the same value across production lots. Varying the wire size and/or turns will affect the values of the parasitic components, however, the specified L, Q, DCR, and SRF will always be in tolerance. Vishay Dale designs and manufactures inductors with respect for the behavior of parasitic elements. Typically, the basic tolerance of the purchased inductor (i.e., 10 µH ± 10 %) can be applied to all the equivalent circuit elements in the inductor model with good success.

I use “S” parameters in my circuit simulator. Are they available for Vishay Dale inductors?

Because of the complexity of distributing “S” parameters for all the inductor series, we have opted not to provide “S” parameters for these products. As an alternative, most circuit simulation programs will generate “S” parameters for a simulated circuit. The equivalent circuit elements for the Vishay Dale inductors can be entered as a separate circuit into the simulator which can in turn generate a table or file of “S” parameters for the inductor model.

I am interested in simulating the performance of a Vishay Dale inductor that is not on the charts contained within this application note. How can I get equivalent circuit information for this inductor?

Vishay Dale will be adding equivalent circuit information for other products as demand requires. If there is a specific inductor you would like information on that has not been published, we can normally supply this information within one week of the request.

My circuit simulator already contains a library of inductive components models from Vishay Dale and other vendor products. How do I know if these are accurate models?

Some component libraries contain models that have been empirically generated from catalog specifications, and so these models may not accurately depict product performance. To have full confidence in your library of inductive component models, we strongly suggest that you contact the vendor of your circuit simulator to determine the source of the supplied inductor model data. All data included here in our Application Note has been generated by testing normally processed product and represents the typical performance you can expect from the Vishay Dale product.