MICROWAVE FERRITES & FDA

Temex Ceramics 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 inheritance 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.

Temex Ceramics 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)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>MKSA system</th>
<th>CGS system</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Magnetic induction</td>
<td>Tesla (T)</td>
<td>Gauss (=10^-4 Tesla)</td>
</tr>
<tr>
<td>Br</td>
<td>Remnant induction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M (4πM_s or M_n), m</td>
<td>Volume magnetization (saturation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H, H_r</td>
<td>Magnetic field (magnetizing force), resonance</td>
<td>A/m</td>
<td>Oersted (Oe) (=10^3/4π A/m)</td>
</tr>
<tr>
<td>H_a</td>
<td>Anisotropy field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_c</td>
<td>Coercive force</td>
<td></td>
<td></td>
</tr>
<tr>
<td>h, h_c</td>
<td>Magnetic wave field, critical wave field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔH</td>
<td>Ferromagnetic resonance line width</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔH_eff</td>
<td>Effective resonance line width</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔH_k</td>
<td>Spin wave line width</td>
<td></td>
<td></td>
</tr>
<tr>
<td>μ_0</td>
<td>Vacuum permeability</td>
<td>4π10^-7 H/m</td>
<td>B = μ_0 (H+M)</td>
</tr>
<tr>
<td>μ =μ_0μ_r</td>
<td>Permeability</td>
<td>B = μ_0μ_rH</td>
<td>B = μ_rH</td>
</tr>
<tr>
<td>χ</td>
<td>Magnetic susceptibility = M/H, m/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>μ_r</td>
<td>Relative permeability</td>
<td>μ_r = 1 + χ</td>
<td>μ_r = 1 +4πχ (or 1+χ)</td>
</tr>
<tr>
<td>f</td>
<td>Wave frequency</td>
<td>MHz</td>
<td>MHz</td>
</tr>
<tr>
<td>γ</td>
<td>Gyromagnetic ratio: f = γ H_r</td>
<td>~35 10^{-3}MHz. m / A</td>
<td>~2.8 MHz / Oe</td>
</tr>
<tr>
<td>g eff</td>
<td>Lande factor ~ 2</td>
<td>= γ / 0.0176</td>
<td>= γ / 1.4</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε'</td>
<td>Relative permittivity (real part)</td>
</tr>
<tr>
<td>ε''</td>
<td>Relative permittivity (imaginary part)</td>
</tr>
<tr>
<td>ε_r</td>
<td>Relative complex permittivity</td>
</tr>
<tr>
<td>tanδ</td>
<td>Dielectric loss tangent: tanδ = ε''/ε'</td>
</tr>
</tbody>
</table>

**Miscellaneous**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>T,Tc</td>
<td>Temperature, Curie temperature</td>
<td>K</td>
</tr>
<tr>
<td>Ra</td>
<td>Surface roughness</td>
<td>µm</td>
</tr>
</tbody>
</table>

**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 (\( M_m = B_m - H_m \)) 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 \( M_s \) 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 \( B_r \) different from zero. This is used in phase shifters to monitor phase shift through the ferromagnetic phase resonance at \( M_r \).

By increasing temperature of the ferrite, the aligning of the spins parallel to the \( H \) field is more and more difficult due to thermal agitation. The magnetization becomes null at the Curie temperature \( T_c \), which are in the range of 120 to 650°C. The evolution of the magnetization with temperature is measured by the parameter:

\[
\alpha = \frac{\Delta M_s}{M_s \Delta T}
\]

in the common range of \( T \): -20 to +60°C.
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**Gyromagnetic resonance – Lande factor $g_{\text{eff}}$**

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 $\gamma f H_r = \gamma$ given by:

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

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

**Permeability, gyro-resonance line width $\Delta H$, non-reciprocal effect**

The magnetization $\vec{M}$ is related to the microwave magnetic field $\vec{H}$ with the tensor of susceptibility $\vec{\chi}$:

$$\vec{M} = \frac{\vec{H}}{\gamma} \cdot \vec{\chi}$$

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 $m$ : $m = \gamma_{\pm} h$. The susceptibilities $\chi_\pm$ are complex numbers. The real and the imaginary part of each of these values are noted $\chi_{\pm} , \chi_{\pm} , \chi_{\pm} , \chi_{\pm}$. The imaginary parts represent the loss. Complex permeability $\mu$ is related to susceptibility:

$$\mu_{\pm} = 1 + \chi_{\pm} , \mu_{\pm} = \mu_{\pm} + j \mu_{\pm} , \mu_{\pm} = 1 + \chi_{\pm} , \mu_{\pm} = \chi_{\pm}$$

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

$$\mu_{\pm} = \frac{1 + M_s}{H_r} \left( \frac{H}{H_r} \right) \left( \frac{\Delta H}{2 H_r} \right)$$

$H$ is the internal static magnetic field $H_r$ is the resonance field $M_s$ is the saturated magnetization $\Delta H/H_r$ is the midpoint width of the Lorentz curve $\gamma$ is the gyromagnetic ratio

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

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**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 $H_r$, so lower than $f/\gamma$, unless it is to be used above the resonance. Finally at low field $H$, the magnetisation should be chosen according to:

$$\frac{1}{3} < \frac{2M_s}{f} < \frac{3}{4}$$

**Operation above resonance (zone A in fig 1)**

In that case the magnetization may be greater than the limit of $f/\gamma$ 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 $\Delta H_{eff}$**

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 $\mu''$, which increases with the gyromagnetic line width $\Delta H$ (fig.1).

Experiment shows that the curve $\mu''(H)$ far away from the resonance is a Lorentz curve with an effective line width denoted $\Delta H_{eff}$ smaller than $\Delta H$. 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 $\Delta H_{eff}$ than line width $\Delta H$, far from resonance.
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The imaginary parts of permeability $\mu_r$ represent losses in the material:

- At the vicinity of the resonance, $\mu_r^-$, describes a Lorentz curve the half width of which, denoted $\Delta H$
- From the values of $\mu_r^-$ far from resonance, a Lorentz curve can be extrapolated the half width of which, denoted $\Delta H_{\text{eff}}$, corresponds to the off resonance magnetic losses.

Depending on their compositions, the ferrites have line width $\Delta H$ in the range 10 to 500 and $\Delta H_{\text{eff}}$ in the range 4 to 50.

**Spin wave line width $\Delta H_k$**

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 $\Delta H_k$.

For a certain static magnetic field $H$ denoted $H_{\text{sub}}$, there is a minimum of the microwave magnetic field $h_c$ related to $\Delta H_k$

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

The higher the value of $\Delta H_k$, the better the high power behavior.

For a static magnetic field higher than $H_{\text{lim}}$, 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 $\Delta H_k$ from 1 to more than 20. The relation between the line widths is $\Delta H_k < \Delta H_{\text{eff}} < \Delta H$

**I.2 Dielectric properties**

The dielectric properties of the ferrites are also of importance in the applications. The relative real permittivity $\varepsilon'$ 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 $\varepsilon''$ or the dielectric loss tangent $\tan \theta = \frac{\varepsilon''}{\varepsilon'}$ 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: $M_s$, $\Delta H$, $\varepsilon'$, $\tan\delta$

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

Others parameters such as $T_c$, $\Delta H_{\text{eff}}$, $\Delta H_k$, and $\alpha$ 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.cm³/g

Gyromagnetic line width $\Delta H$ and effective Lande Factor

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

Relative dielectric constant $\varepsilon'$ and dielectric loss tangent $\tan\delta$

The permittivity is measured using a rod of about 1 mm 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 $B_r$, coercive field $H_c$, 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 $B_m$ 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.

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

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.
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How to order

<table>
<thead>
<tr>
<th>Y101</th>
<th>S</th>
<th>50.8</th>
<th>x</th>
<th>50.8</th>
<th>x</th>
<th>0.63</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Shape</td>
<td>Dimension 1</td>
<td>Dimension 2</td>
<td>Dimension 3</td>
<td>Option</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garnet or Spinel</td>
<td>D : Disk</td>
<td>Diameter for D</td>
<td>Thickness for D</td>
<td>Thickness for S</td>
<td>M : Metallization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garnet family</td>
<td>S : Square</td>
<td>Incircle diameter for T</td>
<td>Length 1 for S</td>
<td>Height for T</td>
<td>CF : Chamfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T : Triangle</td>
<td>Diameter ext for D</td>
<td>Thickness for S</td>
<td>Thickness for T</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Y101</th>
<th>E16</th>
<th>D</th>
<th>19</th>
<th>x</th>
<th>15</th>
<th>x</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material 1</td>
<td>Material 2</td>
<td>Shape</td>
<td>Dimension 1</td>
<td>Dimension 2</td>
<td>Dimension 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>See Garnet family</td>
<td>Epsilon 16</td>
<td>T : Triangle</td>
<td>Incircle diameter for T</td>
<td>Diameter int for T</td>
<td>Thickness for T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D : Disk</td>
<td>Diameter ext for D</td>
<td>Diameter int for D</td>
<td>Thickness for T</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Example for FDA: Y101/E16 D19x15x0.8

Surface finishing

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

<table>
<thead>
<tr>
<th>Surface finishing</th>
<th>Ra (micrometer)</th>
<th>Ra (micro-inch)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>0.8</td>
<td>24</td>
<td>All ferrites</td>
</tr>
<tr>
<td>Lapped</td>
<td>0.4</td>
<td>16</td>
<td>All ferrites</td>
</tr>
<tr>
<td>Polished</td>
<td>0.1</td>
<td>4</td>
<td>All ferrites except A or U family</td>
</tr>
</tbody>
</table>

Metallization

Thick film: Silver
Thin film: on request

Chamfer

As per customer specification.
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**Y - Gd**

Yttrium - Gadolinum

<table>
<thead>
<tr>
<th>Type</th>
<th>$M_s$ (Gauss) ±5%</th>
<th>$T_c$ (°C)</th>
<th>$g_{eff}$</th>
<th>$\Delta H_{(Oe)}$ +20%</th>
<th>$\Delta H_{eff}$ (Oe)</th>
<th>$\Delta H_k$ (Oe) ±5%</th>
<th>$\varepsilon$</th>
<th>$\tan \delta$ $10^4$ max</th>
<th>$\alpha$ $10^{-3}/°C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y101*</td>
<td>1820</td>
<td>280</td>
<td>2.02</td>
<td>18</td>
<td>3</td>
<td>15</td>
<td>2</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>Y11</td>
<td>1600</td>
<td>280</td>
<td>2.00</td>
<td>50</td>
<td>8</td>
<td>3</td>
<td>15.3</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Y12</td>
<td>1420</td>
<td>280</td>
<td>2.01</td>
<td>60</td>
<td>14</td>
<td>5</td>
<td>15.3</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Y13</td>
<td>1250</td>
<td>280</td>
<td>2.01</td>
<td>75</td>
<td>21</td>
<td>7</td>
<td>15.3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Y14</td>
<td>1100</td>
<td>280</td>
<td>2.02</td>
<td>95</td>
<td>28</td>
<td>9</td>
<td>15.4</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Y15</td>
<td>900</td>
<td>280</td>
<td>2.03</td>
<td>130</td>
<td>36</td>
<td>11</td>
<td>15.4</td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td>Y16</td>
<td>750</td>
<td>280</td>
<td>2.02</td>
<td>170</td>
<td>45</td>
<td>13</td>
<td>15.4</td>
<td>2</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* Pure Yttrium iron garnet

**Ms (Gauss)**

![Graph of Ms vs T in °C]

TEMEX CERAMICS reserves the right to modify herein specifications and information at any time when necessary to provide optimum performance and cost.
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**Y - Ca - V - In or Zr**

Yttrium - Calcium - Vanadium - Indium or Zirconium

<table>
<thead>
<tr>
<th>Type</th>
<th>Ms (Gauss)</th>
<th>Tc (°C)</th>
<th>g_{eff}</th>
<th>ΔH (Oe)</th>
<th>H_{eff} (Oe)</th>
<th>ΔH_{k} (Oe)</th>
<th>ε ±5%</th>
<th>tgδ 10^{-4} max</th>
<th>α 10^{-5}/°C ±0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y220</td>
<td>1950</td>
<td>205</td>
<td>2.01</td>
<td>10</td>
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MICROWAVE FERRITES & FDA

Y - Al

Yttrium - Aluminum

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<th>ΔH_{eff} (Oe) ±5%</th>
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Y39
Y34
Y39
Y37
Y33

*lower values of line width are possible on small pieces (about 20)
### MICROWAVE FERRITES & FDA

**Y - Al - Gd**

Yttrium - Aluminum - Gadolinum

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<th>Tc (°C)</th>
<th>g&lt;sub&gt;eff&lt;/sub&gt;</th>
<th>∆H (Oe)</th>
<th>∆H&lt;sub&gt;eff&lt;/sub&gt; (Oe)</th>
<th>∆H&lt;sub&gt;k&lt;/sub&gt; (Oe)</th>
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**Ms (Gauss)**

![Diagram showing Ms (Gauss) vs T (°C)](image-url)
**MICROWAVE FERRITES & FDA**

**Y - Ca - V - Zr - Gd**

Yttrium - Calcium - Vanadium - Zirconium - Gadolinum

<table>
<thead>
<tr>
<th>Type</th>
<th>Ms  (Gauss) ±5%</th>
<th>Tc (°C)</th>
<th>g_{eff}</th>
<th>ΔH (Oe) ±20%</th>
<th>ΔH_{eff} (Oe)</th>
<th>ΔH_k (Oe) ±5%</th>
<th>ε</th>
<th>tgδ \times 10^{-4} max</th>
<th>α \times 10^{-3}/°C ±0.2</th>
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**Ms (Gauss)**

![Ms (Gauss) graph](image-url)
### Yttrium-Dysprosium or Gadolinium-Dysprosium or Aluminum-Dysprosium

<table>
<thead>
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<th>Ms (Gauss)</th>
<th>Tc (°C)</th>
<th>g_{eff}</th>
<th>ΔH (Oe)</th>
<th>ΔH_{eff} (Oe)</th>
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<td>19</td>
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**Ms (Gauss)**

- **D18**: Ms = 1760 Gauss, Tc = 280 °C, g_{eff} = 2.02, ΔH = 85 Oe, ΔH_{eff} = 54 Oe, ε = 18, tgδ = 1.5
- **D1**: Ms = 1400 Gauss, Tc = 270 °C, g_{eff} = 2, ΔH = 110 Oe, ΔH_{eff} = 41 Oe, ε = 14, tgδ = 1.5
- **D5**: Ms = 1070 Gauss, Tc = 270 °C, g_{eff} = 2.02, ΔH = 150 Oe, ΔH_{eff} = 55 Oe, ε = 18, tgδ = 1.5
- **D2**: Ms = 900 Gauss, Tc = 270 °C, g_{eff} = 2.01, ΔH = 185 Oe, ΔH_{eff} = 63 Oe, ε = 20, tgδ = 1.5
- **D3**: Ms = 590 Gauss, Tc = 175 °C, g_{eff} = 2, ΔH = 85 Oe, ΔH_{eff} = 29 Oe, ε = 10, tgδ = 1.5
- **D4**: Ms = 580 Gauss, Tc = 170 °C, g_{eff} = 2, ΔH = 140 Oe, ΔH_{eff} = 56 Oe, ε = 19, tgδ = 1.5

**Graph**

The graph shows the variation of Ms (Gauss) with temperature (T (°C)) for different types of ferrites. The graph is divided into sections for each type (D18, D1, D5, D2, D3, D4) with Ms values plotted against temperature. The graph indicates the magnetic properties at different temperatures and types.
Y - Gd - Al - Co

Yttrium - Gadolinum - Aluminum - Cobalt

<table>
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<th>Ms (Gauss) ±5%</th>
<th>Tc (°C)</th>
<th>g&lt;sub&gt;eff&lt;/sub&gt;</th>
<th>ΔH (Oe) +20%</th>
<th>ΔH&lt;sub&gt;eff&lt;/sub&gt; (Oe)</th>
<th>ΔH&lt;sub&gt;k&lt;/sub&gt; (Oe)</th>
<th>ε ±5%</th>
<th>tgδ&lt;sub&gt;max&lt;/sub&gt;</th>
<th>α 10&lt;sup&gt;-3&lt;/sup&gt;/°C ±0.2</th>
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Ms (Gauss)
Mg - Mn - Al

Magnesium-Manganese or Magnesium-Manganese-Aluminum

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<th>$T_c$ (°C)</th>
<th>$g_{eff}$</th>
<th>$\Delta H$ (Oe) +20%</th>
<th>$\Delta H_{eff}$ (Oe)</th>
<th>$\Delta H_k$ (Oe) ±5%</th>
<th>$\varepsilon$</th>
<th>$\tan \delta$ max</th>
<th>$\alpha$ $10^{-3}/°C$ ±0.2</th>
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Ms (Gauss)

![Graph showing Ms values as a function of temperature (°C). The graph includes points for U21, U20, U19, and U33 ferrites.]
Li – Zn - Ti - Mn - (Co)

Lithium - Zinc - Titanium – Manganese - (Cobalt)

<table>
<thead>
<tr>
<th>Type</th>
<th>Ms (Gauss) ±5%</th>
<th>Tc (°C)</th>
<th>$g_{\text{eff}}$</th>
<th>$\Delta H$ (Oe) +20%</th>
<th>$\Delta H_{\text{eff}}$ (Oe)</th>
<th>$\Delta H_k$ (Oe)</th>
<th>$\varepsilon$ ±5%</th>
<th>$\tan \delta$ 10$^{-4}$ max</th>
<th>$\alpha$ 10$^{-3}$/°C ±0.2</th>
<th>Br (Gauss)</th>
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**Graph:**

- Ms (Gauss) plotted against T (°C)
Ni - Zn - Al

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

<table>
<thead>
<tr>
<th>Type</th>
<th>Ms (Gauss) ±5%</th>
<th>Tc (°C)</th>
<th>g_eff</th>
<th>ΔH (Oe) +20%</th>
<th>ΔH_eff (Oe)</th>
<th>ΔH_K (Oe)</th>
<th>ε ±5%</th>
<th>tgδ 10^-4</th>
<th>α 10^-3/°C ±0.2</th>
<th>Br (Gauss)</th>
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Ms (Gauss)