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. Note that the powdered iron generally has lower losses than the ferrite in narrowband applications. 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 on iron and ferrite cores are attached with important information. You will need to use this information when designing an inductor. The inductances can be estimated from[3]:

Iron powder cores:

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

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[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. You need to scrape the enamel paint off the ends in order to solder to it.

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.

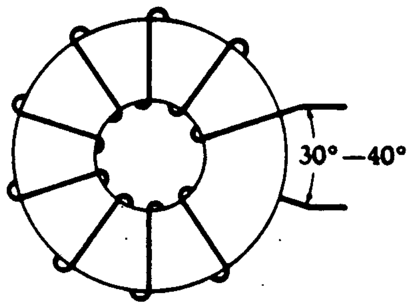
Air core inductors. Sometimes very small value inductors can be more easily constructed using a solenoidal shape. A good way to do this is to wind wire on a threaded shaft such as a screw, then remove the screw after done. These inductors can also be tuned over some range by compressing or expanding 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.

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

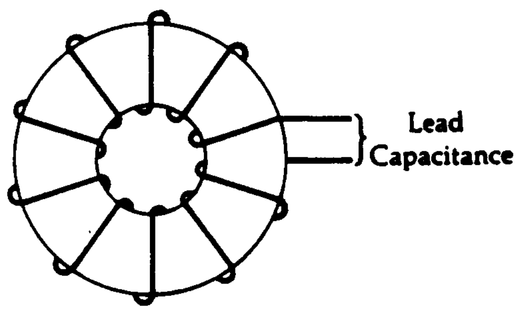
Distributed matching components. Finally, in cases where very small inductance is required at VHF frequencies and above, transmission lines should also be considered to implement distributed matching networks. See Sect. 2.5 in Gonzalez[5] for more information.

[4] op. cit.

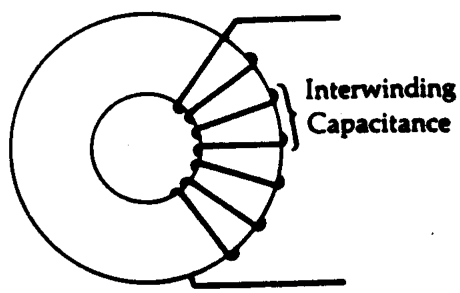
[5] G. Gonzalez, *Microwave Transistor Amplifiers: Analysis and Design*, Second Ed., Prentice Hall, 1997.



(*A*) *Correct.*



(*B*) *Incorrect.*



(*C*) *Incorrect.*

Fig. 1-28. Practical winding hints.

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

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.

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

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 TOROIDAL CORES

A_L VALUE CHART for FERRITE TOROIDAL CORES

core size	material number							
	68 u =20	63 u =40	67 u =40	61 u =125	43 u =850	77 u =2000	72 u =2000	75 u =5000
FT - 23 --	4.0	7.9	7.9	24.8	188	396	396	995
FT - 37 --	8.8	19,7	19.7	55.3	420	884	884	2220
FT - 50 --	11.0	22.0	22.0	68.8	523	1100	1100	2740
FT - 50 - A --	12.0	24,0	24.0	75.0	570	1200	1200	2990
FT - 50 - B --	- -	48.0	48.0	150.0	1140	2400	2400	- -
FT - 82 - -	11.7	22.4	22.4	73.0	557	1172	1172	2940
FT - 114 --	12.7	25.4	25.4	79.3	603	1270	1270	3170
FT - 114-A --	- -	- -	- -	146.0	- -	2340	- -	- -
FT - 140 --	- -	- -	45.0	140.0	952	2240	2240	- -
FT - 240 --	- -	- -	53.0	171.0	1239	- -	3133	- -

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

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

core size	wire 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	48	62	79	101
FT-37 --	0	0	2	4	7	11	15	21	28	36	48	61	79	100	127	161
FT-50 --	2	4	7	10	14	19	26	34	45	58	75	95	121	154	194	245
FT-82 --	3	5	8	12	16	22	29	39	51	65	84	106	135	171	216	273
FT-87 --	10	14	19	25	34	43	56	72	92	118	150	188	239	302	374	478
FT-114 --	16	22	29	38	49	63	80	100	131	166	211	263	334	420	527	665
FT-150 --	16	22	29	38	49	63	80	103	131	166	211	264	335	422	529	667
FT-193 --	31	41	53	68	86	109	139	176	223	282	357	445	562	707	886	1115
FT-240 --	36	46	60	77	98	123	156	198	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.