Appendix A

Practical Information on Inductors

A.1 Air Core Inductors

An approximate formula for the inductance of a close-wound single-layer coil with nonmagnetic core (e.g., air) is

$$L = \frac{(rN)^2}{9r + 10l} \tag{A.1}$$

where

$$\begin{aligned} L &= \text{inductance in } \mu\text{H} \\ N &= \text{number of turns} \\ r &= \text{radius of coil (inches)} \\ l &= \text{length of coil (inches)} \end{aligned}$$

Formula A.1 is accurate to within 1% if $l > 0.8r$, i.e., if the coil is not too short.

A.2 Toroidal Inductors

We will make extensive use of toroidal inductors which are inductors formed by winding a coil of wire around a donut-shaped (toroidal) core. An important advantage of this type of inductor is its self-shielding property. Due to the relatively high magnetic permeability of the core material (compared to air), the magnetic fields are essentially confined to the core. This means that the coil inductance will be unaffected by its physical orientation and also that negligible mutual coupling will exist between toroidal coils in close proximity. Circuit design can be greatly simplified if mutual coupling effects can be neglected. Mutual coupling can also cause serious problems in tuned amplifiers, since coupling between coils in the input and output circuits can cause the circuit to oscillate.

The core material for a toroidal inductor is usually either manufactured from iron powder or a ferrite material. These materials have very different properties. The important parameters of the core material are its relative magnetic permeability, cross-sectional area and diameter and volume resistivity (which determines the loss). Other considerations for high power applications are the saturation flux density, which determines the largest magnetic field that the core can support, and the temperature rise resulting from power dissipation. For small signal applications these need not be considered. Generally, ferrite cores offer higher magnetic permeability than iron-powder cores which results in fewer turns required to realize a given inductance value. Iron-powder cores generally have lower losses and higher saturation flux densities. A general rule of thumb for high power RF applications is that the power handling capability of a ferrite core is limited by flux saturation, while the limiting factor for iron powder is temperature rise.

An approximate formula for the inductance of a toroidal winding having cross sectional area A and effective length l is

$$L = \frac{\mu A}{l} N^2 \tag{A.2}$$

$$= A'_L N^2$$

where

$$\mu = \mu_r \mu_o \tag{A.3}$$

$$A'_L = \frac{\mu A}{l} \tag{A.4}$$

The parameter A'_L has units of (Henries/m)$(m^2)/m$ = Henries. Sometimes manufacturers will give the units of A'_L as H/turn ^{2} or μ H/turn ^{2} (but turn ^{2} is a "non-unit" - like radians). This is done to remind us to multiply the value of A'_L by N^2 in order to find the inductance.

The cores used in the EE453 lab are manufactured by AMIDON Associates. This manufacturer specifies the parameter A_L for their cores. For iron-powder cores A_L is related by A'_L by

$$A_L = A'_L (100)^2 \tag{A.5}$$

and for ferrite cores

$$A_L = A'_L (1000)^2 \tag{A.6}$$

Therefore, the numbers specified on the AMIDON data sheets (A_L) give the inductance of a 100-turn winding. For this reason they give the units of A_L as "μH/(100 turns)" for iron-powder cores and "mH/(1000 turns)" for ferrite cores, although, strictly speaking, their parameter should have the units of μH or mH. In any case, if we take their definition for A_L and assume that the units are in μH for iron powder or mH for ferrite, then the formula for the number of turns, N, can be deduced from Equations A.2 and A.5:

$$N = \sqrt{\frac{L(\mu\mathrm{H})}{A_L/(100)^2}} \quad \text{iron powder} \tag{A.7}$$

$$= 100\sqrt{\frac{L(\mu\mathrm{H})}{A_L}}$$

$$N = \sqrt{\frac{L(\mathrm{mH})}{A_L/(1000)^2}} \text{ ferrite} \tag{A.8}$$

$$= 1000\sqrt{\frac{L(\mathrm{mH})}{A_L}}$$

The iron powder cores can be identified by their color code (see Table A.5). The RED cores are AMIDON material #2 and are intended for use in the range 3 MHz - 30 MHz. The black cores are AMIDON material #10 and are intended for use in the range 30 MHz - 100 MHz. The optimum frequency range is indicated for each of the iron powder core materials listed in table A.5. The properties of iron-powder and ferrite cores are summarized in the tables on the following pages.

Note that the smaller cores are better for small inductance values, and the large cores are more suitable for large inductance values. Once the core size is chosen and the number of turns has been calculated, the wire size must be chosen. Table A.6 gives the maximum number of turns possible on a given core size for a given wire size. It is advisable to use a wire size somewhat smaller than the maximum so that the spacing between windings can be increased. Correct winding technique is shown in Figure A.1. The windings should be evenly spaced with the leads separated by about 30-40 degrees. This will minimize the capacitance between turns and also between the leads and therefore maximize the self-resonant frequency. Small changes in the reactance can be achieved by compressing or expanding the winding.

Core	**OD (in)**	**ID (in)**	**Height (in)**	**Cross sect. (cm^2)**	**Mean length (cm)**	**Vol. (cm^3)**
FT-23	.230	.120	.060	.021	1.34	.029
FT-37	.375	.187	.125	.076	2.15	.163
FT-50	.500	.281	.188	.133	3.02	.401
FT-50A	.500	.312	.250	.152	3.18	.483
FT-50B	.500	.312	.500	.303	3.18	.964
FT-82	.825	.520	.250	.246	5.26	1.29
FT-87A	.870	.540	.500	.522	5.42	2.83
FT-114	1.142	.750	.295	.375	7.42	2.79
FT-114A	1.142	.750	.545	.690	7.42	5.13
FT-150	1.500	.750	.250	.581	8.30	4.82
FT-150A	1.500	.750	.500	1.110	8.30	9.21
FT-193	1.930	1.250	.750	1.460	12.30	18.00
FT-240	2.400	1.400	.500	1.570	14.40	22.70

Table A.1: Physical dimensions of Amidon ferrite toroidal cores.

	#68	**#63**	**#67**	**#61**	**#43**
Relative permeability	20	40	40	125	850
Saturation Flux (Gauss)	2000	1850	3000	3000	2750
Curie Temperature (C)	500	450	500	350	130
Temperature Coefficient (%/C)	.06	.10	.13	.15	1.0
Tuned circuit frequency range (MHz)	80-180	15-25	10-80	0.2-10	.01-1
Frequency range for wide-band apps (MHz)	200-1000	25-200	50-500	10-200	1-50

Table A.2: Properties of Amidon ferrite materials.

Core Size	**#68**	**#63**	**#67**	**#61**	**#43**
FT-23	4.0	7.9	7.9	24.8	188
FT-37	8.8	17.7	17.7	55.3	420
FT-50	11.0	22.0	22.0	68.0	523
FT-50A	12.0	24.0	24.0	75.0	570
FT-50B	NA	48.0	48.0	150.0	1140
FT-82	11.7	22.4	22.4	73.3	557
FT-87A	NA	NA	NA	NA	NA
FT-114	12.7	25.4	25.4	79.3	603
FT-114A	NA	NA	NA	146.0	NA
FT-150	NA	NA	NA	NA	NA
FT-150A	NA	NA	NA	NA	NA
FT-193	NA	NA	NA	NA	NA
FT-240	NA	53.0	NA	173.0	1240

Table A.3: Amidon ferrite toroidal core A_L values (mH/1000 turns).

Core	OD (in)	ID(in)	Height (in)	Cross sect. (cm^2)	Mean Length (cm)
T-400A	4.000	2.250	1.300	7.43	24.93
T-400	4.000	2.250	.650	3.66	24.93
T-300A	3.048	1.925	1.000	3.58	19.83
T-300	3.048	1.925	.500	1.81	19.83
T-225A	2.250	1.405	1.000	2.73	14.59
T-225	2.250	1.405	.550	1.50	14.59
T-200A	2.000	1.250	1.000	2.42	12.97
T-200	2.000	1.250	.550	1.33	12.97
T-184	1.840	.950	.710	2.04	11.12
T-157	1.570	.950	.570	1.14	11.12
T-130	1.300	.780	.437	0.73	8.29
T-106	1.060	.570	.437	0.69	6.50
T-94	.942	.560	.312	.385	6.00
T-80	.795	.495	.250	.242	5.15
T-68	.690	.370	.190	.196	4.24
T-50	.500	.303	.190	.121	3.20
T-44	.440	.229	.159	.107	2.67
T-37	.375	.205	.128	.070	2.32
T-30	.307	.151	.128	.065	1.83
T-25	.255	.120	.096	.042	1.50
T-20	.200	.088	.070	.025	1.15
T-16	.160	.078	.060	.016	0.95
T-12	.125	.062	.050	.010	0.75

Table A.4: Physical dimensions of Amidon iron powder toroidal cores.

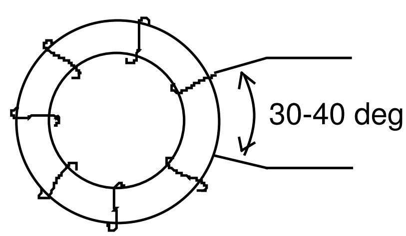

Figure A.1: Correctly wound toroidal inductor

Core	**26**	**3**	**15**	**1**	**2**	**6**	**10**	**12**	**0**
color	**ylw/wht**	**grey**	**red/wht**	**blue**	**red**	**yellow**	**black**	**grn/wht**	**tan**
f (MHz)	**0-1.0**	**.05-.5**	**.1-2**	**.5-5**	**1-30**	**2-50**	**10-100**	**20-200**	**50-300**
	$\mu_r = 75$	$\mu_r = 35$	$\mu_r = 25$	$\mu_r = 20$	$\mu_r = 10$	$\mu_r = 8$	$\mu_r = 6$	$\mu_r = 3$	$\mu_r = 1$
T-400A	2600	-	-	-	360	-	-	-	-
T-400	1320	-	-	-	185	-	-	-	-
T-300A	1600	-	-	-	228	-	-	-	-
T-300	825	-	-	-	115	-	-	-	-
T-225A	1600	-	-	-	215	-	-	-	-
T-225	950	425	-	-	120	100	-	-	-
T-200A	1550	-	-	-	218	180	-	-	-
T-200	895	425	-	250	120	100	-	-	-
T-184	1640	720	-	500	240	195	-	-	-
T-157	970	420	360	320	140	115	-	-	-
T-130	785	350	250	200	110	96	-	-	15
T-106	900	450	345	325	135	116	-	-	19
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	40	31	18	6.4
T-44	360	180	160	105	52	42	33	19	6.5
T-37	275	120	90	80	40	30	25	15	4.9
T-30	325	140	93	85	43	36	25	16	6.0
T-25	-	100	100	70	34	27	19	12	4.5
T-20	-	90	65	52	27	22	16	10	3.5
T-16	-	61	55	44	22	19	13	8	3.0

Table A.5: A_L values (μH / 100 turns) for Amidon iron powder cores.

Table A.6: Approximate maximum number of turns versus core outer diameter.

Core Size	Wire Size												
OD	12	14	16	18	20	22	24	26	28	30	32	34	36
0.25”	1	1	3	4	5	7	11	15	21	28	37	48	62
0.37”	3	5	7	9	12	17	23	31	41	53	67	87	110
0.50”	6	8	11	16	21	28	37	49	63	81	103	131	166
0.68”	9	11	15	21	28	36	47	61	79	101	127	162	205