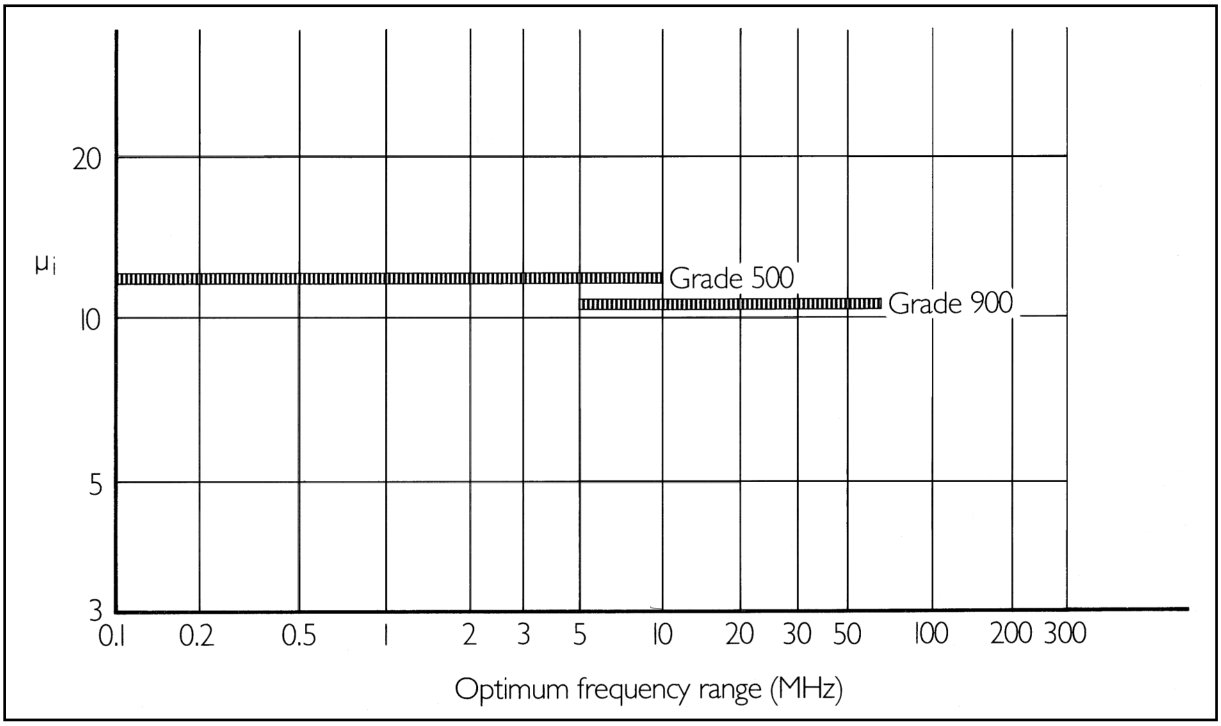
High Frequency Iron Powder Materials

High frequency iron powder cores are pressed from very fine carbonyl iron mixed with a bonding material. High resistivity is required to reduce the eddy current losses and for this purpose the iron powder is subjected to an acid treatment to produce an insulating oxide layer on the surface of each individual particle. A feature of this manufacturing process is that minute gaps appear between the particles and the permeability of the material is severely reduced, the highest obtainable value being approximately 30. Because of these gaps it is difficult to saturate iron powder cores, especially those operating in an open magnetic circuit.

The optimum frequency ranges and initial permeabilities of the grades of iron powder are given below. The frequency range for which a particular grade of material is most suitable depends upon the application, the shape of the core and the configuration of the magnetic circuit. For optimum values of Q the frequency range is clearly indicated. In untuned conditions, for example, suppressor and transformer applications, individual grades of iron powder are successfully used well above frequency limits indicated.

Iron Powder Materials

Parameter	Symbol	Standard Conditions of Test		Unit	500	900
Initial permeability (typical)	μ_i	$B \rightarrow 0$ 25°C		-	12	10
Loss Factor (typical)	$\frac{\tan \delta_{(r+e)}}{\mu_i}$	$B \rightarrow 0$ 25°C	100kHz	10^{-6}	-	-
			1 MHz		70	50
			2 MHz		80	60
			10 MHz		250	130
			50MHz		-	600
			100 MHz		-	-
Temperature Factor (typical)	$\frac{\Delta\mu}{\mu_i^2 . \Delta T}$	B<0.25 mT +25°C to + 55°C		10^{-6}/°C	12	12



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All figures were derived from measurements on toroids, the loss factor (residual plus eddy current) being determined by winding the test toroids with a number of turns suitable for the required frequency and measuring at a low flux density. The temperature factors of permeability were measured between 25 and 55°C.

For inductances wound on toroids, the value of Q obtainable at any frequency with a ‘lossless’ winding is:

$$Q = \frac{10^6}{\mu_i \,.\, \text{loss factor}}$$

Similarly, the value of the temperature coefficient of inductance per °C is,

Temperature coefficient
$= \mu_i$. temperature factor. 10^{-6} per °C.

There is no simple formula for predicting the value of Q or the temperature coefficient of inductors using iron powder cores in open magnetic configurations.

The values given are approximate only, as in each case the characteristics of the core depend upon the manufacturing conditions. These conditions have to be adapted to achieve not only the desired electrical characteristics but also the required mechanical strength.

Applications

Grade 500 is the most popular grade for tuned applications up to frequencies of 10 MHz or higher, if optimum values of Q are not particularly important.

Grade 900 is used to obtain values of Q higher than those obtainable with grade 500 at frequencies between 5 and 60 MHz.

Threaded cores are made in Grades 500 and 900.

When the choice of grade is motivated by the desired degree of variation of inductance as is frequently the case with threaded cores of permeability tuner cores, it should be understood that an increase in the length of the core may be much more effective than the use of a higher permeability grade and may lead to a higher value of Q.

The bonding material used for iron powder cores limits the maximum ambient temperature to 110°C.

Avaliable Torodial sizes (ODxIDxH):
33.00x20.00x11.00
40.00x24.00x14.00
50.00x32.00x25.00
50.80x31.80x14.00

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High Permeability Iron Powder Materials

Neosid high permeability iron powder cores are manufactured in two grades using selected types of iron powder.

During manufacture the powder is insulated by controlled surface treatments prior to mixing with a bonding material and subsequent compaction into practical components. The bonding materials used limit the maximum usage temperature to 110°C.

As with grades of carbonyl iron materials, a pressed compact in effect contains a distributed gap between particles. While this distributed gap constrains the achievable permeabilities of iron powder compacts, it carries considerable advantages in raising the saturation flux density.

High Permeability Iron Powder Materials

Parameter	Symbol	Standard Conditions of Test	Unit	1005	1003
Initial permeability (typical)	μ_i	$B \rightarrow 0$ 25°C 10kHz	-	75	60

Applications

Cores of Grades 1003 and 1005 are characterised by relatively high permeability and high losses in the interference spectrum. Used in RFI suppression of light dimmers, motor speed controllers employing thyristors and triacs and energy storage choke applications for switched mode power supplies.

Specifications for the most popular sizes are shown below:

Iron Powder Toroidal Cores - Component specifications

Part No.	Dimensions (mm)			Material Grade	Effective Length (mm)	Effective Area (mm²)	Effective Volume (mm³)	Core Constant C_1 (mm⁻¹)	AL Value (nH)*	LI² max (mJ)**
	O.D. (A)	I.D. (B)	Height (C)							
17-749-22	13.20	7.80	5.40	1003	31.51	14.25	449	2.21	34	0.38
17-732-22	14.80	8.00	6.40	1003	33.65	20.92	704	1.61	47	0.54
17-750-22A	20.30	12.70	6.40	1005	50.01	23.75	1187	2.11	41	0.89
17-730-22A	24.70	12.70	9.70	1005	54.00	54.00	3064	1.00	97	2.14
17-736-22	27.10	15.00	6.70	1003	62.43	39.37	2457	1.59	47	-
17-742-22A	33.00	19.80	10.00	1005	80.00	63.00	5040	1.28	77	3.60
17-746-22A	39.90	24.10	14.50	1005	96.39	112.10	10800	0.859	109	-
17-769-22A	50.80	31.80	25.40	1005	125.10	236.90	29645	0.528	179	-

* Measured at 10 kHz. B_{max} <1 mT.
** LmH x Amps²

The number of turns required to obtain an inductance L is given by the formula

$$n = 1000 \sqrt{\frac{LmH}{A_L}}$$

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RFI Suppression Requirements

When semiconductor switches are used for the phase-control of the mains current interference is generated because of the fast rise in load current at the instant of switching, i.e. when the switch (triac, thyristor) is triggered. In practice, since the amplitudes of harmonics of a step waveform generally decrease with their order, meeting the interference limit at 150 kHz is the most difficult.

The interference suppression by a commonly used inductance capacitance filter can be imagined to consist of two separate processes:
1. the presence of an inductance in a phase-controlled mains circuit causes the current to rise slower at the trigger instant and this means that the generation of harmonics is lowered;
2. the filter action of the LC circuit reduces the propagation of the generated harmonics along the mains leads.

It is difficult to estimate how these two processes contribute numerically to the total interference suppression. If the inductance is high at the instant of switching, the current step deviates more from vertical rise, so less is required from the LC filtering. If - on the other hand - the inductance at the instant of triggering is relatively low, more LC filtering is required.

However, the inductance at the triggering instant is not identical with the inductance effective at the frequencies in the spectrum to be protected. Because of the eddy currents, the inductance drops as the frequency rises, and it might happen that even a very high inductance at the triggering point is too low to produce sufficient filtering at, say, 150kHz, which is a function of L multiplied by C.

Thus, the frequency response of the inductance of the suppressor coil (i.e. the permeability of its core) is a very important point.

In practice, the higher the permeability is at low frequencies, for instance in purely metallic cores, the more rapidly it drops with the frequency. Hence, a compromise has to be struck; the core permeability has to be as high as possible at the triggering instant, while its fall with the frequency must be as slow as possible.

It should be clearly said that the permeability (inductance) values measured at low flux density (bridge and similar methods) are by no means identical with the values, effective when the relatively low interference currents are superimposed on a high mains current, interrupted at each half-cycle, but experience shows that there is a close correlation between this low flux density inductance and the results of interference measurements: the higher the inductance at, say, 150kHz, the better the suppression.

The importance of high losses in the core material at higher frequencies needs some explanation. Whereas the filters, composed of low loss inductors and capacitors in the low pass band configuration, work by reflecting the high frequencies back to the generating source, the use of high loss inductors allows the unwanted frequencies to be absorbed in the core. In other words, high losses make the filters behave as an RC filter, except at mains frequencies where the value of “R” is negligible. In some applications, for instance, light dimmers, if the losses in the cores are not high enough, i.e. Q of the inductor is high, self oscillations following the instant of switching are not sufficiently damped, which gives rise to the so called “flicker effect”. Typically, Q of grades 1003 and 1005 at 150kHz is less than 5.

Since relatively high mains current flows through the winding on the suppressor core, mains hum can become audible, if insufficient provisions are made to prevent any mechanical movement arising from the variation of the current, especially since phase-control causes abrupt changes in the instantaneous value of the current intensity. As an analogy, the hum of mains transformers, in which the stampings are not rigidly clamped, may be mentioned.

The mains current flowing through the suppressor winding causes a power loss in the winding and a power loss in the core. Of these two, the loss in the winding is more important. It is, therefore, necessary to reduce the resistance of the winding to reasonable minimum, by reducing the number of turns and increasing the cross-sectional area of the wire. The power losses at mains frequency in the core material, although less important, should also be kept low. In addition, attention should be paid to the distributed capacitance which causes self resonance and increases the apparent impedance of the series member of the LC circuit. If possible, this should occur in the lower range of the frequency spectrum (150kHz - 500kHz). Normally this frequency band is most difficult to suppress.

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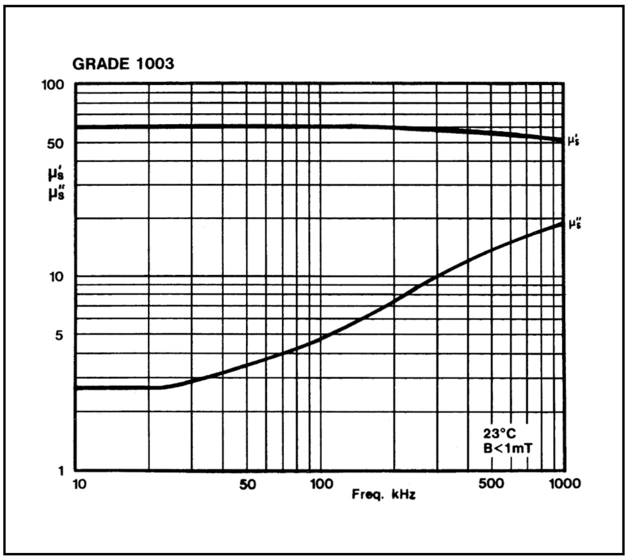
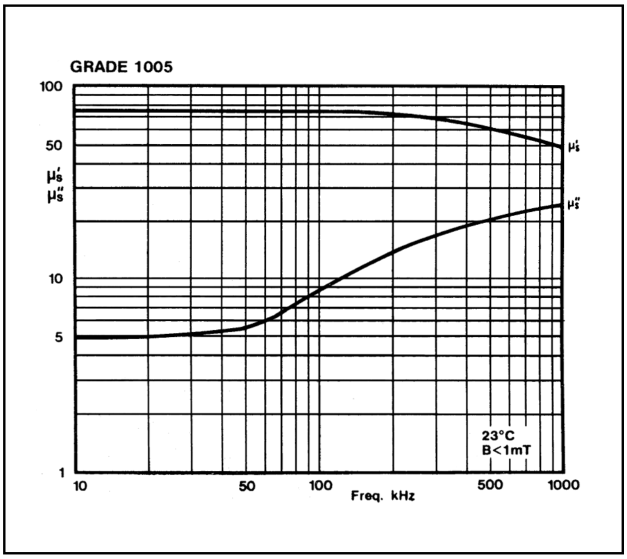
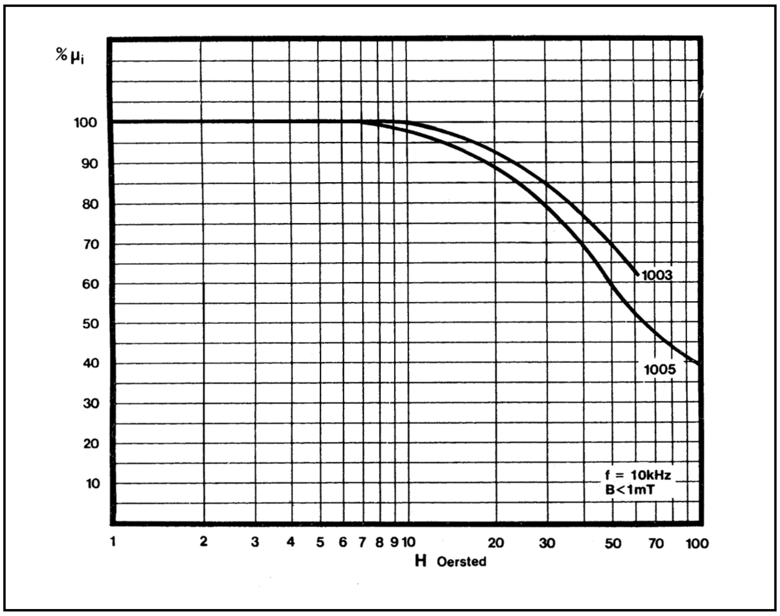
Complex Permeability vs Frequency





Percentage Initial Permeability vs D.C. Magnetisation



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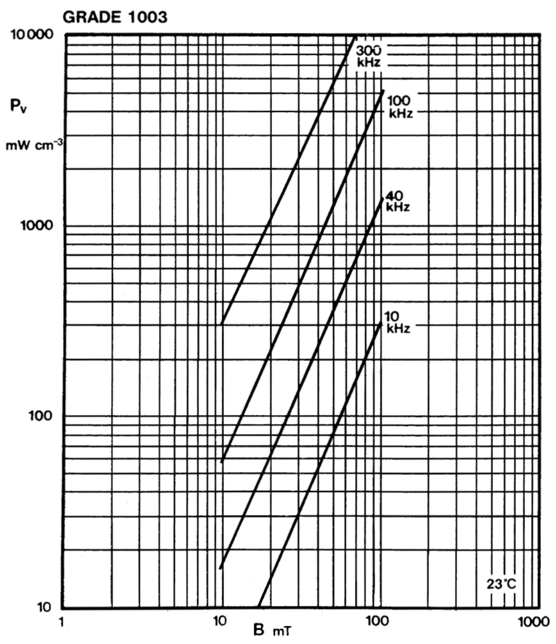
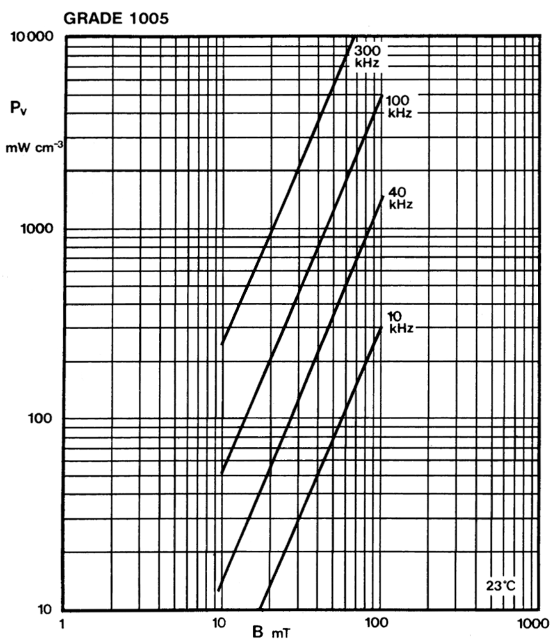
Power Loss Density vs Flux Density Curves





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Core Material Selection

The above discussion leads directly to the conclusion that the permeability, or the inductance for a given number of turns, should be as high as possible, because then the number of turns can be reduced for a given inductance value and, with a specified winding area, the cross-section of the wire can be increased. The losses at a relatively high flux density induced by the mains current must be kept low.

Grades 1003 and 1005 can operate at high flux densities. Saturation flux density is approximately 15,000 gauss and 10,000 gauss is reached when the field strength is 42A/cm. For example, using 33x20x8 toroid wound with 120 turns, and a mains current of 3A pk (2.1A r.m.s.) flowing through the winding, flux density is 10,000 gauss. The total core loss at this flux density is 50mW/cc.

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Filter Inductor Design

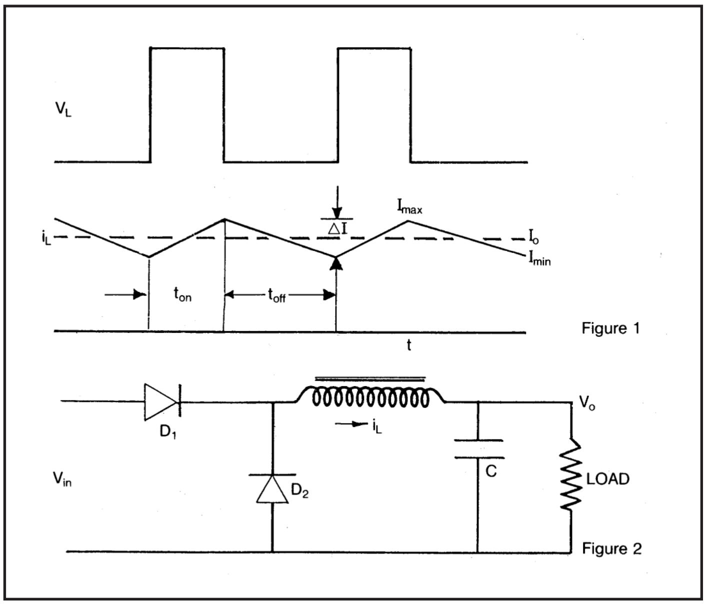

Figure 1 shows typical waveforms of voltage and current through the filter inductor (figure 2) in a forward converter. For a given switching frequency, the turn-off time, t_{off}, can be calculated from:

$$t_{off} = \frac{1}{f}\left(1 - \frac{V_o}{V_{in}}\right) \text{ ---(1)}$$

where,
f = switching frequency
V_o = output voltage
V_{in} = input voltage

V_L = instantaneous voltage across the inductor
i_L = instantaneous current through the inductor
I_o = mean d.c. current
V_o = output voltage (d.c)
ΔI = peak to peak ripple current

A definite LC product is necessary to reduce the ripple voltage to a required value. This can be achieved over a wide range of LC products, but there are several practical considerations to be taken into account before the values of L and C can be determined.

The value of inductance has to be a compromise between the high value desirable for rapid response to load changes. In addition, large values of inductance increase the size of the inductor, and hence its cost. It is, therefore, desirable to keep L as low as possible and C high. In practice ΔI (peak to peak ripple current) dictates the value of the inductance which can be calculated from the equation:

$$L = \frac{(V_o + V_d)\, t_{off}}{\Delta I} \text{ H---(2)}$$

where V_d is the voltage drop across D_2
This value inductance must be maintained under all possible operating conditions.

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Design Example

V_o = 5 volts I_o = 5 A
t_{off} = 17.5 μ sec Max Δ = 25% of I_o

1. Calculate $\Delta I = \frac{5}{4}$ = 1.25 amps

2. Calculate $L = \frac{(V_o + V_d)\, t_{off}}{\Delta i} = \frac{(5 + 0.6)\, 17.5}{1.25}\ \mu H$

   = 80 μH

3. Calculate the energy product LI^2 max (mJ)
   (L in mH, I in amps)
   = $80 \times 10^{-3} \times (5.625)^2$ = 2.53 mJ

   Note: I max = $I_o \times \frac{\Delta i}{2}$

4. Select a toroid of nearest LI^2 max figure from component specification table.
   17-730-23 24.7 x 12.7 x 9.7
   A_L = 54 nH

5. Calculate number of turns $n = 10^3 \sqrt{\frac{L\ mH}{A_L}}$ . . . (3)

$$= 10^3 \sqrt{\frac{80 \times 10^{-3}}{54}} = 39 \text{ turns}$$

It must be remembered that under operating conditions, i.e. d.c. with a substantial ripple current superimposed, the flux conditions and, therefore, permeability differ from the figures given in the table. A_L values given in the table have been measured on a bridge at 10 kHz and B_{max} a.c. less than lmT. It is found that A_L values measured under "Pulse" condition are at least 50% higher than the A_L values tabulated in the above example, therefore, taking a pulse A_L of 80 the revised number of turns are:

$$n = 10^3 \sqrt{\frac{80 \times 10^{-3}}{54}} = 39 \text{ turns}$$

Inductance with 32 turns measured on a bridge will obviously be less than 80 μH but under pulse conditions the value is approximately 80 μH. It is recommended that in the first instance a trial is made by measuring the inductance with an oscilloscope and displaying the current through the inductor. Turn off time V_o can be measured and L can be calculated by using formula (2). The exact number of turns can then be calculated to obtain the inductance required.

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