6.2 Attributes of ferrites

1. Initial permeability μ_i: it is measured in a close magnetic circuit (of rectangular intersection 35x12x18mm) with very small intensity of the magnetic field. It depends on the temperature and the frequency as shown in Fig. 6.4a and b and the following equation is applied:

$$\mu_i = \frac{1}{\mu_0}\,\frac{\Delta B}{\Delta H}\Big|\,\Delta H \cong 0$$

The cut frequency f_c is the one where μ_i is halved, from its value in (1~10)KHz.

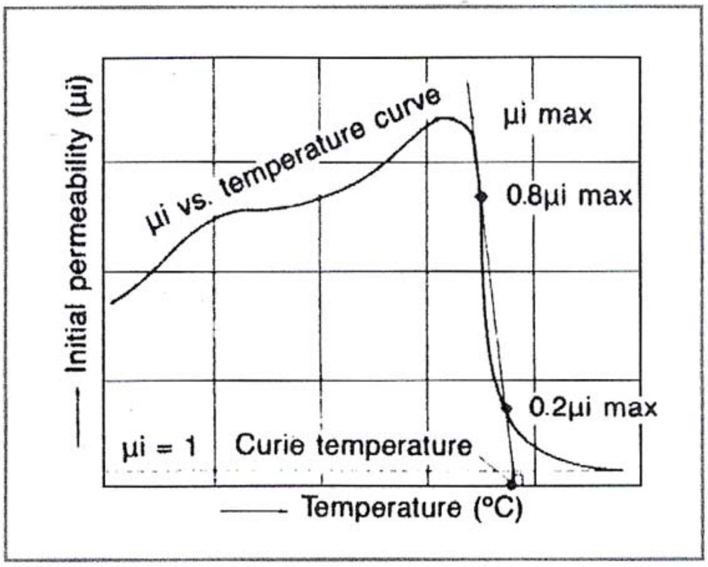


Figure 6.4.a

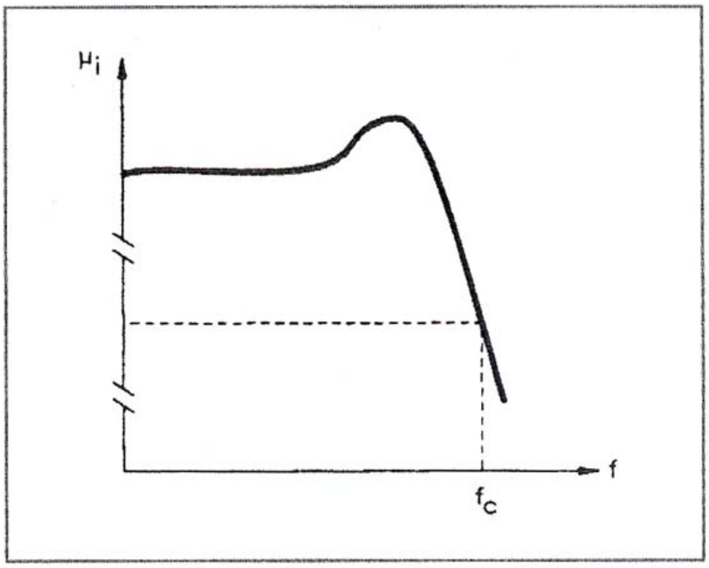


Figure 6.4b

2. Amplitude permeability μ_a: it is the relation between B and H without the presence of a polarization field DC and is provided by the following equation:

$$\mu_a = \frac{1}{\mu_0}\,\frac{B}{H}$$

3. Effective permeability μ_e: when in a close magnetic circuit there is an air void, the magnetic inductance is reduced and μ_e is:

$$\mu_e = \frac{\mu_i}{1 + \frac{G}{\ell_e \cdot \mu_i}}$$

   where G is the void length (G<0.5% of l_e at least) and l_e is the effective length of the magnetic circuit. In Fig. 6.5 you see the variation of μ_e in relation to H.

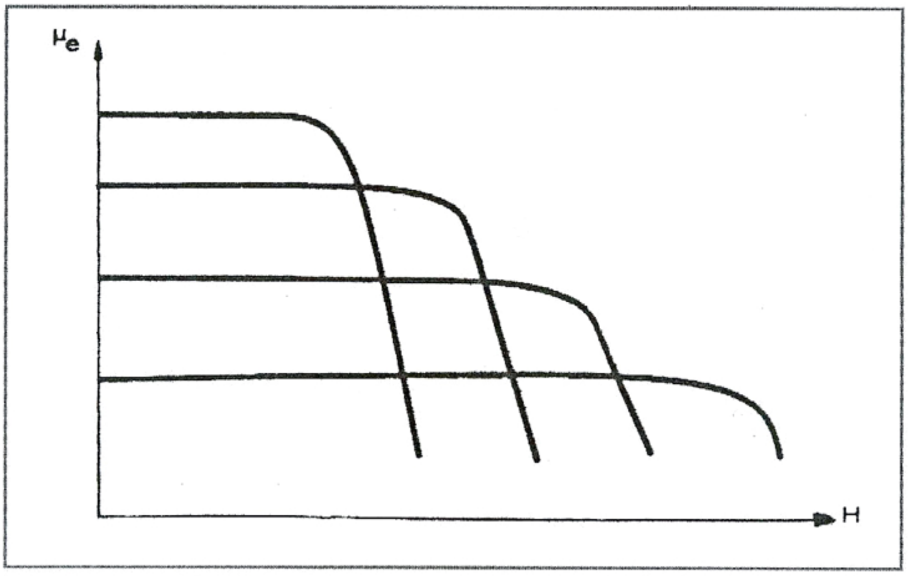


Figure 6.5

4. Incremental permeability μ_Δ: it is perceived when an alternating magnetic field is overlapped in a field of static polarization H_{DC}. When the alternating magnetic field is negligible, the permeability is called reversible permeability μ_{rev}. We then have:

$$\mu_\Delta = \frac{1}{\mu_0} \cdot \frac{\Delta B}{\Delta H} \cdot H_{DC}$$

$$\underset{\Delta H \to 0}{\mu_{rev}} = \frac{1}{\mu_0} \lim \frac{\Delta B}{\Delta H}\Big|\, H_{-}$$

   In Fig. 6.6 we have $\tan\delta_r = \mu_{rev}$ and $\tan_\delta = \mu_i$

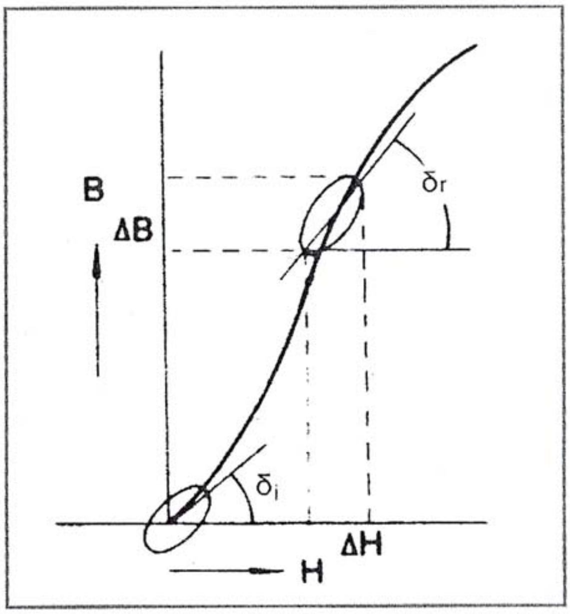


Figure 6.6

5. Complex permeability μ: a coil which has a soft ferrite core equals to an ideal self-inductance with phase +90° in series with an ohmic resistor. We have:

$$\bar{Z} = j\omega L_s + R_s$$

and
$$\bar{\mu} = \mu'_s - j\mu''_s$$

then
$$\tan\delta_m = \frac{R_s}{\omega L_s} = \frac{\mu''_s}{\mu'_s}$$

For the equivalent parallel circuit L_p and R_p we have:

$$\bar{\mu} = \frac{\mu''_p \cdot \mu'_p}{\mu''_p - \mu'_p}$$

and
$$\tan\delta_m = \frac{\omega L_p}{R_p} = \frac{\mu'_p}{\mu''_p}$$

with
$$\bar{Z} = \frac{1}{\frac{1}{j\omega L_p} + \frac{1}{R_p}}$$

We also have

$$\mu'_p = \mu'_s(1 + \tan^2\delta)$$

and $$\mu''_p = \mu''_s(1 + \frac{1}{\tan^2\delta})$$

The variation of $R_s=f(\mu_s'')$, $Ls=(\mu_s')$ and $|Z| = \sqrt{L_s^2 + R_s^2}$, in connection with frequency, is presented in Fig. 6.7.

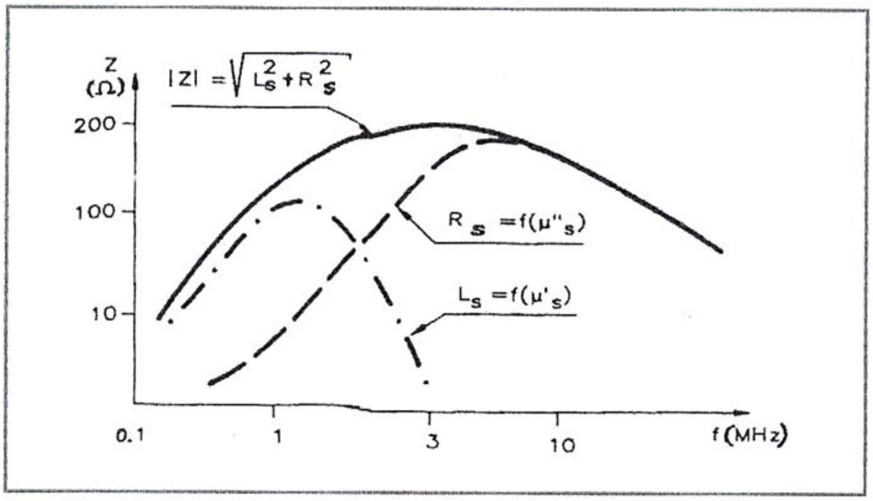


Figure 6.7

μ_s' represents the actual permeability μ_i or μ_e and μ_s'' the virtual caused by the resistance losses.

6. Loss factor $\tan\delta/\mu_i$: the magnetic losses caused by the phase variation δ in Fig. 6.8 are comprised of the following losses:
   a. hysterisis,
   b. Foucault currents, and
   c. permanent magnetism, and they are:

$$\tan\delta_m = \tan\delta_h + \tan\delta_f + \tan\delta_r$$

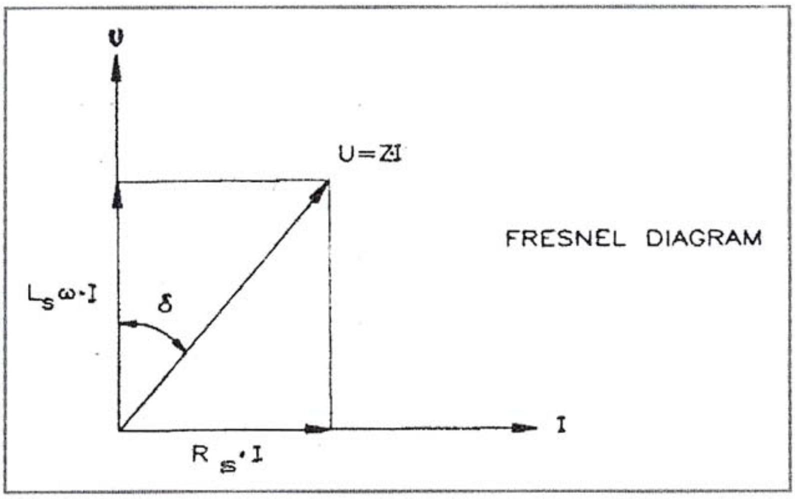


Figure 6.8

The tanδ/μ_i are the magnetic losses besides those caused by hysterisis. The tanδ_h is changing for a very small intensity of magnetic field and tanδ_f is increasing along with frequency (negligible in very low frequencies).

For materials with gap, we have:

$$\tan\delta_{(gap)} = \frac{\tan\delta}{\mu_i}\cdot\mu_e$$

In Fig. 6.9 we give you the variation of magnetic losses along with frequency.

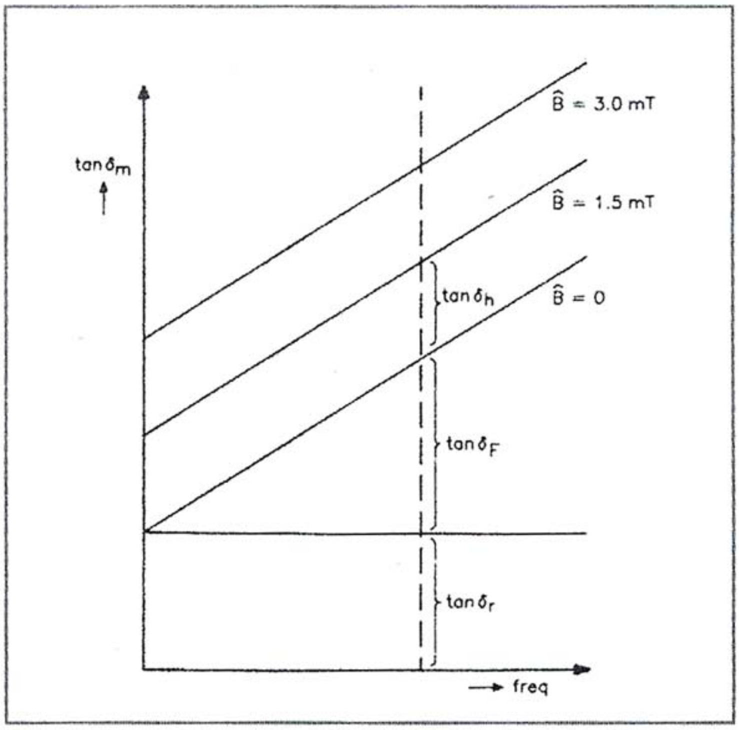


Figure 6.9

7. Hysterisis material constant n_B: when the magnetic inductance in a magnetic core is increased, the losses caused by hysterisis are also increased and are determined after two measurements, usually on the self-inductance levels 1.5 and 3mT (ΔB=1.5mT) in 10KHz:

$$n_B = \frac{\Delta R_h}{\omega \cdot L \cdot \mu_e \cdot \Delta \bar{B}} = \frac{\Delta \tan\delta_n}{\mu_e \cdot \Delta B} (T^{-1})$$

where ΔR_h is the variation of the resistor of losses by hysterisis.
The loss factor by hysterisis is calculated by the equation (proposed by IEC):

$$\tan\delta_h = n_B \cdot \Delta B \cdot \mu_e = \frac{\Delta R_h}{\omega L}$$

8. Core factor $\sum \frac{l}{S}$ or C1: in the calculations of an uneven soft magnetic core we use, for convenience, the so-called effective dimensions, surface S_e, length l_e and volume V_e, which define a hypothetical ring core. This core has the same magnetic properties with the uneven core. The ideal ring core has $X_L = \frac{l_e}{\mu \cdot S_e}$ and the uneven core has $X_L = \frac{1}{\mu_e} \sum \frac{l}{S}$.
Thus, the self-inductance of a core is:

$$L = \frac{1.257 \cdot 10^{-9} \cdot N^2}{\frac{1}{\mu_e} \sum \frac{\ell}{S}} (H)$$

where N is the number of rounds and $\sum \frac{l}{S}$ is measured in mm^{-1} or cm^{-1}.

9. Inductance factor A_L: the inductance of a ferrite core is:

$$L = N^2 A_L \text{ (nH)}$$

The inductance factor is the volume:

$$A_L = \frac{1.257 \cdot \mu_e}{\sum \frac{\ell}{S}} (nH/N^2)$$

and represents the inductance in nH per $spiral^2$.

10. The temperature coefficient α is:

$$\alpha = \frac{\mu_{i2} - \mu_{i1}}{\mu_{i1}} \cdot \frac{1}{T_2 - T_1} (\mathrm{ppm}/{}^0\mathrm{C})$$

and the relative temperature coefficient α_f or else, temperature factor is:

$$\alpha_f = \frac{\alpha}{\mu_i} (\mathrm{ppm}/{}^0\mathrm{C})$$

and for materials with gap, we have:

$$\alpha_e = \alpha_f \cdot \mu_e \ (\mathrm{ppm}/{}^0\mathrm{C})$$

which is the effective temperature coefficient, where μ_{i1} is the initial permeability in 20°C (T_1) and μ_{i2} is the respective one in T_2 temperature.

11. When a soft ferrite shows a magnetic, thermal or mechanical disorder, the magnetic permeability suddenly raises and then falls slowly.
    The disaccommonation coefficient d is:

$$d = \frac{\mu_{i1} - \mu_{i2}}{\mu_{i1} \log \frac{t_2}{t_1}}$$

and the disaccommonation factor D_F is:

$$D_F = \frac{d}{\mu_{i1}} = \frac{\mu_{i1} - \mu_{i2}}{\mu_{i1}^2 \cdot \log \frac{t_2}{t_1}}$$

which is usually measured between 1 and 10 min after demagnetization, where μ_{i1} is the μ_i on time t_1 and μ_{i1} is the μ_i on time t_1 ($t_2 > t_1$). The change of inductance in time, in a coil, is provided by the equation:

$$\frac{\Delta L}{L} = \frac{L_1 - L_2}{L_1} = \mu_e \cdot D_F \cdot \log \frac{t_2}{t_1} \quad \text{provided } t_2 > t_1$$

12. Relative permittivity ε_r: in ferrites it is diminishing when frequency increases. It's about 10^5 for the MnZn ferrites and 25 for the NiZn in 1MHz.
13. Resistivity ρ: ferrites are semiconductive with DC special resistor of crystals $10^{-3}\Omega$m for the MnZn and almost 30Ωm for the NiZn. The insulating layer between the crystals increases the total special resistance in (0.1~10)Ωm for the MnZn and in (10^4~10^6)Ωm for the NiZn and LiZn. The special resistance decreases when temperature or frequency rises.
14. Power losses R_v:

$$P_v = KF^m B^n \ (\mathrm{W})$$

where K is the material factor which depends on the temperature, and:

$$1.3<m<1.6$$
$$2<n<2.6$$

15. Third harmonic distortion factor: when a semitonal signal is applied in a coil, because of the non-linearity (magnetic glut and hysterisis), harmonics will be produced. The equation:

$$K.F = 20\log\frac{u_3}{u_1}\,(dB)$$

is called Klirrfactor, where u_1 and u_3 are the voltages of the basic and the third harmonic respectively. A circuit with complex input resistance 600Ω as basic frequency uses 1KHz or 10KHz, while a circuit with complex resistance 75Ω uses 100KHz.

16. D.C. premagnetization characteristics: as shown in Fig. 6.10, the volume A_L changes when the D.C. magnetic field changes. When we design transformers using EE cores or pot core, there is a D.C. component in the magnetic circuit which must be taken into account. In the figure for the pot core P30/19 from the material H5A with A_L=400nH/N^2, the limit in which the permeability doesn't diminish because of the D.C. magnetic field is 65A·rounds. That means that a single spiral of the transformer can be used as 65A. Similarly, 5 spirals can be used as 13A.
17. α factor or winding coefficient c for a given form of a ferrite core is the number of the coil rounds, for self-inductance 1mH. We have:

$$a = \frac{N}{\sqrt{L}}$$

with L in mH. Thus, for other values of self-inductance, we will take $N = \alpha\sqrt{L}$ (rounds) and L in mH.

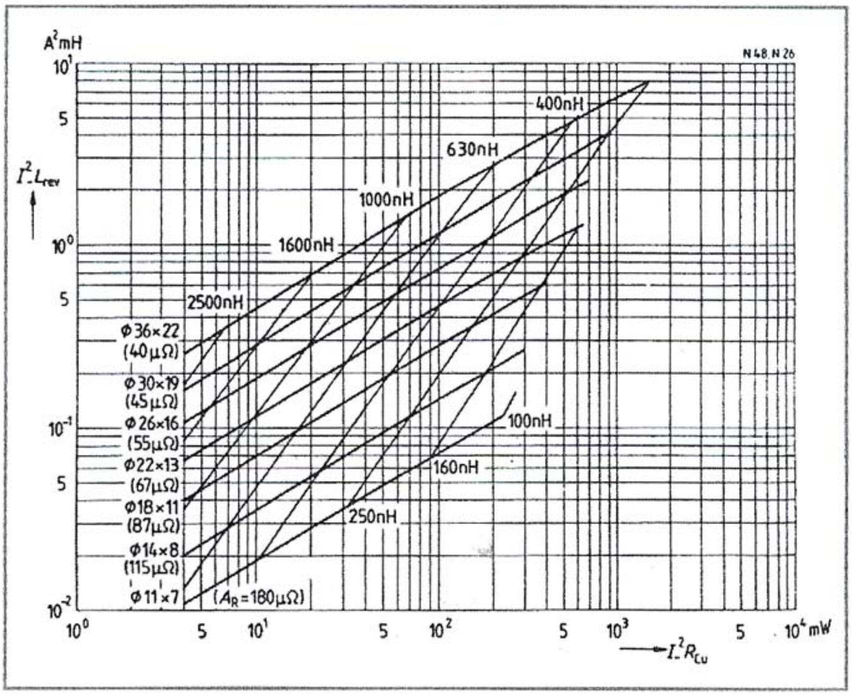


Figure 6.10

18. Magnetostriction λ: it is the phenomenon of elastic distortion which goes with magnetization. The negative magnetostriction –as there is also the positive one, or else Joule- occurs in materials whose length falls away when inductance increases (density of magnetic flow). When an AC current overlaps a DC, in the coil that wraps around the ferrite and the frequency of the AC current coincides with the natural frequency of the ferrite, its mechanical vibrations are maximized. This phenomenon is used in the production of acoustic waves –from acoustic waves to the supersounds- whose frequencies are depending on the dimensions and the vibration mode of the ferrite. We also note the phenomena: a. of linear magnetostriction which is defined by the relative change of the length, and b. of the logarithmic magnetostriction, which is measured in the direction of the magnetization and we have:

$$\lambda = \frac{\Delta l}{l}$$

where λ is the magnetostriction coefficient, a negative number (for negative magnetostriction). Its absolute value increases when the inductance increases and reaches the maximum value (glut) λ_s, which ranges from 0 to $-21\cdot10^{-6}$ for soft ferrites. The ferrites which have very large λ_s and are used because of this attribute, are called magnetostrictive ferrites.

6.4 TYPE AND MATERIAL CODES OF THE FERRITE CORES

A. The ferrite cores, when constructed, they take into account many forms, in regards to the use they are made for and according to the quality control system ISO 9000. The forms are encoded with IEC, DIN, EIA, JIS or some other standard. In Table 6.1 we provide you with the form codes of the soft ferrite cores and their suggested uses. You should consider that no company produces all the cores, that's why it's advised to go back to the corresponding manual for any problem.

Table 6.1

Core forms	Suggested uses
- P - RM - X - Q	- Self-inductance - Filters - Transformers - Chokes
- H - PH - EP	- Wide band transformers - Self-inductance
- E - EC, EE, EF, EI, ER - EFD, ETD, EER, EIR - I - LP - PM, PQ - PCH - U - UI, UU	- Transformers and Chokes of pulse power packs - Transformers inverters - Transformers of telecommunications
- UR - URI	- Return transformers
- EPC	- Transformers of H.F. power packs
- MULTI-HOLE CORES (MHC) - SU, RU - CYLINDRICAL (BB, RH) - FERRITE BEAD CORES (BTL, BHW, BHY, BHZ, BWA, BWB) & CHIP (ABC) - EMI-SUPPRESSION BEADS & BEAD ON WIRE - SMD EMI/RFI (CBD)	- EMI/RFI filters
- DR	- High currents - Filters, coils, oscillators
- RING CORES (RC, RCC, RCL) - CYLINDRICAL (R)	- General applications
- WIDE-BAND CHOKES (WBC)	- Wide band chokes
- RODS - TUBES	- EMI/RFI filters - Resonators
- CIP & MUSHROOM CORE - BOBBIN CORES (BC)	- Filters, coils, oscillators, I.F. resonators
- YOKE RINGS (YR)	- CRT TVs

- BLOCKS (BLK)	- Microwaves, particle accelarators
- PLATES (PLT)	- Microwaves, EMC
- DOSKS (DSK)	- Microwaves
- RHH, R4H, RID	- BALUN transformers and various transformers and coils
- TUBE RI	- Tuners, car stereo
- CYLINDRICAL WITH PROPELLING PART (RB, RS)	- AM/FM
- AP, AR	- LW/MW, MW/SW aerials
- SMD (EE12, ER11, T2, EE5, ER9.5, ER14.5)	- Wide band transformers - Transformers of adapters DC-DC
- LARGE TOROIDAL, DT - SP	- General applications - Particle accelarators
- TOROIDAL (T)	- Pulse/BALUN transformers - Filters, chokes - Current sensors - EMI/RFI filters
- IMPEDER CORES - IMPEDER CORES (ZR, ZRH, ZRS)	- Welding in high frequencies (100~500)Hz
- ELECTRODES (RH, SP, IR, R)	- Protection against electrolysis - Protection of surfaces - Water cleanup
- PROPELLING PART FOR TRIMMERS THP (STANDARD, PS2, PS4, PS5) - PROPELLING FOR TRIMMERSS TH (STANDARD, S4, S8, S14, S17)	- With the DR core for filters, coils, oscillators, I.F. resonators - For variable cores

We give you now the form codes of the hard ferrites, according to the specifications JIS and EIA. Cylindrical (R, RH), ring (Ri, DH, speakers –level motors and magnetrons), disc (D), plates (W), plates with hole (WH), C and CF type.
Last, we must mention that the codes of the cores represent somehow their shape or they are acronyms of their description, i.e. P (Pot), RM (Rectangular Modular), PM (Pot core Module), X (X-shaped), E (E-shaped), PLT (PLATES), WBC (Wide-Band Chokes) or they are codes that don’t describe anything and we must go back to their manuals.
In Fig. 6.11 we show some cores of one or the other standard.

B. The encoding of the materials of the ferrites is different for every standard and manufacturer. For PHILIPS for example, the material 3C85 indicates a ferrite based on MnZn, consisted of 71% Fe_2O_3, 20% MnO, 9% ZnO, or the 4A11 which is based on NiZn, consisted of 50% Fe_2O_3, 24%NiO and 26% ZnO.
SIEMENS MATSUSHITA uses the codes K1, N26, T35, U17 etc.
TDK and other companies from Asia use the codes 4HM, DA2, H5B2, PC30, V3N, K5 etc.
MURATA uses codes like MH, RT, PB etc.

THOMSON-CSF, LCC and others use codes like A2, A3, B1, B2, F1, F2 etc.

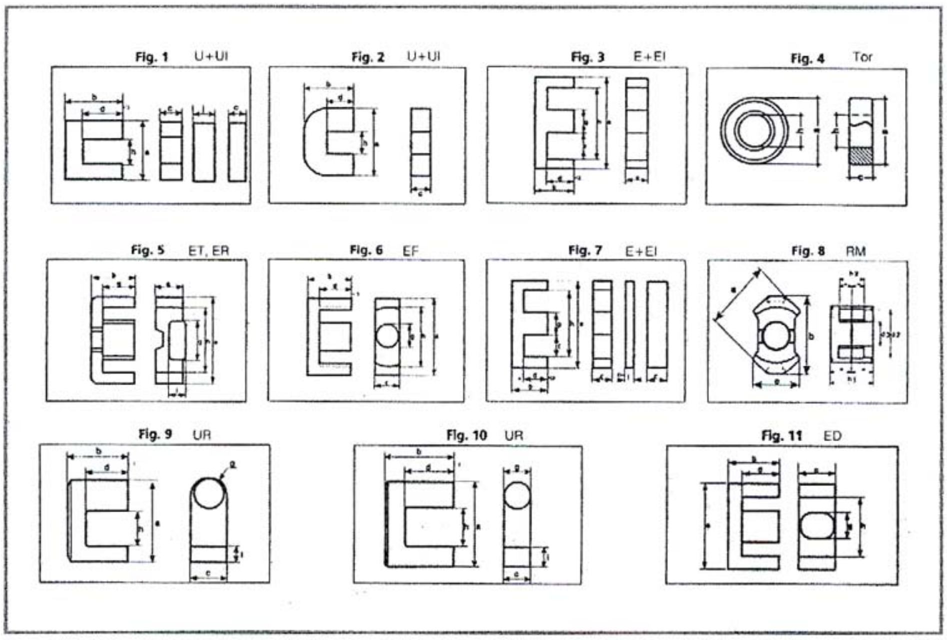
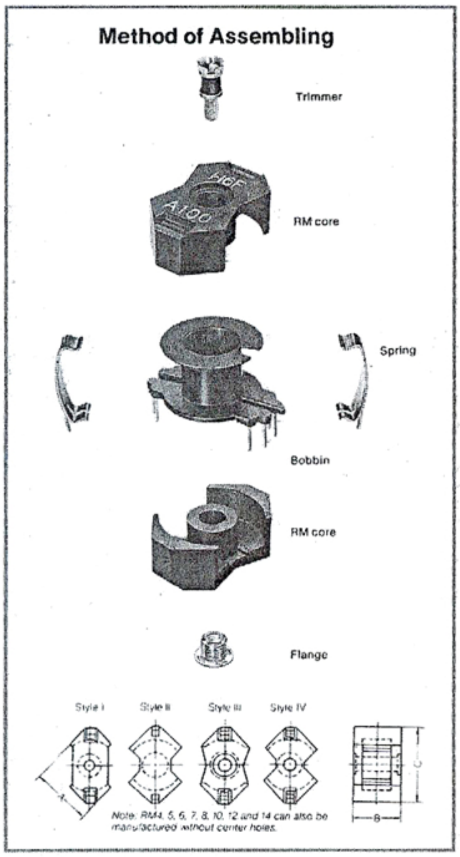


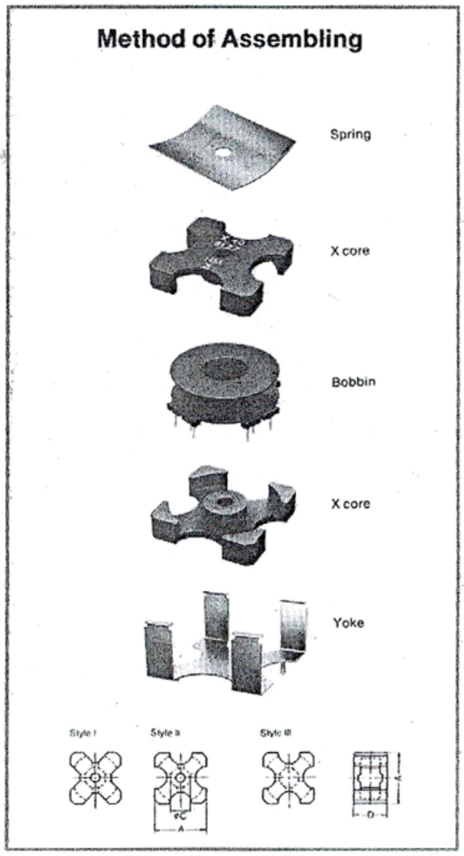
Figure 6.11a

Figure 6.11b



Note: RM4, 5, 6, 7, 8, 10, 12 and 14 can also be manufactured without center holes.

Figure 6.11c



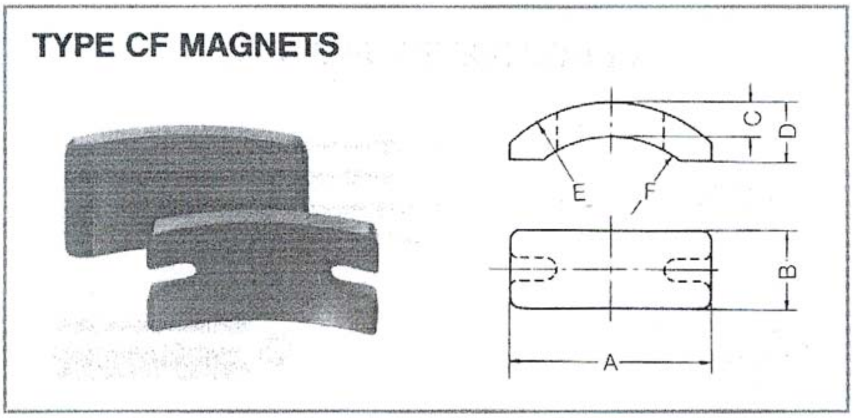


Figure 6.11k

Magnetics Inc. uses letters like A, G, S, V, Wetc, Indiana General uses the codes Q1, Q2, H, TG3, O5, G (different than the G of Magnetics Inc.), Fair-Rite uses 63, 68, 77, 31 etc and finally, Anidon uses FT-63, FT-68, FT-77, FT-31, in relevance with Fair-Rite, where FT means Ferrite Toroide.

We note that the correspondence of materials among the manufacturers is almost non-existent. There certainly are correspondences as in A13=Q3=N28, A16=3C8, 3C5=F=O5P, 4C4=Q1 etc. You should also be aware that from time to time a company removes a certain material, as PHILIPS did with 3C8, 3C5, 4C4 they produced twenty years ago. That's why the only safe and sure solution is a flashback in technical brochure of each company, stuff we already have.

In Table 6.2 we show you some sample elements of materials of different companies, in order to get familiar with them.

Table 6.2

s/n	Ferrite material	μ_i in 25°C	≈Bsat (mT) in 25°C	≥T_C (°C) (curie)	≈p(Ωm) in 25°C	Ferrite type	Main application	Suggested core form
PHILIPS (∅25∅15x10)mm								
1	1P04	4	-	130	-	IRON POWDER	Resonators	RODS, PINS
2	2P40	40	950	140	-	IRON POWDER	EMI/RFI Filters	U, RINGS
3	2A2	350	250	135	10^6	MgZn	Divergence coils	YOKES
4	3H1	2300	400	130	1	MnZn	Filters, transformers	P, X, RM, EP, RINGS
5	4C6	100	380	350	10^5	NiZn	Filters, transformers	P, X, RM, EP, RINGS
6	5G1	-	145	240	10^4	GARNET	Microwaves	PLATES, BLOCKS, DISCS
7	6B1	250	350	250	10^5	LiZn	EMI/RFI resonators	RINGS, RODS, TUBES

8	8E1	3200	400	180	5	MnZn	Eraser heads	-
9	8C	1200	300	125	10^5	NiZn	Particle accelerators	RING, BLOCKS
SIEMENS MATSUSHITA (∅10∅6x4)mm								
1	K1	80±20%	360	400	10^5	NiZn	Filters, coils	P, RM, TUBES, TOROIDES
2	M33	750±20%	450	200	5	MnZn	Filters, coils	P, RM, TUBES, TOROIDES
3	N22	1900±25%	390	145	1	MnZn	Filters, coils	CORE HALVES, BEADS
4	T35	6000±20%	380	130	0.2	MnZn	Filters, coils, transformers	P, RM, EP, TOROIDES
5	U17	10±20%	-	550	10^5	NiZn	EMI/RFI filters	R, DOUBLE, APPERTURE
MURATA (∅30∅20x6)mm 3 TURNS								
1	MH	5000	360	130	0.02	MnZn	EMI/RFI filters	P, U, EI, EE, ER, RODS
2	RL	900	240	80	10^5	NiZn	EMI/RFI filters	BEADS, RIGNS
3	PB	150	220	200	10^4	NiZn	EMI/RFI filters	DRUMS, MULTI-HOLES
THOMSON-CSF/LCC (∅21∅14x10)mm or (∅21∅10x10)mm								
1	A2	10000±30%	330	120	0.3	MnZn	EMI/RFI filters	TOROIDES
2	B1	2500	450	200	1	MnZn	Transformers, power coils	E, U, LARGE TOROIDES
3	C1	650	420	220	10	MnZn	EMI/RFI resonators	RODS, TUBES
4	F1	2300±25%	450	230	6	MnZn	Power resonators	E
5	H1	700±20%	300	140	10^3	NiZn	Transformers, coils	TOROIDES
6	K3	80±20%	350	400	10^5	NiZn	Transformers, coils, filters	VARIOUS
7	S1	2200±20%	400	160	200	MnZn	Transformers, coils, filters	R, PM, POT, FP
8	T4	6000±25%	350	130	50	MnZn	Transformers, coils, filters	R, PM, POT, FP
TDK								
1	DB1	200	310	180	10^6	NiZn	Filters, coils	DR
2	DA2	1900±25%	500	200	0.3	MnZn	Divergence coils	YOKES
3	F3T	18	310	300	10^7	NiZn	AM/FM	RB, RS
4	FA1	1800	440	200	30	MnZn	Filters, coils	DR

5	H5B	5000±40%	420	130	1	MnZn	Various	RM, Q, X, POT, TOR
6	H5B2	7500±25%	420	130	0.1	MnZn	Transformers, BALUN, CHOKES	TOROIDES
7	HF30	45	320	300	10^5	NiZn	EMI/RFI filters	FERRITE BEADS
8	K5	290±20%	330	280	$2x10^5$	NiZn	Transformers, coils, CHOKES	Q, POT, TOROIDES
9	L4	400	330	150	10^7	NiZn	Filters, coils	DR, R
10	L4N	300	260	150	10^7	NiZn	Filters, coils	DR
11	M5E	17	300	300	10^7	NiZn	RF, OSC, IFT, coils	TH, TOROIDES, R
12	M5M	12	240	300	10^7	NiZn	RF, OSC, IFT, coils	TH, POT
13	PE22	1800	200	200	3	MnZn	Transformers, power coils	URI, LARGE TOROIDES
14	Q1C	250	125	125	10^7	NiZn	RF, OSC, IFT, coils	THP, TH, R, TOROIDES
15	V1F	17	300	300	10^7	NiZn	RF, OSC, IFT, coils	TH

From Table 6.2 we notice that each company gives the attributes of its materials for different dimensions for the ferrite ring. Additionally, depending on the material, they provide information for other attributes, like the loss coefficient ($\tan\delta/\mu_i$) ppm, the effective suppression intensity (H_{CMS}) A/m, the material density (d) gr/cm^3, the magnetostriction constant (λ_s), the disaccommonation factor (D_f), the temperature coefficient of relative permeability ($\alpha_{\mu r}$) ppm/ºC etc.

Last, some companies provide information suggesting materials for special purposes so as to achieve the best result. For example, PHILIPS proposes:

- for filtering: 4C6. 3D3, 3H1-3H3,
- for suppression, decoupling, screening: 3E25, 3C11, 3C85, 3F3, 4A11, 4A15, 4C65, 3S1, 3S2,
- for leveling, power storage: 3C85, 3C80, 3F3, 2P...,
- for pulse transformers or general applications: 3B8, 3H1, 3C11, 3E1, 3E4, 3E25, 3E5, 3E6,
- power transformers: 3C80, 3C10, 3C85, 3F3, 3F4, 4F1, and
- resonators: 3D3, 6B1, 4C65, 4D1, 4E1, 1P...

IV. TDK uses the color code of the materials: H5A=white and red, H5B=white and yellow, H5B2=yellow and yellow, H5C2=orange and orange, H6A=white and orange, H6A3=green and green, H6B=white and blue, H7A=white and green, K5=white and light brown, K6A=cyan and cyan.

6.7 Calculation of self-inductance with ferrite core

For the calculation of self-inductance with some ferrite core, manufacturers propose various solutions, some of which we examine here:

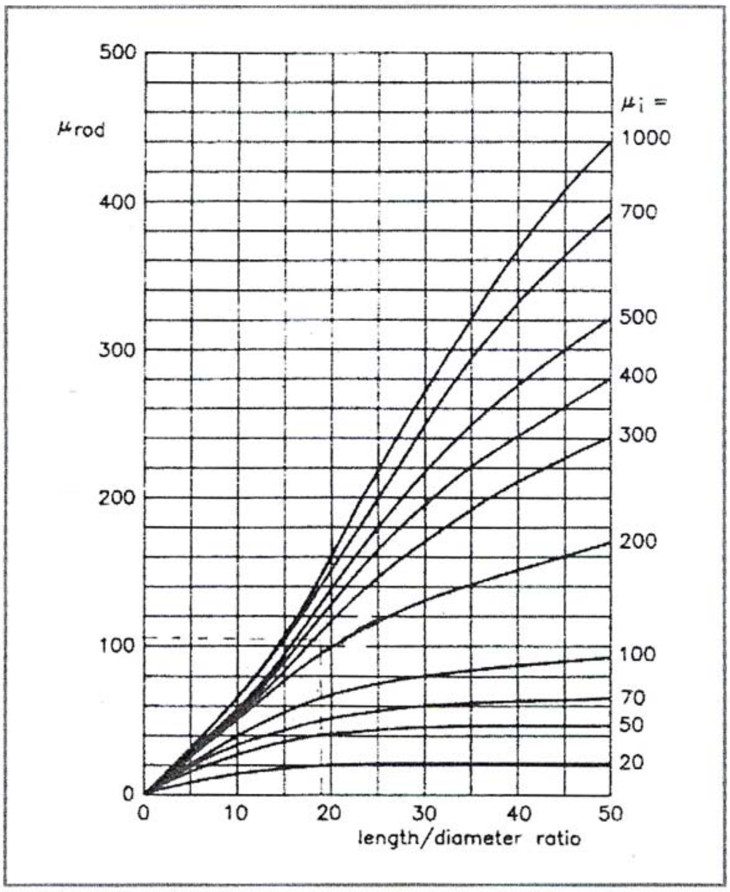
1. The rod and the tube ferrites are generally used for increasing the self-inductance of the coil. Their magnetic circuit is very open, so the dimensions of the ferrite influence the self-inductance of the coil through the initial permeability (μ_i), unless the ferrites are very thin. We can see that more clearly in Fig. 6.14 which is a suggestion of PHILIPS. We also have the following:

   $$L = \mu_0 \cdot \mu_{rod} \frac{N^2 \cdot S}{\ell} \text{ (H)}$$

   Suppose we want to make a ferrite coil in order to use it as AM aerial in medium waves. Let's say that the self-inductance is L = 370μH (see also p.203m, volume A). From the manual, we choose rod ferrite with length l=150mm, diameter d=8mm and material 4B1 with μ_i=250. We have l/d≈19 and μ_{rod}≈105, as shown in fig. 6.13. Since $S = \pi \frac{d^2}{4} = 50{,}265mm^2$, if we apply the equation 6.21:

   $$N = \sqrt{\frac{\ell \cdot L}{\mu_o \cdot \mu_{rod} \cdot S}}$$

   then N≈92 rounds. For a 4D2 ferrite, with μ_i=60 and μ_{rod}≈45, for the same self-inductance, we have N≈140 rounds.



μ_{rod}
500
400
300
200
100
0
μ_i =
1000
700
500
400
300
200
100
70
50
20
0
10
20
30
40
50
length/diameter ratio

Figure 6.14

7. For the calculation of power storing chokes, i.e. in a step-down mode pulse power pack, SIEMENS-MATSUSHITA suggests:

a. Suppose I=0.1!, L_{rev}>10mH and R_{cu}<1Ω, where L_{rev} is the self-inductance mentioned in reversive permeability μ_{rev}.
   In Fig. 6.20, for pot cores of materials N26 and N48 and for $I^2L_{rev}=0.1^2\cdot 10A^2\cdot mH=0.1A^2\cdot mH$ and $I^2L_{cu}=0.1^2\cdot 1A^2\cdot\Omega=0.01W=10mW$, the requirements are met. Thus, the core P22x13 with A_L=1000nH, R_{cu}≈0.86Ω, L_{rev}≈10.6mH and $N = \sqrt{R_{cu}/A_R} = \sqrt{0.86\Omega/67\mu\Omega} \approx 114$ rounds of a part is the most suitable for our application.
b. Suppose $(I^2L)_{max} = 8A^2mH$ and ΔT≈40K the overheating owed to copper losses. In the nomogram of Fig. 6.21 for cores EC and E of the material N27, we notice that for the value $8A^2mH$, the core EC41 with μ_e≈38 causes losses of almost 3W and this is what is required.
   The volume I^2L represents the ability of magnetic polarization.

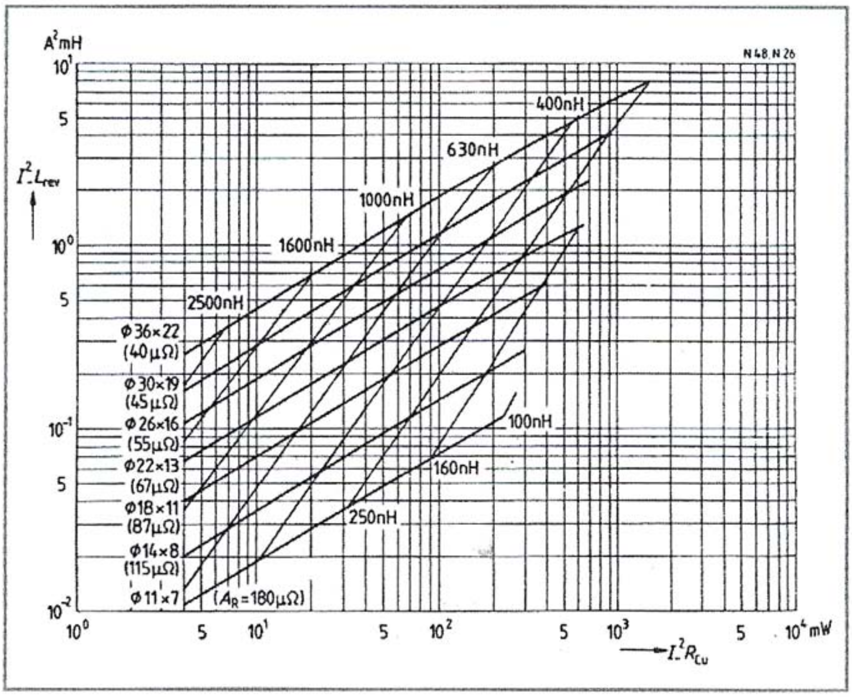


Figure 6.20

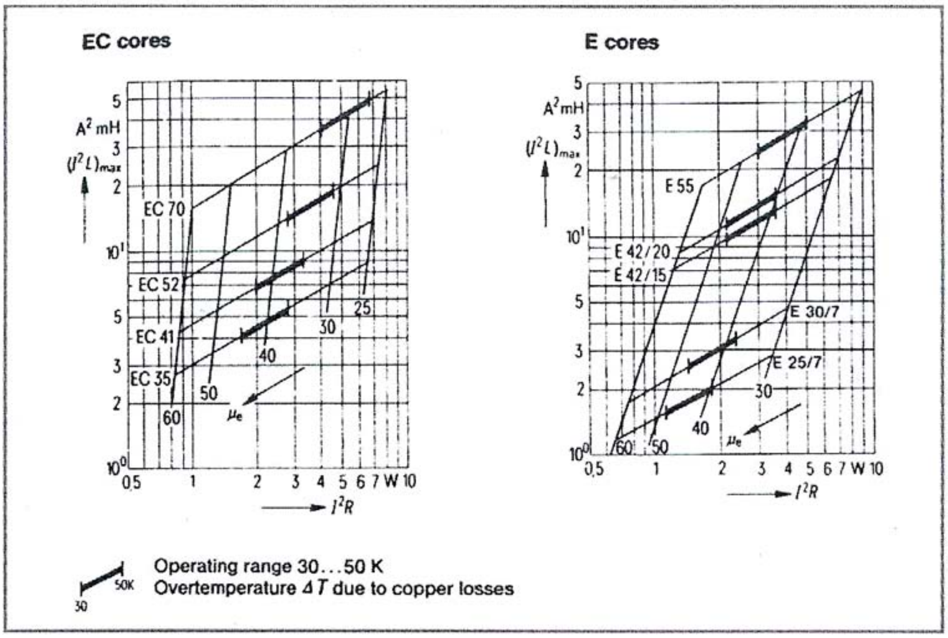

EC cores
A² mH
$(I^2L)_{max}$
5
3
2
10¹
5
3
2
10⁰
EC 70
EC 52
EC 41
EC 35
60
50
40
30
25
μ_e
0,5
1
2
3
4
5
6
7
W
10
I^2R
E cores
A² mH
$(I^2L)_{max}$
E 55
E 42/20
E 42/15
E 30/7
E 25/7
60
50
40
30
μ_e
0,5
1
2
3
4
5
6
7
W
10
I^2R
30
50K
Operating range 30…50 K
Overtemperature ΔT due to copper losses

Figure 6.21