EPSILON 21
Y - BI - CA - ZR

NEW

YTTRIUM - BISMUTH - CALCIUM - ZIRCONIUM

Introducing our latest innovation: a new groundbreaking high epsilon microwave ferrite designed specifically for isolator and circulator applications.

With the ability to reduce the size of current circulators, it offers a compact solution without compromising performance.

Available in multiple power levels, it caters to diverse needs, ensuring versatility and adaptability in various applications of microwave ferrites.

DESCRIPTION:

Yttrium - Bismuth - Calcium - Zirconium garnet ceramic ferrite with high permittivity/dielectric constant

Also available in assembly with dielectric material (availability of several dielectric material. Example: εr = 10 ; 16 ; 20 ; 37 ; 44).

APPLICATIONS:

Circulators, isolators, phase-shifters, filters, diplexers.

FEATURES:

- High permittivity (Eps 21) ferrite for designing smaller microwave devices
- 15%* size reduction of your circulator for the same frequency (vs Eps 15 ferrites)
- Two power levels available (ΔHk = 4.5 and ΔHk = 8.5)
- Frequency applications up to X band (12GHz) below resonance

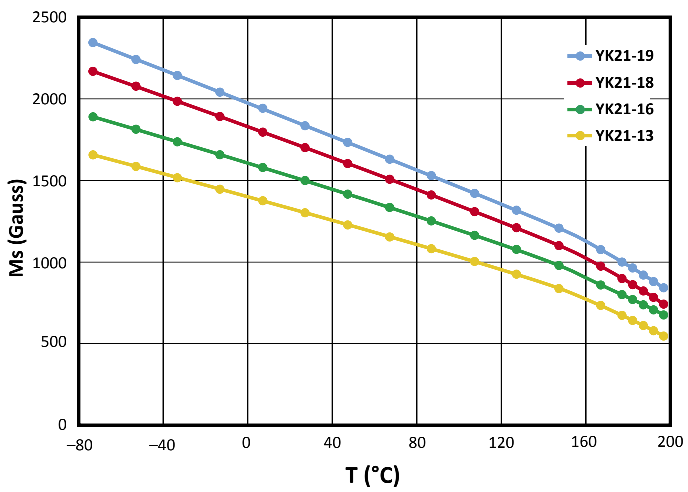
* $$d = k\frac{\lambda}{2} \qquad \lambda = \frac{\lambda_0}{\sqrt{\varepsilon\mu}}$$

λ = wavelength in the material
λ_0 = wavelength in the air
ε = permittivity
μ = permeability
d = dimension

SPECIFICATIONS:

Type	Ms (Gauss) ±5%	g_{eff}	ΔH (Oe) ±20%	ΔH_{eff} (Oe) ±2	ΔHk (Oe) ±0.5	ε ±5%	Tgδ 10^{-4} max.	α 10^{-3}/°C ±0.2
YK21								
19	1900	2.02	80	10	4.5	21	6	2.7
18	1800	2.02	90	14	8	21	6	2.6
16	1600	2.02	80	17	8.5	21	6	2.2
13	1300	2.02	75	8	8	21	6	1.8
DK21								
19	1850	2.04	100	16	8.5	20.5	6	2.6
16	1600	2.04	80	12	8.5	20.5	6	2.2
13	1300	2.04	80	13	8.5	20.5	6	1.8

Ms(T) under satured magnetic field of 0.5 Tesla



HOW TO ORDER (dimensions in mm):

Example: **YK21-16/E16 D19.35x15.35x0.80 Ra0.4**

YK21-16 / **E16** **D** **19.35** x **15.35** x **0.80** **Ra0.4**

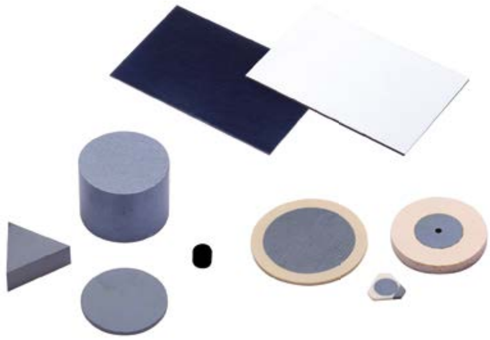
- **YK21-16 — Ferrite type**: See Y- Bi- Ca- Zr family
- **E16 — Additional material for FDA**: Ferrite, Dielectric
- **D — Shape**: D: Disk; C: Cylinder; S: Square; T: Triangle; Y: Switch Y
- **19.35 — Dimension 1**: Diameter for D; Ext. diameter (D_1) for C; Length for S; Incircle diameter for T; Length for Y; **For FDA only**: Ext. diameter (D_1) for D; Incircle diameter (D_1) for T
- **15.35 — Dimension 2**: Thickness for D; Int. diameter (D_2) for C; Height for S; Height for T; Height for Y; **For FDA only**: Int. diameter (D_2) for D; Int. diameter (D_2) for T
- **0.80 — Dimension 3**: Thickness for C; Thickness for S; Thickness for T; Thickness for Y; **For FDA only**: Thickness for D; Thickness for T
- **Ra0.4 — Options**: CF: Chamfer; R: Radius; Ra: Surface finishing; **Excepting FDA**: M: Metallization; Dxxx : Ø Hole for Switch Y

FERRITES & FDA

EXXELIA

FERRITES & FDA

EXXELIA 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 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.

EXXELIA also supply assemblies of ferrite surrounded with dielectric, silver thick film metalized pieces, complex shapes.

SYMBOLS / UNITS

Magnetism parameters

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

Symbol	Parameter	MKSA system	CGS system
B **B_r** **M ($4\pi M_S$ 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** **ΔH** **ΔH_{eff}** **ΔH_k**	Magnetic field (magnetizing force),resonance Anisotropy field | Coercive force Magnetic wave field, c field Ferromagnetic resonance line width Effective resonance line width Spin wave line width	A/m	Oersted (Oe) (=$10^3/4\pi$ A/m)
μ_0	Vacuum permeability	$4\pi 10^{-7}$H/m $B = \mu_0 (H+M)$	1 $B = H+4\pi M$
$\mu = \mu_0 \mu_r$	Permeability	$B = \mu_0.\mu_r.H$	$B = \mu_r.H$
C	Magnetic susceptibility = M/H, m/h	-	-
μ_r	Relative permeability	$\mu_r = 1 + \chi$	$\mu_r = 1 + 4\pi c$ (or $1+\chi$)
α	Magnetization temperature coefficient: $\frac{\Delta M_s}{M_s \Delta T}$	$10^{-3}.K^{-1}$	$10^{-3}.°C^{-1}$
f	Wave frequency	MHz	MHz
γ	Gyromagnetic ratio: $f = \gamma H_r$	~35 10^{-3} MHz. m/A	~2.8 MHz/Oe
γ_{eff}	Landé g-factor ~ 2	= γ/0.0176	= γ/1.4

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

Dielectric properties

Symbol	Parameter
ε'	Relative permittivity (real part)
ε''	Relative permittivity (imaginary part)
ε_r	Relative complex permittivity
tanδ	Dielectric loss tangent: $\tan\delta = \varepsilon''/\varepsilon'$

Other

Symbol	Parameter	Unit
T, T_c	Temperature, Curie temperature	K
R_a	Surface roughness	µm

I. BASIC PROPERTIES

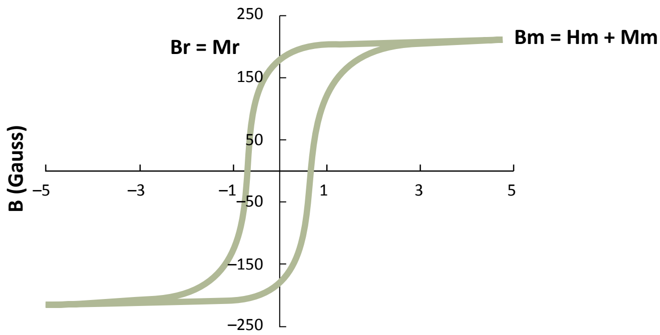
Ferrite materials are used in microwave applications to perform various non-reciprocal devices such as isolators, circulators, diplexers, filters, phase shifters etc. They have dielectric and magnetic properties due to the presence of magnetic ions such as iron within the composition.

I.1 MAGNETIC PROPERTIES

Magnetization M_S

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 Hc) of about 1 to few Oe is enough to get its magnetization value (Mm =Bm - 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 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 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 Tc, which are in the range of 120 to 650°C. The evolution of the magnetization with temperature is measured by the parameter:

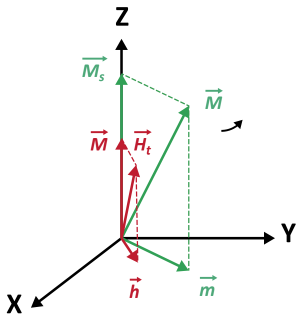
$$\alpha = \frac{\Delta M_s}{M_s \Delta T}$$ in the common range of T: -20 to +60°C

Gyromagnetic resonance - Landé g-factor γ_{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:

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



- γ is the gyromagnetic ratio and is related to the effective Landé g-factor γ_{eff} as
- $\gamma = 1.4 \, . \, \gamma_{eff}$.MHz/Oe. γ_{eff} is about 2 depending on the material: $2 \leq \gamma_{eff} \leq 2.3$

Permeability, gyro-resonance line width ΔH, 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_- :

$$\mu_+ = \chi_+ h_+ \quad \mu_- = \chi_- h_-$$

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

$$\mu_\pm = 1 + \chi_\pm, \; \mu_\pm = \mu'_\pm - j\,\mu''_\pm, \; \mu'_\pm = 1 + \chi'_\pm \mu'_\pm, \; \mu''_\pm = \chi''_\pm$$

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

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

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

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

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

Operation above resonance (zone A in fig 1)

In that case the magnetization may be greater than the limit of f/γ 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 behavior linked to the ferrite's one, etc.). Another advantage is seen in the case of power losses as indicated forward.

Effective line width ΔH_{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 ΔH (fig.1).

Experiment shows that the curve μ''_+ (H) far away from the resonance is a Lorentz curve with an effective line width denoted ΔH_{eff} smaller than ΔH. 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 ΔH_{eff} than line width H, far from resonance.

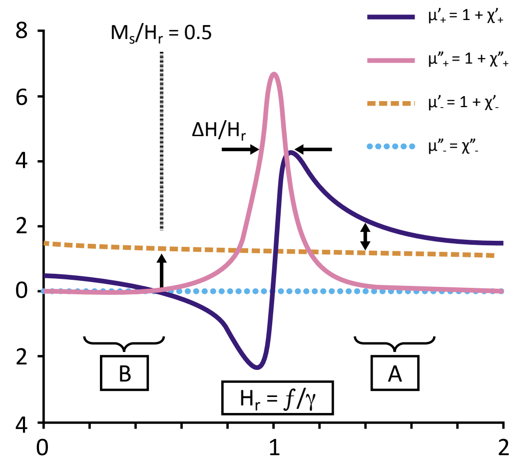

Figure 1 *μ'_+, μ'_-, μ''_+, μ''_- as a function of H/H_r*
"B": below H_r resonance field (low field H)
"A": above H_r resonance field (high field H)

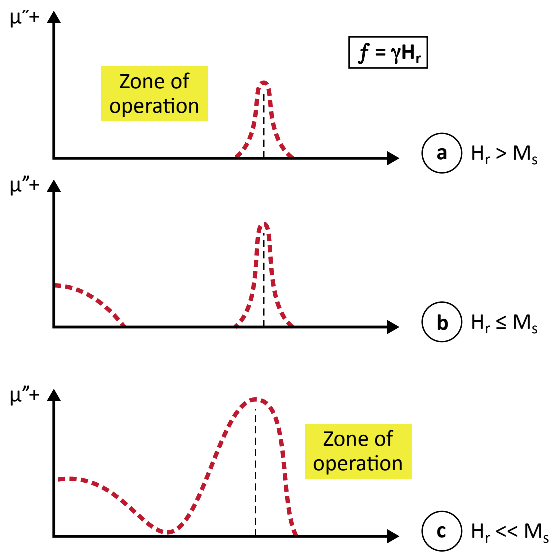

***Figure 2** : permeability μ''_+ versus static field H*

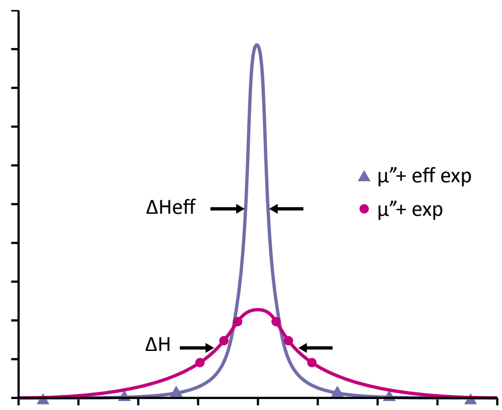

***Figure 3** : ΔH, ΔH_{eff}*

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 ΔH

- From the values of μ''_+, far from resonance, a Lorentz curve can be extrapolated the half width of which, denoted ΔH_{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 ΔH_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 hc, 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 ΔH_k.

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

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

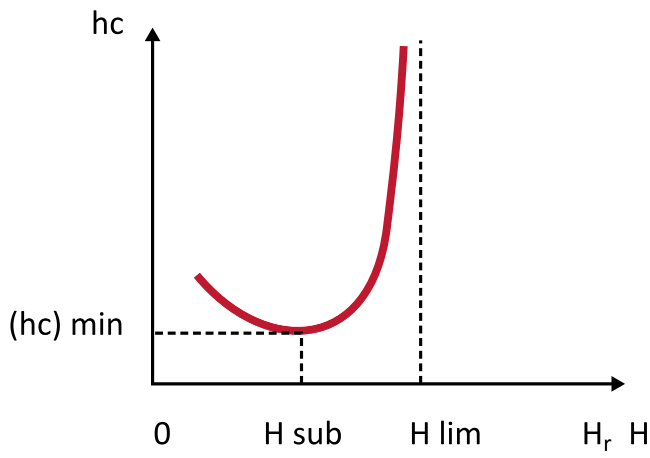

Figure 4: non-linear effect critical field hc versus static field

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 $\tan\delta = \frac{\varepsilon''}{\varepsilon'}$ 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, ε’, tanδ

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

Other parameters such as Tc, ΔH_{eff} , ΔH_k and α 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 ΔH and effective Landé g-factor

The effective Landé g-factor γ_{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 tanδ

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

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Hysteresis parameters

EXXELIA 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 H_c.

II. USER GUIDE

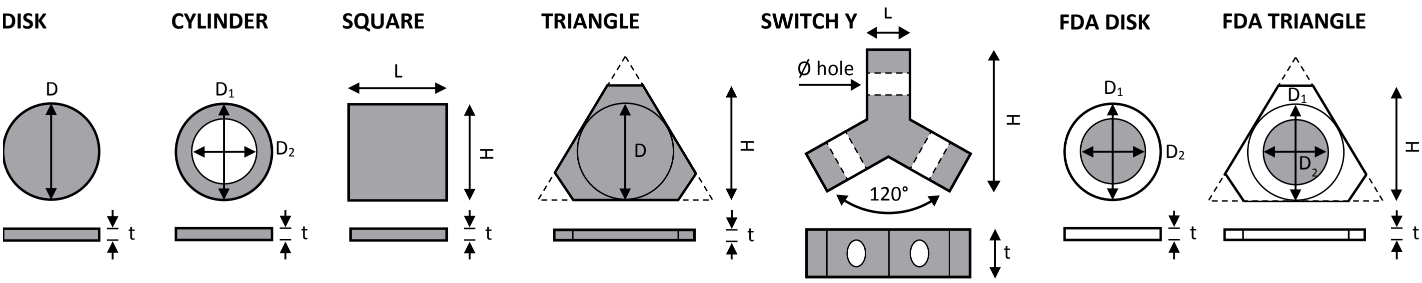
Material properties synthesis

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 ΔH_{eff} (Oe)	Power behaviour ΔH_k (Oe)	Temperature stability α (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
YK21-xx / DK21-xx	Y-V	1.55 ~ 10.9	8 ~ 17	4 ~ 8.5	1.8 ~ 2.7

Shapes

Typical range of shapes which can be produced including single ferrite (F), assembly (FDA) with typical dielectric constant 10, 16, Other on request.



Dimensions mm (inches)

A wide range of dimensions can be made based on customer specifications

- Disks: diameter 1 (0.039) up to 60 (2.362) (typical value)
- Square: max length 50.8 (2.000) x 50.8 (2.000) / Thickness 0.5 (0.020) up to 3 (0.118) (typical value)
- Triangle: in-circle diameter up to 50 (1.969) (typical value)
- Other shapes can be considered on request.

Tolerances on dimensions mm (inches)

- Standard tolerances are ±0.05 (0.002) 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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	Min	Standard / Typical	Max	Typical Tolerance
Ferrite Shape				
Disk / Cylinder				
Diameter	0.6mm		70mm	± 0.05 mm
Internal diameter	1mm		65mm	± 0.05 mm
Square				
Length x Width	0.6 x 0.6mm		100 x 35mm or 50.8 x 50.8mm	± 0.05 mm
Triangle				
Incircle diameter	2.5mm		22mm	± 0.05 mm
Height	2.5mm		30mm	± 0.05 mm
Thickness	0.2mm		16.5mm	± 0.05 mm
Switch Y				
Length	On demand		On demand	
Width	On demand		On demand	
Thickness	On demand		On demand	
Hole diameter	0.5mm		On demand	
FDA				
Internal diameter	1.3mm		65mm	± 0.05 mm
External diameter	2.3mm		70mm	± 0.05 mm
Thickness	0.6mm		16.5mm	± 0.05 mm

Roughness & Metallization				
Finish Ra	0.1µm	0.8µm	As fired	
Metallization Thickness (Not for FDA)- Silver		7- 14µm		

Br value to be defined with the customer because it depends on the dimensions of the ferrite

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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.

Radius

As per customer specification.

How to order

Example for ferrite: **Y101 S50.80x50.80x0.64 M**

Y101	S	50.80	x	50.80	x	0.64	M
Material Garnet or Spinel	**Shape** D: Disk C: Cylinder S: Square T: Triangle Y: Switch Y	**Dimension 1** Diameter for D Ext. diameter (D_1) for C Length for S Incircle diameter for T Length for Y		**Dimension 2** Thickness for D Int. diameter (D_2) for C Height for S Height for T Height for Y		**Dimension 3** Thickness for C Thickness for S Thickness for T Thickness for Y	**Options** M: Metallization CF: Chamfer R: Radius Dxxx : Ø Hole for Switch Y Ra: Surface finishing

Example for FDA: **Y101/E16 D19.35x15.35x0.80 Ra0.4**

Y101	/	E16	D	19.35	x	15.35	x	0.80	Ra0.4
Ferrite type See Garnet family		**Additional Material for FDA** Ferrite / Dielectric	**Shape** D: Disk T: Triangle	**Dimension 1** Ext. diameter (D_1) for D Incircle diameter (D_1) for T		**Dimension 2** Int. diameter (D_2) for D Int. diameter (D_2) for T		**Dimension 3** Thickness for D Thickness for T	**Options** CF: Chamfer R: Radius Ra: Surface finishing