MAGNETIC MATERIALS

There are two basic types of magnetic materials: Metallic, and Metallic Oxide or ceramics, etc. The most common metallic material is the familiar laminated steel that you see in mains power transformers. This material works well at mains frequencies, but rapidly becomes ineffective at frequencies above, say, the audio spectrum.

The other type of metallic magnetic material can basically be described as 'iron powder'. The iron dust is acid treated to produce an oxide layer on the outer surface. This oxide layer effectively insulates each iron particle from the next. The powder is mixed with a (non magnetic) bonding material and pressed or formed into useful shapes, the most common being the *toroid*, or ring core. The use of individual particles of iron each insulated from each other gives many of the benefits of steel (eg. good low frequency performance) but without the disadvantages (eg. high *eddy-current* losses).

Metallic Oxide materials are called **ferrites**. Ferrites are essentially ceramics; the ingredients are mixed, pre-fired, crushed/milled, dried, shaped and finally pressed or extruded and fired into their final hard, brittle state. Newer ferrite materials are called 'rare earth' types. They are primarily used as permanent magnets. Like all ceramics they are very stable, with the excellent characteristic of fairly high *resistivity*.

Clockwise from top left: an LF-1212 multi-aperture core; two standard two-hole balun cores; and two ferrite 'bead' suppression sleeves.

Most common ferrite contains about 50% iron oxide. From there, the balance of the remainder of the material classifies what type of grade of ferrite you end up with. The most common type is made up of oxides of manganese (Mn) and zinc (Zn). Mn-Zn ferrites are used for lower frequency work. They have high *permeability*, but their bulk resistivity is relatively low. The other type of ferrite has nickel and zinc oxide composition. This ferrite has a lower permeability, on average, but will work well at higher frequencies. This material has much higher bulk resistivity. Apart from the material composition the performance of a ferrite has a lot to do with how it is made. The ferrites shown in the Jaycar Electronics catalogue are generally Mn - Zn types.

FERRITE DEFINITIONS

Bulk Resistivity: Materials differ considerably in terms of their ability to conduct an electrical current. The bulk resistivity of a material is defined as **the resistance between opposite sides of a cube** of the material, and is measured in ohms per centimetre per cm^2, which simplifies to **ohm-cm**. Good conductors like metals have very low resistivity, while insulators like glass or ceramic have a high resistivity.

Eddy Current: When a magnetic material is influenced by a magnetic field, the magnetic particles — even down to atomic level in the case of metallic materials — align with that field. If the magnetic material is conductive (eg, as in, say, steel), and the field is changing with time, electric currents are generated within the magnetic material itself. This is not dissimilar to having a short-circuited turn of wire in a transformer. As you can imagine, these intra-magnetic material currents waste energy (as heat) and reduce the efficiency of the magnetic component considerably. The electric currents within the magnetic material itself are called *eddy* currents, and will be higher in material with low resistivity.

If you ever pull apart a conventional transformer, you will find the steel (actually an iron/silicon/carbon alloy) is arranged in thin sheets — or 'laminations' — with an insulating varnish on each lamination. Each lamination is shaped like an 'E' or an 'I'. When the stack is assembled it is done so in a way to effectively insulate each lamination from the other. This is to minimise eddy current losses and therefore maximise the efficiency of the transformer.

Ferrite material has quite high intrinsic resistivity compared to, say, steel. Mn-Zn ferrites have resistivity in the order of 10 - 1,000 ohm-cm, but are still much lower in resistivity than Ni-Zn ferrites at 10^5 - 10^7 ohm-cm.

Eddy current losses are therefore much less of a problem in ferrites, and this is the fundamental reason why they are used in higher frequency applications (the field of the eddy current shrinks in proportion to the increase in frequency but is no less intense). See 'Core Losses' below.

Permeability: This is basically the characteristic of a material which predicts the flux density generated in the material for a given amount of external magnetic force. In other words, for an applied magnetic force 'a', the density of the 'lines of force' in a material of high permeability will be greater than in a material of lower permeability. In semiconductor parlance it can be thought of as magnetic 'gain', but the true story is really more complicated than that.

Saturation: When a magnetic material has an external magnetic field applied beyond a certain level, the magnetic material will cease to respond to the increase — its permeability will start

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From the top down: S1 and L8 ferrite toroids; some clip-on noise suppressors; suppressor sleeves for flat cables; a ferrite rod with AM antenna coil; and a ferrite toroid with prewound inductor.

Summary of Ferrite Properties

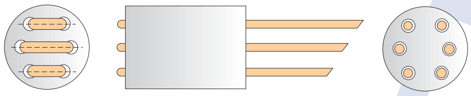
Property	Symbol	Unit	Material			
			L8	J70	M7	S1★
Initial Permeability	μ_i		1500 ±20%	620 ±20%	160 ±20%	120 ±20%
Relative Loss Factor	tan δ/u	x 10^{-5}	<2.8 @ 0.3MHz	<3.89 @ 0.7MHz	<44.6 @ 2MHz	<6.83 @ 1.5MHz
Saturation Flux Density	Bs	Gauss	2550	2500	2205	1625
Residual Flux Density	Br	Gauss	1225	1625	1700	1125
Coercive Force	Hc	Oe	0.225	0.725	1.04	1.275
Curie Temperature	Tc	°C	>120	>150	>150	>200
Disaccommodation Factor	DF	x 10^{-3}	11.8	14.4	1.89	11.7
Density	d	g/cm³	>5.0	>4.8	>4.6	>4.3
Resistivity	ρ	MΩ-cm	19	5.7	19	18

NOTES:
1. Test core size: T - 30.8ϕ x 18.4ϕ x 7.5
2. Winding Method: 0.5U.E.W. 47Ts
3. Temperature: 25°C
4. Initial permeability test frequency: 10kHz 0.8mA

★ Material for Antenna Rod

Performance Data on LF-1212 Multi-Aperture Core (L8 material)

A: Wound with 1 turn x 3 wires 0.6mm ϕ TCW

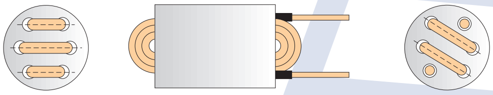


Typical Impedance at 25MHz = 208 Ω; at 100MHz = 248 Ω

B: Wound with 2.5 turns wire 0.6mm ϕ TCW

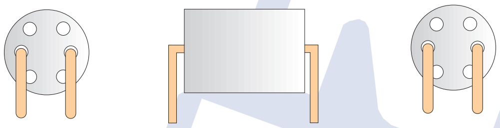
Typical Impedance at 25MHz = 810 Ω; at 100MHz = 612 Ω

C: Wound with 3 turns wire 0.6mm ϕ TCW



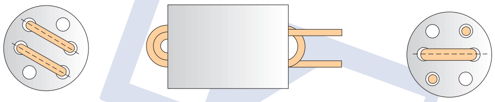
Typical Impedance at 25MHz = 994 Ω; at 100MHz = 624 Ω

D: Wound with 0.5 turn x 2 wire 0.65mm ϕ TCW



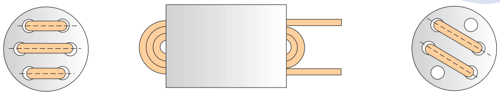
Typical Impedance at 25MHz = 119 Ω; at 100MHz = 145 Ω

E: Wound with 2 turns wire 0.6mm ϕ TCW



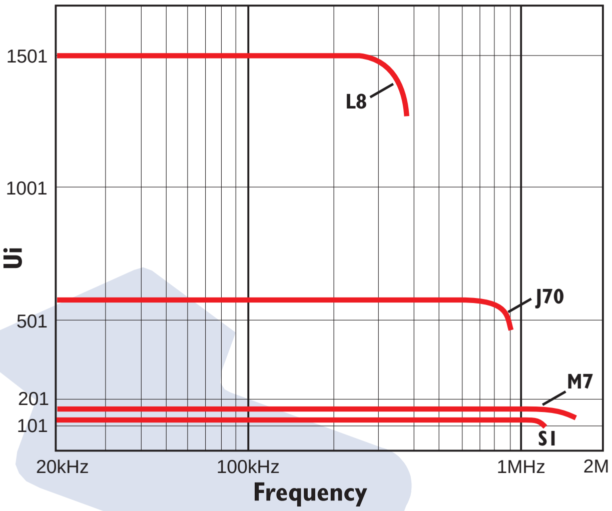
Typical Impedance at 25MHz = 597 Ω; at 100MHz = 546 Ω

F: Wound with 3 turns wire 0.6mm ϕ TCW



Typical Impedance at 25MHz = 1023 Ω; at 100MHz = 945 Ω

Initial Permeability vs. Frequency



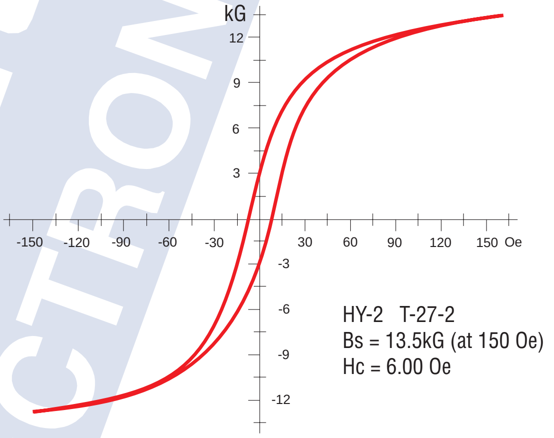
Powdered Iron Material

Properties of powdered iron material

Material	μ_i	Frequency (kHz)	Bs (kG)	Hc (Oe)
HY-2	75	0.05 ~ 50	12	6

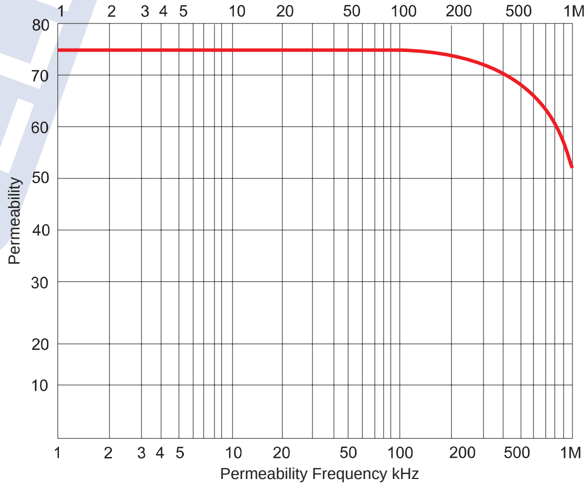
Hysteresis Characteristics

(Fairly typical of T14, 27 and 40)



Permeability vs. Frequency

(Flux Density less than 20 Gauss)



FERRITE DEFINITIONS, Continued

to fall. At this point the magnetic material has reached *saturation*. Higher permeability materials tend to reach saturation earlier than lower types.

Core Losses: ‘Losses’ is the broad term for all of the factors that cause magnetic material to be less than optimally efficient. Eddy currents are the greatest cause of loss in magnetic materials. It is such a problem in steel, for example, that it just cannot be used in high frequency or high switching speed applications.

There are other types of losses which are beyond the scope of this discussion, but they can actually be put to good use. When designing a filter, for example, high frequency noise can be attenuated by the ‘lossy’ characteristics of ferrite at higher frequency. This is the way ferrite beads and suppression sleeves work, when threaded on component leads to prevent HF instability, and also the idea behind split-core spike protector/noise suppressors — the type which clip around mains and signal cables.

Isotropic ferrite: This term refers to the manufacturing process and its effect on the magnetic properties of the final product. The ferrite grains in an isotropic component are not aligned in any direction and are therefore not magnetically polarised. Most non-magnet ferrite is isotropic.

Anisotropic ferrite: Before the ferrite is fired into a ceramic, the particles are aligned by a strong external DC magnetic field. When the ferrite is cooled, you have a product with virtually all of the particles aligned North-South. When the ferrite is then permanantly magnetised, you have a product which is intrinsically more powerful than an isotropic magnet.

Anisotropic magnets also resist demagnetising AC fields better as well. This makes them ideal for speaker magnets, etc.