Inductor Construction

Toroidal Cores.

There are many different types of magnetic material used for fabricating inductors. The purpose of the material is to provide permittivity greater than μ_O so that the inductors can be made more compactly and with fewer turns of wire. This can reduce skin effect losses in the wire and reduce coupling to other inductive components in the circuit, but the circuit losses then may be limited by the magnetic material itself. There are charts of typical unloaded Q's that can be obtained from various materials.

There are correct and incorrect ways of winding the wire around the core. Each pass through the center of the core counts as one turn. See Fig. 1-28 from Bowick[1] (attached) for details on winding. The idea is to minimize capacitive coupling between the turns while still getting enough turns on the core to obtain the needed inductance.

The toroids are designated by a code[2]: T-xxx-yy or FT-xxx-yy. T stands for iron powder materials and FT for ferrite. The first 3 digits (xxx) indicates the core outer diameter in units of 0.01" (10 mils). The last number (yy) designates the code for material type. The iron cores are color coded. The ferrite materials have much higher permeability and so require fewer turns to obtain a given inductance. They are also essential to use for wideband applications like untuned transformers. The iron powder cores simply do not work for this purpose. For narrowband, tuned applications, either type can be used in the frequency ranges in which they provide high unloaded Q. This would include matching networks such as the L or Pi network. The table below gives some specifications on the materials available in the teaching lab.

Material specifications:

Material Type/μ (color)	**Qu xxx=37**	**f Range for wideband use**	**Frequency range for high Qu**
T-xxx-2 (red)/10	> 120	not useful	1 - 20 MHz
T-xxx-6 (yellow)/8	> 120	not useful	2 - 50 MHz
T-xxx-12 (green)/3	> 120	not useful	20 - 200 MHz
FT-xxx-61 /125	> 80	10 - 200 MHz	0.2 - 11 MHz
FT-xxx-63 /40	> 125	25 - 200 MHz	10 - 25 MHz
FT-xxx-68 /20	> 120	200 - 1000 MHz	80 - 180 MHz

Tables are attached with important information regarding these cores that you will need to use when designing an inductor. The inductances can be estimated from[3]:

Iron powder cores:

$$\#\,turns = 100\sqrt{\frac{L(\mu H)}{A_L\,(\mu H\,/\,100\,turns)}}$$

[1] C. Bowick, *RF Circuit Design*, Butterworth-Heinemann, 1982.
[2] Amidon Associates
[3] ARRL Handbook, Chapter 2, American Radio Relay League, 1992.

Ferrite cores: $$\# \, turns = 1000\sqrt{\frac{L(mH)}{A_L\,(mH\ /\ 1000\, turns)}}$$

Experience shows that this formula provides only a rough estimate of inductance. You will need to actually measure the inductor on the network analyzer to determine its inductance precisely. This also has the benefit of telling you where its series resonant frequency can be found - important information for avoiding undesired parasitic oscillations in amplifiers. Squeezing turns closer together or farther apart can be used to make small adjustments in inductance and resonant frequencies.

Wire size. Since our projects are all low power, smaller wire diameters are useful. Experience has shown that #26 enamel-coated wire works well for the small diameter toroidal inductors. It holds its form and is easy to wind.

Example. Suppose you need 100 nH of inductance at 100 MHz for a matching network, so either FT-xxx-68 or T-xxx-12 would be useable at this frequency. Note that the permittivity of the ferrite is much higher, so fewer turns will be needed. However, each turn produces a larger amount of inductance so we might have trouble getting the inductance we desire.

The Ferrite Toroidal Cores table attached tells us that a FT-37-68 has an A_L value of 8.8 mH/1000 turns. The formula tells us that we will need 3.3 turns. Since we cannot get 0.3 turns on a toroidal core (only integer numbers allowed), we will be somewhat low in inductance with 3 turns: about 79 nH.

The Iron Powder table indicates that a T-37-12 core has an A_L value of 15 μH/100 turns. The formula predicts that 8.2 turns will be required. 8 turns will give us 96 nH, much closer to the goal. The unloaded Q is similar for the two materials in this frequency range. The tables also show that the 0.375” diameter core is more than sufficient for 8 turns of #26 wire.

Air core inductors. Sometimes very small value inductors can be more easily constructed using a solenoidal shape. A good way to do this is to wind wire on a threaded shaft such as a screw, then remove the screw after done. These inductors can also be tuned over some range by compressing or expanding the turns. The formula below can be used to estimate the number of turns, n, required from the diameter d and length l in inches[4]. Again, plan on verifying the inductance on the network analyzer.

$$n = \frac{\sqrt{L(\mu H)(18d + 40l)}}{d}$$

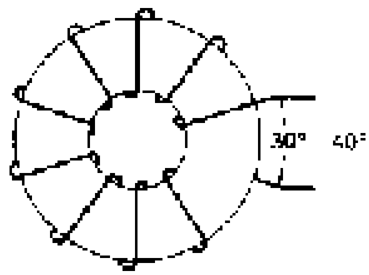
Distributed matching components. Finally, in cases where very small inductance is required at VHF frequencies and above, transmission lines should also be considered to implement distributed matching networks. See Sect. 2.5 in Gonzalez[5] for more information.

---

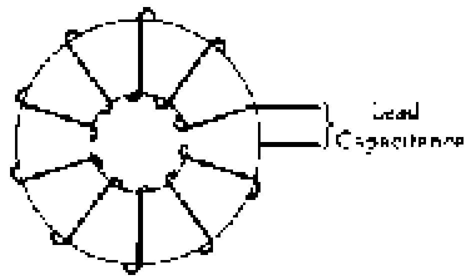
[4] op. cit.

[5] G. Gonzalez, *Microwave Transistor Amplifiers: Analysis and Design*, Second Ed., Prentice Hall, 1997.

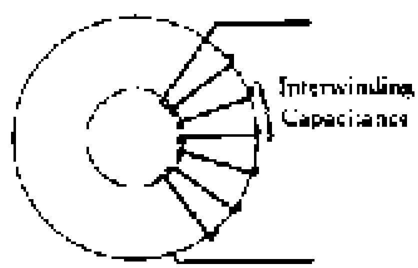
Radio Frequency Chokes (RFC). The requirements for an RFC are different than that of a tuned inductor that is to be used in a resonant circuit. The RFC must provide a high impedance over a wide range of frequencies. This implies that a low Q, wideband circuit is better for this purpose than a high Q resonant circuit. Ferrite is also manufactured in the form of cylindrical beads with one or more holes through the axis. For RFC use, choose a ferrite whose Q has already peaked at lower frequencies and is becoming more lossy as frequency increases. For example, the type 43 ferrite is useable for tuned circuits up to 50 MHz and for RFCs from 30 to 600 MHz. See the tables on Ferrite Beads for more information. Losses can be increased by adding a series resistor as shown in the RF Prototyping Techniques document.



(A) Correct.



(B) Incorrect.



(C) Incorrect.

Fig. 1-28. Practical winding hints.

From: C. Bowick, RF Circuit Design, Butterworth-Heinemann, 1982.

FERRITE TOROIDAL CORES

A_L VALUE CHART for FERRITE TOROIDAL CORES

core size	68 μ=20	63 μ=40	67 μ=40	61 μ=125	43 μ=850	77 μ=2000	72 μ=2000	75 μ=5000
FT - 23 --	4.0	7.9	7.9	24.0	188	396	396	990
FT - 37 --	8.8	19.7	19.7	55.3	420	884	884	2210
FT - 50 --	11.0	22.0	22.0	68.0	523	1100	1100	2750
FT - 50 - A --	12.0	24.0	24.0	75.0	570	1200	1200	3000
FT - 50 - B --	--	48.0	48.0	150.0	1140	2400	2400	--
FT - 82 --	23.4	22.4	22.4	73.3	557	1170	1170	2930
FT - 114 --	12.7	25.4	25.4	79.3	603	1270	1270	3170
FT - 114-A --	--	--	--	146.0	--	2340	--	--
FT - 150 --	--	--	42.0	140.0	952	2240	2240	--
FT - 240 --	--	--	53.0	173.0	1240	--	3130	--

$$\text{number of turns} = 1000 \sqrt{\frac{\text{desired L (mh)}}{A_L \text{ value above (mh/1000 t)}}}$$

WIRE SIZING CHART for FERRITE TOROIDAL CORES
core size vs. wire size: single layer wound

core size	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
FT-23 --	0	0	0	0	2	4	7	11	15	21	28	37	49	62	79	101
FT-37 --	0	0	2	4	7	11	15	21	28	36	48	63	79	100	127	161
FT-50 --	2	4	7	10	14	19	26	34	45	58	75	95	123	154	194	245
FT-82 --	3	5	8	12	16	22	29	39	51	63	84	106	135	171	216	273
FT-87 --	10	14	19	25	34	43	56	72	92	119	150	188	239	302	374	478
FT-114 --	16	22	29	38	49	63	80	100	133	166	211	263	334	420	527	665
FT-150 --	16	22	29	38	49	63	80	101	131	166	211	264	335	422	529	667
FT-193 --	31	41	53	68	86	109	139	176	223	282	357	443	562	707	886	1135
FT-240 --	36	46	60	77	98	123	154	196	250	317	400	499	631	793	993	1250

Note: Allowance has been made for winding error. A few more turns may be possible with very careful winding and close positioning of each turn.

Table 6

Powdered-Iron Toroidal Cores—A_L Values (μH per 100 turns)

Core Size	*41-Mix* Green μ = 75	*3-Mix* Grey μ = 35 0.05-5 MHz	*15-Mix* Rd & Wh μ = 25 0.1-2 MHz	*1-Mix* Blue μ = 20 0.5-5 MHz	*2-Mix* Red μ = 10 2-30 MHz	*6-Mix* Yellow μ = 8 10-50 MHz	*10-Mix* Black μ = 6 30-100 MHz	*12-Mix* Gn & Wh μ = 3 50-200 MHz	*0-Mix* Tan μ = 1 100-300 MHz
T-200	755	425	NA	250	120	100	NA	NA	NA
T-184	1640	720	NA	500	240	195	NA	NA	NA
T-157	970	420	360	320	140	115	NA	NA	NA
T-130	785	350	250	200	110	96	NA	NA	15.0
T-106	900	450	345	325	135	116	NA	NA	19.0
T-94	590	248	200	160	84	70	58	32	10.6
T-80	450	180	170	115	55	45	32	22	8.5
T-68	420	195	180	115	57	47	32	21	7.5
T-50	320	175	135	100	49	46	31	18	6.4
T-44	229	180	160	105	52	42	33	18.5	6.5
T-37	308	120	90	80	40	30	25	15	4.9
T-30	375	140	93	85	43	36	25	16	6.0
T-25	225	100	85	70	34	27	19	12	4.5
T-20	175	76	65	52	25	22	16	10	3.5
T-16	130	61	55	44	22	19	13	8	3.0
T-12	112	60	50	48	20	17	12	7.5	3.0

NA—Not available in that size.

Turns = 100 $\sqrt{L(\mu H)} \div A_L$ value (above)

All frequency figures optimum.

From: ARRL Handbook, Chap. 2, American Radio Relay League, 1992.

Number of Turns vs. Wire Size and Core Size

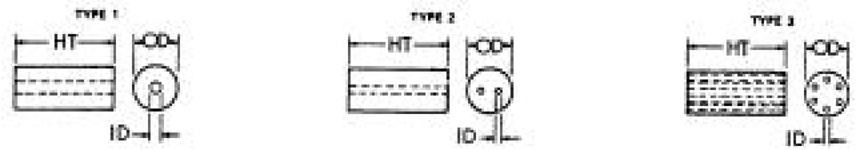
Approximate maximum of turns—single-layer-wound enameled wire

Wire Size	*T-200*	*T-130*	*T-106*	*T-94*	*T-80*	*T-68*	*T-50*	*T-37*	*T-25*	*T-12*
10	31	17	10	10	8	7	5	1	1	0
12	41	23	14	14	12	9	6	3	1	0
14	53	30	20	20	17	12	8	5	1	0
16	68	40	27	27	23	15	11	7	3	1
18	86	51	35	35	30	21	16	9	4	1
20	109	66	45	45	39	28	21	12	5	1
22	139	83	58	58	51	36	28	17	7	2
24	176	107	75	75	66	47	37	23	11	4
26	223	137	96	96	84	61	49	31	15	5
28	282	173	123	123	108	79	63	41	21	8
30	357	220	156	156	137	101	81	53	28	11
32	445	275	195	195	172	127	103	67	37	15
34	562	348	248	248	219	162	131	87	48	21
36	707	439	313	313	276	205	166	110	62	29

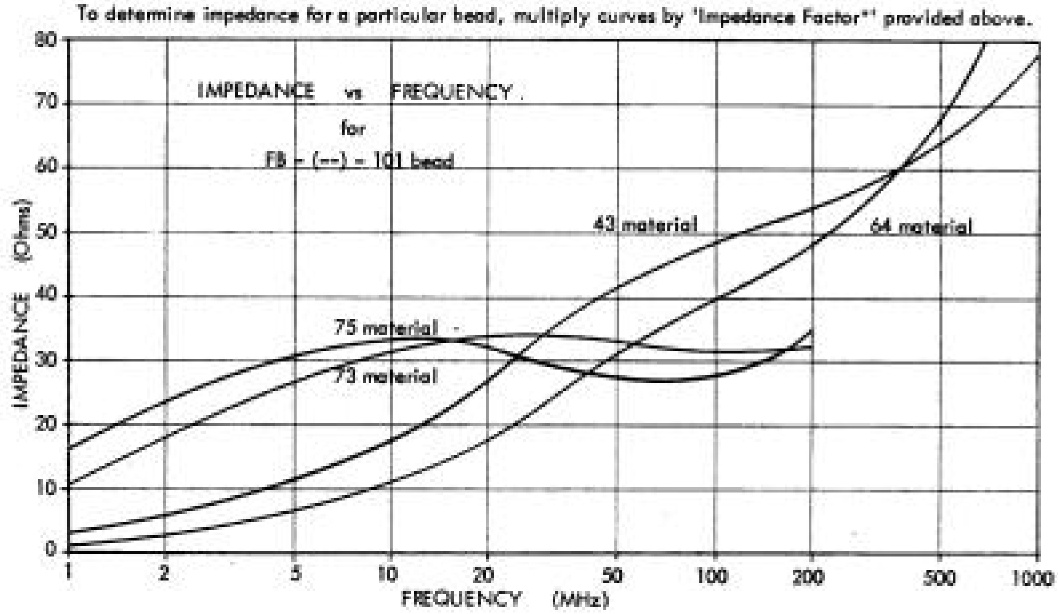
FERRITE BEADS

Part number	Bead Type	Dimensions (inches)			A_L Values (nanohenries/turn^2)					Impedance Factor *
		OD	ID	HT	43	64	73	75-8	77	
FB - (--) - 101	1	.138	.051	.118	510	150	1500	3000	---	1.0
FB - (--) - 201	1	.076	.043	.150	360		1100	---	---	0.7
FB - (--) - 801	1	.296	.094	.297	1300	390	3900	---	---	2.2
FB - (--) - 901	2	.250	.050	.417	---	1130	---	---	---	7.0
FB - (--) - 1801	1	.200	.062	.437	2000	---	5900	---	---	4.0
FB - (--) - 2401	1	.380	.197	.190	520	---	1530	---	---	1.1
FB - (--) - 5111	3	.236	.032	.394	3540	1010	---	---	---	6.7
FB - (--) - 562-1	1	.562	.250	1.125	3800	---	---	---	---	7.0
FB - (--) - 6301	1	.375	.194	.410	1100	---	---	---	2600	2.2
Complete the above part number by adding the material number in the space (--)										

Note: A_L Value (nanohenries/turn^2 = millihenries/1000 turns) based on low frequency measurement



To determine impedance for a particular bead, multiply curves by 'Impedance Factor*' provided above.



MAGNETIC PROPERTIES OF SHIELD BEAD MATERIALS						
PROPERTY	UNITS	64 material	43 material	73 material	75 material	77 material
Init. Permeability	---	250	850	2500	5000	2000
Vol. Resistivity	ohm-cm	10^8	10^5	10^2	10^2	10^3
Freq. Range for Shield Bead use	MHz	200 - 2000	30 - 600	10 - 50	5 - 15	10 - 50

NOTE: For additional material specifications, see pages 49 through 60.