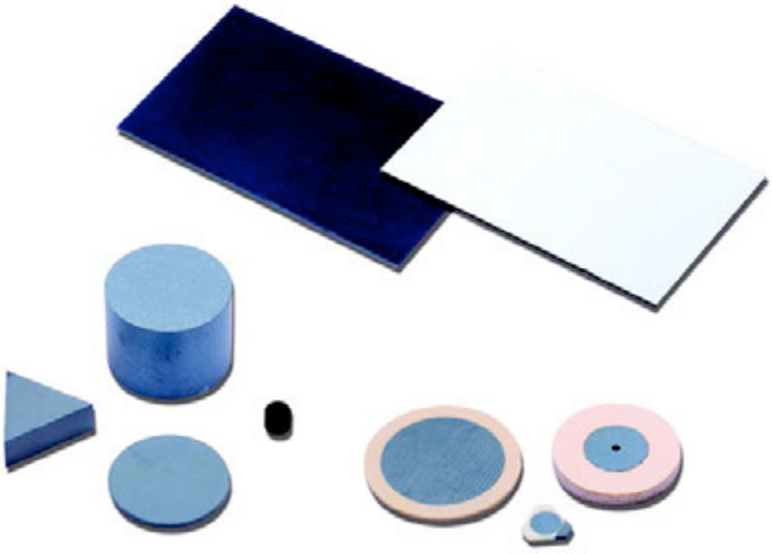
MICROWAVE FERRITES & FDA

EXXELIA TEMEX offers a wide range of ferrite materials, yttrium garnets (“Y” series or “D” series), magnesium (“U” series), nickel (“N” series) and lithium (“A” series) ferrites, as a result of their own developments on inheritage of the formerly companies CSF, LTT, Thomson. The offer covers need at frequencies from 0.1 to more than 30 GHz, high power, with temperature exigencies as well.

EXXELIA TEMEX manufactures their own ferrite powders from simple oxides or carbonates raw materials, then produce pressed and fired ceramics, machine them at tight tolerances and surface finishing up to polishing. Temex ceramics also supply assemblies of ferrite surrounded with dielectric, silver thick film metallized pieces, complex shapes.



Symbols / Units

Magnetism parameters

Great letters: time constant (DC) / Small letters: frequency, time dependant (RF)

Symbol	Parameter	MKSA system	CGS system
B Br M (4pM$_s$ or M$_s$), m	Magnetic induction Remnant induction Volume magnetization (saturation)	Tesla (T)	Gauss (=10^{-4} Tesla)
H, H$_r$ H$_a$ H$_c$ h, h$_c$ DH DH$_{eff}$ DH$_K$	Magnetic field (magnetizing force), resonance Anisotropy field Coercive force Magnetic wave field, critical wave field Ferromagnetic resonance line width Effective resonance line width Spin wave line width	A/m	Oersted (Oe) (=10^3/4p A/m)
μ_0	Vacuum permeability	4p10^{-7}H/m B = μ_0 (H+M)	1 B = H+4pM
$\mu = \mu_0 \mu_r$	Permeability	B = $\mu_0.\mu_r$.H	B = μ_r.H
c	Magnetic susceptibility = M/H, m/h	-	-
μ_r	Relative permeability	μ_r = 1 + c	μ_r = 1 +4pc (or 1+c)
a	Magnetization temperature coefficient: $\frac{\Delta M_S}{M_S \Delta T}$	10^{-3}.K^{-1}	10^{-3}.°C^{-1}
f	Wave frequency	MHz	MHz
g	Gyromagnetic ratio: f = g H$_r$	~35 10^{-3} MHz. m / A	~2.8 MHz / Oe
g$_{eff}$	Lande factor ~ 2	= g / 0.0176	= g / 1.4

In the below text, CGS system is mainly used with simplified expression (without the factor 4p).

Dielectric

Symbol	Parameter
e’	Relative permittivity (real part)
e’’	Relative permittivity (imaginary part)
e_r	Relative complex permittivity
tand	Dielectric loss tangent: tand = e’’/e’

Miscellaneous

Symbol	Parameter	Unit
T,Tc	Temperature, Curie temperature	K
Ra	Surface roughness	µm

I. Basic Properties

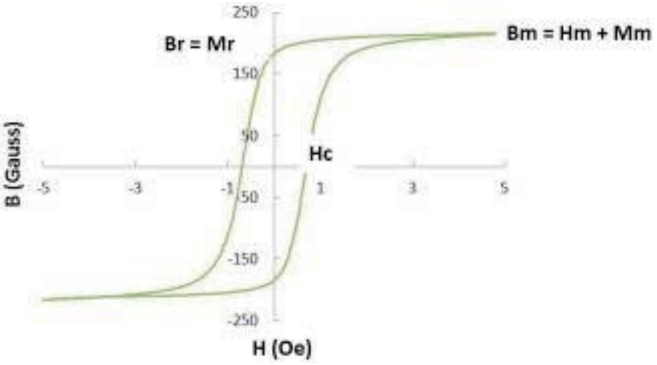
Ferrite materials are used in microwave applications to perform various non-reciprocal devices such as isolators, circulators, diplexers, filters, phase shifters etc. They have dielectric and magnetic properties due to the presence of magnetic ions such as iron within the composition.

I.1 Magnetic properties

Magnetization Ms

This property is based on the alignment of the spins of electrons parallel to an applied magnetic field H. Because the material is a “soft magnetic material”, a small field (close to coercive force H_c) of about 1 to few Oe is enough to get its magnetization value (Mm =B_m - Hm) close to its saturated maximum M_s (values in the range 290 to 5000 Gauss). This is shown on the curves of the hysteresis loop. However this Ms value is really obtained at much higher field, the measurement is made with a 8000 Oe magnet.

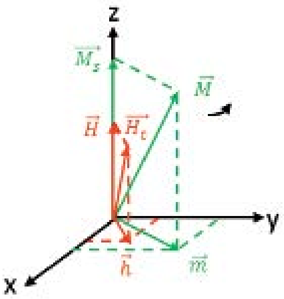
The hysteresis loop also shows, how for the null H field, the material can be in a remnant state with an induced field Br different from zero. This is used in phase shifters to monitor phase shift through the ferromagnetic resonance at Mr.



By increasing temperature of the ferrite, the aligning t
due to thermal agitation. The magnetization become f
120 to 650°C. The evolution of the magnetization wit

$$\alpha = \frac{\Delta M_s}{M_s \Delta T}$$ in the common range of T: -20 to +60°C

Gyromagnetic resonance – Lande factor g_{eff}



The gyromagnetic resonance, and so the non-reciprocal effect, is created in ferrite devices isolators, circulators, phase shifters, switches under a static magnetic field $\vec{H}$.

In case of saturation of the ferrite to M_s, and in case of a wave propagating parallel to the z axis, the microwave field $\vec{h}$ is in a plane "x y" perpendicular to the z axis and rotating at a frequency f magnetization $\vec{M}$ discloses a precession motion about the field $\vec{H}$ at the frequency f. There is a resonance for $\|\vec{H}\| = H_r$ given by:

$$H_r = \frac{f}{\gamma}$$

- g is the gyromagnetic ratio and is related to the effective Lande factor g_{eff} as
- g = 1.4 . g_{eff}.MHz/Oe. g_{eff} is about 2 depending on the material: $2 \le g_{eff} \le 2.3$

Permeability, gyro-resonance line width DH, non-reciprocal effect

The magnetization $\vec{m}$ is related to the microwave magnetic field $\vec{h}$ with the tensor of susceptibility $\bar{\bar{\chi}}$: $\vec{m} = \bar{\bar{\chi}} \times \vec{h}$. This tensor (named Polder tensor) owns two eigenvalues associated respectively to a positive (+) circularly polarized wave and to a negative (-) circularly polarized wave. Thus in a system of coordinates rotating about H axis at the frequency f, the magnetization $\vec{m}$ is described with two components only, m_+ and m_- :
$m_+ = c_+ h_+$ $\quad$ $m_- = c\ h_-$

The susceptibilities c_+ and c are complex numbers. The real and the imaginary part of each of these values are noted c'_+, c'_-, c''_+, c''_-. The imaginary parts represent the loss. Complex permeability μ is related to susceptibility:

$$\mu_\pm = 1 + c_\pm,\ \mu_\pm = \mu'_\pm - j\,\mu''_\pm,\ \mu'_\pm = 1 + c'_\pm,\ \mu''_\pm = c''_\pm$$

Permeability can be expressed as a function of frequency or magnetic field H, or normalized to H_r, thus fig.1

$$\mu'_\pm = 1 + \frac{M_s}{H_r}\,\frac{\left(\frac{H}{H_r} \mp 1\right)}{\left(\frac{H}{H_r} \mp 1\right)^2 + \left(\frac{\Delta H}{2H_r}\right)^2} \qquad \mu''_\pm = \frac{M_s}{H_r}\,\frac{\frac{\Delta H}{2H_r}}{\left(\frac{H}{H_r} \mp 1\right)^2 + \left(\frac{\Delta H}{2H_r}\right)^2}$$

H is the internal static magnetic field
H_r is the resonance field
M_s is the saturated magnetization
ΔH/Hr is the midpoint width of the Lorentz curve
ΔH gyromagnetic line width
g is the gyromagnetic ratio

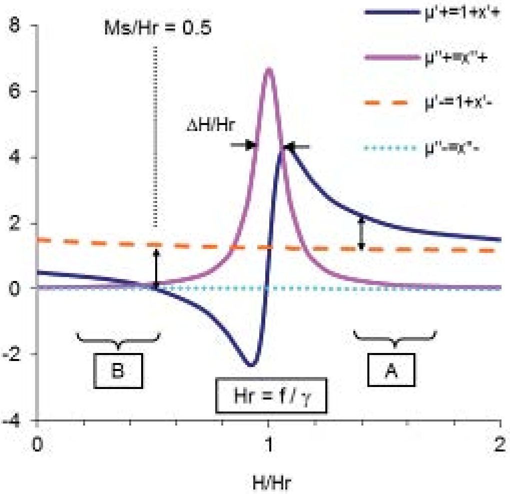


Figure 1 μ'+ , μ'- , μ''+ , μ''- , as a function of H/H_r
"B": below H_r resonance field (low field H)
"A": above H_r resonance field (high field H)

Within a given magnetic field range, it is possible to find values of H such that the permeabilities μ'_+ and μ'_- are different, while μ''_+ and μ''_- have very low values (fig 1). .This property has for consequence, the non-reciprocity of devices behavior: the greater the difference Δμ between μ'+ and μ'-, the more efficient the device. The field H can be either lower or higher than the resonant field H_r

Operation below resonance (zone B in fig 1)

The difference $\Delta\mu$ is greater than in the case of high field (B zone in fig 1) and more constant over the H field locally. Moreover the external field required is lower, and so the magnet strength too so that smaller magnets are required.

Nevertheless magnetization of the ferrite should be lower than a certain limit and is a limiting factor for the difference $\Delta\mu$ since magnetization is a multiplicative factors in all terms of the susceptibility. The limit is due to the phenomenon of natural resonance in unsaturated materials. This leads to "low magnetic field loss" (fig 2). Consequently, for a given frequency f, the material selected must have a magnetization lower than the field of resonance Hr, so lower than f/g , unless it is to be used above the resonance.
Finally at low field H, the magnetisation should be chosen according to:

$$\frac{1}{3} < \frac{\gamma M_s}{f} < \frac{3}{4}$$

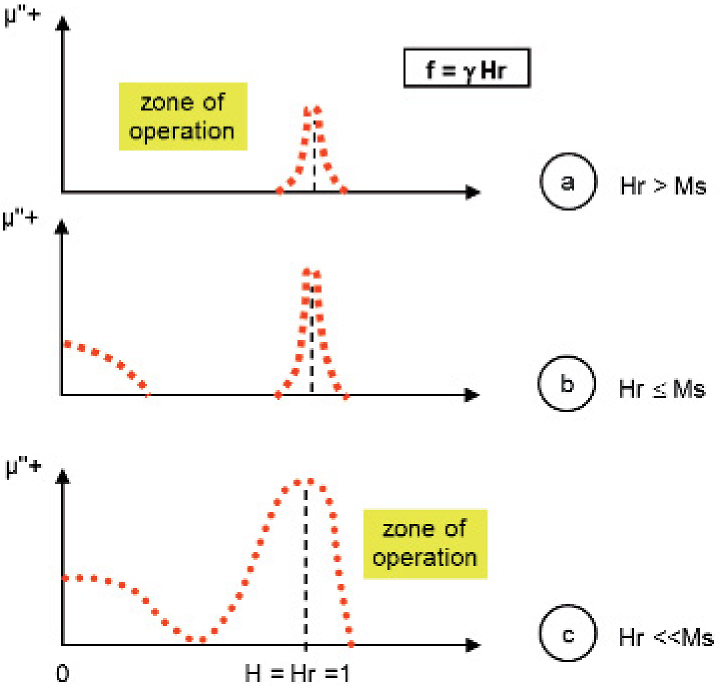


Figure 2 : permeability μ_+ *versus static field H*

Operation above resonance (zone A in fig 1)

In that case the magnetization may be greater than the limit of f/g and so efficiency is improved as a consequence of a larger difference in $\Delta\mu$. This case should be applied as soon as magnet conditions for H field are fulfilled (strength, temperature behaviour linked to the ferrite's one, etc.). Another advantage is seen in the case of power losses as indicated forward.

Effective line width DH_{eff}

The magnetic losses in the ferrites affect the insertion loss of the device. It is related to the imaginary part of the permeability of the positive polarization μ''_+, which increases with the gyromagnetic line width DH (fig.1).

Experiment shows that the curve $\mu''_+(H)$ far away from the resonance is a Lorentz curve with an effective line width denoted DH_{eff} smaller than DH. Near the resonant frequency, the line width is broadening by several phenomena such as porosity, magneto crystalline anisotropy.

There is much practical interest involved in the concept of effective line width DH_{eff} than line width DH, far from resonance.

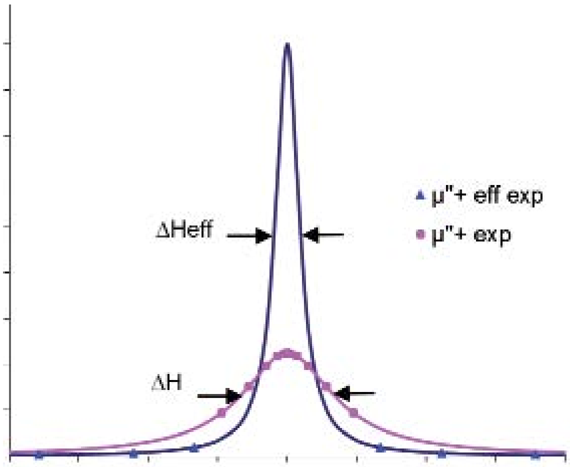


Figure 3 : ΔH, ΔH_{eff}

The imaginary parts of permeability μ''_+ represent losses in the material:
- At the vicinity of the resonance, μ''_+, describes a Lorentz curve the half width of which, denoted DH
- From the values of μ''_+, far from resonance, a Lorentz curve can be extrapolated the half width of which, denoted DH_{eff}, corresponds to the off resonance magnetic losses.

Depending on their compositions, the ferrites have line width ΔH in the range 10 to 500 and ΔH_{eff} in the range 4 to 50.

Spin wave line width DH_k

Above a certain microwave power level, nonlinear phenomena take place resulting in additional magnetic loss which rapidly becomes prohibitive in the devices.

The critical magnetic microwave field h_c, from which such effects appear, depends on the applied static field. The nonlinear effects are associated with the excitation of the spin waves, the attenuation of which is described by DH_k.

For a certain static magnetic field H denoted Hsub, there is a minimum of the microwave magnetic field hc related to DH_k

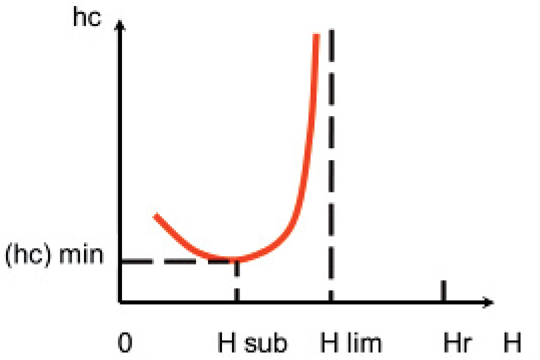


Figure 4: non-linear effect critical field hc versus static field

$$h_c \min = \frac{2 f \Delta H_k}{\gamma M_S}$$

The higher the value of ΔH_k, the better the high power behavior.

For a static magnetic field higher than H lim, there is no effect of the power on losses: this is the case for devices operating at high static field (above resonance).

The ferrites have ΔH_k from 1 to more than 20. The relation between the line widths is $\Delta H_k < \Delta H_{eff} < \Delta H$

I.2 Dielectric properties

The dielectric properties of the ferrites are also of importance in the applications. The relative real permittivity e' is within the range of about 12 to 16 and affects the wave length in the material and the impedance. The relative imaginary part of the permittivity e'' or the dielectric loss tangent $tg\delta = \frac{\varepsilon''}{\varepsilon'}$ affects the insertion losses. Ferrites, depending on their compositions have dielectric loss tangent at 10 GHz between 10^{-4} and 10^{-3}. In this range, the insertion loss of the device is more affected by the magnetic losses.

I.3 Characterization

Four parameters are tested in standard production. The result of test is compared with the values in the tables at the end: Ms, ΔH, e', tand

The Landé factor g_{eff} and the hysteresis cycle parameters are given on request.

Others parameters such as Tc, ΔH_{eff} , ΔH_k and a are not tested but the values are given in the tables, considered as heritage.

Saturation Magnetization M_s

Saturation magnetization is measured at room temperature by the Weiss method. A sample of one gram typically is moved through the air gap of a magnet delivering a magnetic field of 8000 Oe. A flux variation is produced through Helmholtz bobbins fixed on the magnet poles and read on an integrator: the signal of a material is compared to a pure nickel's one with admitted value is 54.56 Gauss.cm^3/g

Gyromagnetic line width DH and effective Lande Factor

The effective Landé factor g_{eff} and line width ΔH are measured in a rectangular cavity at 9.3 GHz and at room temperature. The test sample is a sphere of about 1mm in diameter. The test complies with the IEC 60556 publication.

Relative dielectric constant ε' and dielectric loss tangent tand

The permittivity is measured using a rod of about 1mm in diameter in a rectangular cavity at 8.2 GHz.

Hysteresis parameters

Temex Ceramics offers the possibility to perform hysteresis on request and give remnant induction Br, coercive field Hc, temperature dependence. Values are given for the Axx families and NZ50 material.

A toroidal sample is double winded and used as a transformer. The primary winding magnetizes the sample through a 50 Hz frequency signal. The applied field H is proportional to the primary current; the signal induced in the secondary winding is proportional to the magnetic flux variation and is integrated to obtain the magnetic induction B.

The induction value Bm is obtained for an applied field of 5 Hc.

II. User Guide

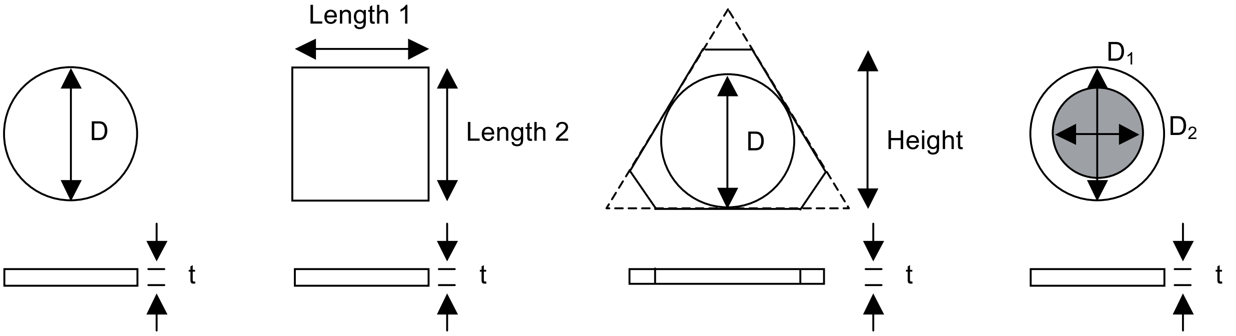
Material properties synthesis

Table below summarizes the properties of materials in term of magnetization, stability of magnetization, line widths.

Ferrite family	Chemical composition	Frequency range (GHz) (below resonance)	Magnetic losses DH$_{eff}$ (Oe)	Power behaviour DH$_k$ (Oe)	Temperature stability a (10^{-3}/°C)
Y1xx	Y-Gd	1.55 ~ 10.9	3 ~ 45	1.5 ~ 13	0.9~2.2
Y2xx	Ca-V-Y (CVG)	1.55 ~ 10.9	2	1	2.6~3.7
Y3xx	Y-Al	0.34~6.2	4	2	2.6~5
Y4xxx	CVG-Gd	1.55~6.2	12~18	9~12	0.8~1.4
Y7xx	Y-Gd-Al	0.34~6.2	6~15	5~10	0.5~3.4
Y9xx	Y-Gd-Al Co-doped	0.34~10.9	9~15	25~46	0.3~1.3
Dx	Y-Gd-Al Dy-doped	0.34~10.9	29~63	10~20	0.5~3
Uxx	Mn-Mg	1.55~36	6	4	2.2~3.3
Axxx	Li	6.2~40	4~9	3~10	0.9~1.6
Nxxx	Ni	1.55~40	30~50	12~25	0.7~2

Shapes

Typical range of shapes which can be produced including single ferrite (F), assembly (FDA) with typical dielectric constant 16, others on request



Dimensioning (mm)

A wide range of dimensions can be made based on customer specifications
- Disks: diameter 1.5 up to 55 mm (typical value)
- Square: max length 50.8 x 50.8 mm / Thickness 0.5 mm up to 3 mm (typical value)
- Triangle: in-circle diameter up to 50 mm (typical value)

Tolerances on dimensions (mm)

- Standard tolerances are +/-0.05 mm on both diameter and thickness.
- As-fired parts (no machining requested => lower cost) are available for +/-1% tolerance.
- Smaller tolerances can be considered on request.

MICROWAVE FERRITES & FDA

How to order

Y101	S	50.8	x	50.8	x	0.635	M
Material Garnet or Spinel	**Shape** D : Disk S : Square T : Triangle	**Dimension 1** Diameter for D Length 1 for S Incircle diameter for T		**Dimension 2** Thickness for D Length 2 for S Height for T		**Dimension 3** Thickness for S Thickness for T Thickness for C	**Option** M : Metallization CF : Chamfer

Example for ferrite: Y101 S50.8x50.8x0.63 M

Y101	/	E16	D	19	x	15	x	0.8
Material 1 See Garnet family		**Material 2** Epsilon 16	**Shape** T : Triangle D : Disk	**Dimension 1** Incircle diameter for T Diameter ext for D		**Dimension 2** Diameter int for T Diameter int for D		**Dimension 3** Thickness for T Thickness for D

Example for FDA: Y101/E16 D19x15x0.8

Surface finishing

As-fired parts can be grinded, lapped or polished.
Standard average peak-to-valley height (Ra) is specified here below.

Surface finishing	Ra (micrometer)	Ra (micro-inch)	Remarks
Standard	0.8	24	All ferrites
Lapped	0.4	16	All ferrites
Polished	0.1	4	All ferrites except A or U family

Metallization

Thick film: Silver
Thin film: on request

Chamfer

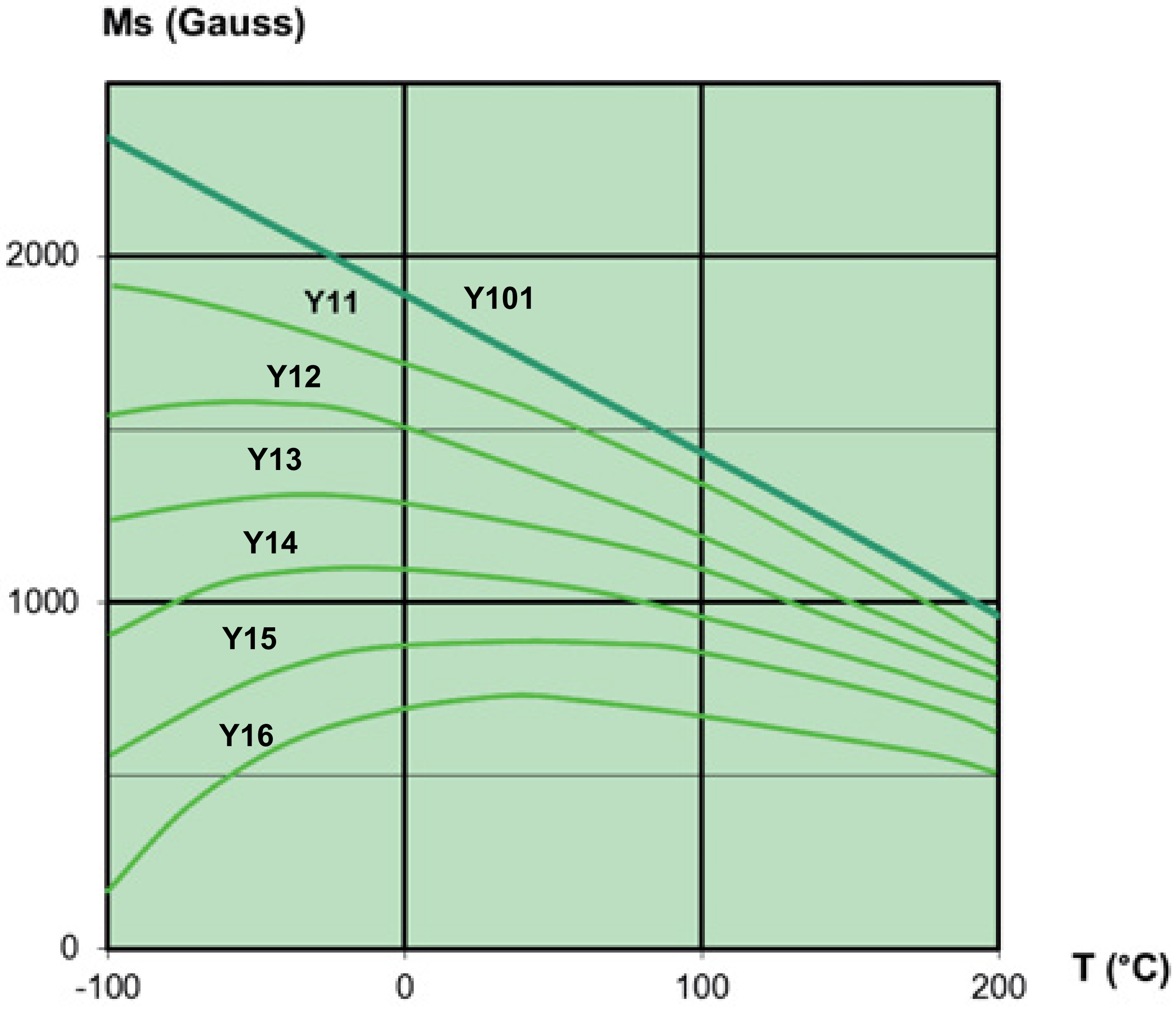
As per customer specification.

Y - Gd

Yttrium - Gadolinum

Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2
Y101*	1820	280	2.02	18	3	1.5	15	2	2.2
Y11	1600	280	2.00	50	8	3	15.3	2	1.8
Y12	1420	280	2.01	60	14	5	15.3	2	1.5
Y13	1250	280	2.01	75	21	7	15.3	2	1
Y14	1100	280	2.02	95	28	9	15.4	2	0.5
Y15	900	280	2.03	130	36	11	15.4	2	0.7
Y16	750	280	2.02	170	45	13	15.4	2	0.9

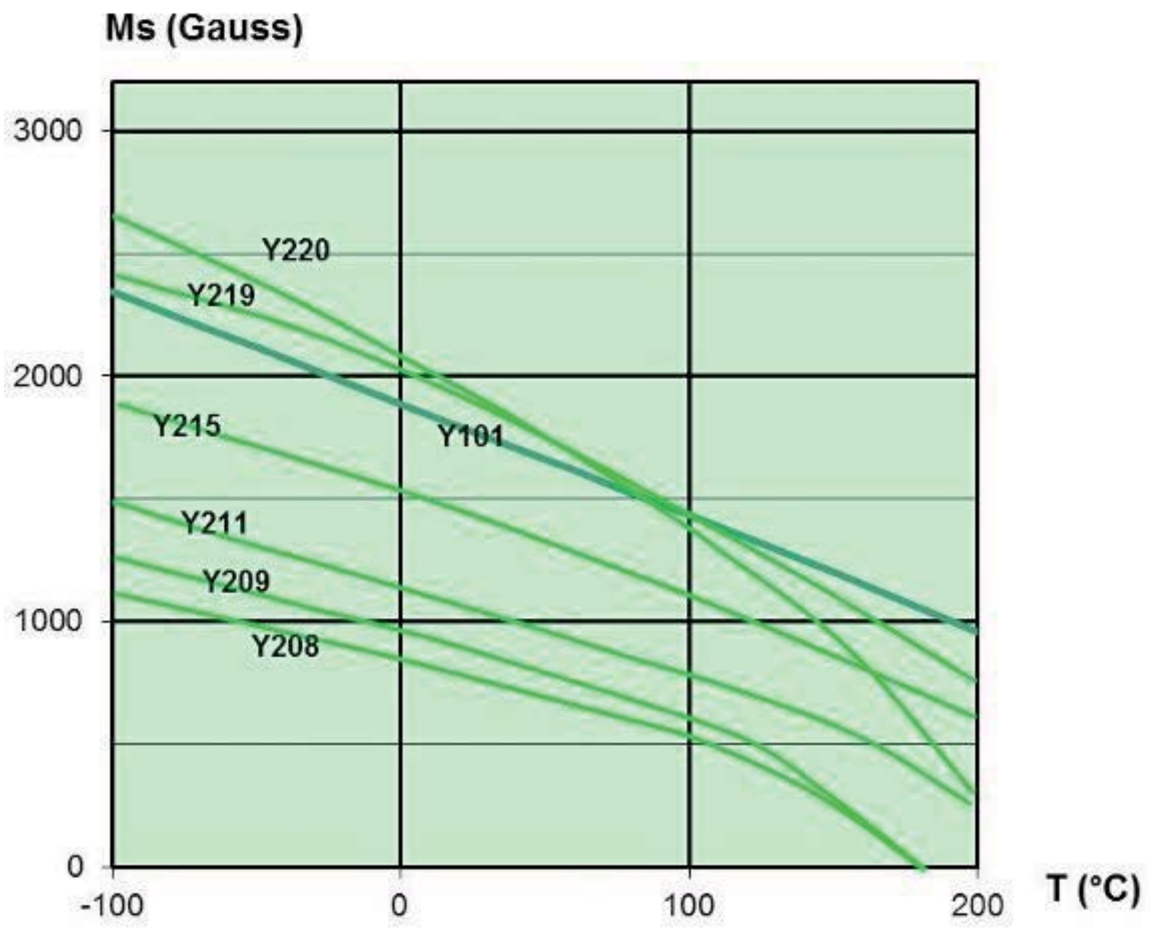
* Pure Yttrium iron garnet



Y - Ca - V - In or Zr

Yttrium - Calcium - Vanadium - Indium or Zirconium

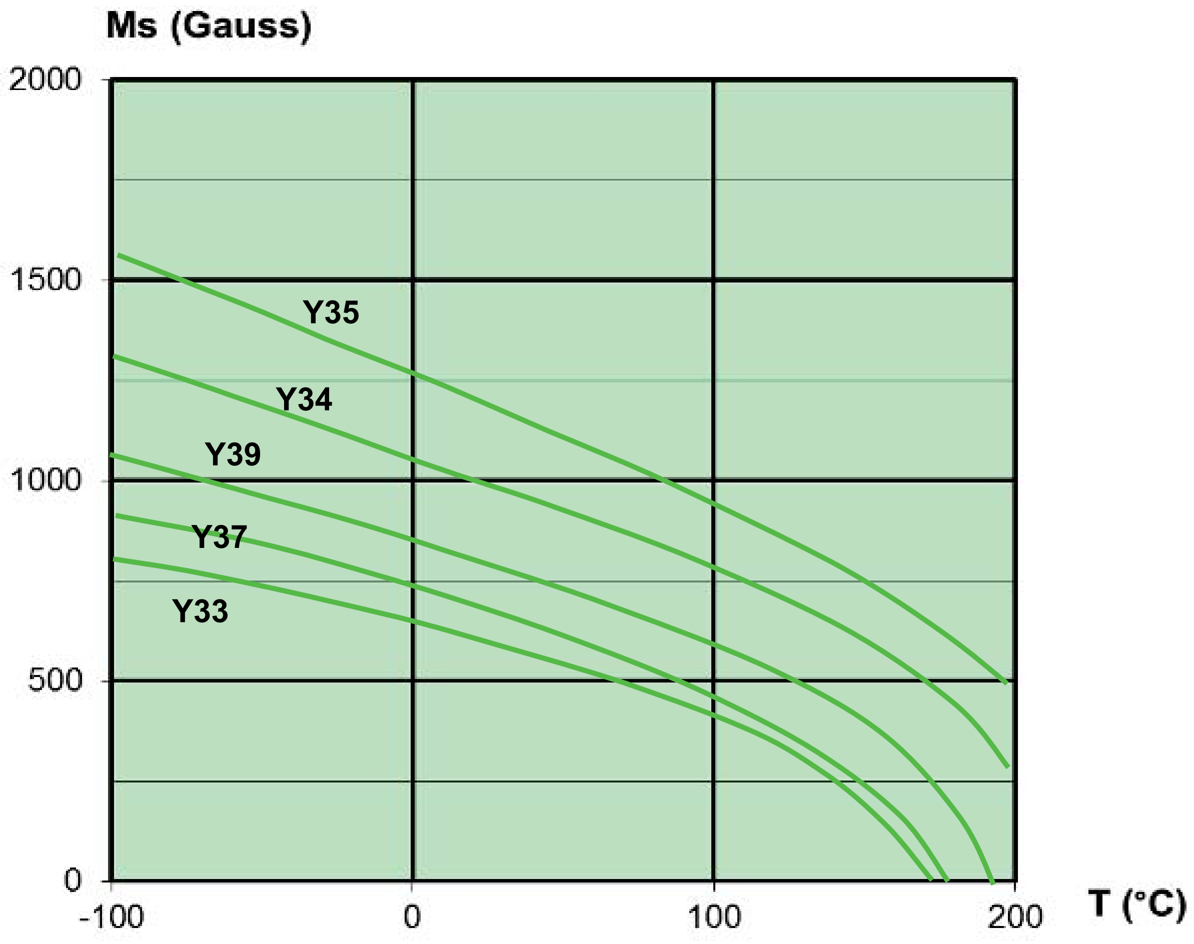
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2
Y220	1950	205	2.01	10	2	1	15.4	2	3.1
Y219	1900	240	2.02	15	3	1.5	15.2	2	2.6
Y218	1850	215	2.01	10	2	1	14.8	2	2.8
Y216	1600	218	2.01	10	2	1	14.8	2	2.6
Y215	1450	215	2.01	10	2	1	14.7	2	2.7
Y212	1200	209	2.01	10	2	1	14.5	2	2.9
Y211	1100	205	2.01	10	2	1	14.2	2	3
Y210	1000	200	2.01	10	2	1	14.2	2	3.3
Y209	900	180	2.01	10	2	1	14.1	2	3.5
Y208	800	177	2.01	10	2	1	14	2	3.7



Y - Al

Yttrium - Aluminum

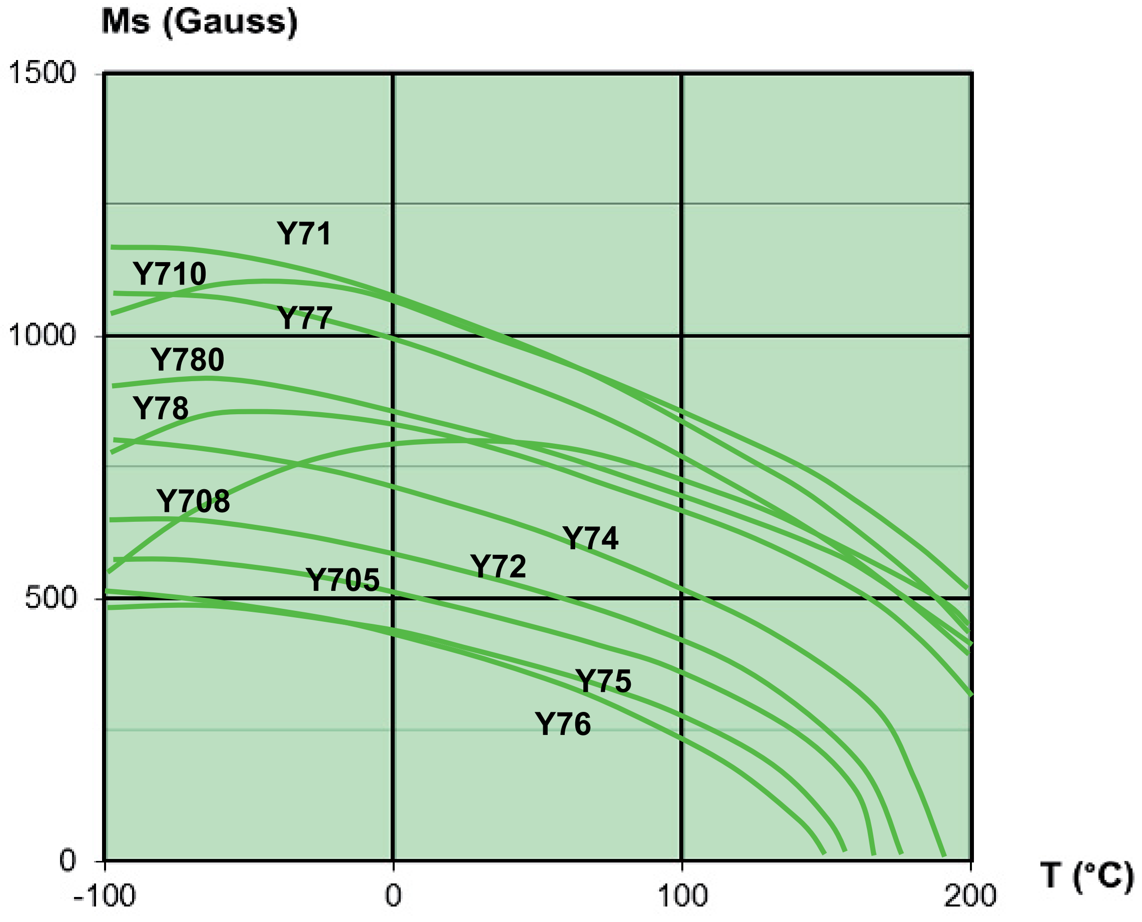
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH* (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2
Y35	1200	225	2.01	40	4	2	14.9	2	2.6
Y34	1030	210	2.01	40	4	2	14.9	2	2.7
Y39	800	195	2.01	40	4	2	14.6	2	2.9
Y38	760	190	2.01	40	4	2	14.5	2	2.9
Y37	680	180	2.01	40	4	2	14.5	2	2.9
Y33	615	175	2.01	40	4	2	14.5	2	3.2
Y30	565	160	2.01	30	4	2	14.4	2	3.4
Y32	420	135	2.01	30	4	2	14.4	2	3.8
Y31	370	125	2.01	30	4	2	14.1	2	4.1
Y36	290	115	2.01	25	4	2	14	2	4.6



Y - Al - Gd

Yttrium - Aluminum - Gadolinum

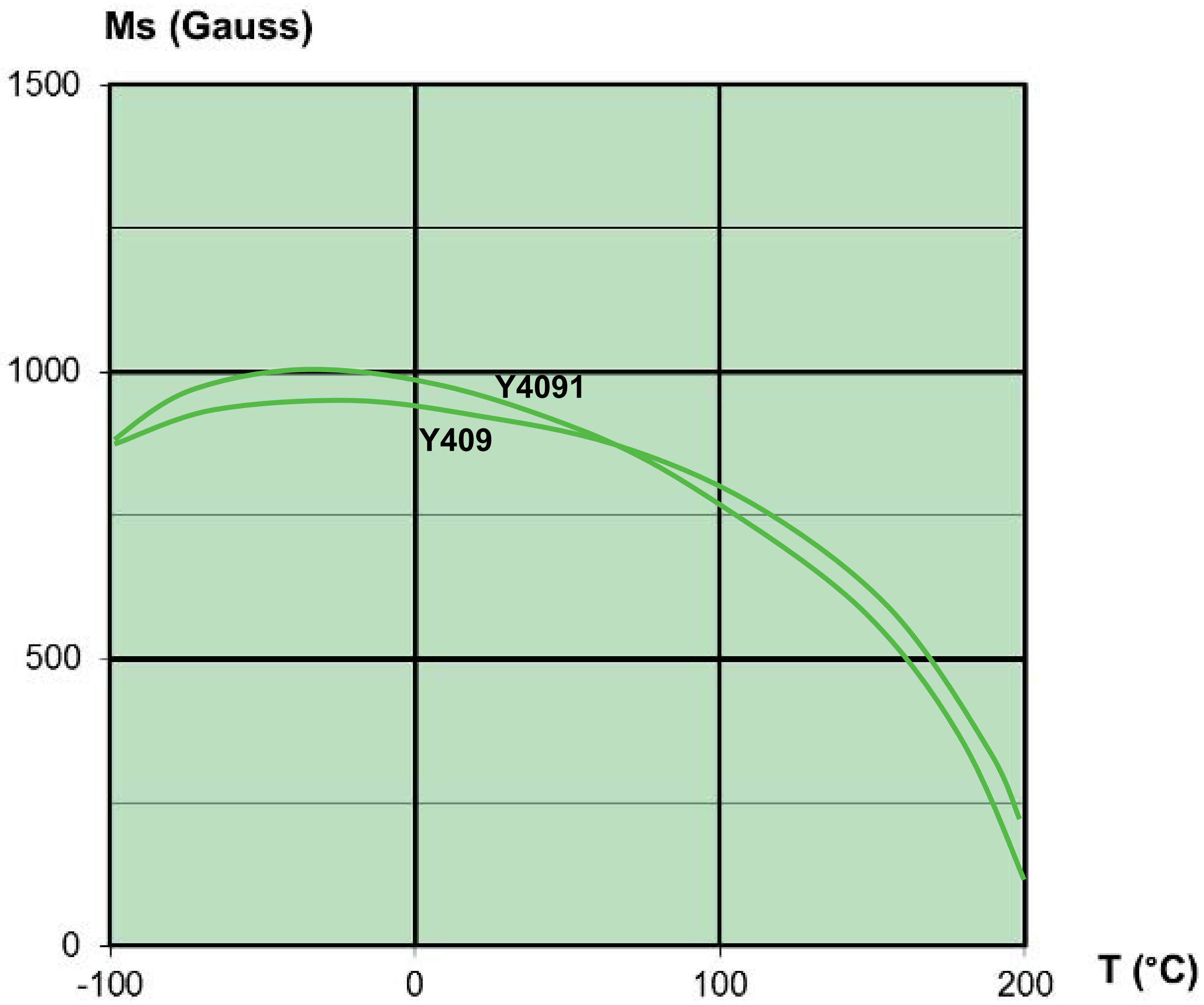
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	$tg\delta$ 10^{-4} max	α 10^{-3}/°C ±0.2
Y71	1020	235	2.01	60	7	5	15	2	2.2
Y710	1020	240	2.02	75	9	7	15	2	1.7
Y77	950	230	2.01	60	6	5	14.9	2	2
Y780	830	235	2.02	60	6	5	14.8	2	1.6
Y78	800	220	2	80	8	7	15	2	1.3
Y708	800	260	2.04	140	15	10	15.2	2	0.5
Y74	570	190	2.01	60	6	5	14.9	2	2.3
Y72	540	175	2.01	60	6	5	14.6	2	2.3
Y705	470	170	2.02	65	6	5	14.3	2	2.8
Y75	400	160	2.03	65	6	5	14.3	2	2.7
Y76	390	150	2.02	50	6	5	14.2	2	3.4



Y - Ca - V - Zr - Gd

Yttrium - Calcium – Vanadium - Zirconium - Gadolinum

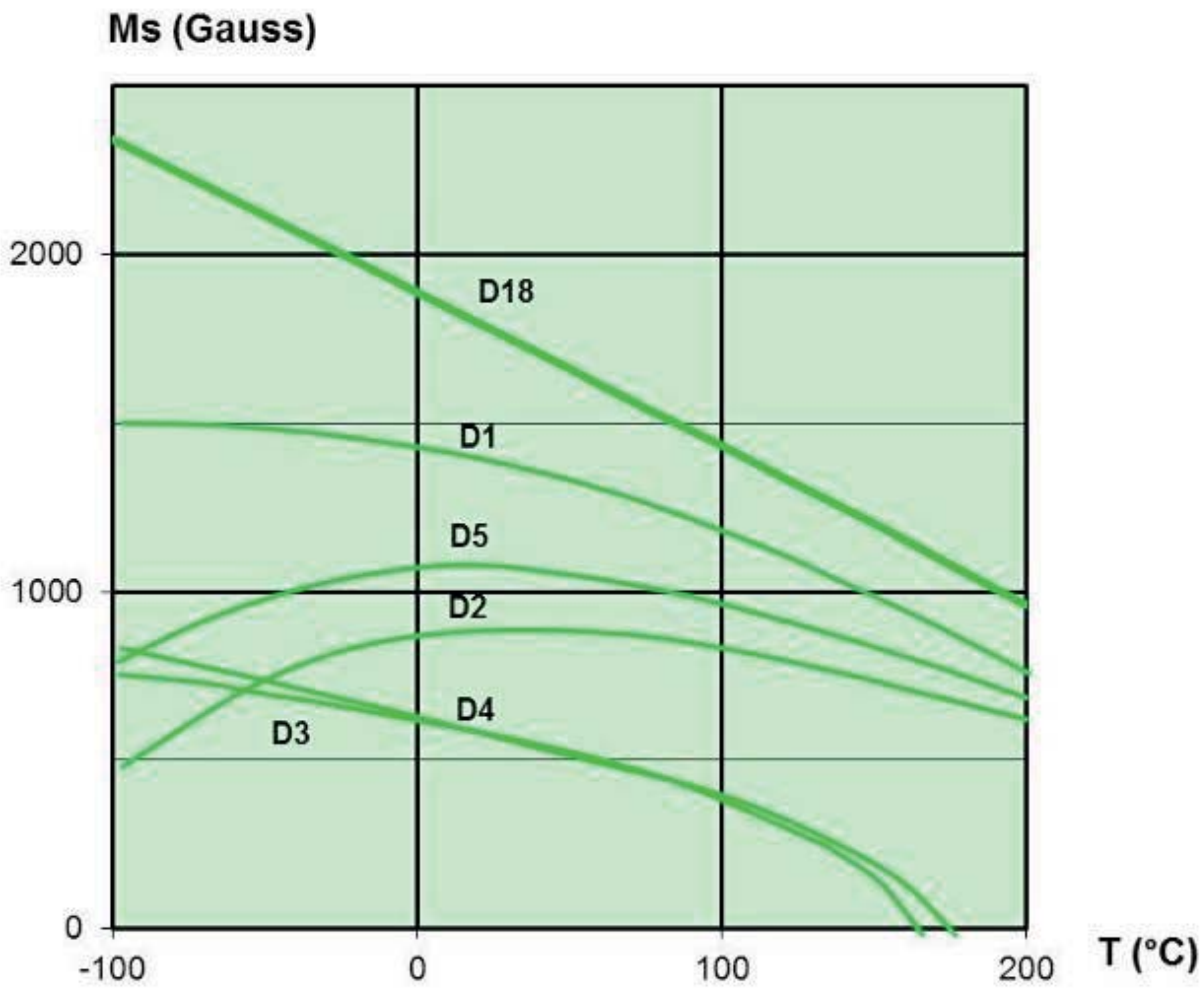
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2
Y4091	960	195	2.02	35	12	9	15.2	2	1.4
Y409	920	223	2.02	50	18	12	15.2	2	0.8



Y- Gd - Dy - Al

Yttrium-Dysprosium or Gadolinum-Dysprosium or Aluminum-Dysprosium

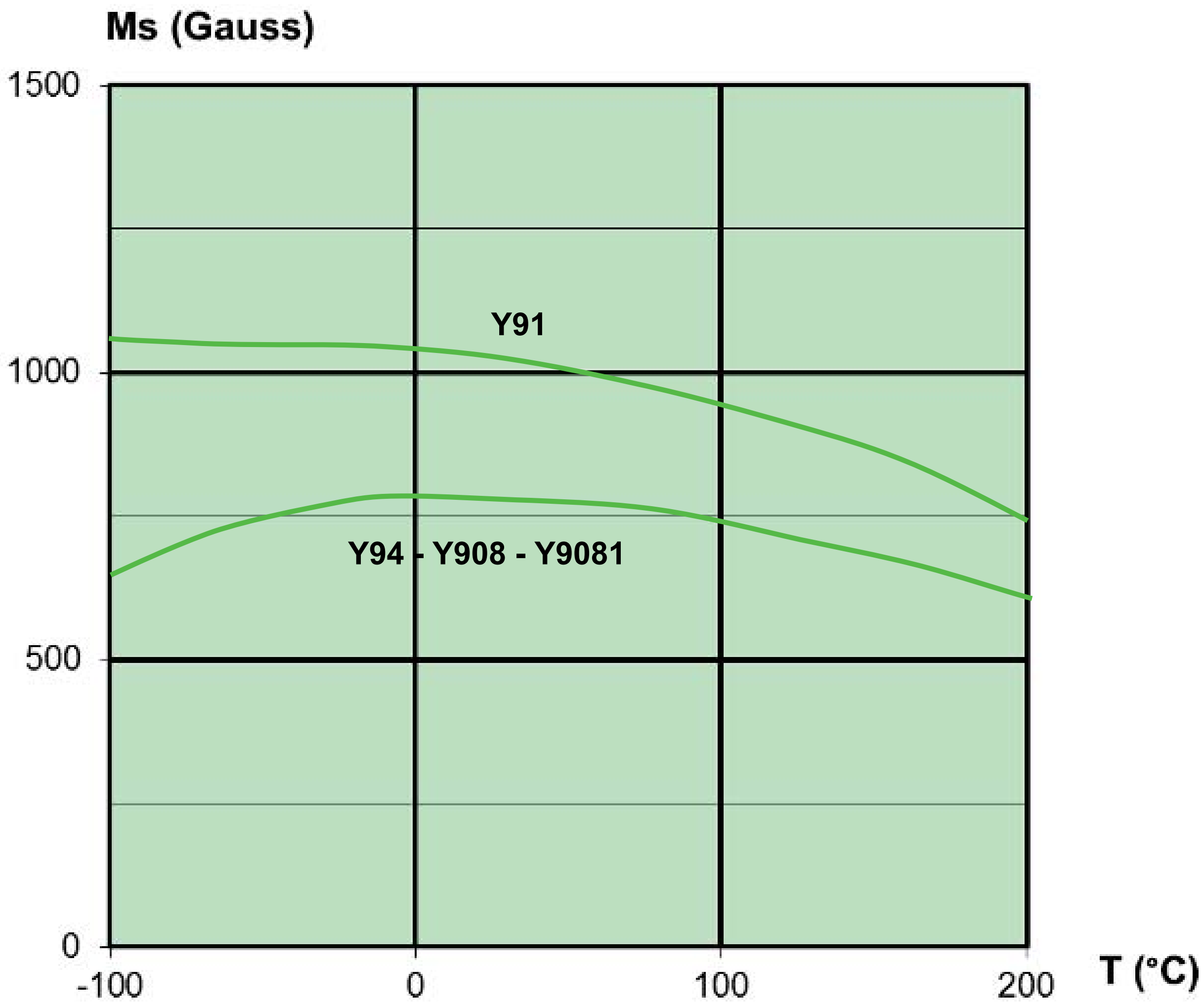
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	$tg\delta$ 10^{-4} max	α 10^{-3}/°C ±0.2
D18	1760	280	2.02	85	54	18	15	2	2.2
D1	1400	270	2	110	41	14	15.5	2	1.4
D5	1070	270	2.02	150	55	18	15.5	2	0.5
D2	900	270	2.01	185	63	20	15.5	2	0.8
D3	590	175	2	85	29	10	14.5	2	3.5
D4	580	170	2	140	56	19	14.4	2	3



Y - Gd - Al - Co

Yttrium - Gadolinum - Aluminum - Cobalt

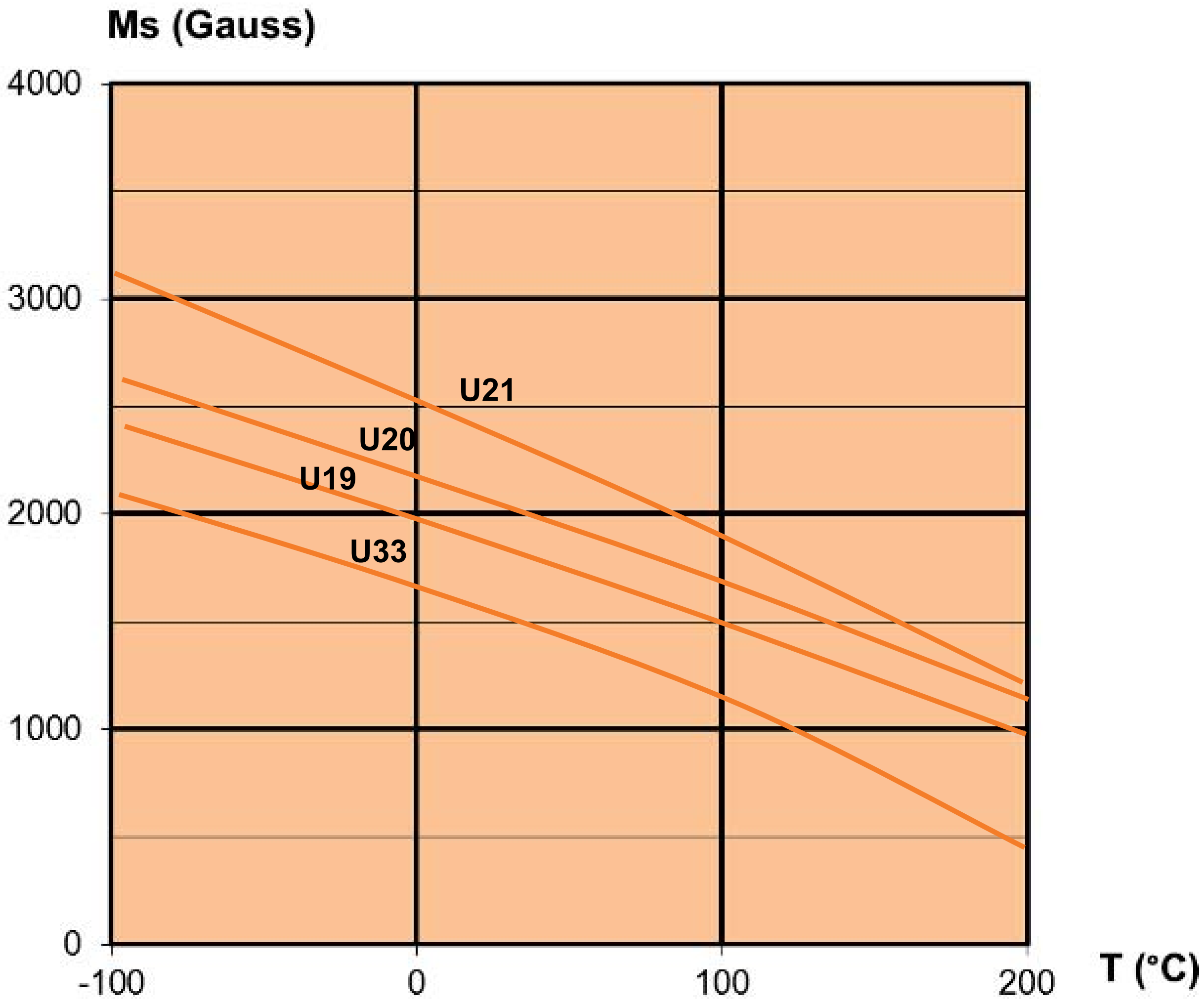
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2
Y91	1020	240	2.02	60	25	9	15.1	2	1.3
Y94	780	250	2.02	75	40	13	15.2	2	0.3
Y908	780	250	2.02	85	43	14	15.2	2	0.3
Y9081	780	250	2.02	120	46	15	15.2	2	0.3



Mg - Mn - Al

Magnesium-Manganese or Magnesium-Manganese-Aluminum

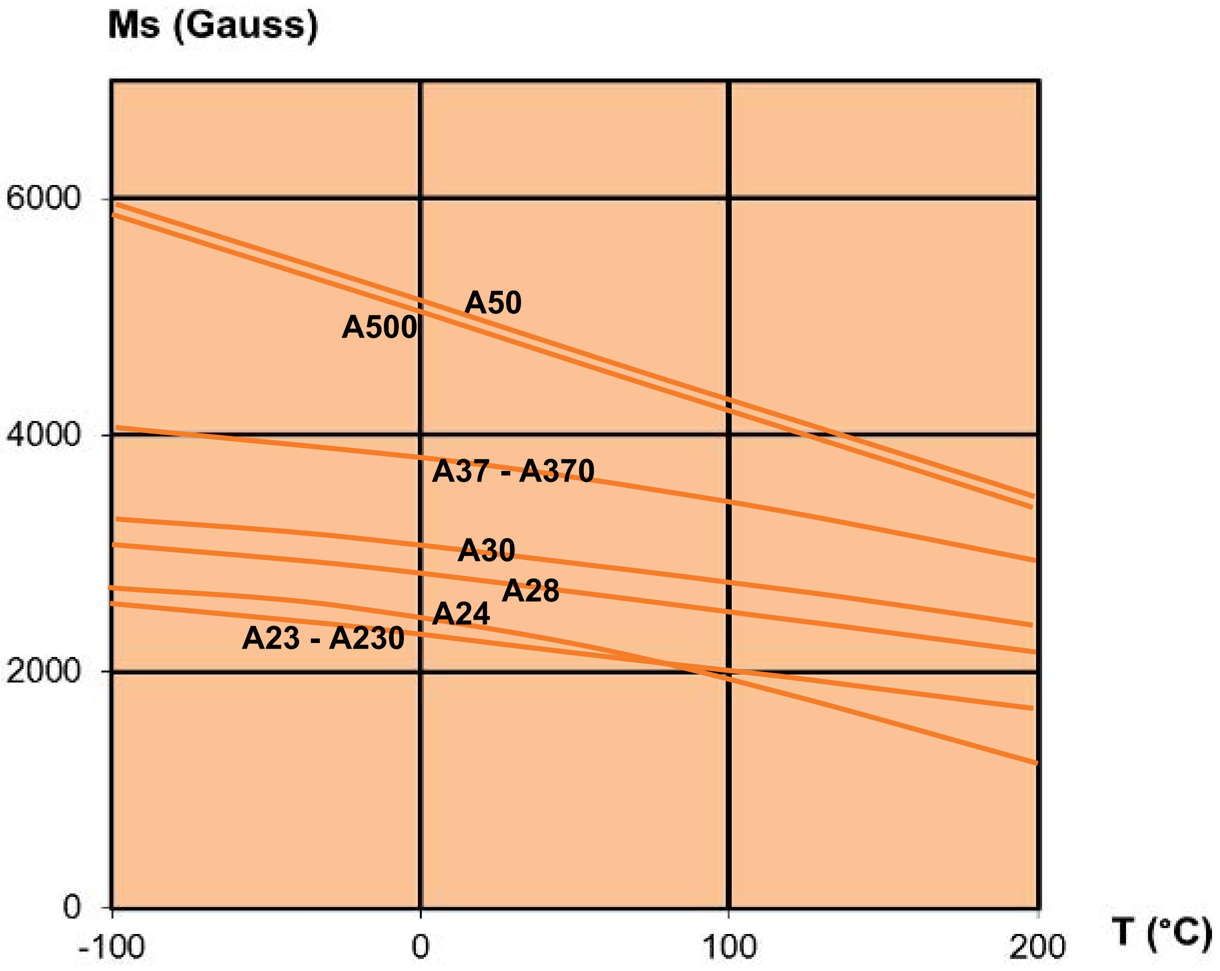
Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2
U21	2400	275	2.03	290	6	4	13	3	2.7
U20	2100	300	2.01	360	6	4	13	3	2.3
U19	1900	280	2.01	350	6	4	13	3	2.2
U33	1600	230	2.02	290	8	4	12.4	3	3.3



Li – Zn - Ti - Mn - (Co)

Lithium - Zinc - Titanium – Manganese - (Cobalt)

Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2	Br (Gauss)
A50	5000	450	2.06	170	4	3	15.3	5	1.6	3300
A500	4900	450	2.06	200	20	10	15.3	5	1.6	3200
A37	3700	565	2.08	400	4	3	16	5	1	2500
A370	3700	565	2.07	400	7	6	15.9	5	1	2500
A30	3000	555	2.08	450	4	3	16.4	5	0.8	2000
A28	2800	540	2.08	450	4	3	16.6	5	0.9	1900
A24	2450	390	2.08	250	4	3	16.8	5	1.6	1700
A23	2300	505	2.08	450	4	3	16.8	5	1.2	1600
A230	2300	505	2.08	450	9	8	16.7	5	1.2	1600



Ni - Zn - Al

Nickel or Nickel-Zinc or Nickel-Aluminum (with Cobalt - Manganese - Copper)

Type	Ms (Gauss) ±5%	Tc (°C)	g_{eff}	ΔH (Oe) +20%	ΔH_{eff} (Oe)	ΔH_k (Oe)	ε ±5%	tgδ 10^{-4} max	α 10^{-3}/°C ±0.2	Br (Gauss)
NZ50	5000	375	2.1	125	30	12	13.7	5	2	3650
NZ40	4000	470	2.2	200	40	15	13.4	5	1.7	-
N32	3200	560	2.3	200	50	25	13.2	6	1	-
N28	2800	550	2.3	200	50	25	13	6	0.8	-
N24	2400	520	2.3	200	50	25	12.7	6	0.7	-
N19	1900	480	2.3	200	50	25	12.4	6	0.7	-