SIMPLE INDUCTOR DESIGN

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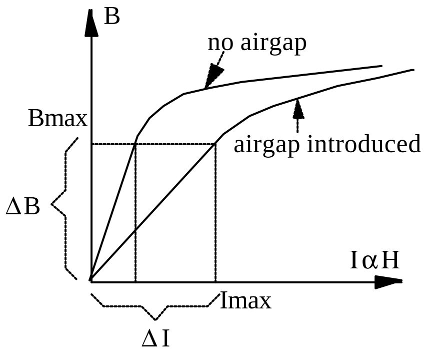
Standard ferrite pot cores are used with an airgap to avoid saturation. Toroids do not generally have airgaps.

The voltage induced across a coil as a result of a changing flux within the coil or a changing current in the coil is given by:

$$e = N\frac{d\Phi}{dt} = L\frac{di}{dt} \quad \text{Volts} \qquad (1)$$

Equating the second two terms and cancelling dt:

$$L = N\frac{d\Phi}{di} = NA\frac{dB}{di} = NA\frac{\Delta B}{\Delta I} = NA_e\frac{B_{max}}{I_{max}} \quad \text{Henry} \qquad (2)$$



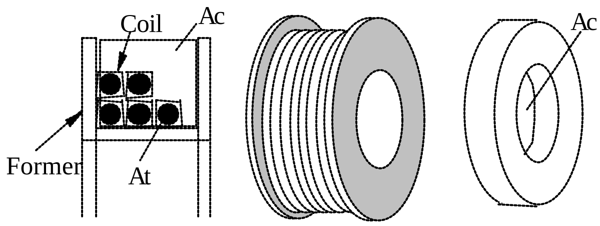
The effective area of the core is therefore:

$$A_e = \frac{LI_{max}}{NB_{max}} \quad m^2 \qquad (3)$$

While the area that the coil takes up in the pot core former or toroid internal diameter is approximately given by:

$$A_c = NA_t \quad m^2 \qquad (4)$$

Where A_t = (diameter of wire)^2.



The "square area" of each conductor is used to account for the packing of the conductor in the former. The 'mean' or 'rms' currents are used to find the conductor diameter (refer table 1).

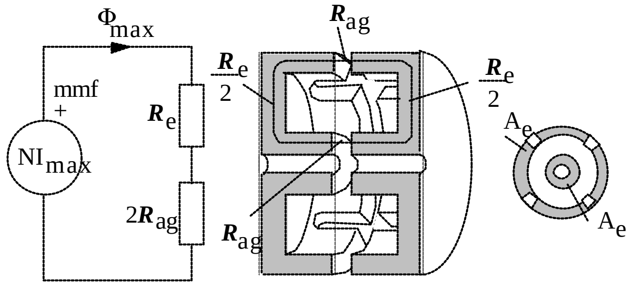
The product A_eA_c is often used to determine whether a particular pot core or toroid can accommodate the energy transfer. Therefore:

$$\boxed{A_eA_c = \frac{LI_{max}}{NB_{max}}\cdot NA_t = \frac{LI_{max}A_t}{B_{max}}} \quad m^4 \qquad (5)$$

Equation (5) is the **first calculation** to be performed to find which pot core size will suit the particular application (refer table 2). The A_eA_c product for the core must be greater or equal to that calculated by equation (5). Rewriting equation (2) will give the **second calculation** which determines the number of turns needed for the coil:

$$\boxed{N = \frac{LI_{max}}{A_eB_{max}}} \quad \text{turns} \qquad (6)$$

An airgap may be needed to avoid saturating the core. Fringing effects (increasing airgap area) can be ignored if the airgap is narrow which is usually the case. Utilising the magnetic equivalent circuit and equating mmf's:



$$NI_{max} = \Phi_{max}(\boldsymbol{R}_e + 2\boldsymbol{R}_{airgap})$$
$$= \Phi_{max}\left(\frac{\ell_e}{m_em_oA_e} + \frac{2\ell_{ag}}{m_oA_{ag}}\right) \qquad (7)$$

where $\boldsymbol{R}_e$ = reluctance of core & $\boldsymbol{R}_{ag}$ = reluctance of airgap.

For a small airgap $A_e \cong A_{ag}$ and substituting in equation (7):

$$NI_{max} = \frac{\Phi_{max}}{m_oA_e}\left(\frac{\ell_e}{m_e} + 2\ell_{ag}\right) \quad \text{Ampere-turns} \qquad (8)$$
$$= \frac{B_{max}}{m_o}\left(\frac{\ell_e}{m_e} + 2\ell_{ag}\right)$$

And because there are two airgaps within the potcore magnetic circuit the **third calculation** will give the airgap width as:

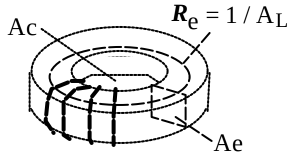
$$Airgap = \ell_{ag} = \frac{1}{2}\left(\frac{NI_{max}m_o}{B_{max}} - \frac{\ell_e}{m_e}\right) \quad m \qquad (9)$$

Where $\mu_o = 4\pi \times 10^{-7}$.

A term A_L (nH/turn^2) is often given for a pot core and toroid. This term refers to $1/\boldsymbol{R}_e$ when *no airgap* or a manufacturers *preset airgap* exists and can be used directly to find the number of turns.

$$N = 1000\sqrt{\frac{L(mH)}{A_L}} \qquad (10)$$

This equation is derived from (1) $N\Phi_{max} = LI_{max}$ and (7) $NI_{max} = \Phi_{max}\boldsymbol{R}_e = \Phi_{max}/A_L$.



The A_eA_c calculation is still required to size toroid.

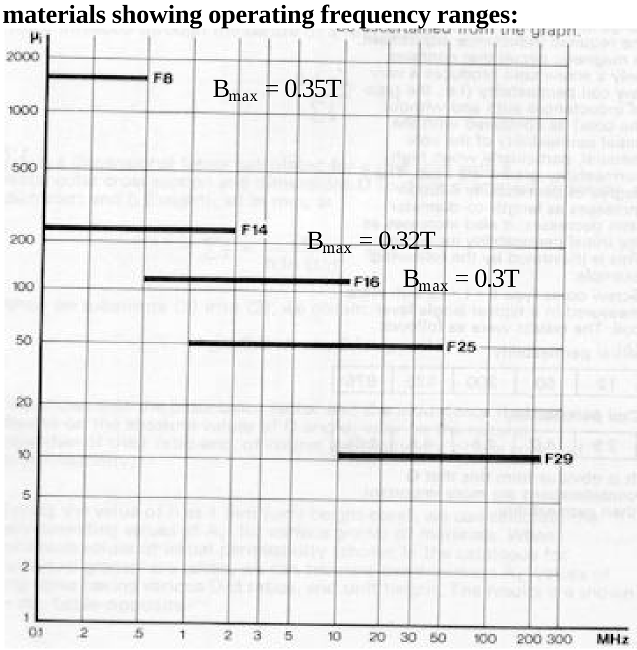
Table 1: Wire date for coil winding:

SWG	Diameter mm	Area mm^2	Current density $155A/cm^2$	Current density $186A/cm^2$	Current density $310A/cm^2$	Copper resistance Ω/100m	Eureka resistance Ω/100m
10	3.25	8.3	13	15	26	0.171	
12	2.65	5.48	8.5	10	17	0.258	
14	2.03	3.24	5	6	10	0.437	13.0
16	1.63	2.07	3.2	4	6.5	0.684	20.3
18	1.22	1.17	1.8	2.2	3.6	1.22	36.0
20	0.91	0.657	1	1.2	2	2.16	64.0
22	0.71	0.397	0.6	0.7	1.2	3.58	106
24	0.56	0.245	0.4	0.5	0.8	5.78	172
26	0.46	0.164	0.25	0.3	0.5	8.72	256
28	0.38	0.111	0.17	0.2	0.35	12.8	379
30	0.32	0.078	0.12	0.14	0.24	18.2	539
32	0.27	0.059	0.09	0.11	0.18	24.0	711
34	0.23	0.043	0.07	0.08	0.14	33.1	981

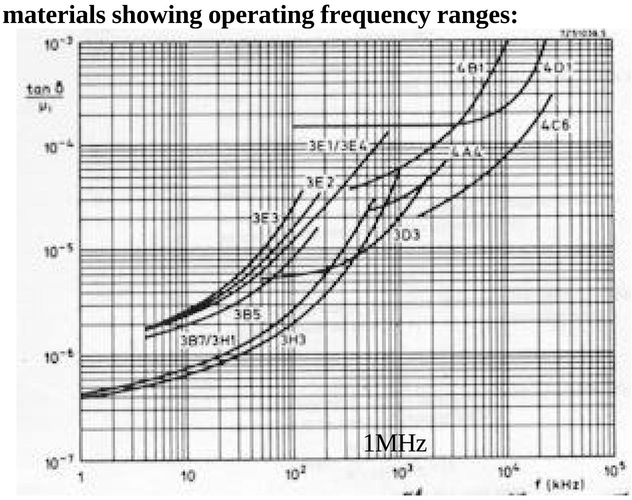
Table 2: Phillips pot core data, material grade 3H1 (MnZn), B_{max} = 0.3T:

Type P dia /height	A_eA_c (m^4)	A_e (mm^2)	A_c (mm^2)	ℓ_e (mm)	μ_e
P5.8/2.5	$2.68x10^{-12}$	4.7	0.57	6.3	715
P5.8/3.3	$5.17x10^{-12}$	4.7	1.1	7.9	820
P7.4/4.2	$15.4x10^{-12}$	7	2.2	10	970
P9/5	$34.3x10^{-12}$	10.1	3.4	12.5	1260
P11/7	$89.1x10^{-12}$	16.2	5.5	15.5	1300
P14/8	$0.243x10^{-9}$	25.1	9.7	19.8	1400
P18/11	$0.779x10^{-9}$	43.3	18	25.8	1750
P22/13	$1.78x10^{-9}$	63.4	28	31.5	1860
P26/16	$3.66x10^{-9}$	93.9	39	37.6	1900
P30/19	$7.54x10^{-9}$	137	55	45.2	1985
P36/22	$15.2x10^{-9}$	202	75	53.2	2025
P42/29	$37.1x10^{-9}$	265	140	68.6	2100
P66/56	$0.29x10^{-6}$	717	400	123	≥1970, 3E1

Initial permeability vs frequency for different ferrite materials showing operating frequency ranges:

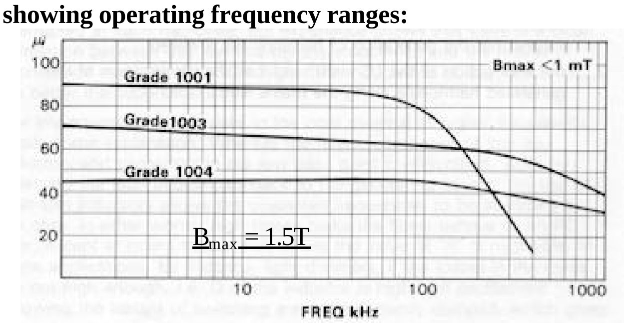


Loss vs frequency for different MnZi & NiZn ferrite materials showing operating frequency ranges:



All these ferrite materials have B_{max} ≈ 0.3T

Initial permeability vs fequency for iron powder toroids showing operating frequency ranges:



Note: Very high maximum flux density allows higher currents to be supported without an airgap.

NEOSID Neofer Iron Powder Toroids:

Part Number	D	d	H	ℓ_e	A_e	V_e	$\sum \frac{\ell}{A}$
	mm			mm	mm^2	mm^3	mm^{-1}
17-649-	13.2	7.8	5.4	33	14.5	479	2.28
17-632-	14.8	8.0	6.35	34	20.0	680	1.70
17-630-	24.7	12.7	9.7	54	54	2916	1.0
17-638-	33	20	6	80	37	2960	2.17
17-640-	33	20	8	80	50	4000	1.61
17-642-	33	20	10	80	63	5040	1.28
17-645-	44	24	16.5	101	155	15655	0.65
17-647-	44	24	8.5	101	80	8080	1.26

A_L for Neofer Iron Powder Toroids:

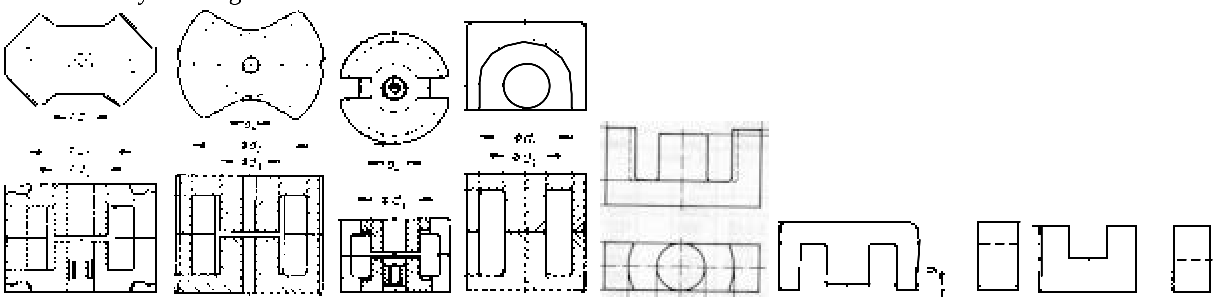
Part Number	Minimum A_L values in nH *			LI^2 max. (mJ) **
	Grade 1001	Grade 1003	Grade 1004	Grade 1004
17-649-	47	33	24	0.5
17-632-	63	44	32	0.71
17-630-	107	75	54	3.0
17-638-	50	35	25	3.1
17-640-	67	47	34	4.2
17-642-	84	59	42	5.1
17-645-	164	116	82	16.0
17-647-	85	60	43	8.4

Small selection of NEOSID Nickel-Zinc Ferrite Toroids showing A_L:

	Dimensions			Effective Geometric Parameters				Minimum A_L values in nH for uncoated cores in preferred grades										
Part Number	O.D.	I.D.	HT.	ℓ_e	A_e	V_e	C_1	F5	F6	F8	F9	F10	F14	F16	F25	F29	P10	P11
28-052-	16.0	9.6	2.54	38.5	7.95	306	4.84	—	—	—	—	—	—	—	—	—	415.4	—
28-059-	16.0	9.6	5.0	38.5	15.66	603	2.46	—	—	—	1788	—	—	—	—	—	—	—
28-021-	19.05	12.7	3.18	48.5	9.96	483	4.87	—	—	—	—	—	45	—	10.3	—	—	—
28-022-	19.05	12.7	6.35	48.5	19.92	966	2.43	—	—	620	1809	—	91	—	20.7	—	—	—
28-023-	19.05	12.7	9.52	48.5	29.88	1449	1.62	—	—	930	2713	—	—	—	—	—	—	—
28-057-	20.0	10.0	10.0	43.55	48.05	2092	0.51	—	2957	—	—	—	—	—	—	—	—	—
28-055-	24.0	12.0	12.0	52.36	69.2	3616	0.755	—	—	—	—	—	—	—	—	—	—	2996
28-035-	25.0	15.0	7.0	60.2	34.3	2065	1.75	—	—	—	2503	—	—	—	—	—	—	—
28-034-	25.0	15.0	10.0	60.2	49.0	2950	1.23	—	—	—	3575	—	—	—	—	—	—	—
28-080-	25.0	15.0	10.0	60.2	49.0	2950	1.23	—	—	—	4000	—	—	—	—	—	—	—
28-036-	25.0	15.0	16.0	60.2	78.4	4720	0.77	—	—	—	5720	—	—	—	—	—	—	—
28-081-	25.0	15.0	20.0	60.2	98.0	5900	0.615	—	—	—	7150	—	—	—	—	—	—	—
28-031-	25.4	19.05	4.75	68.9	15.0	1040	4.58	—	—	329	960	—	—	—	10.9	—	—	—
28-032-	25.4	19.05	9.52	68.9	30.0	2080	2.29	—	—	—	—	—	96	—	21.8	—	—	—
28-033-	25.4	19.05	14.30	68.9	45.0	3120	1.53	—	—	985	2880	—	144	—	32.8	—	—	—

(F5 - B_{max} = 0.47T; F6 - B_{max} = 0.45T; F8,F9 - B_{max} = 0.38T; F10 - B_{max} = 0.35T; F14 - B_{max} = 0.32T; F16 - B_{max} = 0.3T; F25,F29,P10,P11 - B_{max} = ?)

The range of ferrite pot cores cores is very large and obtainable from such companies as Phillips, Siemens and Neosid. Shapes of pot cores are different and the types are RM, PM, P and EP. Other ferrite cores that look like conventional transformers are made up of two halves of types ETD,EFD, EC, ER, E and U. An I section can be used at the end of a single E or U. Generally P type pot cores have the minimum leakage, if properly designed, because the coils are nearly totally surrounded by the magnetic core.



RM PM P EP ETD E U