Technical Bulletin

BULLETIN FC-S7

Curve Fit Equations for Ferrite Materials

Ferrite Materials have found widespread use throughout the power supply industry, and many tried and true methods have been developed for core geometry and material selection. However, as the industry has matured, so have the design methods and tools. Among these renovated design techniques are computer simulations and modeling of core and material attributes.

Material characteristics such as watt loss, frequency response, and permeability changes versus temperature are of definite interest to design engineers and core specifiers. Many such features are included in the curves and equations following, along with a few suggestions for their use. These design aids were developed by Magnetics and are based entirely on ferrite materials featured in Magnetics Ferrite Cores Catalog (FC-601).

Curve Fit Formulae for Filtering Applications

Ferrite cores (usually toroids) used in filtering networks are often characterized by their permeability under a range of operational conditions. For example, high permeability (μ) ferrites retain the bulk of their initial permeability (and therefore their inductance) over a limited frequency range, with permeability decreasing as frequency is increased. Likewise, many ferrites have non-linear μ vs. temperature relationships. The following equations and sample curves describe these characteristics for Magnetics' high permeability and power ferrite materials. Figures 1 and 2 depict examples of variations of material permeability and their corresponding curve fit formulae.

P&R Material Permeability vs. Frequency

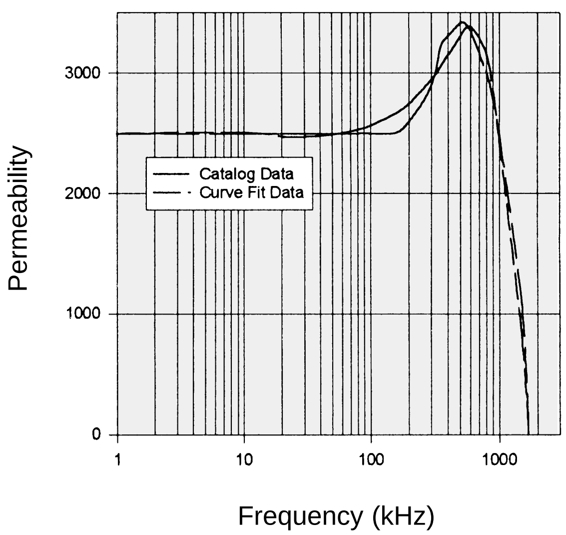
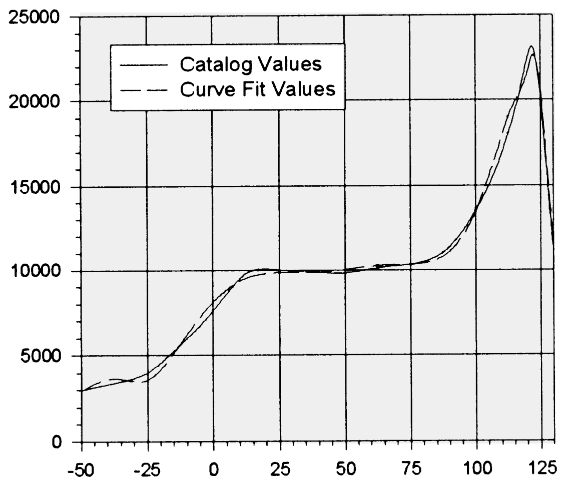


Figure 1

W Material Permeability vs. Temperature



Temperature (degrees C)

Figure 2

As the graphs display, the fits are not exact at every point along the curves, but they do represent a close approximation along the entire length of both graphs. Also worth noting are the limitations on every curve shown in this note; the curve fits are only valid for the range of values shown on the actual graph. In other words, these equations should not be used to predict performance at extrapolated points, for instance, temperatures greater than 125°C for W material. One final point is that the values used to compile the form fits (and the original curves) represent typical ranges which most cores should exhibit, but these data points are generally not guaranteed. Should special requirements relating to these characteristics arise, please contact Magnetics Applications Engineering Group at (724) 282-8282.

Table 1 Material Permeability vs. Frequency

Material	Format	a	b	c	d	e	g	h	i	j
K	1	1167	$1.150*10^{5}$	-21.38	0	$-6.312*10^{-7}$	2994	-0.6772	0	0
P&R	2	$-9.716*10^{7}$	$7.675*10^{7}$	$1.094*10^{8}$	$-5.638*10^{4}$	-4.705	-6.043	19.31	-0.03630	$2.485*10^{-5}$
F	3	3008	0.2825	-0.02084	$1.894*10^{-4}$	$-5.040*10^{-7}$	$5.753*10^{-10}$	$-2.988*10^{-13}$	$5.802*10^{-17}$	0
J	1	$-1.854*10^{5}$	$1.367*10^{7}$	$4.926*10^{4}$	771.8	-0.3794	$1.906*10^{5}$	889.8	7.984	0
W	1	$1.560*10^{5}$	$1.417*10^{7}$	$-1.265*10^{5}$	933.9	-0.6116	$1.434*10^{5}$	-1412	10.14	0
H	2	$2.247*10^{8}$	$-8.986*10^{5}$	1581	0	$-1.546*10^{-3}$	$-5.117*10^{-3}$	$6.844*10^{-5}$	0	0

FORMAT 1: $\mu = ((a + bf + cf^2 + df^3 + ef^4)/(1 + gf + hf^2 + if^3))^2$

FORMAT 2: $\mu = ((a + bf + cf^2 + df^3 + ef^4)/(1 + gf + hf^2 + if^3 + jf^4))^{1/2}$ *All frequencies in kHz*

FORMAT 3: $\mu = a + bf + cf^2 + df^3 + ef^4 + gf^5 + hf^6 + if^7$

Table 2 Material Permeability vs. Temperature

Material	a	b	c	d	e	f	g	h	i
K	1516	4.088	$-3.309*10^{-3}$	$-3.506*10^{-4}$	$2.455*10^{-6}$	0	0	0	0
R	2075	16.12	0.1295	$5.934*10^{-4}$	$-1.001*10^{-5}$	0	0	0	0
P	2239	20.97	0.1298	$7.159*10^{-4}$	$-2.038*10^{-5}$	0	0	0	0
F	2488	21.55	$-4.243*10^{-2}$	$-2.724*10^{-3}$	$8.284*10^{-6}$	0	0	0	0
J	4333	32.94	$7.733*10^{-2}$	$-2.648*10^{-3}$	$1.457*10^{-5}$	0	0	0	0
W	8118	163.5	-3.894	$-5.684*10^{-2}$	$2.984*10^{-3}$	$-1.176*10^{-5}$	$-6.070*10^{-7}$	$7.846*10^{-9}$	$-2.737*10^{-11}$
H	11160	214.9	1.444	$-7.530*10^{-2}$	$-6.667*10^{-4}$	$1.802*10^{-5}$	0	$-6.075*10^{-10}$	0

FORMAT: $\mu = a + bT + cT^2 + dT^3 + eT^4 + fT^5 + gT^6 + hT^7 + iT^8$ T in °C

These equations are of greatest use for evaluating common mode and other types of filtering applications. Using the above curve fits, reactive impedance (XL) can be approximated across given temperature or frequency ranges to determine the most appropriate operational points, and to provide some insight into worst case situations. Additionally, the ferrite's effect on higher order harmonics may be determined with assistance from these equations. Most power transformer designs are not very sensitive to the core's initial permeability, so the usefulness of these formulae will be generally limited for that class of applications.

Curve Fit Formulae for Power Applications

Of more practical use for power supply applications are form fits for watt loss, power loss versus temperature, and effective permeability versus DC bias (for gapped cores). Table 3 describes watt loss characteristics for various ferrite materials from Magnetics.

Table 3 Power Loss

Material	Frequency	a	c	d
K at 80°C	**f<500 kHz**	0.0530	1.60	3.15
	500 kHz≤f<1 MHz	0.00113	2.19	3.10
	f≥1 MHz	$1.77*10^{-9}$	4.13	2.98
R at 100°C	**f<100 kHz**	0.074	1.43	2.85
	100 kHz≤f<500 kHz	0.036	1.64	2.68
	f≥500 kHz	0.014	1.84	2.2
P at 80°C	**f<100 kHz**	0.158	1.36	2.86
	100 kHz≤f<500 kHz	0.0434	1.63	2.62
	f≥500 kHz	$7.36*10^{-7}$	3.47	2.54
F at 25°C	**f≤10 kHz**	0.790	1.06	2.85
	10 kHz<f<100 kHz	0.0717	1.72	2.66
	100 kHz≤f<500 kHz	0.0573	1.66	2.68
	f≥500 kHz	0.0126	1.88	2.29
J at 25°C	**f≤20 kHz**	0.245	1.39	2.50
	f>20 kHz	0.00458	2.42	2.50
W at 25°C	**f≤20 kHz**	0.300	1.26	2.60
	f>20 kHz	0.00382	2.32	2.62
H at 25°C	**f≤20 kHz**	0.148	1.50	2.25
	f>20 kHz	0.135	1.62	2.15

FORMAT: $P_L = af^cB^d$ P_L in mW/cm^3, B in kG, f in kHz

Power losses, like permeability, vary with temperature. In fact many power ferrite materials are tailor-made to exhibit a very specific loss vs. temperature profile. Figure 3 and Table 4 show this characteristic for all of Magnetics' power and high permeability ferrites. Because ferrites are often used at temperatures different from those used to measure power loss for catalog data, these equations may be used for determining operational losses more precisely at different ambient temperatures.

Table 4 Power Loss vs. Temperature

Material	a	b	c	d	e
K	0.983	$-1.12*10^{-2}$	$1.95*10^{-4}$	$-6.51*10^{-7}$	0
R	2.67	$-3.42*10^{-2}$	$1.75*10^{-4}$	0	0
P	1.92	$-2.77*10^{-2}$	$1.91*10^{-4}$	0	0
F	1.44	$-2.61*10^{-2}$	$4.51*10^{-4}$	$1.82*10^{-6}$	$-2.65*10^{-8}$
J	1.22	$-1.37*10^{-2}$	$2.02*10^{-4}$	0	0
W	1.19	$-1.16*10^{-2}$	$1.96*10^{-4}$	0	0
H	1.17	$-1.38*10^{-2}$	$2.70*10^{-4}$	$-8.89*10^{-7}$	0

FORMAT: $T_c = a + bT + cT^2 + dT^3 + eT^4$ T (temperature of operation) in °C

F Material (curve fit in dashed)

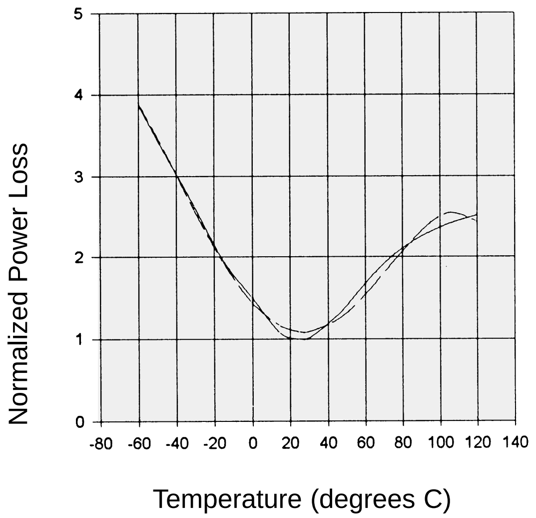


Figure 3

K Material Effective Permeability vs DC Bias

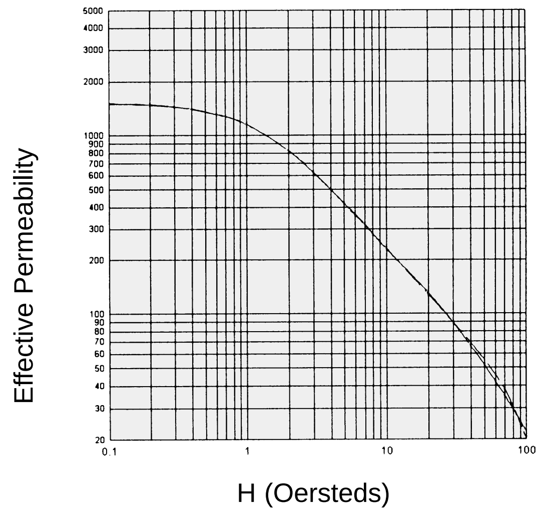


Figure 4

The two final curves sets and equations relate to the maximum DC bias gapped core sets may withstand without a reduction in permeability (inductance). These curves are useful for determining a suitable DC bias operating point for a gapped ferrite, but do not evaluate how the gapped cores' permeability changes with varying DC bias. For instance, a K material core set gapped to an effective permeability of 200 will support a DC bias of about eleven Oersteds without loss of inductance (permeability). This use of the curves is counter to the utility of µ vs. DC bias curves for MPP, High Flux, and Kool Mµ powder cores, where the permeability of the core is expected to "roll off" with increasing magnetizing force. Note that Tables 5 and 6 both offer equations to describe Figure 4; the independent and dependent variables are simply reversed.

Table 5 Maximum Effective Permeability vs. Magnetizing Force

Material	a	b	c	d	e	f
F	10^7	$6.66*10^5$	-7200	0.648	3.00	0
P&R	$4.49*10^6$	$6.32*10^7$	$-3.73*10^5$	3.48	37.7	4.01
K	$2.35*10^6$	$6.54*10^4$	-686	-0.319	0.511	0

FORMAT: $\mu_e=((a + bH + cH^2)/(1 + dH + eH^2 + fH^3))^{1/2}$ H in Oersteds

Table 6 Maximum Magnetizing Force vs. Effective Permeability

	F Material	P&R Materials	K Material
a	$1.013*10^8$	$8.822*10^7$	$4.970*10^8$
b	$-1.260*10^5$	$-1.230*10^5$	$2.065*10^6$
c	65.34	64.30	-1466
d	-0.01150	-0.01128	-0.08204
e	182.5	155.5	1471
f	11.54	5.928	33.96
g	0	0	0.5145

FORMAT: $H=((a + b\mu + c\mu^2 + d\mu^3)/(1 + e\mu + f\mu^2 + g\mu^3))^{1/2}$ H in Oersteds

The two groups of equations above can be used to predict core saturation in a variety of devices, such as DC output inductors, flyback transformer cores, and high current AC inductors.

These curve fit approximations should provide a reasonable groundwork for any number of computer aids, including spreadsheet design routines, performance simulations, and frequency response predictions. Should there be other computer simulation or modeling needs that are not covered in this application note, please feel free to contact **Magnetics Applications Engineering.**

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