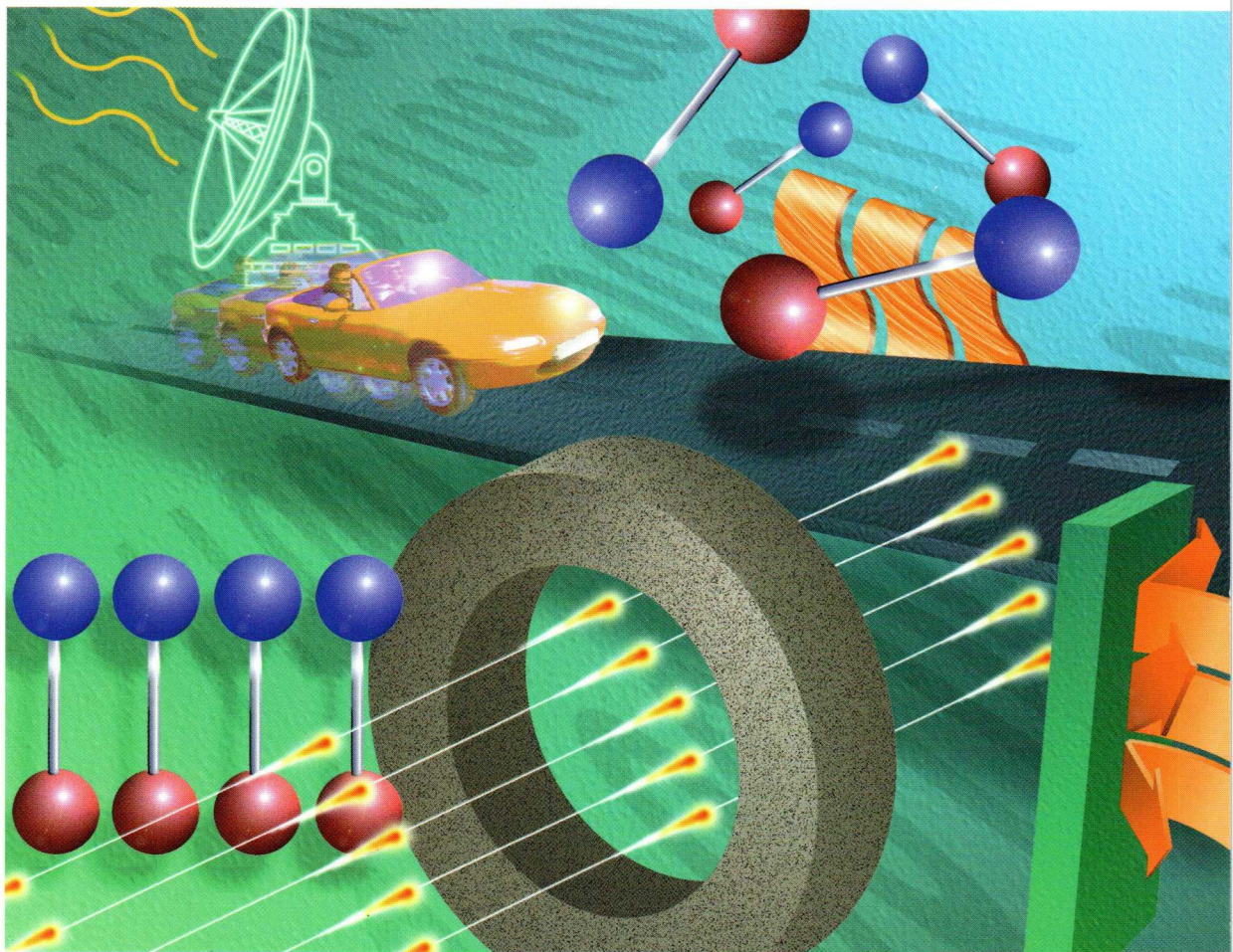


Piezoelectric Ceramics Specialty Ferrites



1997

DATA HANDBOOK MA03

QUALITY ASSURED

Our quality system focuses on the continuing high quality of our components and the best possible service for our customers. We have a three-sided quality strategy: we apply a system of total quality control and assurance; we operate customer-oriented dynamic improvement programmes; and we promote a partnering relationship with our customers and suppliers.

PRODUCT SAFETY

In striving for state-of-the-art perfection, we continuously improve components and processes with respect to environmental demands. Our components offer no hazard to the environment in normal use when operated or stored within the limits specified in the data sheet.

Some components unavoidably contain substances that, if exposed by accident or misuse, are potentially hazardous to health. Users of these components are informed of the danger by warning notices in the data sheets supporting the components. Where necessary the warning notices also indicate safety precautions to be taken and disposal instructions to be followed. Obviously users of these components, in general the set-making industry, assume responsibility towards the consumer with respect to safety matters and environmental demands.

All used or obsolete components should be disposed of according to the regulations applying at the disposal location. Depending on the location, electronic components are considered to be 'chemical', 'special' or sometimes 'industrial' waste. Disposal as domestic waste is usually not permitted.

PIEZOELECTRIC CERAMICS SPECIALTY FERRITES

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DEFINITIONS

Data sheet status	
Objective specification	This data sheet contains target or goal specifications for product development.
Preliminary specification	This data sheet contains preliminary data; supplementary data may be published later.
Product specification	This data sheet contains final product specifications.
Application information	
Where application information is given, it is advisory and does not form part of the specification.	

LIFE SUPPORT APPLICATIONS

These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Philips customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips for any damages resulting from such improper use or sale.

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Piezoelectric Ceramics

Introduction

THE NATURE OF PIEZOELECTRIC CERAMICS

Piezoelectricity is the general term to describe the property exhibited by certain crystals of becoming electrically polarized when stress is applied to them. Quartz is a good example of a piezoelectric crystal. If stress is applied to such a crystal, it will develop an electric moment proportional to the applied stress.

This is the direct piezoelectric effect. Conversely, if it is placed in an electric field, a piezoelectric crystal changes its shape slightly. This is the inverse piezoelectric effect.

Piezoelectricity is also exhibited by ferroelectric crystals, e.g. tourmaline and Rochelle salt. These already have a spontaneous polarization, and the piezoelectric effect shows up in them as a change in this polarization.

In addition to the crystals mentioned above, an important group of piezoelectric materials are the piezoelectric ceramics, of which PXE (Philips trade mark) is an example. These are polycrystalline ferroelectric materials with the perovskite crystal structure, a tetragonal/rhombohedral structure very close to cubic. They have the general formula ABO_3 (Fig.1), in which A denotes a large divalent metal ion such as Pb, and B denotes a small tetravalent metal ion such as Zr or Ti.

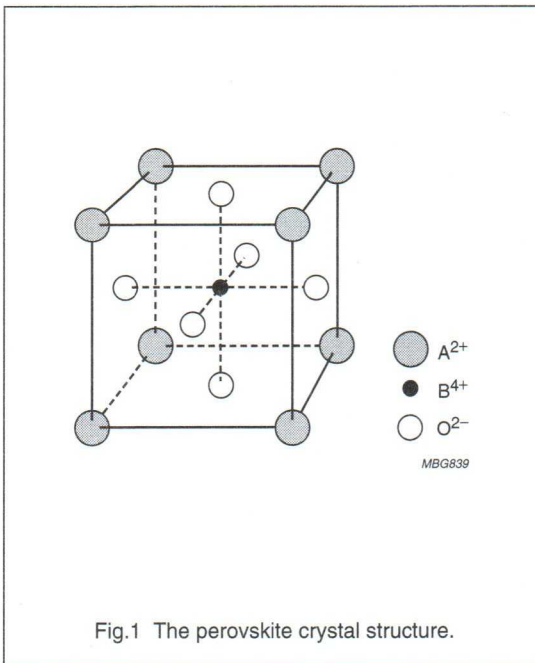
PXE can be fashioned into components of almost any shape and size. As well as being strongly piezoelectric, PXE is hard, strong, chemically inert and completely unaffected by humid environments.

The PXE ceramics in this Data Handbook are solid solutions of lead titanate ($PbTiO_3$), and lead zirconate ($PbZrO_3$), modified by additives, a group of piezoceramics generally known as PZT. They are available in several grades distinguished by their electrical and physical properties to meet particular requirements.

Piezoelectric effect in ceramic materials

In a ferroelectric crystal, each cell of the crystal lattice spontaneously polarizes along one of a series of allowed directions. This spontaneous polarization disappears at a critical temperature (the Curie point), above which the crystal becomes paraelectric.

If the crystal is cooled through its Curie point in the presence of an external electric field, the dipoles tend to align in the allowed direction most nearly aligned with the field. If this crystal is then stressed, the lattice will distort, leading to a change in the dipole moment of the crystal (piezoelectric effect). Within a certain stress range (which depends on the crystal concerned), this change in dipole moment with stress is approximately linear and reversible.



A PXE ceramic may be regarded as a mass of minute crystallites, randomly oriented. After it has been sintered, the ceramic material will be isotropic and will exhibit no piezoelectric effect because of this random orientation. The ceramic may be made piezoelectric in any chosen direction by a poling treatment which involves exposing it to a strong electric field. When the field is removed, the dipoles remain locked in alignment, giving the ceramic material a remnant polarization and a permanent deformation (i.e. making it anisotropic), as well as making it permanently piezoelectric. This poling treatment is usually the final stage of PXE component manufacture.

A PXE component will usually have metal electrodes deposited on its surface perpendicular to its poling axis (Fig.2). When a voltage is applied between them, the body distorts along its poling axis. The random orientation of the crystallites, and the fact that only certain polarization directions are allowed, means that it is not possible to get perfect dipole alignment with the field. A reasonable degree of alignment is, however, possible since there are several allowed directions within each crystal.

Piezoelectric Ceramics

Introduction

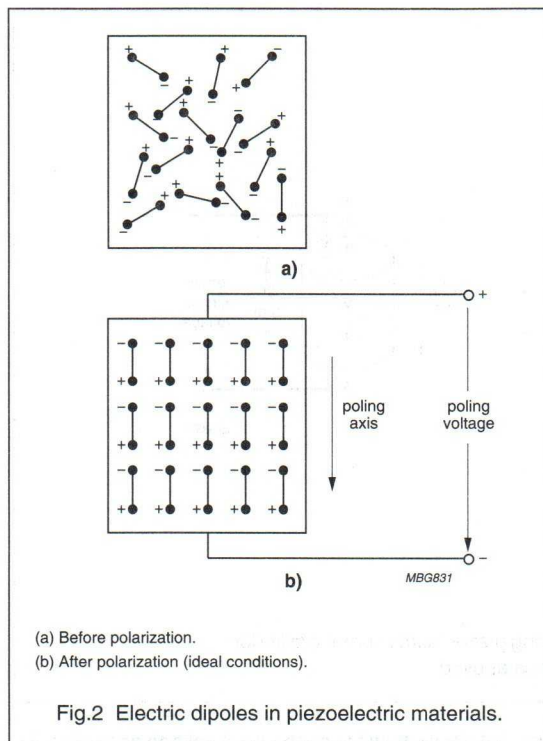
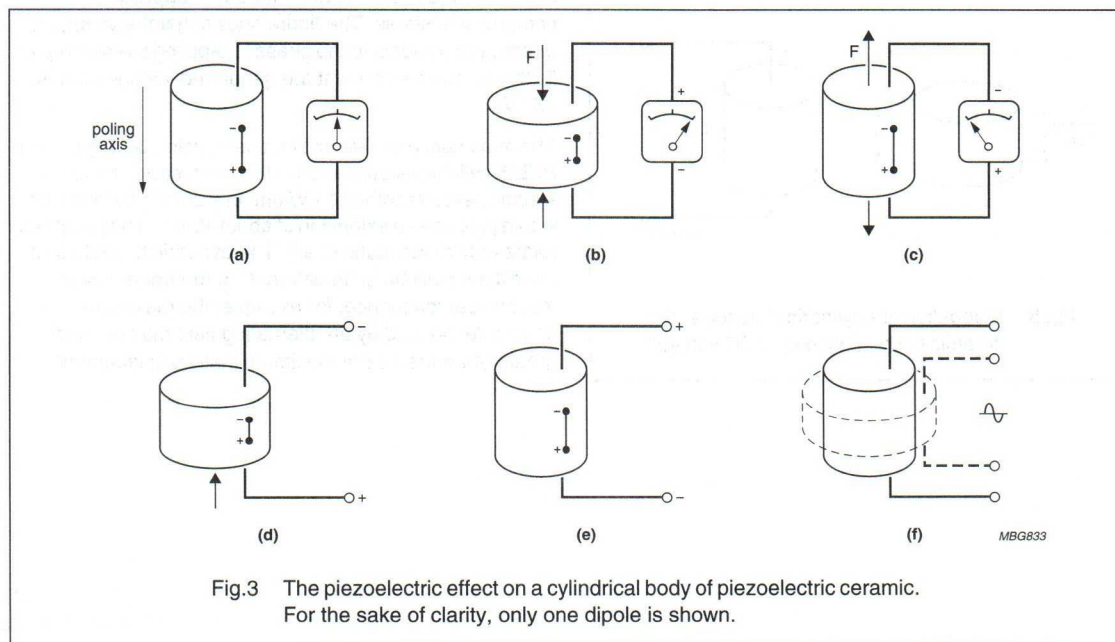


Figure 3 illustrates the piezoelectric effect in a cylinder of PXE material. For clarity, the magnitude of the effect has been exaggerated.

Figure 3a shows the cylinder under no-load conditions. If an external force produces compressive or tensile strain in the material, the resulting change in dipole moment causes a voltage to appear between the electrodes. If the cylinder is compressed, the voltage will have the same polarity as the poling voltage (Fig.3b). If it is stretched, the voltage across the electrodes will have opposite polarity to the poling voltage (Fig.3c). These are examples of generator action, the conversion of mechanical energy into electrical energy. Examples of piezoelectric-induced generator action can be found in cigarette and gas lighters, gramophone pick-ups, accelerometers, hydrophones and microphones.

If a voltage of opposite polarity to the poling voltage is applied to the electrodes, the cylinder will shorten (Fig.3d). If the applied voltage has the same polarity as the poling voltages, the cylinder will lengthen (Fig.3e). Finally, if an alternating voltage is applied to the electrodes, the cylinder will grow and shrink at the same frequency as that of the applied voltage (Fig.3f). These are examples of motor or actuator action, conversion of electrical energy into mechanical energy. PXE-induced motor action is found in transducers for ultrasonic cleaning equipment, ultrasonic atomizers, fuel injection systems and piezoelectric motors.



Piezoelectric Ceramics

Introduction

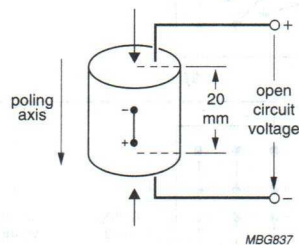
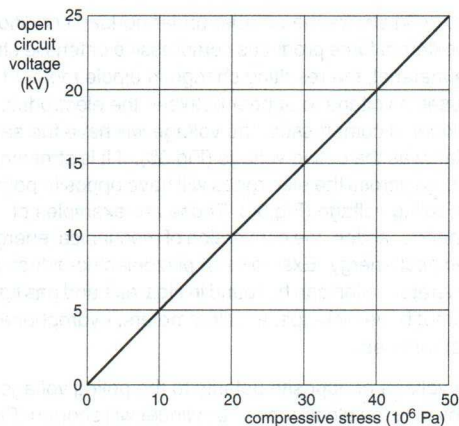


Fig.4 Open circuit voltage of a 20 mm long piezoelectric ceramic cylinder as a function of compressive stress applied.

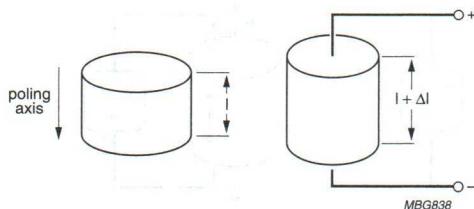


Fig.5 Elongation of a cylindrical piezoelectric ceramic body caused by a DC voltage.

Figure 4 shows how the open-circuit voltage generated by a 20 mm long PXE cylinder varies with applied compressive stress. The figure shows that the voltage is directly proportional to the stress for applied stresses up to 50000 kPa at which point the generated voltage equals 25 kV.

The maximum piezoelectric induced strain, $\Delta l/l$ (Fig.5), in a PXE 5 cylinder is around 5×10^{-4} , corresponding to an electric field strength of 1 kV/mm. In a 20 mm cylinder, this would produce an extension of about 10 μm . These figures relate only to the static strain. The dynamic behaviour of the cylinder will be quite different. At the frequency of mechanical resonance, for example, the maximum amplitude induced by an alternating field may be much greater than the 10 μm maximum static displacement.

APPLICATIONS**High voltage generators (for ignition purposes)**

- Gas appliances
- Cigarette lighters
- Fuses for explosives
- Flash bulbs.

High power ultrasonic generators

- Ultrasonic cleaning for industrial and domestic appliances
- Sonar
- Echo sounding
- Ultrasonic welding of plastics and metals
- Ultrasonic drilling and machining of brittle materials
- Ultrasonic soldering
- Atomizing of fluids.

Transducers for sound and ultrasound in air

- Microphones
 - for telephones
- Intruder alarm systems
- Remote control
- Loudspeakers
 - tweeters
- Audio tone generators in signalling devices.

Sensors

- Record players
- Accelerometers
- Detection systems in machinery
 - textile
- Medical equipment
- Motor cars
 - knock sensor
 - crash/airbag sensor.

Resonators and filters

- Radio
- Television
- Telecommunications.

Delay lines

- Colour television.

Push buttons and keyboards

- Teleprinters
- Desk calculators and electronic computers
- Slot machines
- Telephones.

Miscellaneous

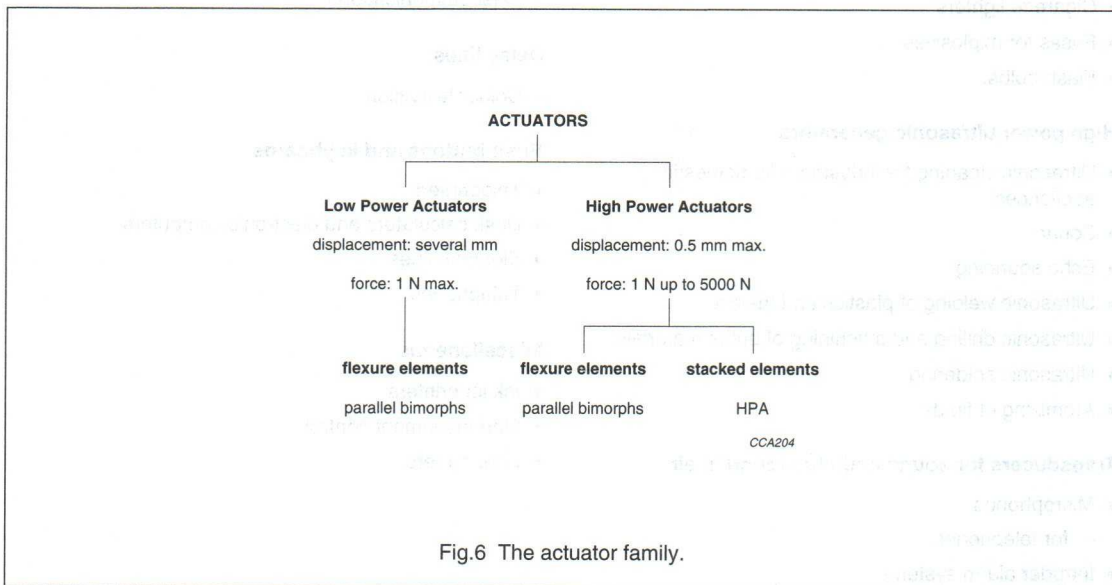
- Ink jet printers
- Fine movement control
- Flow meters.

Piezoelectric Ceramics

Introduction

Actuators

Operating in the d_{31} or d_{33} mode below the resonant frequency, actuators transfer electrical energy into 'large' or high voltage displacements in comparison with the displacements of simple PXE transducers.



Piezoelectric Ceramics

Introduction

PXE flexure elements: Bimorph

Many applications require displacements far greater than are possible with simple PXE transducers operating in the d_{31} or d_{33} modes. Moreover, the voltages required to produce these displacements are very high, and because they present a considerable mismatch to air, these elements are unsuitable for use as electro-acoustic transducers.

A much more compliant structure operating in the d_{31} mode is the flexure element, the simplest form of which is the bilaminar cantilever or bimorph. This consists of two thin PXE strips bonded together. Bimorphs are usually mounted as a cantilever and usually operate in the d_{31} mode (see Figs 7 and 8).

In a series bimorph PXE strips are connected to the voltage source in series (Fig.7), and in a parallel bimorph strips are individually connected to the voltage source (Fig.8).

In the series bimorph, one of the PXE strips will always be subject to a voltage opposite to the polarizing voltage, so there is always a danger of depolarization. This is also true of the parallel bimorph configuration of Fig.8, but if it is connected as shown in Fig.9, both strips will be driven in the polarization direction, thereby avoiding drift in characteristics caused by depolarization.

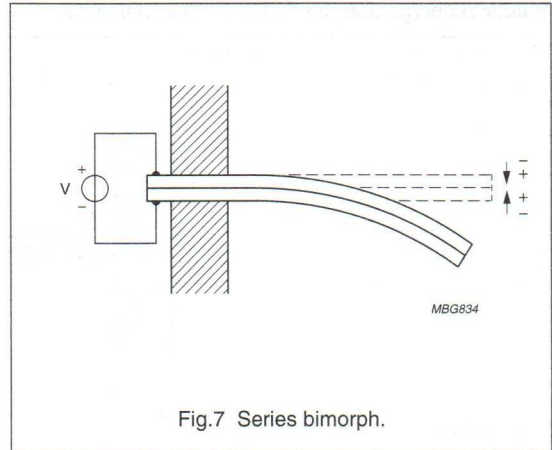


Fig.7 Series bimorph.

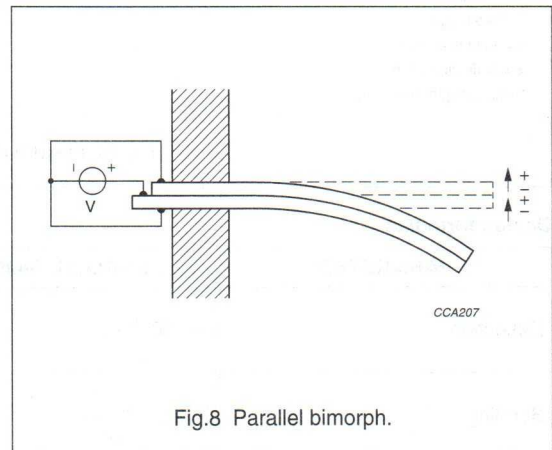


Fig.8 Parallel bimorph.

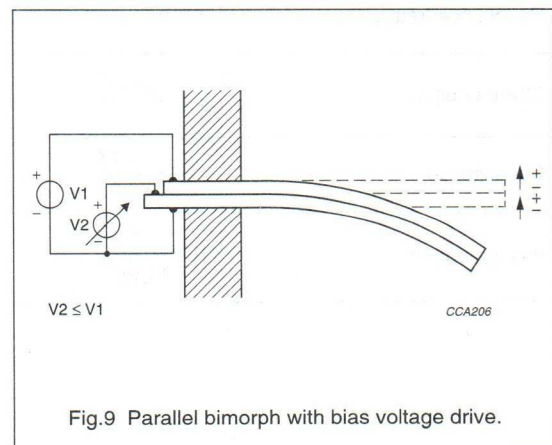
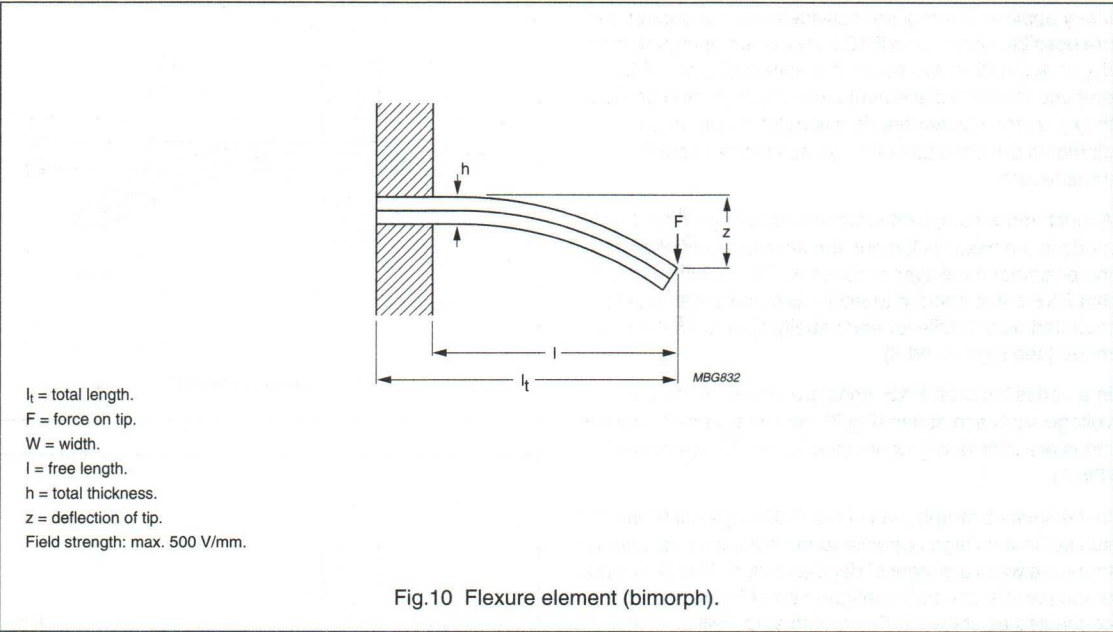


Fig.9 Parallel bimorph with bias voltage drive.

Practical design data for PXE 5 flexure elements



Design formulas

PARAMETER	PARALLEL BIMORPH	SERIES BIMORPH	UNIT
Deflection	$9 \times 10^{-10} \frac{l^2}{h^2}$		m/V
Bending	$7 \times 10^{-11} \frac{l^3}{Wh^3}$	$7 \times 10^{-11} \frac{l^3}{Wh^3}$	m/N
Resonance frequency	$400 \frac{h}{l^2}$	$400 \frac{h}{l^2}$	Hz
Charge output	$8 \times 10^{-10} \frac{l^2}{h^2}$	$4 \times 10^{-10} \frac{l^2}{h^2}$	C/N
Capacitance	$8 \times 10^{-8} \frac{l_t W}{h}$	$2 \times 10^{-8} \frac{l_t W}{h}$	F
Voltage output	$10^{-2} \frac{l^2}{h l_t W^2}$	$2 \times 10^{-2} \frac{l^2}{h l_t W^2}$	V/N

PIEZOELECTRIC CERAMICS FOR ULTRASONIC TRANSDUCERS

Principles of ultrasonic transducers

PXE, usually in the form of axially poled discs or rings, may be used in high-intensity ultrasonic transducers. Typical applications are echo-sounding (PXE 41), ultrasonic cleaning (PXE 42), and ultrasonic welding and machining (PXE 43).

For echo-sounding, a disc is driven in the d_{33} thickness mode and is usually housed in a protective plastic encapsulation. The preferred operating frequency lies between 150 and 200 kHz, which gives a compact transducer with adequate directivity and reasonable range.

A simple ultrasonic cleaning transducer is formed by a PXE disc, bonded to a metal disc that is itself bonded to the underside of a cleaning tank. The disc is driven in the radial mode at a frequency in the range 40 to 60 kHz and causes the tank wall to vibrate in complex flexure modes, radiating ultrasound in the tank. For highest ultrasonic intensities, it is advisable to adopt a pre-stressed sandwich construction, in which two PXE discs or rings, separated by a thin metal shim are sandwiched between two metal blocks. The PXE elements are driven in the d_{33} thickness mode and the complete assembly constitutes a half wave resonator. The whole structure is held together by bolts, which subject the ceramic to a compressive force. In this way, the ceramic is prevented from going into tension when vibrating.

This structure also has the advantages of good heat dissipation, reduced losses owing to the good mechanical properties of metals, and a piezoelectric coupling which need not be much lower than that of a single-piece ceramic transducer. Such sandwich transducers operate in the frequency range 20 to 50 kHz. They may be used for ultrasonic cleaning, in which case they are bonded to the underside of the cleaning tank. For welding or machining, the transducer is bolted to an additional mechanical transformer (horn) which serves to match the output to the acoustic load.

Acoustic matching of transducers

When a transducer is coupled to a solid load, matching is usually achieved by means of a horn transformer. For matching to a liquid load, an extra layer with a thickness of one quarter wavelength may be interposed between transducer and liquid. This interface layer should have an acoustic impedance, intermediate between that of the transducer and the liquid. Many synthetic materials, such as epoxy resins and other plastics, fall within this range.

In sandwich transducers, matching with liquids may also be assisted by forming the radiating metal block from a metal of low acoustic impedance, such as aluminium or magnesium alloy.

Dynamic behaviour of the transducer

High intensity transducers are normally driven at resonance, and the equivalent circuit is as in Fig.13. For maximum efficiency, the transducer should be tuned electrically by means of an inductance given by:

$$L = \frac{1}{4\pi^2 f^2 C_0}$$

The impedance of the transducer then appears as purely ohmic.

Piezoelectric Ceramics

Introduction

DESCRIPTION OF SYMBOLS

SYMBOL	DESCRIPTION
ϵ_0	dielectric constant of free space = 8.85×10^{-12} F/m
$\epsilon_r^T, \epsilon^T/\epsilon_0$	relative dielectric constant at constant stress
$\epsilon_r^S, \epsilon^S/\epsilon_0$	relative dielectric at constant strain
$\tan \delta$	dissipation factor at 1 kHz at low electric field strength
k_p	planar coupling factor
k_{31}	transverse or lateral coupling factor
k_{33}	longitudinal coupling factor
k_{15}	shear coupling factor
k_t	thickness coupling factor (laterally clamped)
d	piezoelectric charge constant
g	piezoelectric voltage constant
S^E	elastic compliance at constant electric field
S^D	elastic compliance at constant charge density
C^E	elastic stiffness at constant electric field
C^D	elastic stiffness at constant electric charge density
Q^{Em}	mechanical quality factor radial mode
N_1	frequency constant of lateral resonance
N_p	frequency constant of planar resonance

EXPLANATION OF TERMS AND FORMULAS

Direct piezoelectric effect

The electric dipole P developed in a piezoelectric ceramic medium by a tensile stress T parallel to its poling axis is given by:

$$P = dT \quad (1)$$

in which d is a material constant known as the piezoelectric charge constant. (Note that for compressive stress, the sign of T is reversed).

In terms of the electric field E and electric displacement D , the polarization is given by:

$$P = D - \epsilon^T E \quad (2)$$

in which ϵ^T is the permittivity, itself a stress-dependent quantity.

To a first approximation, this dependence can be neglected and equations (1) and (2) combined to give:

$$dT = D - \epsilon^T E \text{ or } D = dT + \epsilon^T E \quad (3)$$

where ϵ^T is the permittivity at constant stress. This can also be written as:

$$E = -gT + \frac{D}{\epsilon^T} \quad (4)$$

where $g = \frac{d}{\epsilon^T}$ is known as the piezoelectric voltage constant.

Piezoelectric Ceramics

Introduction

Inverse piezoelectric effect

In the absence of mechanical stresses, the strain S (i.e. $\Delta l/l$) experienced by a piezoelectric ceramic medium when subjected to an external electric field is given by:

$$S = dE \text{ or } S = gD$$

The strain experienced by an elastic medium subjected to a tensile stress T is in accordance with Hooke's Law:

$$S = sT$$

where S is the compliance of the medium. Generally, however, the response of a stressed piezoelectric medium will be a complex interaction between both electrical and mechanical parameters.

To a good approximation, the total strain S experienced by the medium is:

$$S = S^E T + dE \quad (5)$$

$$S = S^D T + gD \quad (6)$$

in which S^E and S^D are respectively the specific compliances at constant electric field and constant electric displacement. (Note that in SI units, d is expressed in C/N, or its equivalent m/V, and g is expressed in Vm/N, or its equivalent m²/C).

Coupling factor k

From equations (5) and (6), S^E and S^D are related by:

$$S^D = (1 - k^2)S^E$$

$$\text{with } k^2 = \frac{d^2}{S^E \epsilon_T}$$

$$\text{or } \frac{k^2}{1 - k^2} = \frac{g^2 \epsilon_T}{S^D}$$

Introduced this way, k is merely a convenient numerical quantity, but at frequencies well below the resonant frequency of the ceramic body, it has real physical meaning. Then:

$$k^2 = \frac{\text{stored energy converted}}{\text{stored input energy}}$$

where k is referred to as the coupling factor.

This formula holds for both electromechanical and mechanical-electrical conversions. A study of the values of k in the table of principal properties shows that up to 50% of the stored energy can be converted at low frequencies. The values of k^2 quoted in the table are the theoretical maxima. In practical transducers, the coupling factor is usually lower.

Although a high value of k is usually desirable for efficient transduction, it should not be thought of as an efficiency. Equations (3) to (6) take no account of dissipative mechanisms and energy that is not converted can, in principle, still be recovered. For instance, in the case of electromechanical action, the unconverted energy remains as a charge in the capacitance of the PXE.

Depolarization

The polarization (poling) of piezoelectric materials is permanent. However, when working with these materials, the following points should be borne in mind:

1. The temperature of the material should be kept well below the Curie point.
2. The material should not be exposed to very strong alternating electric fields or direct fields, opposing the direction of poling.
3. Mechanical stress, exercised on the material, should not exceed specified limits.

Failure to comply with these three conditions may result in depolarization (depoling) of the material so that the piezoelectric properties become less pronounced or disappear completely. Table 1 provides a guide for these limits.

Table 1 Electrical and mechanical limits

PXE GRADE	ELECTRIC FIELD STRENGTH (V/mm)	MECHANICAL PRE-STRESS (MPa)
PXE 59	350	5
PXE 5	300	2.5
PXE 52	100	—
PXE 41	300	10
PXE 42	400	25
PXE 43	500	35

Direction dependence

The discussions so far relate to uniaxial stress/electric-field conditions. Under more general conditions, the anisotropic nature of the piezoelectric material must be considered. This can be described in terms of the anisotropic properties of the piezoelectric and coupling constants, permittivity and compliance. To do this, it is necessary to define directional and shear axes.

For PXE ceramics, the direction of positive polarization is usually taken as that of the Z axis of a right-hand orthogonal crystallographic axial set X, Y, and Z. Since PXE materials have complete rotational symmetry about the polar axis, the senses of X and Y chosen in an element are not important. If, as shown in Fig.11, the X, Y and Z directions are represented by 1, 2 and 3 respectively, and the shear about these axis by 4, 5 and 6, the various related parameters can be written with subscripts referring to these.

Permittivity

The first subscript gives the direction of the dielectric displacement, the second indicates the electric field direction. For example:

ϵ_{11}^T is the permittivity for dielectric displacement and electric field in the 1-direction under conditions of constant stress, and

ϵ_{33}^T is the permittivity for dielectric displacement and electric field in the 3-direction under conditions of constant stress.

The table of principal properties gives the relative

permittivity $\epsilon_r = \frac{\epsilon}{\epsilon_0}$ (ϵ_0 is the permittivity of

vacuum = 8.85×10^{-12} F/m).

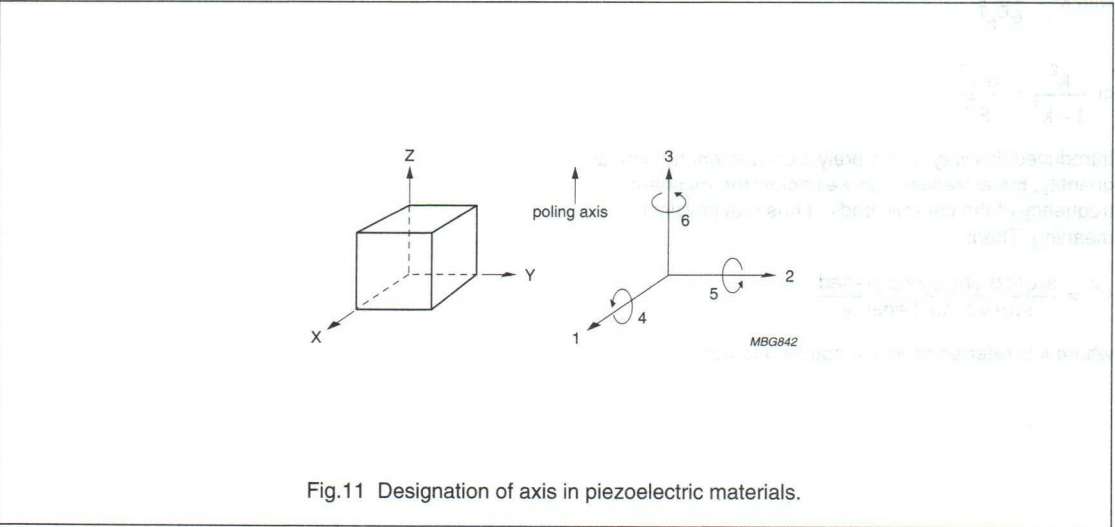


Fig.11 Designation of axis in piezoelectric materials.

Piezoelectric Ceramics

Introduction

Compliance S, modulus of elasticity Y

The first subscript refers to the direction of strain and the second gives the direction of stress. For example:

$$S_{33}^D = \frac{1}{Y_{33}^E} \text{ is the strain per unit stress in the 3-direction}$$

at constant electric field.

$$S_{55}^D = \frac{1}{Y_{55}^D} \text{ is the shear strain per unit shear stress}$$

about an axis perpendicular to the poling direction at constant electric displacement.

Piezoelectric constants d, g and k

The first subscript refers to the electric field or displacement direction, and the second gives the direction of the mechanical stress or strain. For example:

d_{33} is the induced strain per unit field in the 3-direction. Alternatively, it is the electric dipole per unit applied stress in the 3-direction.

g_{31} is the electric field in the 3-direction per unit applied stress in the 1-direction. Alternatively, it is the induced strain in the 1-direction per unit dielectric displacement in 3-direction.

Coupling factor k

Coupling factor k_{31} is the relation between the stored mechanical energy input in the 1-direction and the stored electrical energy converted in the 3-direction (or vice versa).

Special cases k_p and k_t

The planar coupling factor k_p of a thin disc denotes the coupling between the electric field in the 3-direction (thickness direction), and the simultaneous mechanical actions in the 1- and 2-directions which results in radial vibration (Fig.12); hence the term radial coupling ($k_r = k_p$).

The thickness coupling factor k_t of a thin disc with arbitrary contour denotes the coupling between the electric field in the 3-direction (thickness direction) and the mechanical vibration in the 3-direction. This is smaller than k_{33} because of the constraint imposed by the large lateral dimensions of the disc relative to the thickness.

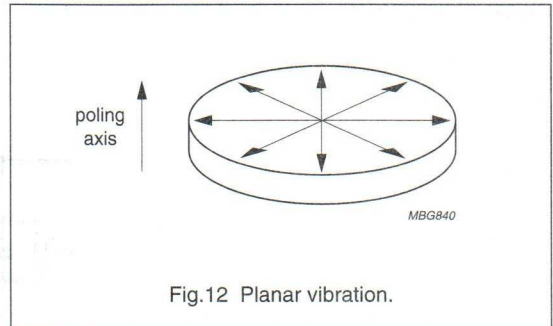


Fig.12 Planar vibration.

Frequency constant N

The frequency constant is the product of a resonant frequency and the linear dimension governing the resonance. For a 31, 15 or 33 mode resonance, and for planar or radial mode resonance, the relevant frequency constants are N_1 , N_5 , N_3 and N_p .

Example: For a disc with diameter D and thickness d, the radial resonant frequency is:

$$f_{\text{rad}} = \frac{N_p}{D}$$

The thickness resonant frequency is:

$$f_{\text{th}} = \frac{N_p}{d}$$

The frequency constants are equal to half the governing sound velocity in the ceramic body, except for the constant N_p .

Dynamic behaviour

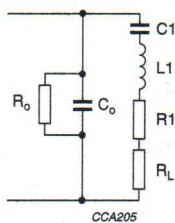
A piezoelectric transducer, operating near or at the mechanical resonant frequency can be characterized by simple equivalent circuit (Fig.13).

If the electrical admittance (Y) of the vibrating transducer is plotted against the frequency, one obtains the following resonant curve (Fig.14).

The frequency f_s , at which the admittance is maximum, is called the series resonant frequency. The minimum value of the admittance is found at the parallel resonant frequency f_p .

Piezoelectric Ceramics

Introduction



C_0 = capacitance of the clamped transducer.

R_0 = dielectric loss of the transducer. $[2\pi f(C_0 + C_1) \tan]^{-1}$.

R_1 represents the mechanical loss in the transducer.

R_L represents the acoustic or mechanical load.

C_1 and L_1 represent the rigidity and the mass of the material.

Fig.13 Equivalent circuit.

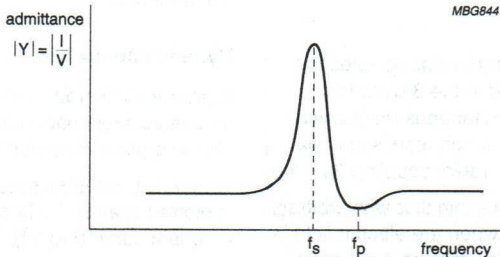


Fig.14 Admittance curve.

Piezoelectric Ceramics

Introduction

ORDERING INFORMATION

The products in this handbook are identified by type numbers. All physical and technical properties of the product are described by these type numbers. They are therefore recommended for both ordering and use on technical drawings and equipment parts lists.

The 11-digit code used in former editions of this data handbook may also appear on some packaging labels.

Smallest Packaging Quantities (SPQ) are packs which are ready for shipment to our customers. The information on the barcoded label consists of:

Barcode information

technical information:	name of product
	11-digit code number
	delivery and/or production
	batch numbers
logistic information:	12-digit code number
	quantity
	country of origin
	production week
	production centre

The Philips 12-digit code used on the packaging labels, provides full logistic information as well.

During all stages of the production process, data are collected and documented with reference to a unique batch number, which is printed on the packaging label. With this batch number it is always possible to trace the results of process steps afterwards and in the event of customer complaints, this number should always be quoted.

Samples

For a range of preferred products, smaller packaging units are also available for sampling and design-in support. These are identified by a '9' as the 12th digit.

ELECTRICAL CONNECTIONS

An electrical contact can be made by soldering, gluing or clamping wires to the silver or nickel electrodes.

Soldering

The electrode surface should be free from grease and dust. If tarnished, an india-rubber eraser may be used to lightly clean the silver. Suggested soldering method:

- Soldering iron: standard 25 to 50 W type with copper bit
- Soldering iron temperature: 250 to 300 °C for silver electrodes and 400 °C for nickel electrodes
- Preferred solder: Sn/Pb 60/40, with slightly activated resin, e.g. 'Fluitin' (SnPb 60/1532); 'Billiton' (SnPb 60/RS4); or 'Multicore' (SnPb 60/366)
- Soldering time: 3 ± 1 s
- Standard wire diameter: 0.3 mm, or fine-stranded flex.

The soldering time should be kept as short as possible; otherwise, the disc or plate may be partly depolarized (to an extent dependent upon temperature and time).

Piezoelectric Ceramics

Introduction

SAFETY AND ENVIRONMENTAL ASPECTS

Environmental aspects of piezoceramics

Our piezoceramic products generally consist of one or more layers of ceramic material (PXE) covered with metal electrodes.

The chemical composition of the range of PXE grades is Pb (ZrTi) Ox (lead titanate zirconate) with some minor dopes of, for example La, Sr or Fe. More exactly, PXE 5 has the following main composition (weight percent).

PXE 5 main composition

SYMBOL	PERCENTAGE
PbO	66%
ZrO ₂	21%
TiO ₂	11%

Silver (Ag) electrodes have a thickness of some micrometers (μm), whereas nickel (Ni) electrodes, combined with some chromium (Cr) have a thickness of about 0.5 μm . Materials and electrodes contain no measurable amounts of cadmium (Cd).

General warning rules

- With strong acids, the metals chromium, nickel and silver may be partially extracted. Other metals on a smaller scale, due to their very strong chemical bonds.
- In a fire, at temperatures higher than 800 °C, lead oxide will evaporate from the products.
- Disposal as industrial, chemical or special waste depending on local rules and circumstances.

QUALITY

Our production centre for piezoceramics has received the ISO 9001 certificate from KEMA, the Dutch audit authority.

Our piezoceramic products are produced to meet constantly high quality standards. High quality components in mass production require advanced production techniques as well as background knowledge of the product itself. The quality standard is achieved in our production centres by implementation of a quality assurance system based on Statistical Process Control (SPC).

To implement SPC, the production is divided in stages which correspond to production steps, or groups of steps. The output of each stage is statistically checked by C_{pk} .

The obtained results are measured against built-in control, warning and reject levels. If an unfavourable trend is observed in the results from a production stage, corrective action is taken immediately. Quality is 'built-in' by continuous improvement.

The system is applicable to the total manufacturing process, which includes:

- Raw materials
- Production process
- Finished products.

Piezoelectric Ceramics

Material grades

PXE 5

This material combines a high coupling coefficient and high piezoelectric charge constant. It is ideally suited for low-power applications. Among these are numerous non-resonant applications such as pick-up elements, fine movement control, feedback plates, microphones, pressure and acceleration sensors, and hydrophones. PXE 5 can also be used for low-power resonant applications (e.g. air transducers for remote control purposes). This grade has an excellent time stability characteristic, and a high electrical resistivity at high temperatures.

PXE 52

A material with a higher permittivity and a higher charge constant than PXE 5. Due to its lower Curie point it also has a lower temperature stability. The material is suitable for sensitive detection, tone generation and for fine movement control applications.

PXE 59

A material with a slightly lower permittivity and charge constant than PXE 5. Due to its high Curie temperature it has a high temperature stability and a higher stress stability than PXE 5.

PXE 21

A grade which has been developed for ignition purposes. It has a high voltage constant which ensures a high voltage output. This material is suitable for impact mechanisms used for the ignition of gases and explosives.

PXE 41

A low-loss material for medium power applications. In particular, the high mechanical quality factor and low loss factor (even at intensive drive) make PXE 41 suitable for high power ultrasound applications at medium range temperatures and pre-stresses. Furthermore, PXE 41 can be exposed to high repetitive quasi-static loads and dynamic loads for ignition purposes.

PXE 42

A low loss material for high power applications. Its low dielectric loss and high mechanical quality factor, combined with a tolerance of high temperature and mechanical stress, make it particularly suitable for the generation of ultrasonic power. It is the recommended material for ultrasonic cleaning.

PXE 43

A low loss material for high power applications. Its low dielectric loss and high mechanical quality factor, combined with very good behaviour at high electric fields and increased temperatures, make it suitable for ultrasonic welding.

PXE 71

A grade with moderate permittivity and high temperature stability as well as a high shear coupling coefficient. Ageing of the permittivity of this material, and hence phase distortion of the electrical resonance circuit, is extremely low; it is therefore suitable for HF shear resonance applications where phase is important, e.g. in ultrasonic delay lines for colour television receivers.

Piezoelectric Ceramics

Material grades

SURVEY OF GRADES

The following grades, consisting of modified lead zirconate titanates, are distinguished according to their electrical and mechanical properties and field of application.

Table 1 gives typical values measured on discs
 $\varnothing 16 \times 1$ mm at 21 ± 1 °C, 24 hours after poling.

The properties of components manufactured with these grades depend upon the dimensions of the product, the method of manufacture and on the applied voltage level. Therefore, a meaningful interpretation of the properties of the material is best made in consultation with the supplier.

Table 1 Typical values

PROPERTY AND SYMBOL	PXE 5	PXE 52	PXE 59	PXE 21	PXE 41	PXE 42	PXE 43	PXE 71	UNIT
Thermal data									
Curie temperature	285	165	360	270	315	325	300	270	°C
Specific heat	420	420	420	420	420	420	420	420	J/kg K
Thermal conductivity	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	W/m K
Mechanical data									
Density ρ_m	7.8	7.8	7.9	7.8	7.9	7.8	7.8	7.8	10^3 kg/m ³
Compliance									
S_{33}^E	18	20	18	19	15	15	13	—	10^{-12} /Pa
S_{11}^E	15	16	16	15	12	13	11	15	10^{-12} /Pa
S_{55}^E	39	—	45	—	37	—	—	38	10^{-12} /Pa
Poisson's ratio σ	0.3	0.3	0.35	0.3	0.3	0.3	0.3	0.3	
Mechanical quality factor for radial mode Q_m^E	75	65	80	75	1200	750	1000	80	
Frequency constants									
N_P^E	1975	1925	1970	2000	2175	2200	2350	2100	Hz m or m/s
$N_3^D = 1/2v_3^D$	1850	1800	2060	1900	2000	2015	2050	—	Hz m or m/s
$N_1^E = 1/2v_1^E$	1450	1400	1400	—	1620	—	—	1500	Hz m or m/s
$N_5^E = 1/2v_5^E$	930	—	900	—	950	—	—	920	Hz m or m/s
Compressive strength	>600	>600	>600	>600	>600	>600	>600	>600	10^6 Pa
Tensile strength	80	80	100	80	80	80	80	80	10^6 Pa

Piezoelectric Ceramics

Material grades

PROPERTY AND SYMBOL	PXE 5	PXE 52	PXE 59	PXE 21	PXE 41	PXE 42	PXE 43	PXE 71	UNIT
Electrical data									
Relative permittivity ($\epsilon_0 = 8.85 \times 10^{-12}$ F/m)									
$\epsilon_{33}^T \epsilon_0$	2100	3900	1850	2000	1225	1325	1000	1100	
$\epsilon_{11}^T \epsilon_0$	1800	3300	1650	—	1400	—	—	1700	
Resistivity ρ	5	1	5	5	1	1	1	5	10^{10} Ω m
Time constant $\rho \epsilon_{33}^T$ (25 °C)	>300	>500	>100	>25	>7	—	—	>250	minute
Dielectric loss factor $\tan \delta$	20	16	17	15	2.5	3.5	2	29	10^{-3}
Electro-mechanical data									
Coupling factor									
k_p	0.68	0.70	0.66	0.64	0.64	0.61	0.53	0.63	
k_{33}	0.75	0.80	0.71	0.74	0.74	0.70	0.66	0.73	
k_{31}	0.38	0.39	0.37	0.37	0.38	0.34	0.30	0.37	
k_{15}	0.66	—	0.68	—	0.70	—	—	0.68	
Piezoelectric charge constants									
d_{33}	500	700	460	450	325	315	230	340	10^{-12} C/N or m/V
d_{31}	−215	−280	−195	−200	−150	−130	−100	−150	10^{-12} C/N or m/V
d_{15}	515	—	550	—	480	—	—	500	10^{-12} C/N or m/V
Piezoelectric voltage constants									
g_{33}	24	20	28	25	30	27	27	30	10^{-3} Vm/N or m ² /C
g_{31}	−10	−10	−13	−12	−12	−11	−11	−10	10^{-3} Vm/N or m ² /C
g_{15}	33	—	37	—	39	—	—	33	10^{-3} Vm/N or m ² /C
Time stability (%)									
Coupling factor k_p	−0.5	−0.6	−0.1	−1.5	−1.5	−2.5	−2.0	−0.5	relative change per time decade (days)
Permittivity ϵ_{33}^T	−1.0	−1.0	−2.0	−2.0	1.0	−6.0	−4.5	−0.5	
Frequency constant N_P^E	0.5	0.3	+0.1	0.5	0.5	1.5	1.0	0.5	
Quality factor Q_m^E	—	−3.0	+0.1	—	10.0	—	—	—	
Dielectric loss factor $\tan \delta$	—	—	−0.1	—	−10	—	—	—	

Material grade specification

PXE 5

PXE 5 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	500	10^{-12} m/V
d_{31}	-215	10^{-12} m/V
g_{33}	24	10^{-3} Vm/N
g_{31}	-10	10^{-3} Vm/N
k_p	0.68	
$\frac{T}{\epsilon_{33}}$ ϵ_0	2100	
N_P^E	1975	Hzm
S_{33}^E	18	10^{-12} /Pa
T_C	285	$^{\circ}\text{C}$

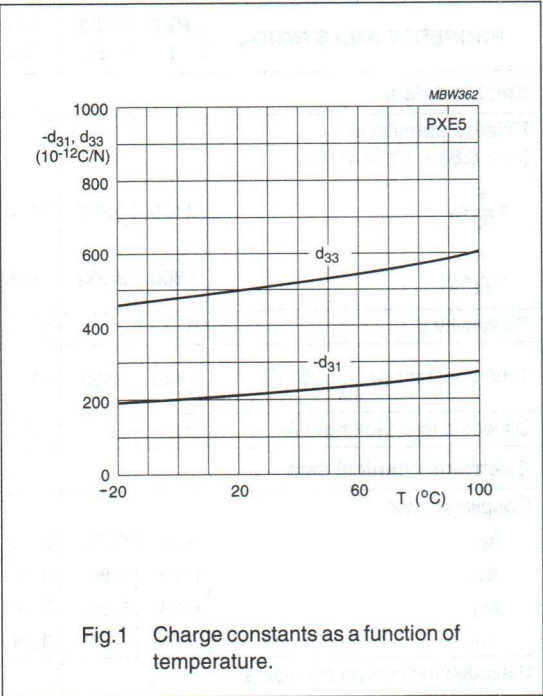


Fig.1 Charge constants as a function of temperature.

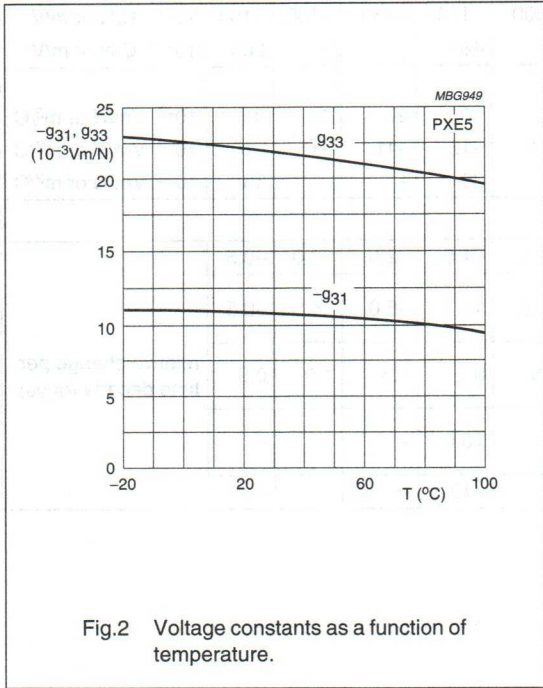


Fig.2 Voltage constants as a function of temperature.

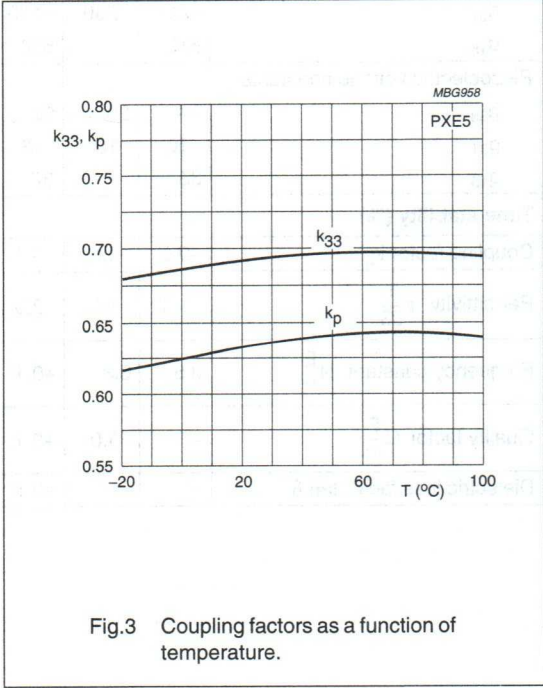


Fig.3 Coupling factors as a function of temperature.

Material grade specification

PXE 5

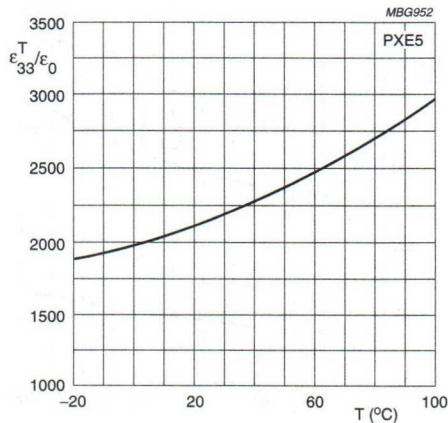


Fig.4 Dielectric constant as a function of temperature.

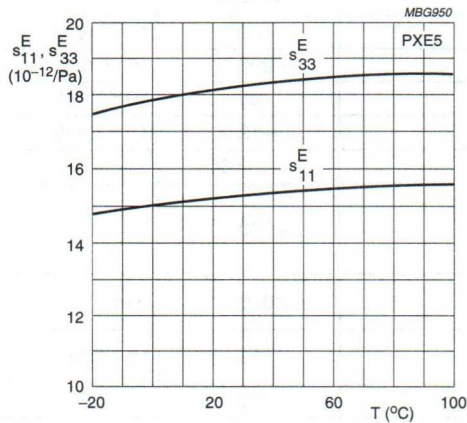


Fig.5 Compliances as a function of temperature.

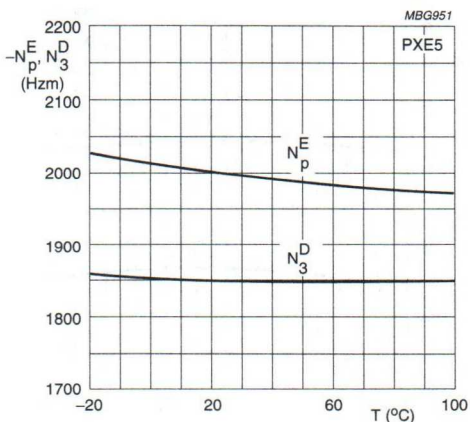


Fig.6 Frequency constants as a function of temperature.

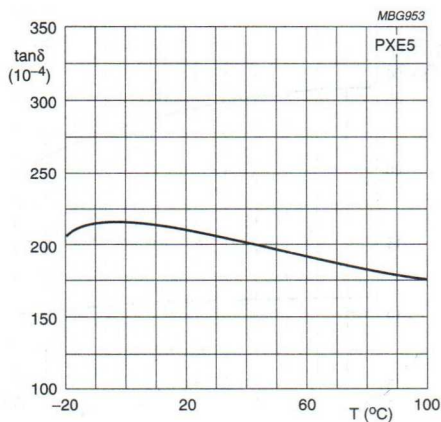


Fig.7 Dielectric loss factor as a function of temperature.

Material grade specification

PXE 21

PXE 21 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	450	10^{-12} m/V
d_{31}	-200	10^{-12} m/V
g_{33}	25	10^{-3} Vm/N
g_{31}	-12	10^{-3} Vm/N
k_p	0.64	
$\frac{\epsilon_{33}^T}{\epsilon_0}$	2000	
N_P^E	2000	Hzm
S_{33}^E	19	10^{-12} /Pa
T_C	270	$^{\circ}\text{C}$

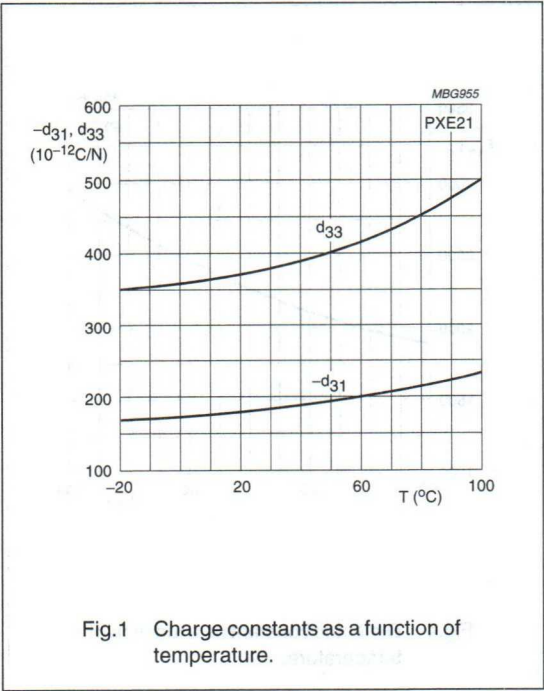


Fig.1 Charge constants as a function of temperature.

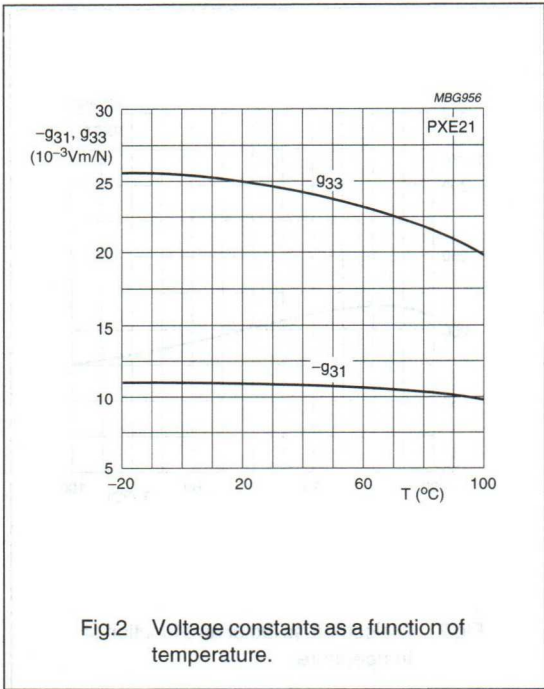


Fig.2 Voltage constants as a function of temperature.

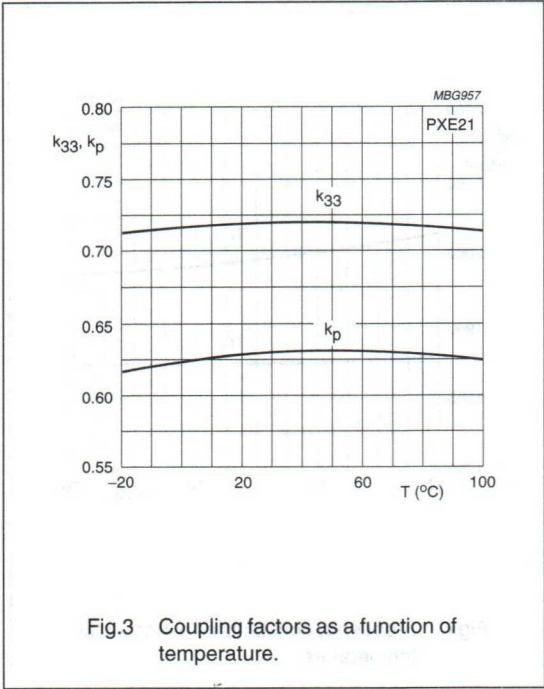


Fig.3 Coupling factors as a function of temperature.

Material grade specification

PXE 21

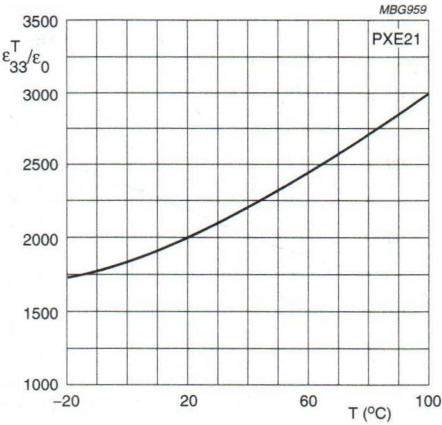


Fig.4 Dielectric constant as a function of temperature.

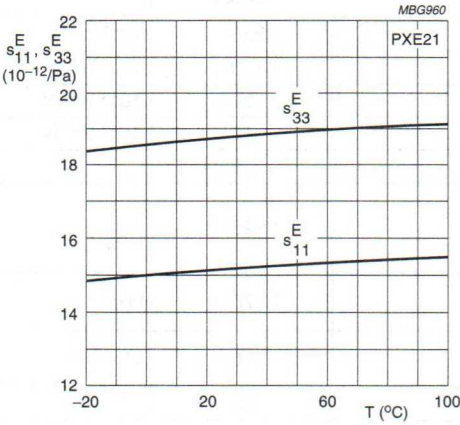


Fig.5 Compliances as a function of temperature.

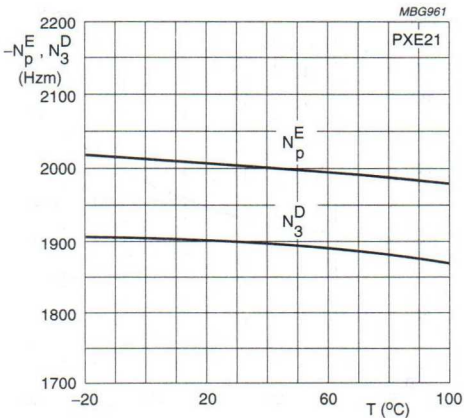


Fig.6 Frequency constants as a function of temperature.

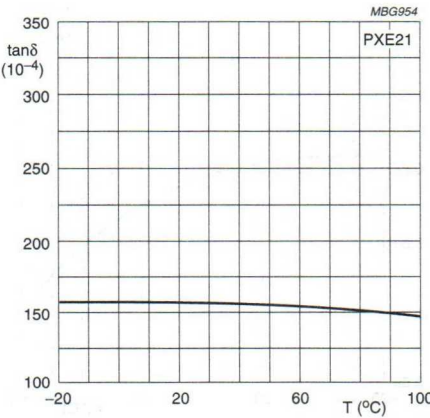


Fig.7 Dielectric loss factor as a function of temperature.

Material grade specification

PXE 41 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	325	10^{-12} m/V
d_{31}	-150	10^{-12} m/V
g_{33}	30	10^{-3} Vm/N
g_{31}	-12	10^{-3} Vm/N
k_p	0.64	
$\frac{\epsilon_{33}^T}{\epsilon_0}$	1225	
N_P^E	2175	H/m
S_{33}^E	15	10^{-12} /Pa
T_C	315	$^{\circ}\text{C}$

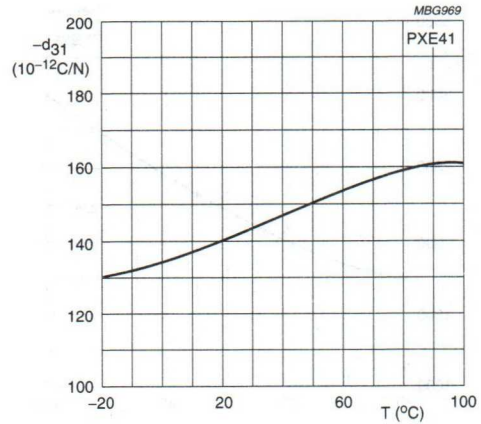


Fig.1 Charge constants as a function of temperature.

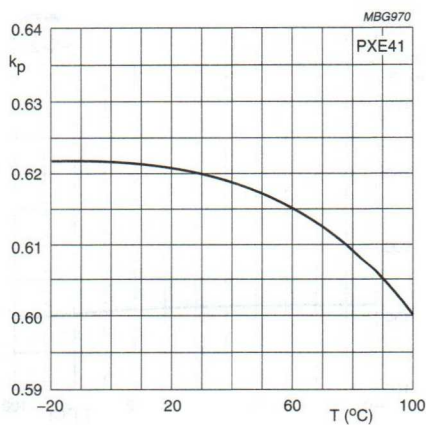


Fig.2 Coupling factors as a function of temperature.

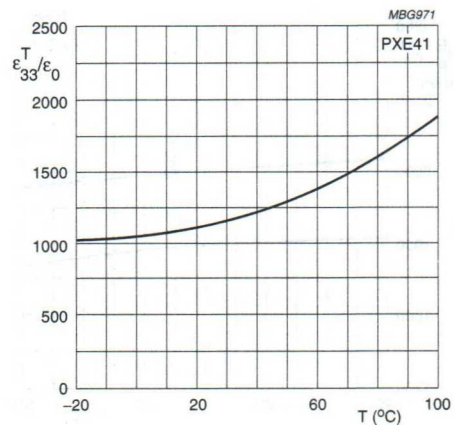


Fig.3 Dielectric constant as a function of temperature.

Material grade specification

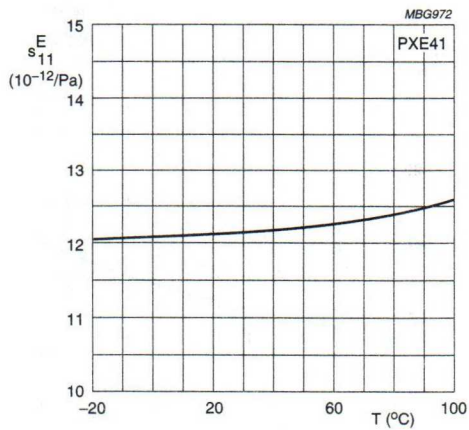


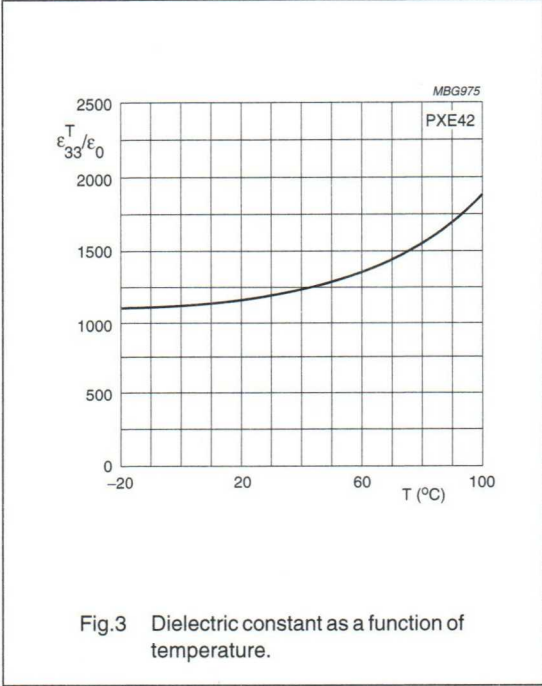
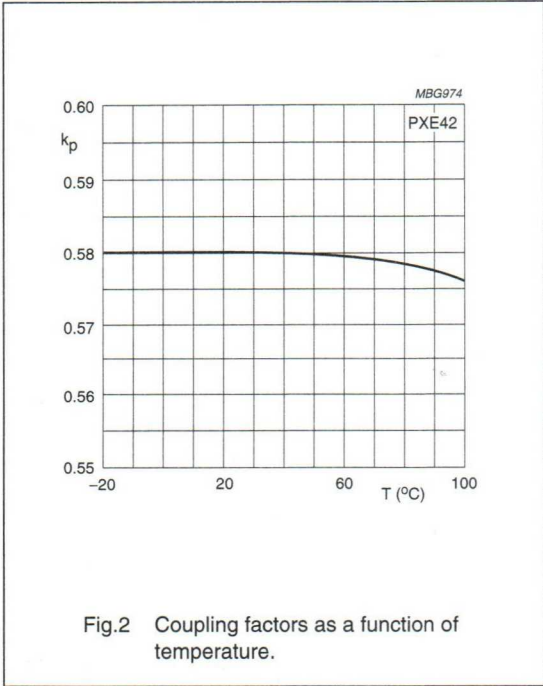
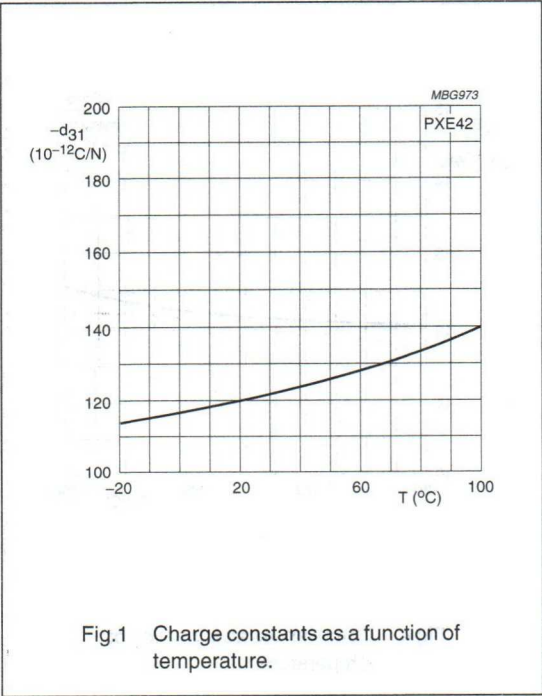
Fig.4 Compliances as a function of temperature.

Material grade specification

PXE 42

PXE 42 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	315	10^{-12} m/V
d_{31}	-130	10^{-12} m/V
g_{33}	27	10^{-3} Vm/N
g_{31}	-11	10^{-3} Vm/N
k_p	0.61	
$\frac{T}{\epsilon_0} \epsilon_{33}^E$	1325	
N_P^E	2200	Hzm
S_{33}^E	15	10^{-12} /Pa
T_C	325	$^{\circ}\text{C}$



Material grade specification

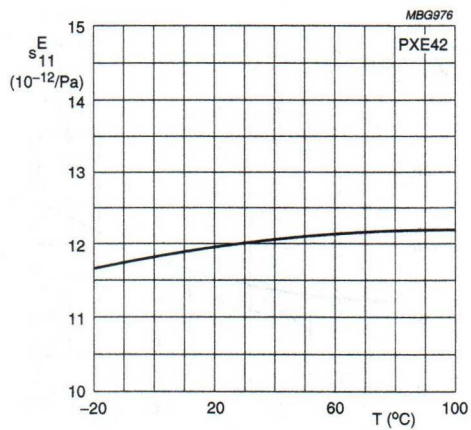


Fig.4 Compliances as a function of temperature.

Material grade specification

PXE 43

PXE 43 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	230	10^{-12} m/V
d_{31}	-100	10^{-12} m/V
g_{33}	27	10^{-3} Vm/N
g_{31}	-11	10^{-3} Vm/N
k_p	0.53	
$\frac{\epsilon_{33}^T}{\epsilon_0}$	950	
N_P^E	2350	Hzm
S_{33}^E	13	10^{-12} /Pa
T_C	300	$^{\circ}\text{C}$

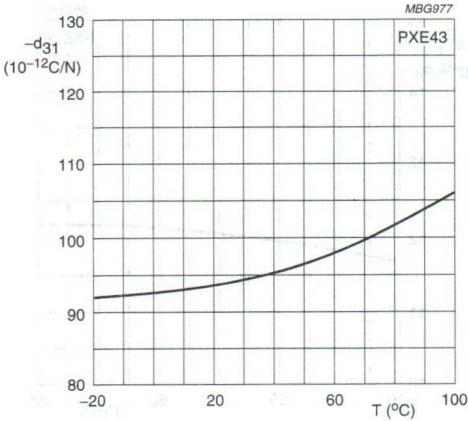


Fig.1 Charge constants as a function of temperature.

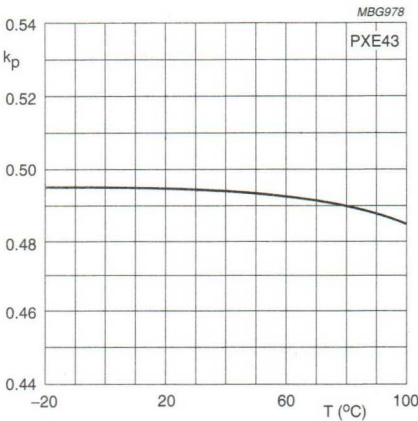


Fig.2 Coupling factors as a function of temperature.

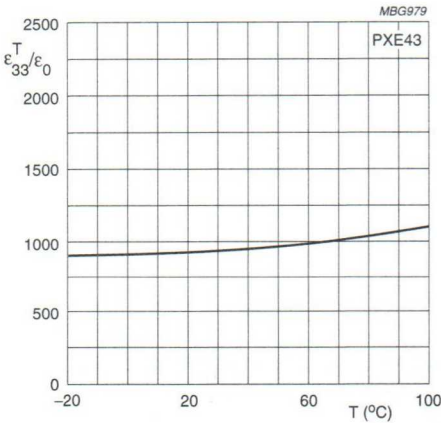
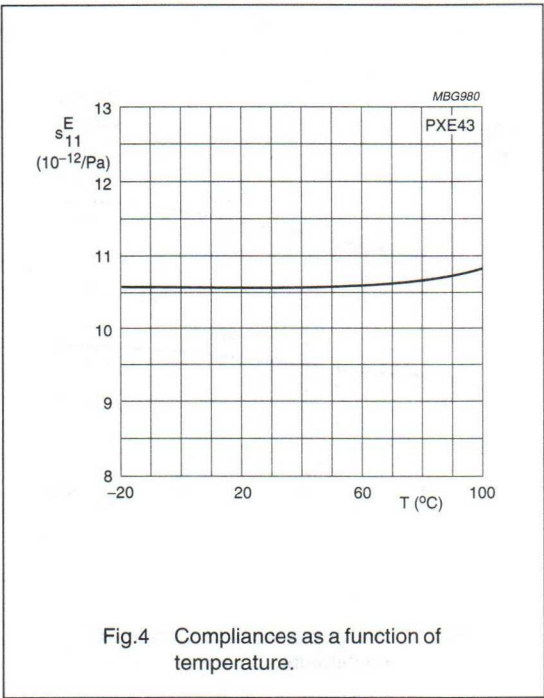


Fig.3 Dielectric constant as a function of temperature.

Material grade specification

PXE 43



Material grade specification

PXE 52 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	700	10^{-12} m/V
d_{31}	-280	10^{-12} m/V
g_{33}	20	10^{-3} Vm/N
g_{31}	-10	10^{-3} Vm/N
k_p	0.70	
$\frac{\epsilon_{33}^T}{\epsilon_0}$	3900	
N_P^E	1925	Hzm
S_{33}^E	20	10^{-12} /Pa
T_C	165	$^{\circ}\text{C}$

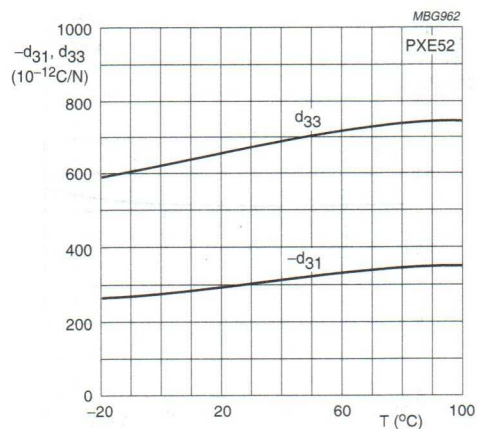


Fig.1 Charge constants as a function of temperature.

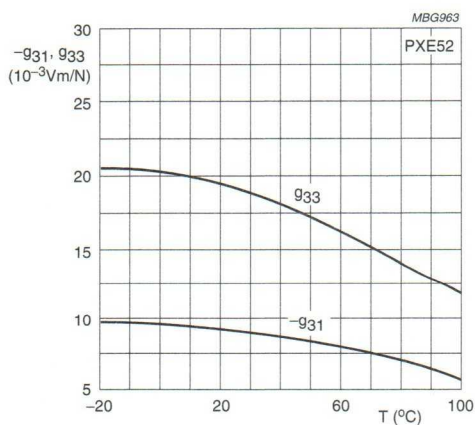


Fig.2 Voltage constants as a function of temperature.

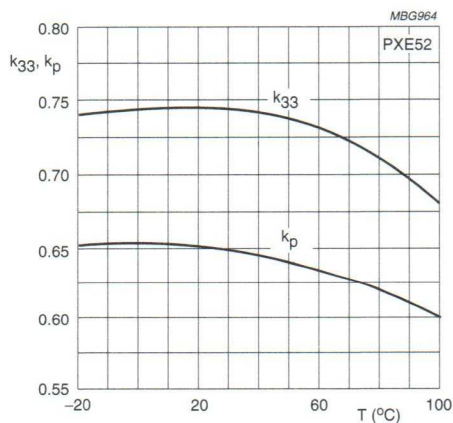


Fig.3 Coupling factors as a function of temperature.

Material grade specification

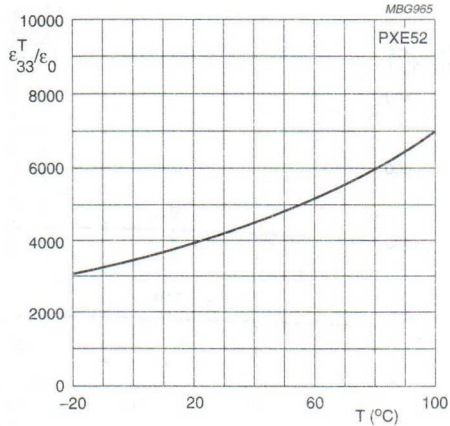


Fig. 4 Dielectric constant as a function of temperature.

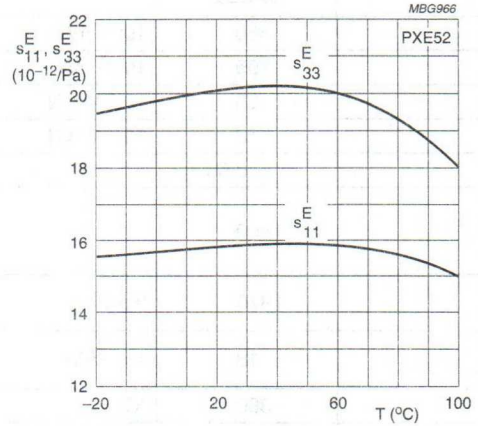


Fig. 5 Compliances as a function of temperature.

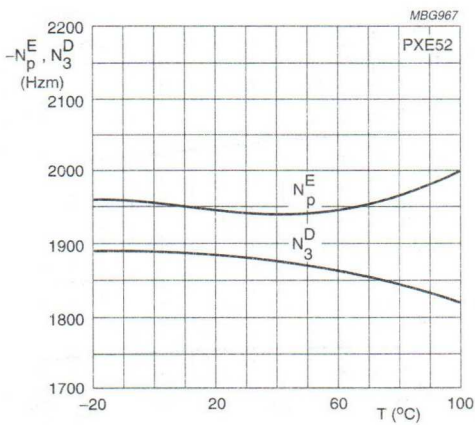


Fig. 6 Frequency constants as a function of temperature.

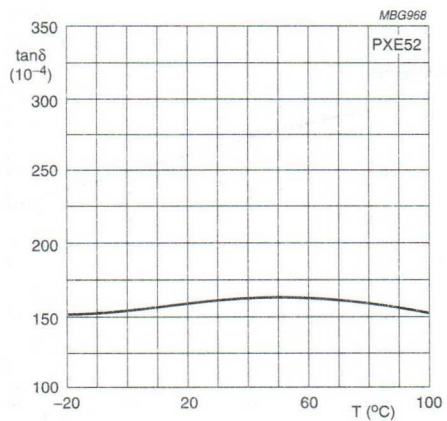


Fig. 7 Dielectric loss factor as a function of temperature.

Material grade specification

PXE 59

PXE 59 SPECIFICATIONS

SYMBOL	TYPICAL VALUE	UNIT
d_{33}	460	10^{-12} m/V
d_{31}	-195	10^{-12} m/V
g_{33}	28	10^{-3} Vm/N
g_{31}	-13	10^{-3} Vm/N
k_p	0.66	
$\frac{\epsilon_{33}^T}{\epsilon_0}$	1850	
N_P^E	1970	Hzm
S_{33}^E	18	10^{-12} /Pa
T_C	360	$^{\circ}\text{C}$

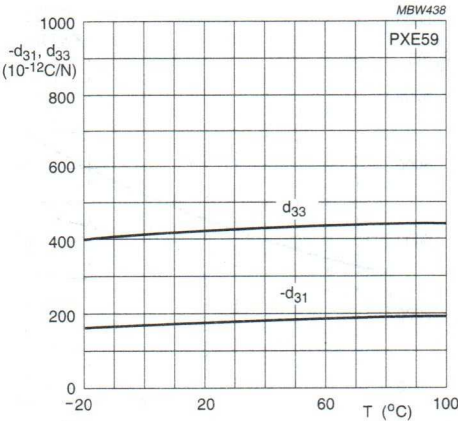


Fig.1 Charge constants as a function of temperature.

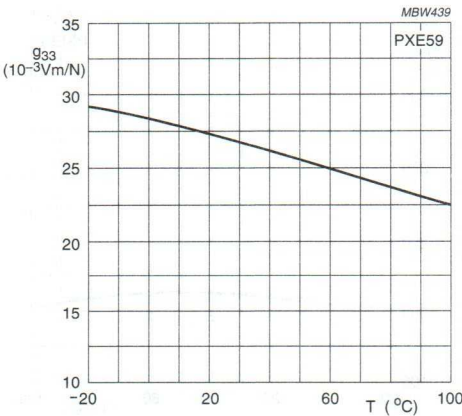


Fig.2 Voltage constants as a function of temperature.

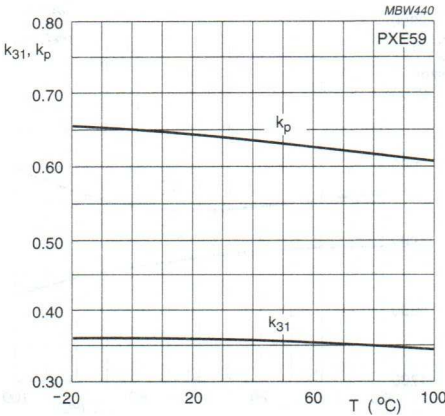


Fig.3 Coupling factors as a function of temperature.

Material grade specification

PXE 59

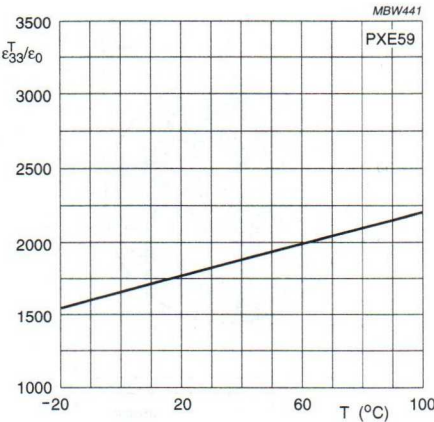


Fig.4 Dielectric constant as a function of temperature.

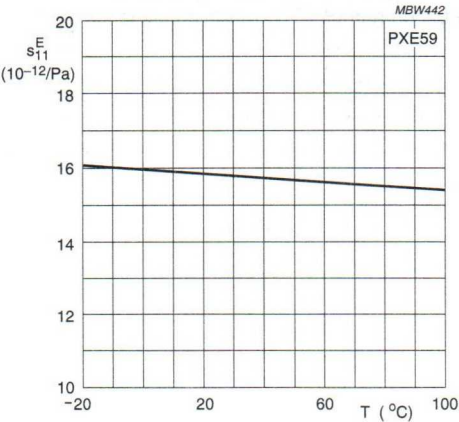


Fig.5 Compliances as a function of temperature.

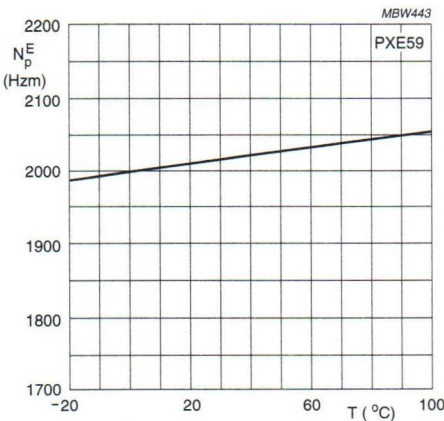


Fig.6 Frequency constants as a function of temperature.

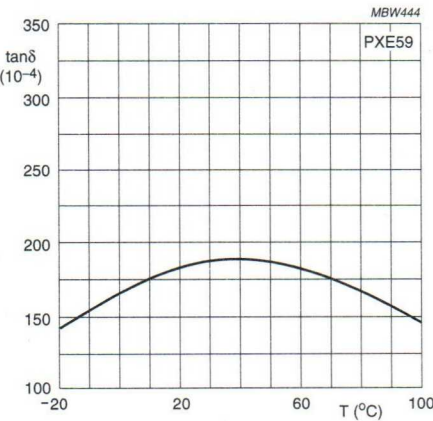


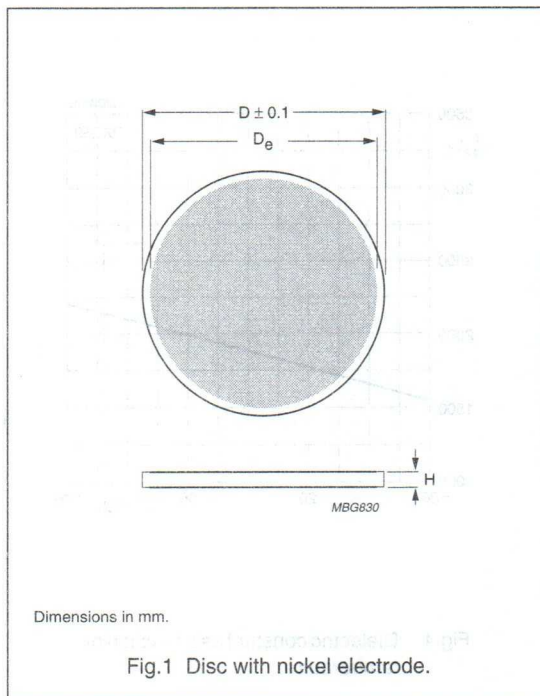
Fig.7 Dielectric loss factor as a function of temperature.

Product specifications

Discs

DISCS WITH NICKEL ELECTRODES

Our standard range of discs with nickel electrodes is available in grade PXE 5. Other grades and sizes are available on request. The positive pole is marked.



Product specifications

Discs

Disc data, nickel electrode; see Fig.1

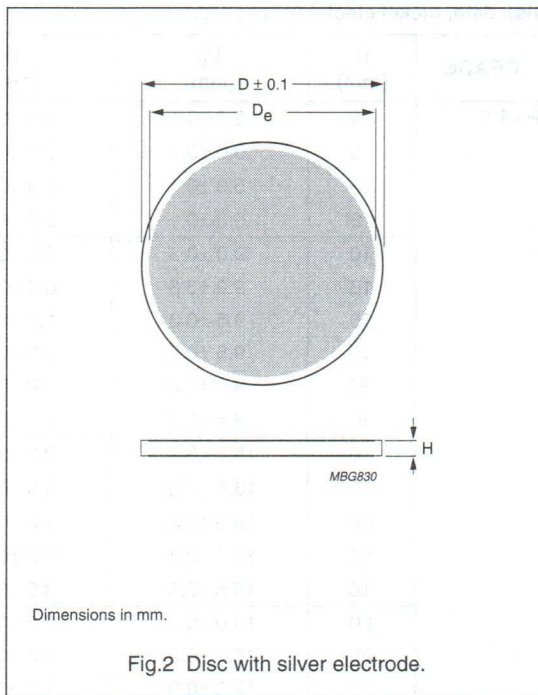
GRADE	D (mm)	D _e (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	5	5.0 ±0.1	0.3 ±0.03	1220 ±25%	DSC5/0.3-PX5-N
	5	5.0 ±0.1	0.5 ±0.03	750 ±25%	DSC5/0.5-PX5-N
	5	5.0 ±0.1	1.0 ±0.03	375 ±25%	DSC5/1-PX5-N
	5	5.0 ±0.1	2.0 ±0.1	185 ±25%	DSC5/2-PX5-N
	10	9.0 ±0.3	0.2 ±0.03	5900 ±25%	DSC10/0.2-PX5-N
	10	9.0 ±0.3	0.5 ±0.03	2360 ±25%	DSC10/0.5-PX5-N
	10	9.5 ±0.3	1.0 ±0.03	1390 ±25%	DSC10/1-PX5-N
	10	9.5 ±0.3	2.0 ±0.1	700 ±25%	DSC10/2-PX5-N
	10	9.5 ±0.3	3.0 ±0.1	460 ±25%	DSC10/3-PX5-N
	10	9.5 ±0.3	5.0 ±0.1	280 ±25%	DSC10/5-PX5-N
	16	15.0 ±0.3	0.2 ±0.03	17000 ±25%	DSC16/0.2-PX5-N
	16	15.5 ±0.3	0.5 ±0.03	6800 ±25%	DSC16/0.5-PX5-N
	16	15.5 ±0.3	1.0 ±0.03	3620 ±25%	DSC16/1-PX5-N
	16	15.5 ±0.3	2.0 ±0.1	1800 ±25%	DSC16/2-PX5-N
	16	15.5 ±0.3	3.0 ±0.1	1200 ±25%	DSC16/3-PX5-N
	20	19.0 ±0.3	0.2 ±0.03	27000 ±25%	DSC20/0.2-PX5-N
	20	19.5 ±0.3	0.5 ±0.03	10800 ±25%	DSC20/0.5-PX5-N
	20	19.5 ±0.3	1.0 ±0.03	5700 ±25%	DSC20/1-PX5-N
	20	19.5 ±0.3	2.0 ±0.1	2850 ±25%	DSC20/2-PX5-N
	25	24.0 ±0.3	0.2 ±0.03	42925 ±25%	DSC25/0.2-PX5-N
	25	24.5 ±0.3	0.5 ±0.03	17200 ±25%	DSC25/0.5-PX5-N
	25	24.5 ±0.3	1.0 ±0.03	9000 ±25%	DSC25/1-PX5-N
	25	24.5 ±0.3	2.0 ±0.1	4500 ±25%	DSC25/2-PX5-N

Product specifications

Discs

DISCS WITH SILVER ELECTRODES

Our standard range of discs with silver electrodes is available in grade PXE 5, PXE 41 and PXE 42. Other grades and sizes are available on request. The positive pole is marked.



Product specifications

Discs

Disc data, silver electrode; see Fig.2

GRADE	D (mm)	D _e (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	5	=D	0.3 ±0.03	1220 ±25%	DSC5/0.3-PX5-S
	5	=D	0.5 ±0.03	750 ±25%	DSC5/0.5-PX5-S
	5	=D	1.0 ±0.03	375 ±25%	DSC5/1-PX5-S
	5	=D	2.0 ±0.1	185 ±25%	DSC5/2-PX5-S
	10	9 ±0.3	0.5 ±0.03	2360 ±25%	DSC10/0.5-PX5-S
	10	=D	1.0 ±0.03	1460 ±25%	DSC10/1.0-PX5-S
	10	=D	2.0 ±0.1	730 ±25%	DSC10/2-PX5-S
	10	=D	3.0 ±0.1	490 ±25%	DSC10/3-PX5-S
	10	=D	5.0 ±0.1	290 ±25%	DSC10/5-PX5-S
	16	15 ±0.3	0.5 ±0.03	6800 ±25%	DSC16/0.5-PX5-S
	16	=D	1.0 ±0.03	3735 ±25%	DSC16/1-PX5-S
	25	24 ±0.3	0.5 ±0.03	17200 ±25%	DSC25/0.5-PX5-S
	25	=D	1.0 ±0.03	9125 ±25%	DSC25/1-PX5-S
	25	=D	2.0 ±0.1	4560 ±25%	DSC25/2-PX5-S
PXE 41	31.75 ±0.5	—	≈14.3; note 1	650 ±25%	DSC32/14-PX41-S-T
	25.4 ±0.5	—	≈10.2; note 2	550 ±25%	DSC25/10-PX41-S-T
PXE 42	25.0 ±0.1	—	1 ±0.1	5750 ±25%	DSC25/1-PX42-S
	25.0 ±0.1	—	2 ±0.1	2870 ±25%	DSC25/2-PX42-S
	38.0 ±0.5	—	3 ±0.1	4430 ±25%	DSC38/3-PX42-S
	38.0 ±0.5	—	6 ±0.1	2215 ±25%	DSC38/3-PX42-S
	50.0 ±1.0	—	3 ±0.1	7670 ±25%	DSC50/3-PX42-S
	50.0 ±1.0	—	6 ±0.1	3835 ±25%	DSC50/6-PX42-S

Notes

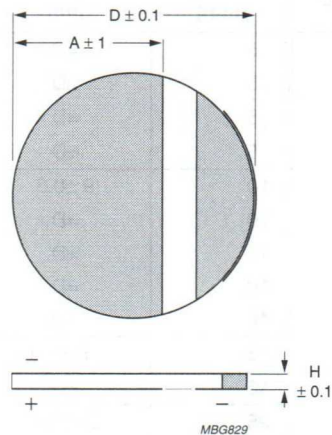
1. Tuned for 151 kHz.
2. Tuned for 200 kHz.

Product specifications

Discs

DISCS WITH WRAP-AROUND ELECTRODES

These discs have provision for connecting both electrodes from one side by means of a wrap-around electrode as shown. They are therefore particularly suitable for bonding to flat substrates where electrical connection to both sides is difficult. The material is PXE 5, but other grades and sizes are available on request.



Dimensions in mm.

Fig.3 Disc with wrap-around electrode.

Disc data, wrap-around electrode; see Fig.3

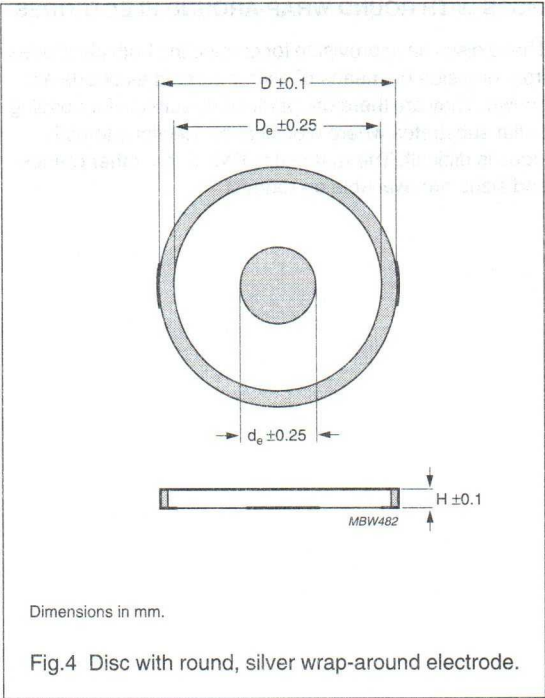
GRADE	D (mm)	A (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	10	6.5	1	1000 ±25%	DSC10/1/WL-PX5-S
	16	10	1	2600 ±25%	DSC16/1/WL-PX5-S

Product specifications

Discs

DISCS WITH ROUND WRAP-AROUND ELECTRODES

These discs have provision for connecting both electrodes from one side by means of a wrap-around electrode as shown. They are therefore particularly suitable for bonding to flat substrates where electrical connections to both sides is difficult. The material is PXE 42, but other grades and sizes are available on request



Disc data, round silver wrap-around electrode; see Fig.4

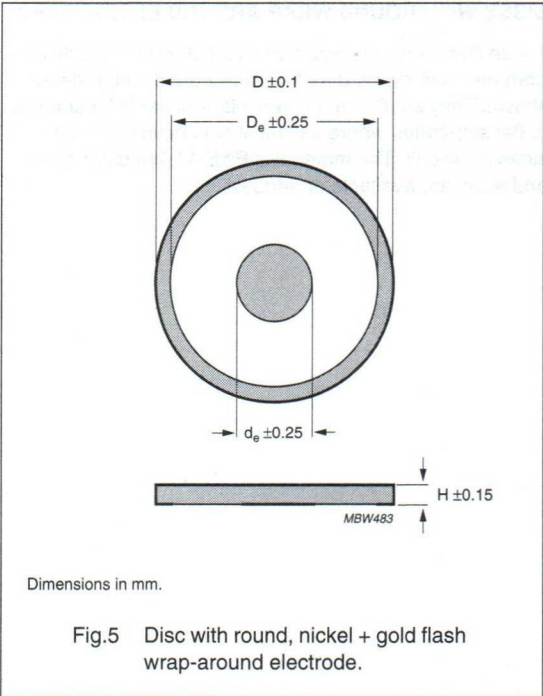
GRADE	D (mm)	D _e (mm)	d _e (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 42	20	17	7	0.85	730 ±20%	DSC20/0.9/WR-PX42-S
	20	17	7	1.2	520 ±20%	DSC20/1.2/WR-PX42-S

Product specifications

Discs

DISCS WITH ROUND WRAP-AROUND ELECTRODES

These discs have provision for connecting both electrodes from one side by means of a wrap around electrode as shown. They are therefore particularly suitable for bonding to flat substrates where electrical connections to both sides is difficult. The material is PXE 5, but other grades and sizes are available on request



Disc data, round nickel + gold flash wrap-around electrode; see Fig.5

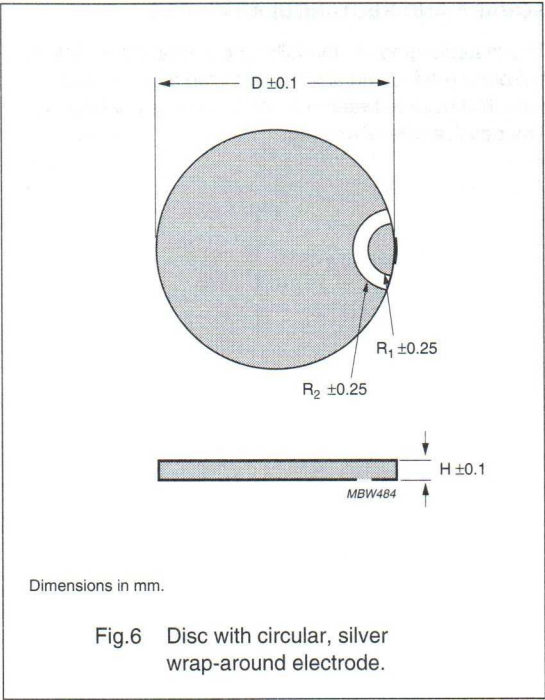
GRADE	D (mm)	D _e (mm)	d _e (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	16	14	7	2	490 ±20%	DSC16/2/WR-PX5-NG
	25	23	8	2	640 ±20%	DSC25/2/WR-PX5-NG
	25.4	23	8	2	640 ±20%	DSC25.4/2/WR-PX5-NG

Product specifications

Discs

DISCS WITH CIRCULAR WRAP-AROUND ELECTRODES

These discs have provision for connecting both electrodes from one side by means of a wrap around electrode as shown. They are therefore particularly suitable for bonding to flat substrates where electrical connections to both sides is difficult. The material is PXE 5, but other grades and sizes are available on request



Disc data, circular silver wrap-around electrode; see Fig.6

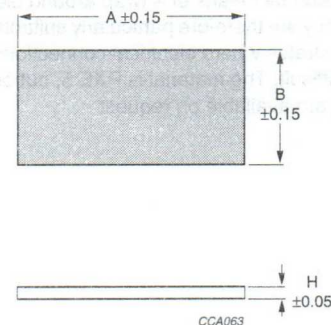
GRADE	D (mm)	D _e (mm)	d _e (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	16	2.5	3.5	1	3350 ±25%	DSC16/1/WC-PX5-S
	20	3	4	1	5230 ±25%	DSC20/1/WC-PX5-S
	25	3	4	1	8200 ±25%	DSC25/1/WC-PX5-S

Product specifications

Plates

SQUARE AND RECTANGULAR PLATES

The material grade in the following two tables is PXE 5, but other grades and sizes are available on request (any thickness between 0.2 and 3.0 mm is possible). The positive pole is marked.



Dimensions in mm.

Fig.1 Plate.

Plate data, nickel electrode; see Fig.1

GRADE	A (mm)	B (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	4	4	0.3	990 $\pm 20\%$	PLT4/4/0.3-PX5-N
	8	4	0.3	1980 $\pm 20\%$	PLT8/4/0.3-PX5-N
	12	4	0.3	2970 $\pm 20\%$	PLT12/4/0.3-PX5-N
	6	6	0.3	2230 $\pm 20\%$	PLT6/6/0.3-PX5-N
	12	6	0.3	4460 $\pm 20\%$	PLT12/6/0.3-PX5-N
	8	8	0.3	3960 $\pm 20\%$	PLT8/8/0.3-PX5-N
	10	10	0.3	6200 $\pm 20\%$	PLT10/10/0.3-PX5-N
	12	12	0.3	8920 $\pm 20\%$	PLT12/12/0.3-PX5-N
	12	6	0.5	2670 $\pm 20\%$	PLT12/6/0.5-PX5-N
	12	6	1.0	1340 $\pm 20\%$	PLT12/6/1.0-PX5-N

Plate data, silver electrode; see Fig.1

GRADE	A (mm)	B (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	16	12	1	3500 $\pm 20\%$	PLT16/12/1-PX5-S
	12	6	0.5	2670 $\pm 20\%$	PLT12/6/0.5-PX5-S
	12	6	1	1340 $\pm 20\%$	PLT12/6/1-PX5-S
	12	6	1.25	1070 $\pm 20\%$	PLT12/6/1.3-PX5-S

Product specifications

Product Specifications Plates

PLATES WITH WRAP-AROUND ELECTRODES

These plates have provision for connecting both electrodes from one side by means of a wrap-around electrode as shown. They are therefore particularly suitable for bonding to flat substrates where electrical connection to both sides is difficult. The material is PXE 5, but other grades and sizes are available on request.

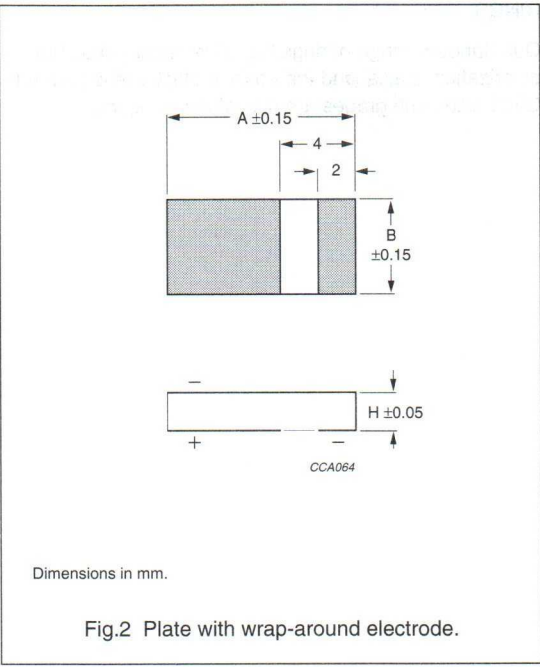


Plate data, silver electrode; see Fig.2

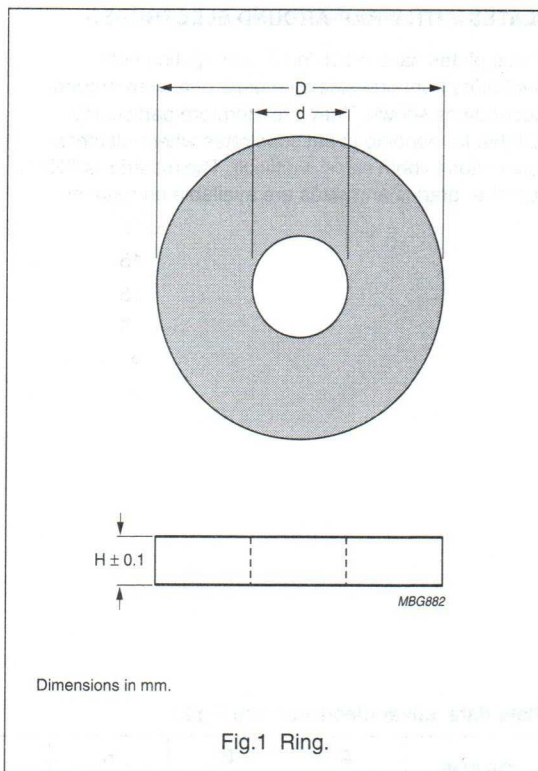
GRADE	A (mm)	B (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	10	4	1	480 ±25%	PLT10/4/1/W-PX5-S
	10	4	2	240 ±25%	PLT10/4/2/W-PX5-S
	10	5	1	600 ±25%	PLT10/5/1/W-PX5-S
	10	5	2	300 ±25%	PLT10/5/2/W-PX5-S
	15	5	2	550 ±25%	PLT15/5/2/W-PX5-S

Product specifications

MBG882 Rings

RINGS

Our standard range of rings has silver electrodes. The polarization is axial and the positive electrode is marked. Other sizes and grades are available on request.



Product specifications

Rings

Ring data, silver electrode; see Fig.1

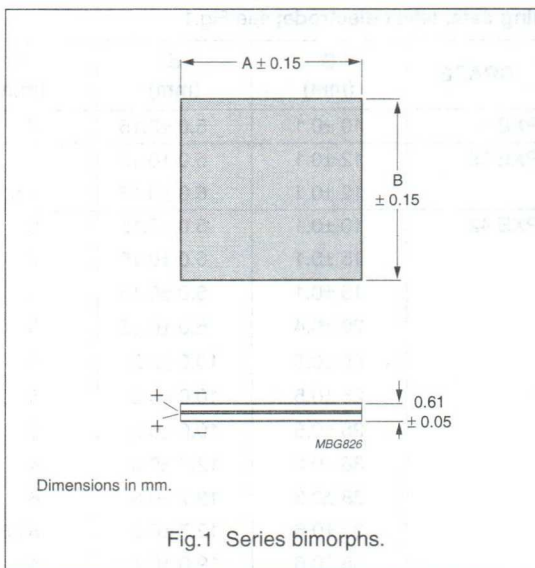
GRADE	D (mm)	d (mm)	H (mm)	CAPACITANCE (pF)	TYPE NUMBER
PXE 5	10 ±0.1	5.0 ±0.15	2	550 ±25%	RNG10/5/2-PX5-S
PXE 59	12 ±0.1	6.0 ±0.15	1	1200 ±25%	RNG12/6/1-PX59-S
	12 ±0.1	6.0 ±0.15	1.5	865 ±25%	RNG12/6/1.5-PX59-S
PXE 42	10 ±0.1	5.0 ±0.15	2	340 ±25%	RNG10/5/2-PX42-S
	15 ±0.1	6.0 ±0.15	3	580 ±25%	RNG15/6/3-PX42-S
	15 ±0.1	8.0 ±0.15	2	740 ±25%	RNG15/8/2-PX42-S
	20 ±0.4	6.0 ±0.15	5	670 ±25%	RNG20/6/5-PX42-S
	25 ±0.5	10.0 ±0.2	4	1200 ±25%	RNG25/10/4-PX42-S
	25 ±0.5	10.0 ±0.2	5	965 ±25%	RNG25/10/5-PX42-S
	25 ±0.5	10.0 ±0.2	6	800 ±25%	RNG25/10/6-PX42-S
	38 ±0.6	12.7 ±0.3	4	2950 ±25%	RNG38/13/4-PX42-S
	38 ±0.6	12.7 ±0.3	6	1970 ±25%	RNG38/13/6-PX42-S
	38 ±0.6	12.7 ±0.3	6.35	1870 ±25%	RNG38/13/6-PX42-S
	38 ±0.6	19.0 ±0.4	4	2490 ±25%	RNG38/19/4-PX42-S
	38 ±0.6	19.0 ±0.4	6.35	1570 ±25%	RNG38/19/6-PX42-S
	50 ±1.0	20.0 ±0.4	5	3865 ±25%	RNG50/20/5-PX42-S
	50 ±1.0	20.0 ±0.4	6	3220 ±25%	RNG50/20/6-PX42-S
	50 ±1.0	20.0 ±0.4	6.35	3040 ±25%	RNG50/20/6.4-PX42-S
PXE 43	10 ±0.1	5.0 ±0.15	2	260 ±25%	RNG10/5/2-PX43-S
	15 ±0.1	8.0 ±0.15	2	530 ±25%	RNG15/8/2-PX43-S
	20 ±0.4	6.0 ±0.15	5	500 ±25%	RNG20/6/5-PX43-S
	25 ±0.5	10.0 ±0.2	4	910 ±25%	RNG25/10/4-PX43-S
	25 ±0.5	10.0 ±0.2	5	730 ±25%	RNG25/10/5-PX43-S
	25 ±0.5	10.0 ±0.2	6	610 ±25%	RNG25/10/6-PX43-S
	38 ±0.6	12.7 ±0.3	4	2220 ±25%	RNG38/13/4-PX43-S
	38 ±0.6	12.7 ±0.3	6	1480 ±25%	RNG38/13/6-PX43-S
	38 ±0.6	12.7 ±0.3	6.35	1400 ±25%	RNG38/13/6.4-PX43-S
	50 ±1.0	20.0 ±0.5	5	2910 ±25%	RNG50/20/5-PX43-S
	50 ±1.0	20.0 ±0.5	6	2425 ±25%	RNG50/20/6-PX43-S

Product specifications

Series bimorphs

SERIES BIMORPH ELEMENTS

A range of square and rectangular bimorphs in grade PXE 5 for use in record players, accelerometers, detection systems in machinery, medical equipment and air transducers. The electrodes are nickel-plated. Series bimorphs are not recommended for use as actuators.



Bimorph data, nickel electrode; see Fig.1

A (mm) (note 1)	B (mm) (note 1)	CAPACITANCE (pF)	TYPE NUMBER
4.0	4.0	420 $\pm 20\%$	BIMS4/4/0.6-PX5-N
6.0	4.0	630 $\pm 20\%$	BIMS6/4/0.6-PX5-N
8.0	4.0	840 $\pm 20\%$	BIMS8/4/0.6-PX5-N
10.0	4.0	1050 $\pm 20\%$	BIMS10/4/0.6-PX5-N
12.0	4.0	1250 $\pm 20\%$	BIMS12/4/0.6-PX5-N
6.0	6.0	950 $\pm 20\%$	BIMS6s/6/0.6-PX5-N
8.0	6.0	1250 $\pm 20\%$	BIMS8/6/0.6-PX5-N
10.0	6.0	1600 $\pm 20\%$	BIMS10/6/0.6-PX5-N
12.0	6.0	1900 $\pm 20\%$	BIMS12/6/0.6-PX5-N
8.0	8.0	1700 $\pm 20\%$	BIMS8/8/0.6-PX5-N
10.0	8.0	2100 $\pm 20\%$	BIMS10/8/0.6-PX5-N
12.0	8.0	2550 $\pm 20\%$	BIMS12/8/0.6-PX5-N
10.0	10.0	2650 $\pm 20\%$	BIMS10/10/0.6-PX5-N
12.0	10.0	3150 $\pm 20\%$	BIMS12/10/0.6-PX5-N
12.0	12.0	3800 $\pm 20\%$	BIMS12/12/0.6-PX5-N
12.7	1.6	535 $\pm 20\%$	BIMS13/1.6/0.6-PX5-N
15.5	1.6	650 $\pm 20\%$	BIMS16/1.6/0.6-PX5-N
70.0	1.6	3000 $\pm 20\%$	BIMS70/1.6/0.6-PX5-N

Note

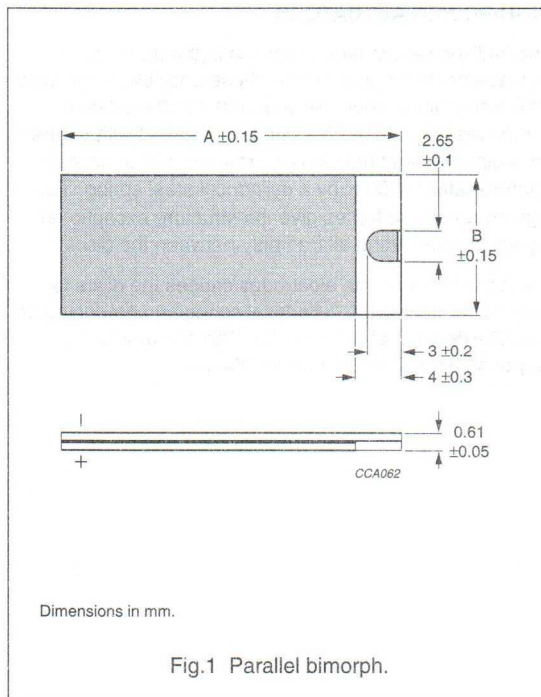
- Other sizes are available on request.

Product specifications

Parallel bimorphs

PARALLEL BIMORPH ELEMENTS

A range of rectangular parallel bimorph elements in grade PXE 5. The electrodes are nickel-plated and the inner electrode is accessible through a small cut-out in the upper plate. Parallel bimorphs are especially recommended for use as actuators.



Bimorph data, nickel electrode; see Fig.1

A (mm) (note 1)	B (mm) (note 1)	CAPACITANCE (pF) (note 2)	F _r MIN. (Hz)	DEFLECTION (μ m) (notes 3 and 4)	TYPE NUMBER
15	6	9000	2200	95 $\pm 20\%$	BIMP15/6/0.6-PX5-N
20	6	13000	1000	225 $\pm 20\%$	BIMP20/6/0.6-PX5-N
25	6	16500	500	400 $\pm 20\%$	BIMP25/6/0.6-PX5-N
30	6	20000	350	640 $\pm 20\%$	BIMP30/6/0.6-PX5-N
35	6	24000	240	935 $\pm 20\%$	BIMP35/6/0.6-PX5-N
15	12	18000	2200	95 $\pm 20\%$	BIMP15/12/0.6-PX5-N
20	12	25000	1000	225 $\pm 20\%$	BIMP20/12/0.6-PX5-N
25	12	33000	500	400 $\pm 20\%$	BIMP25/12/0.6-PX5-N
30	12	40000	350	640 $\pm 20\%$	BIMP30/12/0.6-PX5-N
35	12	48 000	240	935 $\pm 20\%$	BIMP35/12/0.6-PX5-N

Notes

- Other sizes are available on request.
- The capacitance between the central electrode and the interconnected outer electrodes.
- Deflection peak-to-peak at 300 V peak-to-peak (± 150 V) with free length is A – 5 mm.
- Bimorph not mechanically loaded.

Product specifications

High-power actuators

HIGH-POWER ACTUATORS

The high-power actuator produces in the 33 mode, displacements far greater than those possible with simple PXE transducers operating in the 31 or 33 modes. It comprises of a pile of PXE discs interleaved with copper foil electrodes and held in compression with a force of approximately 1000 N by a cylindrical steel spring. The high compressive forces give the structure exceptional rigidity by eliminating all free play between the discs.

A voltage between the electrodes causes the discs to expand, stretching the cylindrical spring and producing an overall extension of the actuator. The actuator has a response time of approximately 200 μ s.

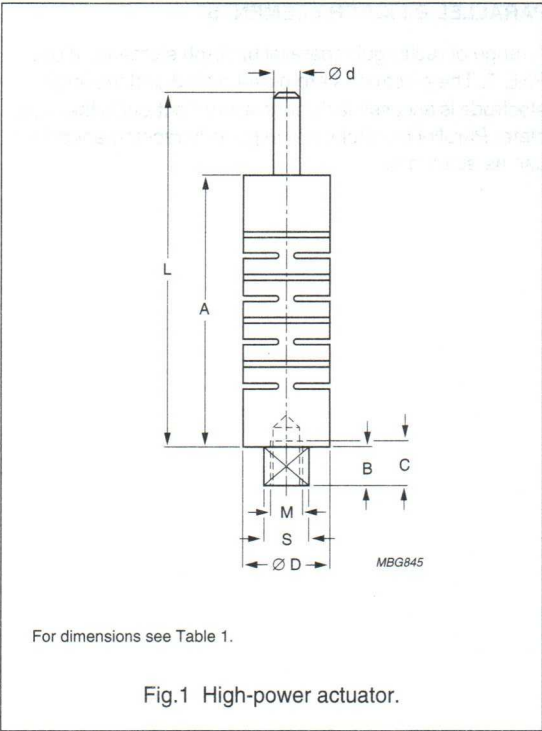


Table 1 Ordering codes and relevant physical dimensions; see Fig.1

PARAMETER	ORDERING CODE			UNIT
	HPA 16/50-PX52	HPA 22/75-PX52	HPA 30/100-PX52	
A	50 +0.5	75 +0.7	100 +1	mm
B	7 ±0.25	8 ±0.25	10 ±0.25	mm
C	7 ±1	9 ±1	10 ±1	mm
D	16 ±0.1	22 ±0.1	30 ±0.1	mm
M	M 6 × 0.75	M 8 × 1	M 12 × 1	mm
L	80 ±2	104 ±2	130 ±2	mm
d	5 h 6	8 h 6	10 h 6	mm
s	8	12	17	mm
Stroke 0 to 500 V	≈20	≈30	≈50	μm
Stroke 0 to 800 V	≈35	≈50	≈80	μm
Capacitance at 25 °C	≈100	≈250	≈800	nF
Stiffness	≈30	≈50	≈80	N/μm
Maximum loading force	2000	3000	5000	N
Mass	60	140	440	g
Spring stiffness	≈3	3	3	N/μm

SPECIALTY FERRITES

Specialty ferrites

Introduction

THE NATURE OF SOFT FERRITES

Composition

Ferrites are dark grey or black ceramic materials. They are very hard, brittle and chemically inert. Most modern magnetically soft ferrites have a cubic (spinel) structure.

The general composition of such ferrites is MeFe_2O_4 where Me represents one or several of the divalent transition metals such as manganese (Mn), zinc (Zn), nickel (Ni), cobalt (Co), copper (Cu), iron (Fe) or magnesium (Mg).

The most popular combinations are manganese and zinc (MnZn) or nickel and zinc (NiZn). These compounds exhibit good magnetic properties below a certain temperature, called the Curie Temperature (T_C). They can easily be magnetized and have a rather high intrinsic resistivity. These materials can be used up to very high frequencies without laminating, as is the normal requirement for magnetic metals.

NiZn ferrites have a very high resistivity and are most suitable for frequencies over 1 MHz, however, MnZn ferrites exhibit higher permeability (μ_i) and saturation induction levels (B_s) and are suitable up to 3 MHz.

For certain special applications, single crystal ferrites can be produced, but the majority of ferrites are manufactured as polycrystalline ceramics.

Manufacturing process

The following description of the production process is typical for the manufacture of our range of soft ferrites, which is marketed under the trade name 'Ferroxcube'.

RAW MATERIALS

The raw materials used are oxides or carbonates of the constituent metals. The final material grade determines the necessary purity of the raw materials used, which, as a result is reflected in the overall cost.

PROPORTIONS OF THE COMPOSITION

The base materials are weighed into the correct proportions required for the final composition.

MIXING

The powders are mixed to obtain a uniform distribution of the components.

PRE-SINTERING

The mixed oxides are calcined at approximately 1000 °C. A solid state reaction takes place between the constituents and, at this stage, a ferrite is already formed.

Pre-sintering is not essential but provides a number of advantages during the remainder of the production process.

MILLING AND GRANULATION

The pre-sintered material is milled to a specific particle size, usually in a slurry with water. A small proportion of organic binder is added, and then the slurry is spray-dried to form granules suitable for the forming process.

FORMING

Most ferrite parts are formed by pressing. The granules are poured into a suitable die and then compressed. The organic binder acts in a similar way to an adhesive and a so-called 'green' product is formed. It is still very fragile and requires sintering to obtain the final ferrite properties.

For some products, for example, long rods or tubes, the material is mixed into a dough and extruded through a suitable orifice. The final products are cut to the required length before or after sintering.

SINTERING

The 'green' cores are loaded on refractory plates and sintered at a temperature between 1150 °C and 1300 °C depending on the ferrite grade. A linear shrinkage of up to 20% (50% in volume) takes place. The sintering may take place in tunnel kilns having a fixed temperature and atmosphere distribution or in box kilns where temperature and atmosphere are computer controlled as a function of time. The latter type is more suitable for high grade ferrites which require a very stringent control in conditions.

FINISHING

After sintering, the ferrite core has the required magnetic properties. It can easily be magnetized by an external field (see Fig.2), exhibiting the well-known hysteresis effect (see Fig.1). Dimensions are typically within 2% of nominal due to 10- 20% shrinkage. If this tolerance is too large or if some surfaces require a smooth finish (e.g. mating faces between core halves) a grinding operation is necessary. Usually diamond-coated wheels are used. For high permeability materials, very smooth, lapped, mating surfaces are required. If an air-gap is required in the application, it may be provided by centre pole grinding.

Specialty ferrites

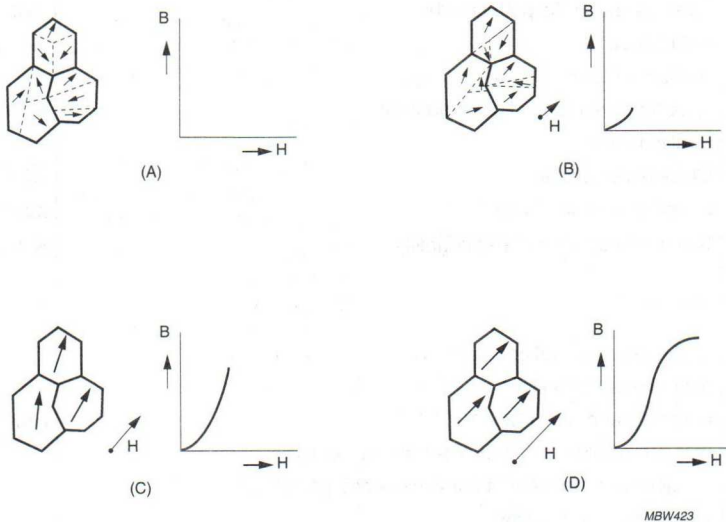
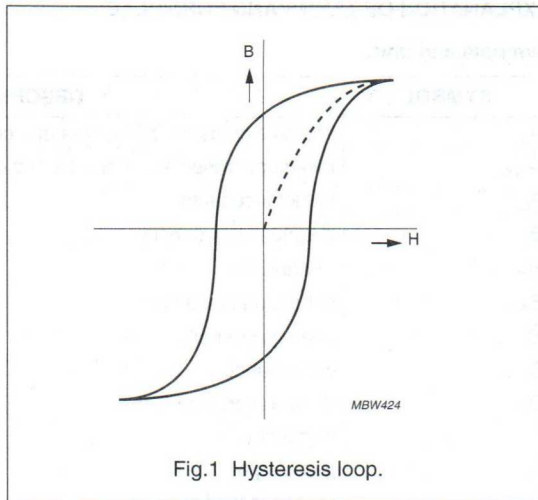
Introduction

Magnetism in ferrites

A sintered ferrite consists of small crystals, typically 10 to 20 μm in dimension. Domains exist within these crystals (Weiss domains) in which the molecular magnets are already aligned (ferrimagnetism). When a driving magnetic field (H) is applied to the material the domains progressively align with it, as shown in Fig.2.

During this magnetization process energy barriers have to be overcome. Therefore the magnetization will always lag behind the field. A so-called hysteresis loop (see Fig.1) is the result.

If the resistance against magnetization is small, a large induced flux will result at a given magnetic field. The value of the permeability is high. The shape of the hysteresis loop also has a marked influence on other properties, for example, power losses.



Specialty ferrites

Introduction

EXPLANATION OF TERMS AND FORMULAE

Symbols and units

SYMBOL	DESCRIPTION	UNIT
A_e	effective cross-sectional area of a core	mm^2
$A_{\min}$	minimum cross-sectional area of a core	mm^2
A_L	inductance factor	nH
B	magnetic flux density	T
B_r	remanence	T
B_s	saturation flux density	T
$\hat{B}$	peak flux density	T
C	capacitance	F
D_F	disaccommodation factor	—
f	frequency	Hz
G	gap length	μm
H	magnetic field strength	A/m
H_c	coercivity	A/m
$\hat{H}$	peak magnetic field strength	A/m
I	current	A
l_e	effective magnetic path length	mm
L	inductance	H
N	number of turns	—
P_v	specific power loss of core material	kW/m^3
Q	quality factor	—
T_c	Curie temperature	$^{\circ}\text{C}$
V_e	effective volume of core	mm^3
α_F	temperature factor of permeability	K^{-1}
$\frac{\tan \delta}{\mu_i}$	loss factor	—
η_B	hysteresis material constant	T^{-1}
μ	absolute permeability	—
μ_0	magnetic constant ($4\pi \times 10^{-7}$)	Hm^{-1}
μ_s'	real component of complex series permeability	—
μ_s''	imaginary component of complex series permeability	—
μ_a	amplitude permeability	—
μ_e	effective permeability	—
μ_i	initial permeability	—
μ_r	relative permeability	—
μ_{Δ}	incremental permeability	—
ρ	resistivity	Ωm
$\Sigma(I/A)$	core factor (C1)	mm^{-1}

Specialty ferrites

Introduction

Definition of terms

PERMEABILITY

When a magnetic field is applied to a soft magnetic material, the resulting flux density is composed of that of free space plus the contribution of the aligned domains.

$$B = \mu_0 H + J \quad \text{or} \quad B = \mu_0 (H + M) \quad (1)$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m, J is the magnetic polarization and M is the magnetization.

The ratio of flux density and applied field is called absolute permeability.

$$\frac{B}{H} = \mu_0 \left(1 + \frac{M}{H} \right) = \mu_{\text{absolute}} \quad (2)$$

It is usual to express this absolute permeability as the product of the magnetic constant of free space and the relative permeability (μ_r).

$$\frac{B}{H} = \mu_0 \mu_r \quad (3)$$

Since there are several versions of μ_r depending on conditions the index 'r' is generally removed and replaced by the applicable symbol e.g. μ_i , μ_a , μ_Δ etc.

INITIAL PERMEABILITY

The initial permeability is measured in a closed magnetic circuit (ring core) using a very low field strength.

$$\mu_i = \frac{1}{\mu_0} \times \frac{\Delta B}{\Delta H} \quad (\Delta H \rightarrow 0) \quad (4)$$

Initial permeability is dependent on temperature and frequency.

EFFECTIVE PERMEABILITY

If the air-gap is introduced in a closed magnetic circuit, magnetic polarization becomes more difficult. As a result, the flux density for a given magnetic field strength is lower.

Effective permeability is dependent on the initial permeability of the soft magnetic material and the dimensions of air-gap and circuit.

$$\mu_e = \frac{\mu_i}{1 + \frac{G \times \mu_i}{l_e}} \quad (5)$$

where G is the gap length and l_e is the effective length of magnetic circuit. This simple formula is a good approximation only for small air-gaps. For longer air-gaps some flux will cross the gap outside its normal area (stray flux) causing an increase of the effective permeability.

AMPLITUDE PERMEABILITY

The relationship between higher field strength and flux densities without the presence of a bias field, is given by the amplitude permeability.

$$\mu_a = \frac{1}{\mu_0} \times \frac{\hat{B}}{\hat{H}} \quad (6)$$

Since the BH loop is far from linear, values depend on the applied field peak strength.

INCREMENTAL PERMEABILITY

The permeability observed when an alternating magnetic field is superimposed on a static bias field, is called the incremental permeability.

$$\mu_\Delta = \frac{1}{\mu_0} \left[\frac{\Delta B}{\Delta H} \right]_{H_{DC}} \quad (7)$$

If the amplitude of the alternating field is negligibly small, the permeability is then called the reversible permeability (μ_{rev}).

COMPLEX PERMEABILITY

A coil consisting of windings on a soft magnetic core will never be an ideal inductance with a phase angle of 90° . There will always be losses of some kind, causing a phase shift, which can be represented by a series or parallel resistance as shown in Figs 3 and 4.

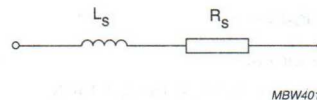


Fig.3 Series representation.

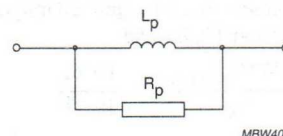


Fig.4 Parallel representation.

Specialty ferrites

Introduction

For series representation

$$Z = j\omega L_s + R_s \quad (8)$$

and for parallel representation,

$$Z = \frac{1}{1/(j\omega L_p) + 1/R_p} \quad (9)$$

the magnetic losses are accounted for if a resistive term is added to the permeability.

$$\mu = \mu'_s - j\mu''_s \quad \text{or} \quad \frac{1}{\mu} = \frac{1}{\mu'_p} - \frac{1}{\mu''_p} \quad (10)$$

The phase shift caused by magnetic losses is given by:

$$\tan \delta_m = \frac{R_s}{\omega L_s} = \frac{\mu''_s}{\mu'_s} \quad \text{or} \quad \frac{\omega L_p}{R_p} = \frac{\mu'_p}{\mu''_p} \quad (11)$$

For calculations on inductors and also to characterize ferrites, the series representations is generally used (μ'_s and μ''_s). In some applications e.g. signal transformers, the use of the parallel representation (μ'_p and μ''_p) is more convenient.

The relationship between the representations is given by:

$$\mu'_p = \mu'_s \left(1 + \tan^2 \delta^2 \right) \quad \text{and} \quad \mu''_p = \mu''_s \left(1 + \frac{1}{\tan^2 \delta^2} \right) \quad (12)$$

LOSS FACTOR

The magnetic losses which cause the phase shift can be split up into three components:

1. Hysteresis losses
2. Eddy current losses
3. Residual losses.

This gives the formula:

$$\tan \delta_m = \tan \delta_h + \tan \delta_f + \tan \delta_r \quad (13)$$

Figure 5 shows the magnetic losses as a function of frequency.

Hysteresis losses vanish at very low field strengths. Eddy current losses increase with frequency and are negligible at very low frequency. The remaining part is called residual loss. It can be proven that for a gapped magnetic circuit, the following relationship is valid:

$$\frac{(\tan \delta_m)_{\text{gapped}}}{\mu_e - 1} = \frac{\tan \delta_m}{\mu_i - 1} \quad (14)$$

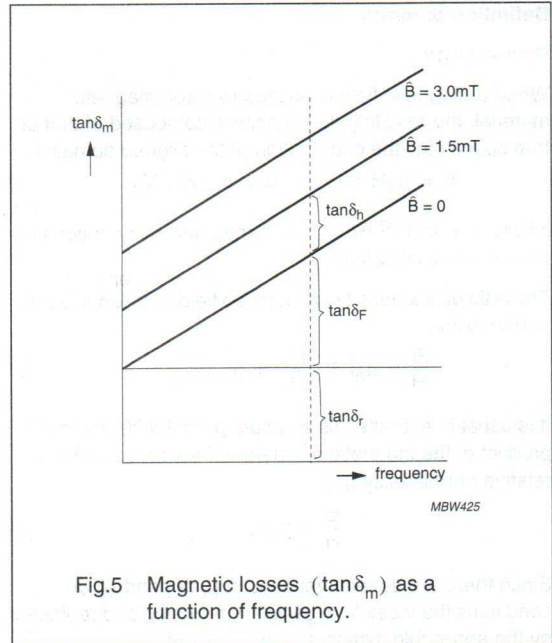


Fig.5 Magnetic losses ($\tan \delta_m$) as a function of frequency.

Since μ_i and μ_e are usually much greater than 1, a good approximation is:

$$\frac{(\tan \delta_m)_{\text{gapped}}}{\mu_e} = \frac{\tan \delta_m}{\mu_i} \quad (15)$$

From this formula, the magnetic losses in a gapped circuit can be derived from:

$$(\tan \delta_m)_{\text{gapped}} = \frac{\tan \delta_m}{\mu_i} \times \mu_e \quad (16)$$

Normally, the index 'm' is dropped when material properties are discussed:

$$(\tan \delta)_{\text{gapped}} = \frac{\tan \delta}{\mu_i} \times \mu_e \quad (17)$$

In material specifications, the loss factor ($\tan \delta/\mu_i$) is used to describe the magnetic losses. These include residual and eddy current losses, but not hysteresis losses.

For inductors used in filter applications, the quality factor (Q) is often used as a measure of performance. It is defined as:

$$Q = \frac{1}{\tan \delta} = \frac{\omega L}{R_{\text{tot}}} = \frac{\text{reactance}}{\text{total resistance}} \quad (18)$$

The total resistance includes the effective resistance of the winding at the design frequency.

Specialty ferrites

HYSTERESIS MATERIAL CONSTANT

When the flux density of a core is increased, hysteresis losses are more noticeable. Their contribution to the total losses can be obtained by means of two measurements, usually at the induction levels of 1.5 mT and 3 mT. The hysteresis constant is found from:

$$\eta_B = \frac{\Delta \tan \delta_m}{\mu_e \times \Delta \hat{B}} \quad (19)$$

The hysteresis loss factor for a certain flux density can be calculated using:

$$\frac{\tan \delta_h}{\mu_e} = \eta_B \times \hat{B} \quad (20)$$

This formula is also the IEC definition for the hysteresis constant.

EFFECTIVE CORE DIMENSIONS

To facilitate calculations on a non-uniform soft magnetic cores, a set of effective dimensions is given on each data sheet. These dimensions, effective area (A_e), effective length (l_e) and effective volume (V_e) define a hypothetical ring core which would have the same magnetic properties as the non-uniform core.

The reluctance of the ideal ring core would be:

$$\frac{l_e}{\mu \times A_e} \quad (21)$$

For the non-uniform core shapes, this is usually written as:

$$\frac{1}{\mu_e} \times \Sigma \frac{l}{A} \quad (22)$$

the core factor divided by the permeability. The inductance of the core can now be calculated using this core factor:

$$L = \frac{\mu_0 \times N^2}{\frac{1}{\mu_e} \times \Sigma \frac{l}{A}} = \frac{1.257 \times 10^{-9} \times N^2}{\frac{1}{\mu_e} \times \Sigma \frac{l}{A}} \text{ (in H)} \quad (23)$$

The effective area is used to calculate the flux density in a core,

for sine wave:

$$\hat{B} = \frac{U \sqrt{2} \times 10^9}{\omega A_e N} = \frac{2.25 U \times 10^8}{f N A_e} \text{ (in mT)} \quad (24)$$

for square wave:

$$\hat{B} = \frac{0.25 \hat{U} \times 10^9}{f N A_e} \text{ (in mT)} \quad (25)$$

where:

A_e is the effective area in mm².

U is the voltage in V

f is the frequency in Hz

N is the number of turns.

The magnetic field strength (H) is calculated using the effective length (l_e):

$$\hat{H} = \frac{IN \sqrt{2}}{l_e} \text{ (A/m)} \quad (26)$$

If the cross-sectional area of a core is non-uniform, there will always be a point where the real cross-section is minimal. This value is known as $A_{\min}$ and is used to calculate the maximum flux density in a core. A well designed ferrite core avoids a large difference between A_e and $A_{\min}$. Narrow parts of the core could saturate or cause much higher hysteresis losses.

INDUCTANCE FACTOR (A_L)

To make the calculation of the inductance of a coil easier, the inductance factor, known as the A_L value, is given in each data sheet (in nano Henry). The inductance of the core is defined as:

$$L = N^2 \times A_L \text{ (nH)} \quad (27)$$

The value is calculated using the core factor and the effective permeability:

$$A_L = \frac{\mu_0 \mu_e \times 10^6}{\Sigma (l/A)} = \frac{1.257 \mu_e}{\Sigma (l/A)} \text{ (nH)} \quad (28)$$

MAGNETIZATION CURVES (H_c , B_R , B_s)

If an alternating field is applied to a soft magnetic material, a hysteresis loop is obtained. For very high field strengths, the maximum attainable flux density is reached. This is known as the saturation flux density (B_s).

If the field is removed, the material returns to a state where, depending on the material grade, a certain flux density remains. This the remanent flux density (B_R).

This remanent flux returns to zero for a certain negative field strength which is referred to a coercivity (H_c).

These points are clearly shown in Fig.6.

Specialty ferrites

Introduction

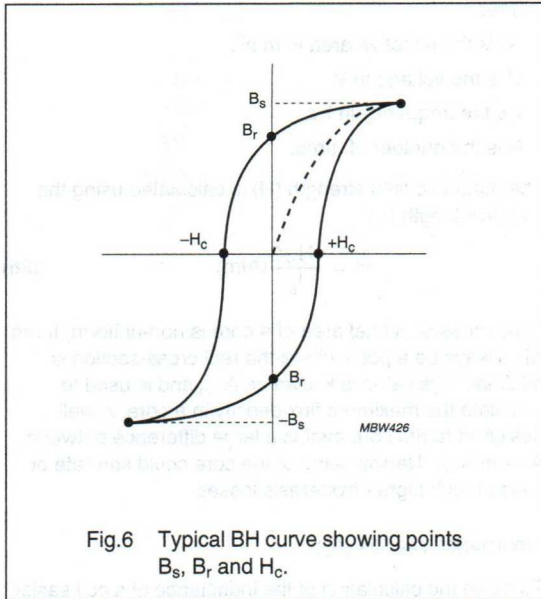


Fig.6 Typical BH curve showing points B_s , B_r and H_c .

TEMPERATURE DEPENDENCE OF THE PERMEABILITY

The permeability of a ferrite is a function of temperature. It generally increases with temperature to a maximum value and then drops sharply to a value of 1. The temperature at which this happens is called the Curie temperature (T_c). Typical curves of our grades are given in the material data section.

For filter applications, the temperature dependence of the permeability is a very important parameter. A filter coil should be designed in such a way that the combination it forms with a high quality capacitor results in an LC filter with excellent temperature stability.

The temperature coefficient (TC) of the permeability is given by:

$$TC = \frac{(\mu_i)_{T_2} - (\mu_i)_{T_1}}{(\mu_i)_{T_1}} \times \frac{1}{T_2 - T_1} \quad (29)$$

For a gapped magnetic circuit, the influence of the permeability temperature dependence is reduced by the factor μ_e/μ_i . Hence:

$$TC_{gap} = \frac{\mu_e}{(\mu_i)_{T_1}} \times \frac{(\mu_i)_{T_2} - (\mu_i)_{T_1}}{(\mu_i)_{T_1}^2} \times \frac{1}{T_2 - T_1} = \mu_e \times \alpha_F \quad (30)$$

So α_F is defined as:

$$\alpha_F = \frac{(\mu_i)_{T_2} - (\mu_i)_{T_1}}{(\mu_i)_{T_1}^2} \times \frac{1}{T_2 - T_1} \quad (31)$$

Or, to be more precise, if the change in permeability over the specified area is rather large:

$$\alpha_F = \frac{(\mu_i)_{T_2} - (\mu_i)_{T_1}}{(\mu_i)_{T_1} \times (\mu_i)_{T_2}} \times \frac{1}{T_2 - T_1} \quad (32)$$

The temperature factors for several temperature trajectories of the grades intended for filter applications are given in the material specifications. They offer a simple means to calculate the temperature coefficient of any coil made with these ferrites.

TIME STABILITY

When a soft magnetic material is given a magnetic or thermal disturbance, the permeability rises suddenly and then decreases slowly with time. For a defined time interval, this 'disaccommodation' can be expressed as:

$$D = \frac{\mu_1 - \mu_2}{\mu_1} \quad (33)$$

The decrease of permeability appears to be almost proportional to the logarithm of time. For this reason, IEC has defined a disaccommodation coefficient:

$$d = \frac{\mu_1 - \mu_2}{\mu_1 \times \log(t_2/t_1)} \quad (34)$$

As with temperature dependence, the influence of disaccommodation on the inductance drift of a coil will be reduced by μ_e/μ_i .

Therefore, a disaccommodation factor D_F is defined:

$$D_F = \frac{d}{\mu_i} = \frac{\mu_1 - \mu_2}{\mu_i^2 \times \log(t_2/t_1)} \quad (35)$$

The variability with time of a coil can now be predicted by:

$$\frac{L_1 - L_2}{L_1} = \mu_e \times D_F \quad (36)$$

Specialty ferrites

Introduction

RESISTIVITY

Ferrite is a semiconductor with a DC resistivity in the crystallites of the order of $10^{-3} \Omega\text{m}$ for a MnZn type ferrite, and about $30 \Omega\text{m}$ for a NiZn ferrite.

Since there is an isolating layer between the crystals, the bulk resistivity is much higher: 0.1 to $10 \Omega\text{m}$ for MnZn ferrites and 10^4 to $10^6 \Omega\text{m}$ for NiZn and MgZn ferrites.

This resistivity depends on temperature and measuring frequency, which is clearly demonstrated in Tables 1 and 2 which show resistivity as a function of temperature for different materials.

Table 1 Resistivity as a function of temperature of a MnZn-ferrite (3C80)

TEMPERATURE (°C)	RESISTIVITY (Ωm)
-20	≈ 10
0	≈ 7
20	≈ 4
50	≈ 2
100	≈ 1

Table 2 Resistivity as a function of temperature of a NiZn-ferrite (4C6)

TEMPERATURE (°C)	RESISTIVITY (Ωm)
0	$\approx 5 \cdot 10^7$
20	$\approx 10^7$
60	$\approx 10^6$
100	$\approx 10^5$

At higher frequencies the crystal boundaries are more or less short-circuited by their capacitance and the measured resistivity decreases, as shown in Tables 3 and 4.

Table 3 Resistivity as function of frequency for MnZn ferrites

FREQUENCY (MHz)	RESISTIVITY (Ωm)
0.1	≈ 2
1	≈ 0.5
10	≈ 0.1
100	≈ 0.01

Table 4 Resistivity as function of frequency for NiZn ferrites

FREQUENCY (MHz)	RESISTIVITY (Ωm)
0.1	$\approx 10^5$
1	$\approx 5 \cdot 10^4$
10	$\approx 10^4$
100	$\approx 10^3$

PERMITTIVITY

The basic permittivity of all ferrites is of the order of 10. This is valid for MnZn and NiZn materials. The isolating material on the grain boundaries also has a permittivity of approximately 10. However, if the bulk permittivity of a ferrite is measured, very different values of apparent permittivity result. This is caused by the conductivity inside the crystallites. The complicated network of more or less leaky capacitors also shows a strong frequency dependence.

Tables 5 and 6 show the relationship between permittivity and frequency for both MnZn and NiZn ferrites.

Table 5 Permittivity as a function of frequency for MnZn ferrites

FREQUENCY (MHz)	PERMITTIVITY (ϵ_r)
0.1	$\approx 2 \cdot 10^5$
1	$\approx 10^5$
10	$\approx 5 \cdot 10^4$
100	$\approx 10^4$

Table 6 Permittivity as a function of frequency for NiZn ferrites

FREQUENCY (MHz)	PERMITTIVITY (ϵ_r)
0.001	≈ 100
0.01	≈ 50
1	≈ 25
10	≈ 15
100	≈ 12

Specialty ferrites

Introduction

ORDERING INFORMATION

The products in this handbook are identified by type numbers. All physical and technical properties of the product are expressed by these numbers. They are therefore recommended for both ordering and use on technical drawings and equipment parts lists.

The 11-digit code, used in former editions of this data handbook, also appears on packaging material.

Smallest Packaging Quantities (SPQ) are packs which are ready for shipment to our customers. The information on the barcoded label consists of:

Barcode information

Technical information: type number
11-digit code number
delivery and/or production
batch numbers

Logistic information: 12-digit code number
quantity
country of origin
production week
production centre

The Philips 12-digit code used on the packaging labels, provides full logistic information as well.

During all stages of the production process, data are collected and documented with reference to a unique batch number, which is printed on the packaging label. With this batch number it is always possible to trace the results of process steps afterwards and in the event of customer complaints, this number should always be quoted.

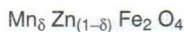
SAFETY AND ENVIRONMENTAL ASPECTS

Environmental aspects of soft ferrites

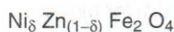
Our range of soft ferrites has the general composition MeFe_2O_4 where Me represents one or several of the divalent transition metals such as manganese (Mn), zinc (Zn), nickel (Ni), or magnesium (Mg).

To be more specific, all materials starting with digit 3 are manganese zinc ferrites based on the MnZn composition

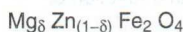
Their general chemical formula is:



Materials starting with digit 4 are nickel zinc ferrites based on the NiZn composition. Their general chemical formula is:



Materials starting with digit 2 are magnesium zinc ferrites based on the MgZn composition. Their general chemical formula is:



General warning rules

- With strong acids, the metals iron, manganese, nickel and zinc may be partially extracted.
- In the event of fire, dust particles with metal oxides will be formed.
- Disposal as industrial waste, depending on local rules and circumstances.

QUALITY

Our production centre for piezoceramics has received the ISO 9001 certificate from KEMA, the Dutch audit authority.

Our piezoceramic products are produced to meet constantly high quality standards. High quality components in mass production require advanced production techniques as well as background knowledge of the product itself. The quality standard is achieved in our production centres by implementation of a quality assurance system based on Statistical Process Control (SPC).

To implement SPC, the production is divided in stages which correspond to production steps, or groups of steps. The output of each stage is statistically checked by C_{pk} .

The obtained results are measured against built-in control, warning and reject levels. If an unfavourable trend is observed in the results from a production stage, corrective action is taken immediately. Quality is 'built-in' by continuous improvement.

The system is applicable to the total manufacturing process, which includes:

- Raw materials
- Production process
- Finished products.

Specialty ferrites

Survey of grades

SURVEY OF FERRITE MATERIALS

Unless otherwise stated, properties specified in this section are related to room temperature (25 °C). They have been measured on sintered, non-ground ring cores of dimension $\varnothing 25 \times \varnothing 15 \times 10$ mm, which are not subjected to external stresses.

Generally, products do not fully comply with the material specification. Deviations may occur due to shape, size and grinding operations. Specific product properties are given in the data sheets or product drawings.

Survey of ferrite materials

FERRITE GRADE	μ_i at 25 °C ($\pm 20\%$)	B_{sat} at 3000 A/m and 25 °C TYP. (mT)	T_c (°C)	ρ TYP. (Ωm)	FERRITE TYPE	MAIN APPLICATION
3C11	4300	400	≥ 125	1	MnZn	EMI-suppression and general purpose
3E25	6000	400	≥ 125	0.5	MnZn	
3E27	6000	480	≥ 175	0.5	MnZn	
3C85	2000	500	≥ 200	2	MnZn	Power conversion
3C90	2000	450	≥ 220	5	MnZn	
3F3	1800	500	≥ 200	2	MnZn	
3F4	900	450	≥ 220	10	MnZn	
4F1	80	320	≥ 260	10^5	NiZn	
3R1	800	450	≥ 230	1	MnZn	
4E1	15	200	≥ 500	10^5	NiZn	EMI-suppression, tuning and general purpose
4D2	60	240	≥ 400	10^5	NiZn	
4C65	125	350	≥ 350	10^5	NiZn	
4B1	250	350	≥ 250	10^5	NiZn	
4A11	700	350	≥ 125	10^5	NiZn	
4A15	1200	350	≥ 125	10^5	NiZn	
4E2	25	300	≥ 400	10^5	NiZn	Particle accelerators
4M2	140	300	≥ 150	10^5	NiZn	
4B3	300	400	≥ 260	10^5	NiZn	
8C12	900	250	≥ 125	10^5	NiZn	
8C11	1200	300	≥ 125	10^5	NiZn	
2S10	350	250	≥ 140	10^6	MgZn	EMI-suppression absorption
4S10	1200	350	≥ 130	10^5	NiZn	

Typical mechanical and thermal properties

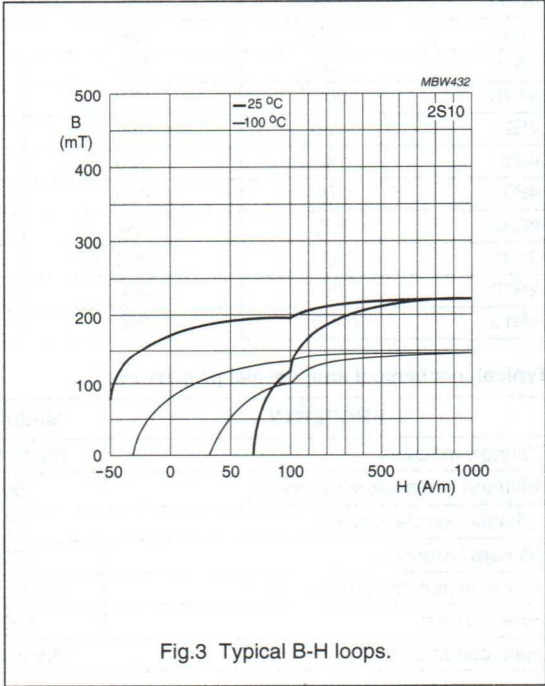
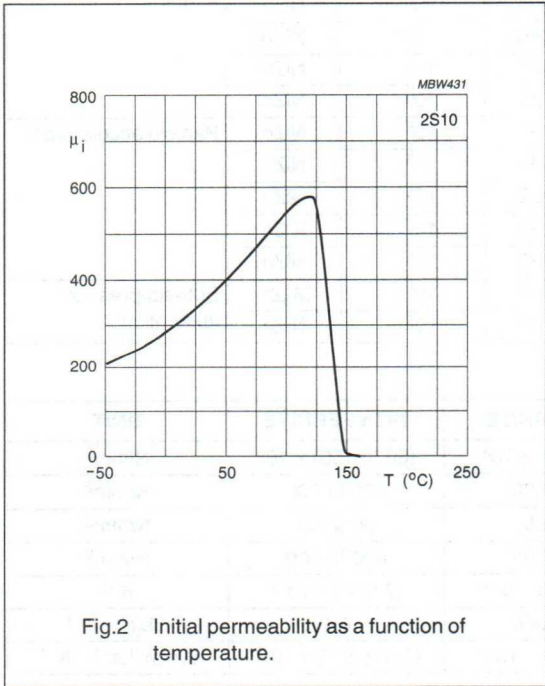
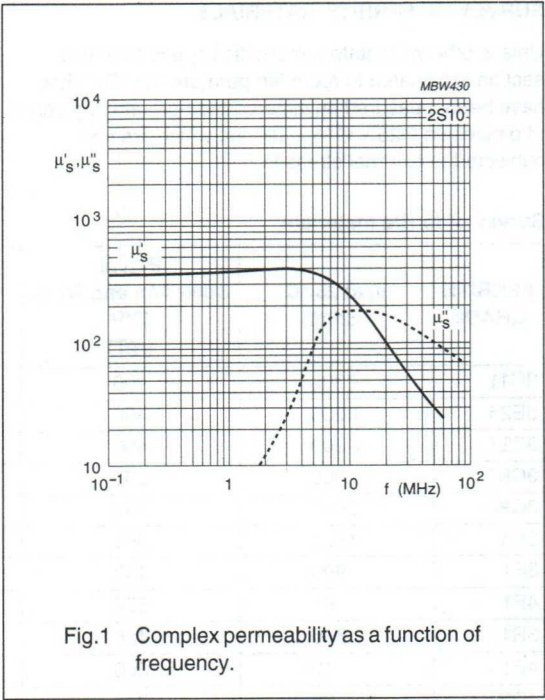
PROPERTY	MnZn FERRITE	NiZn FERRITE	UNIT
Young's modulus	$(90 \text{ to } 150) \times 10^3$	$(80 \text{ to } 150) \times 10^3$	N/mm ²
Ultimate compressive strength	200 to 600	200 to 700	N/mm ²
Ultimate tensile strength	20 to 65	30 to 60	N/mm ²
Vickers hardness	600 to 700	800 to 900	N/mm ²
Linear expansion coefficient	$(10 \text{ to } 12) \times 10^{-6}$	$(7 \text{ to } 8) \times 10^{-6}$	K ⁻¹
Specific heat	700 to 800	750	J.kg ⁻¹ · K ⁻¹
Heat conductivity	$(3.5 \text{ to } 5.0) \times 10^{-3}$	$(3.5 \text{ to } 5.0) \times 10^{-3}$	J.mm ⁻¹ .s ⁻¹ · K ⁻¹

Material grade specification

2S10

2S10 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$350 \pm 20\%$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 135	$^{\circ}\text{C}$
density		≈ 4300	kg/m^3



Material grade specification

3C11

3C11 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$4300 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≥ 350	mT
	100 °C; 10 kHz; 250 A/m	≥ 180	mT
$\tan\delta/\mu_i$	25 °C; 100 kHz; 0.1 mT	$\leq 20 \times 10^{-6}$	
	25 °C; 300 kHz; 0.1 mT	$\leq 200 \times 10^{-6}$	
ρ	DC; 25 °C	≈ 1	Ωm
T_C		≥ 125	°C
density		≈ 4900	kg/m^3

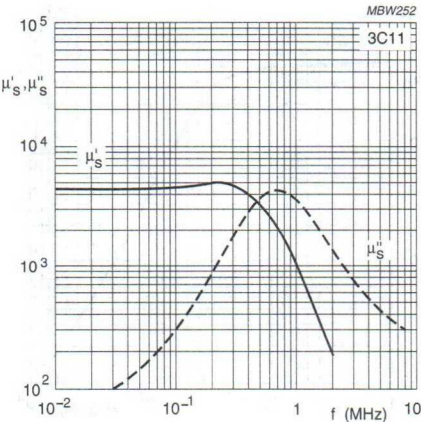


Fig.1 Complex permeability as a function of frequency.

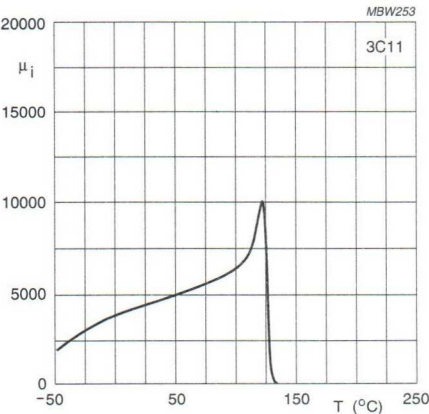


Fig.2 Initial permeability as a function of temperature.

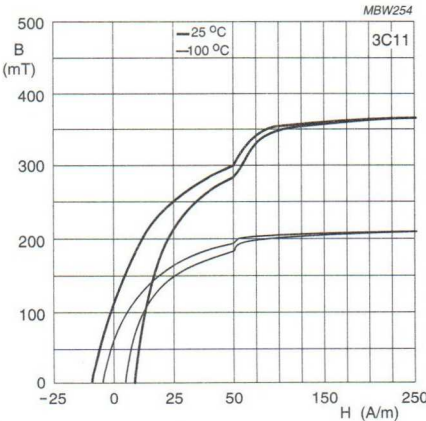


Fig.3 Typical B-H loops.

Material grade specification

3C11

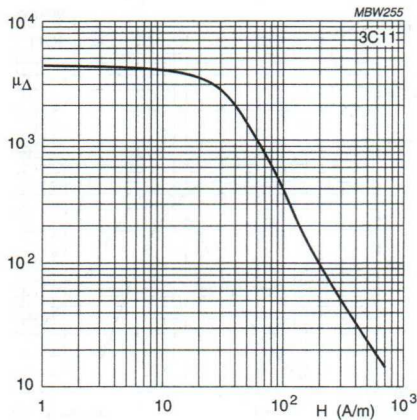


Fig.4 Incremental permeability as a function of magnetic field strength.

Material grade specification

3C85 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$2000 \pm 20\%$	
μ_a	100 °C; 25 kHz; 200 mT	$5500 \pm 25\%$	
B	25 °C; 10 kHz; 250 A/m	≥ 400	mT
	100 °C; 10 kHz; 250 A/m	≥ 330	mT
P _v	100 °C; 25 kHz; 200 mT	≤ 140	kW/m ³
	100 °C; 100 kHz; 100 mT	≤ 165	kW/m ³
ρ	DC; 25 °C	≈ 2	Ωm
T _C		≥ 200	°C
density		≈ 4800	kg/m ³

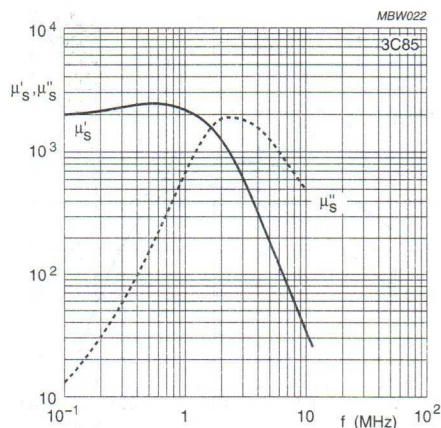


Fig.1 Complex permeability as a function of frequency.

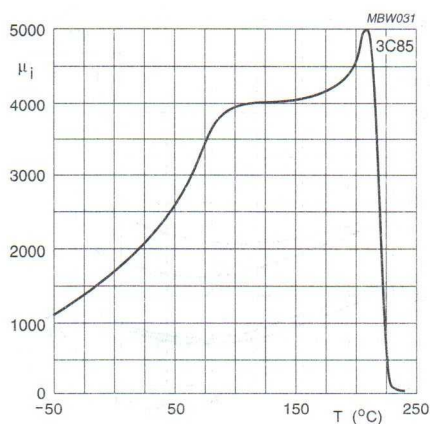


Fig.2 Initial permeability as a function of temperature.

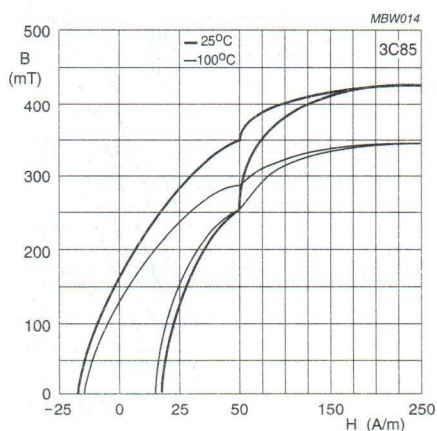


Fig.3 Typical B-H loops.

Material grade specification

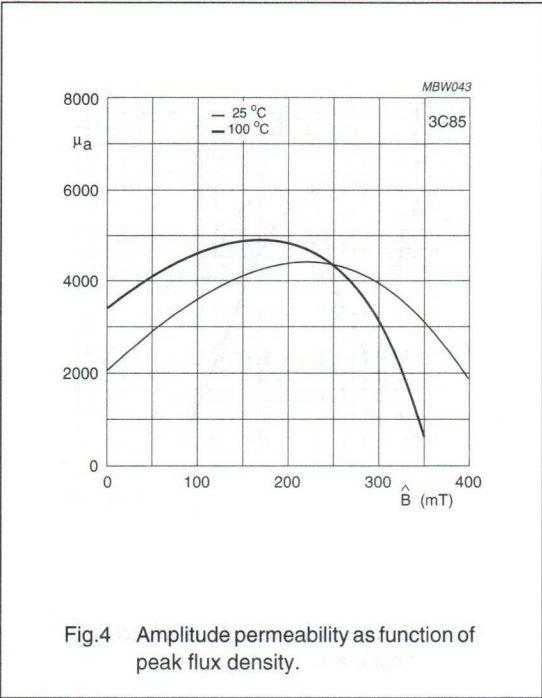


Fig.4 Amplitude permeability as function of peak flux density.

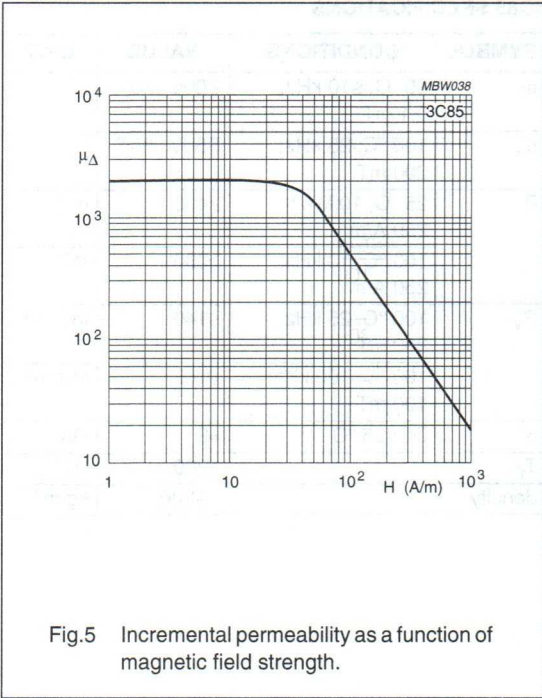


Fig.5 Incremental permeability as a function of magnetic field strength.

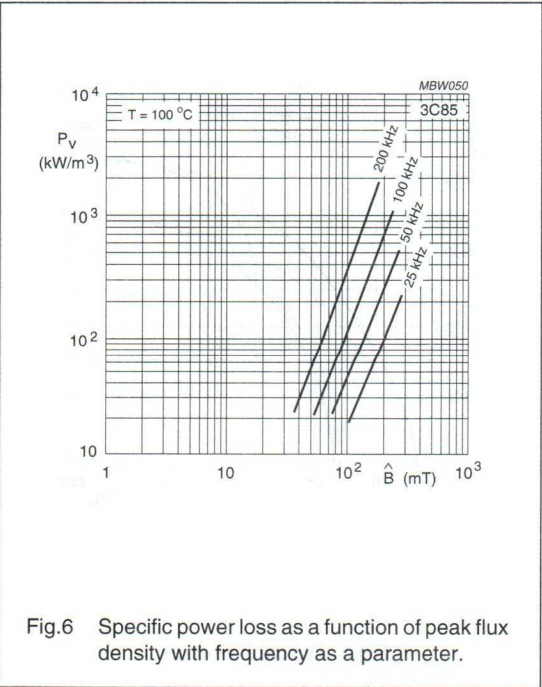


Fig.6 Specific power loss as a function of peak flux density with frequency as a parameter.

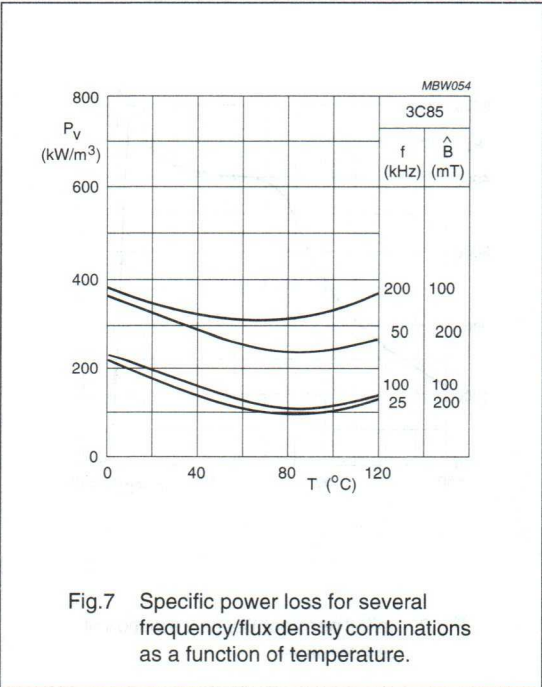


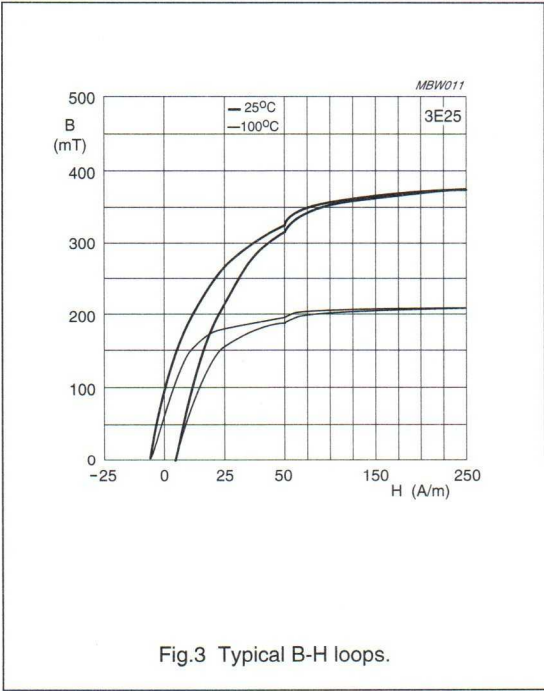
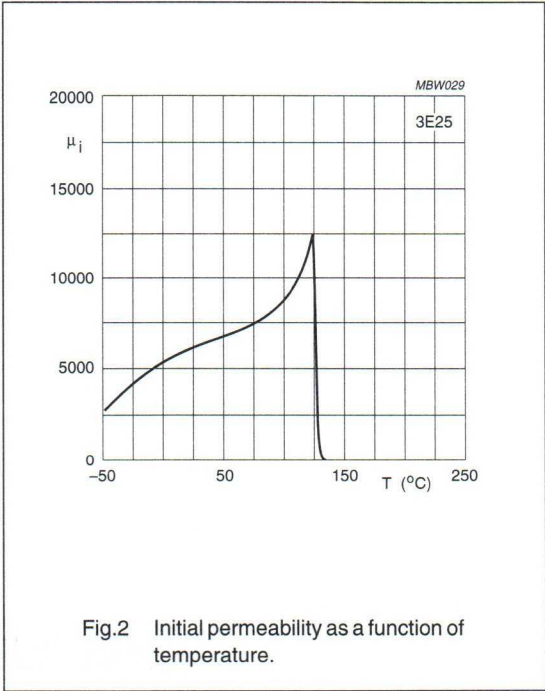
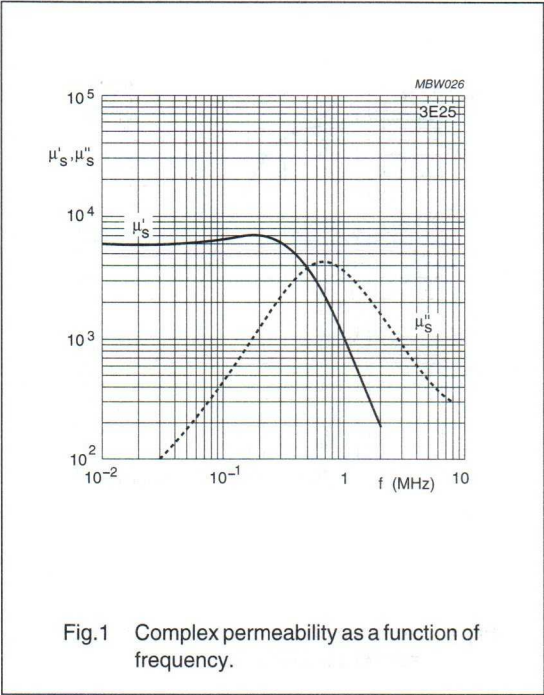
Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification

3E25

3E25 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$6000 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 350	mT
	100 °C; 10 kHz; 250 A/m	≈ 180	mT
$\tan\delta/\mu_i$	25 °C; 100 kHz; 0.1 mT	$\leq 25 \times 10^{-6}$	
	25 °C; 300 kHz; 0.1 mT	$\leq 200 \times 10^{-6}$	
ρ	DC; 25 °C	≈ 0.5	Ωm
T_C		≥ 125	°C
density		≈ 4900	kg/m^3



Material grade specification

3E25

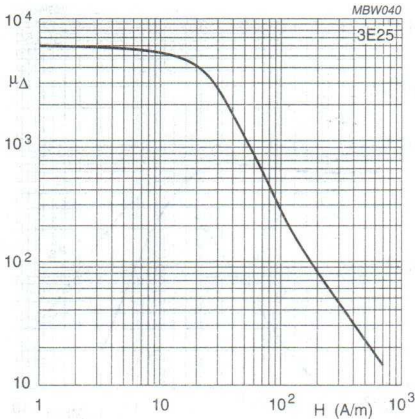


Fig.4 Incremental permeability as a function of magnetic field strength.

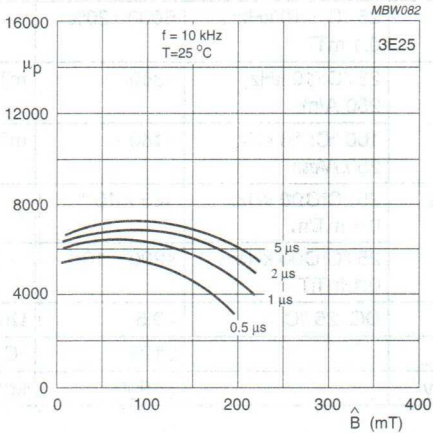


Fig.5 Pulse characteristics (unipolar pulses).

Material grade specification

3F3

3F3 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$1800 \pm 20\%$	
μ_a	100 °C; 25 kHz; 200 mT	≈ 4000	
B	25 °C; 10 kHz; 250 A/m	≥ 400	mT
	100 °C; 10 kHz; 250 A/m	≥ 330	mT
P_v	100 °C; 100 kHz; 100 mT	≤ 80	kW/m ³
	100 °C; 400 kHz; 50 mT	≤ 150	kW/m ³
ρ	DC; 25 °C	≈ 2	Ωm
T_C		≥ 200	°C
density		≈ 4750	kg/m ³

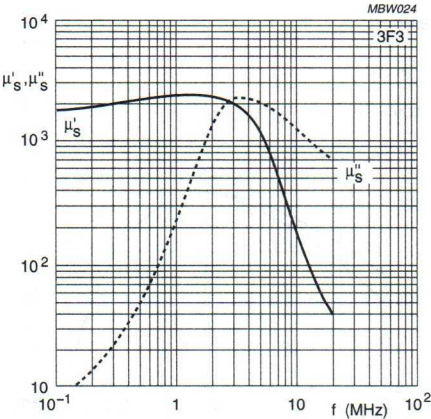


Fig.1 Complex permeability as a function of frequency.

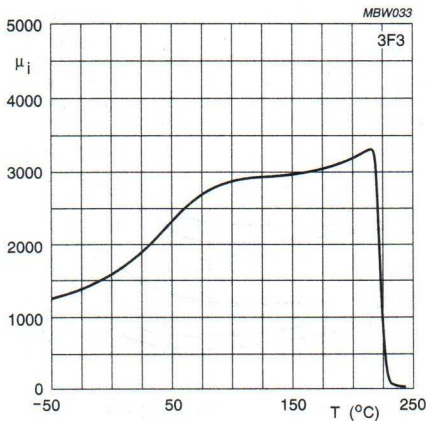


Fig.2 Initial permeability as a function of temperature.

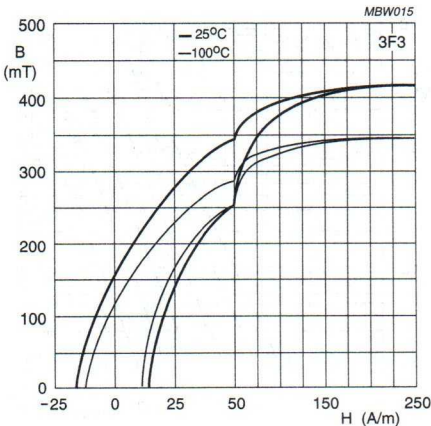


Fig.3 Typical B-H loops.

Material grade specification

3F3

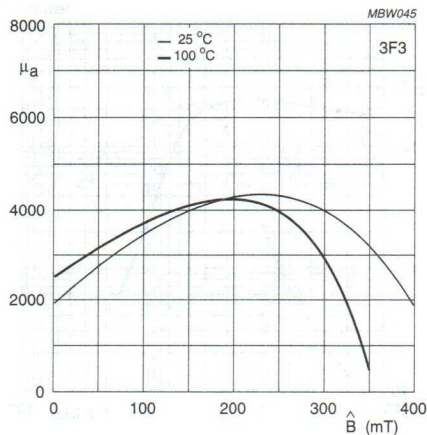


Fig.4 Amplitude permeability as function of peak flux density.

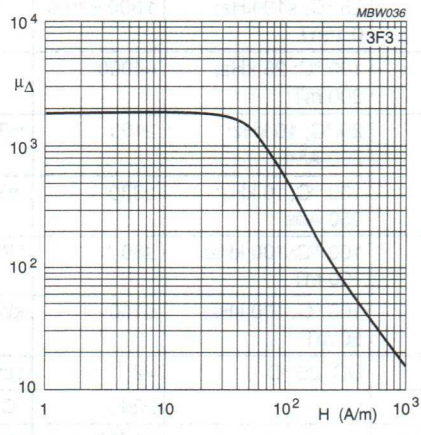


Fig.5 Incremental permeability as a function of magnetic field strength.

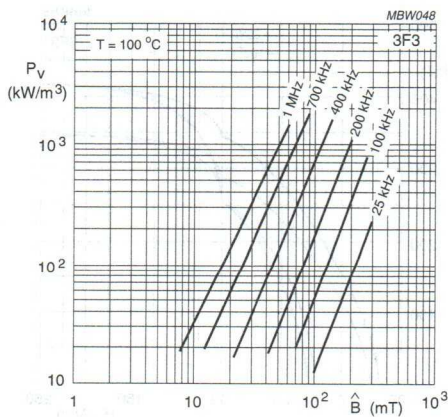


Fig.6 Specific power loss as a function of peak flux density with frequency as a parameter.

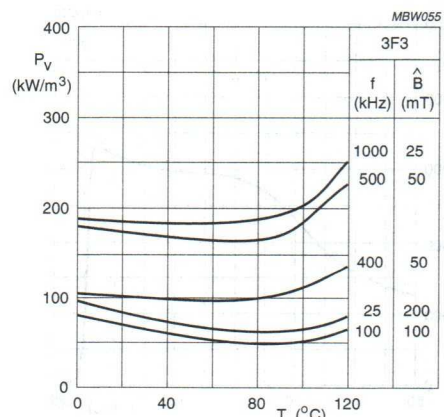


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification

3F4

3F4 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$900 \pm 20\%$	
μ_a	100 °C; 25 kHz; 200 mT	≈ 1700	
B	25 °C; 10 kHz; 250 A/m	≥ 350	mT
	100 °C; 10 kHz; 250 A/m	≥ 300	mT
P_v	100 °C; 1 MHz; 30 mT	≤ 200	kW/m ³
	100 °C; 3 MHz; 10 mT	≤ 320	kW/m ³
ρ	DC; 25 °C	≈ 10	Ωm
T_c		≥ 220	°C
density		≈ 4700	kg/m ³

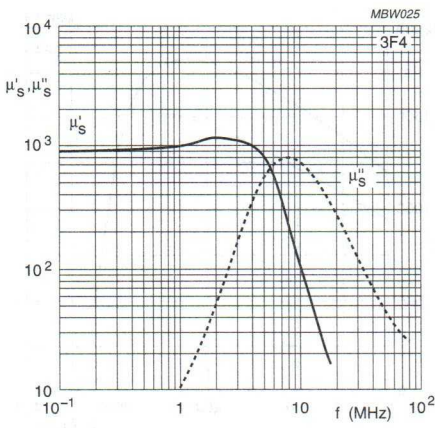


Fig.1 Complex permeability as a function of frequency.

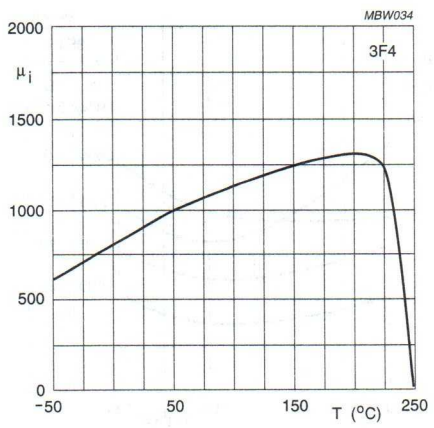


Fig.2 Initial permeability as a function of temperature.

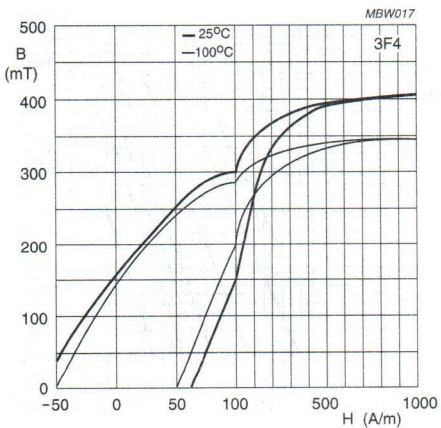


Fig.3 Typical B-H loops.

Material grade specification

3F4

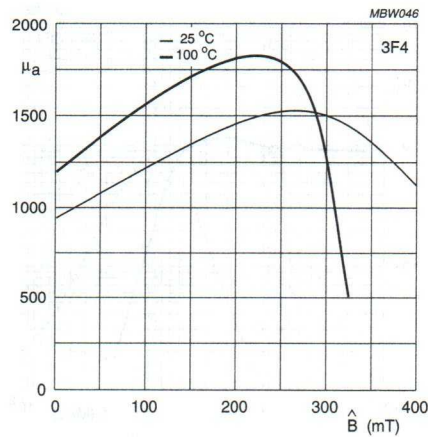


Fig.4 Amplitude permeability as function of peak flux density.

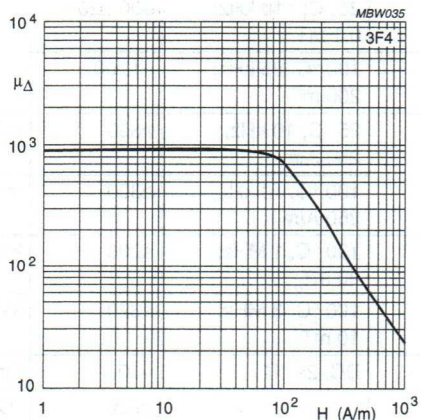


Fig.5 Incremental permeability as a function of magnetic field strength.

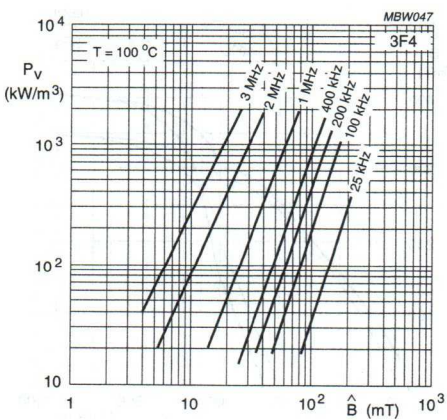


Fig.6 Specific power loss as a function of peak flux density with frequency as a parameter.

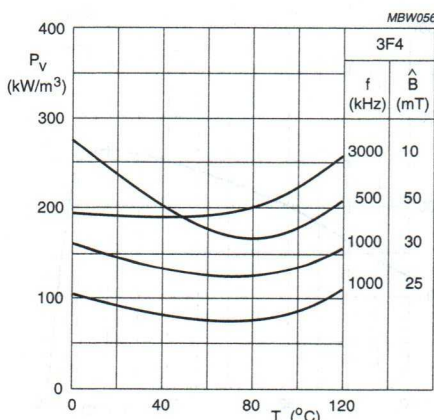


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification

3R1

3R1 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$800 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≥ 360	mT
	100 °C; 10 kHz; 250 A/m	≥ 285	mT
B_r	from 1 kA/m; 25 °C	≥ 310	mT
	from 1 kA/m; 100 °C	≥ 220	mT
H_c	from 1 kA/m; 25 °C	≤ 52	A/m
	from 1 kA/m; 100 °C	≤ 23	A/m
ρ	DC; 25 °C	$\approx 10^3$	Ωm
T_C		≥ 230	°C
density		≈ 4700	kg/m^3

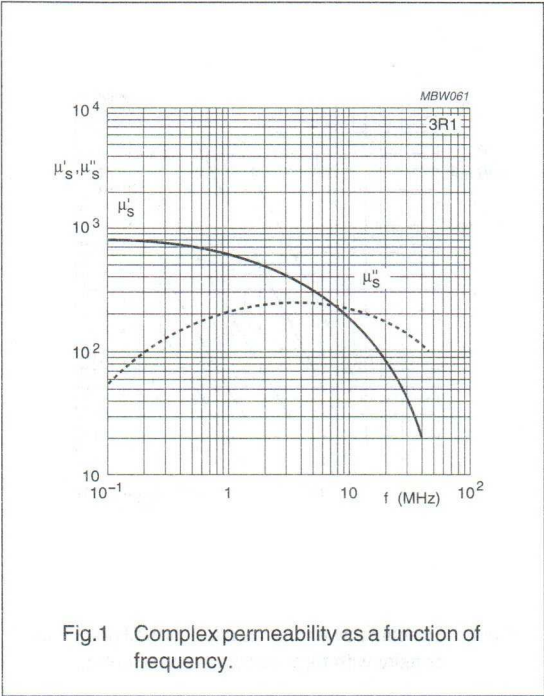


Fig.1 Complex permeability as a function of frequency.

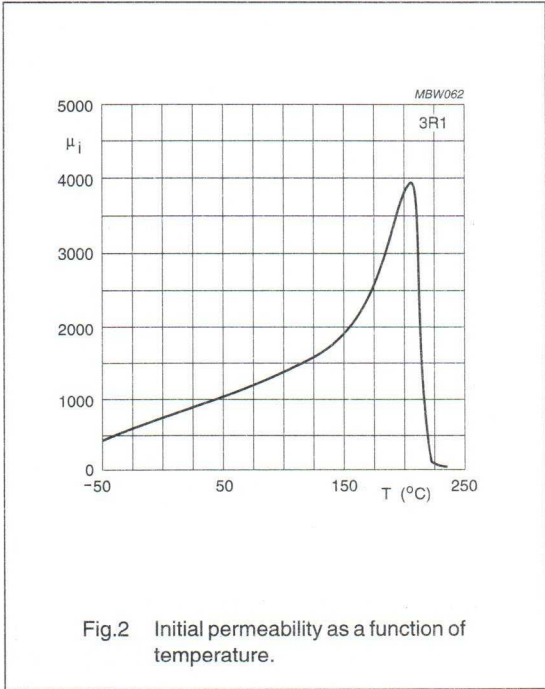


Fig.2 Initial permeability as a function of temperature.

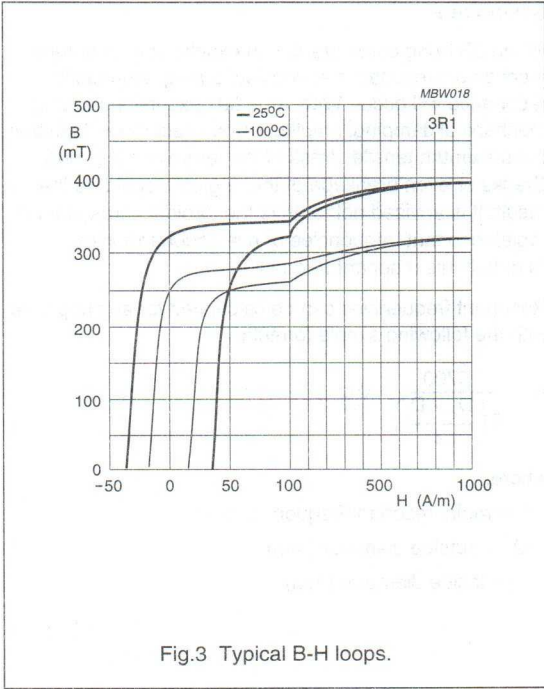
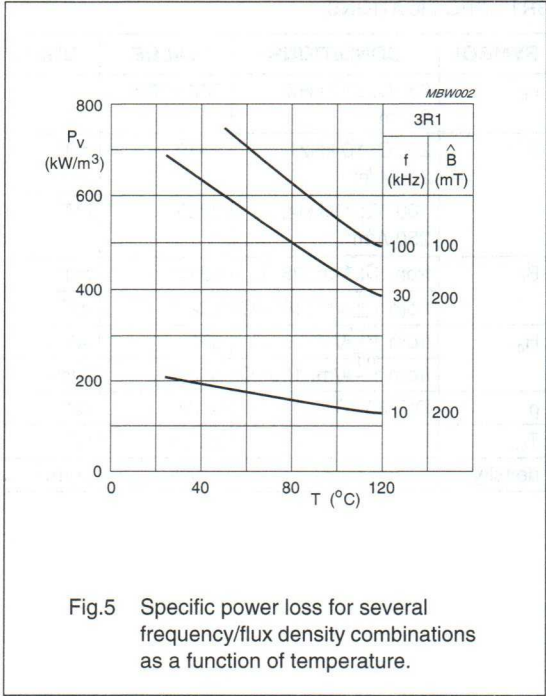
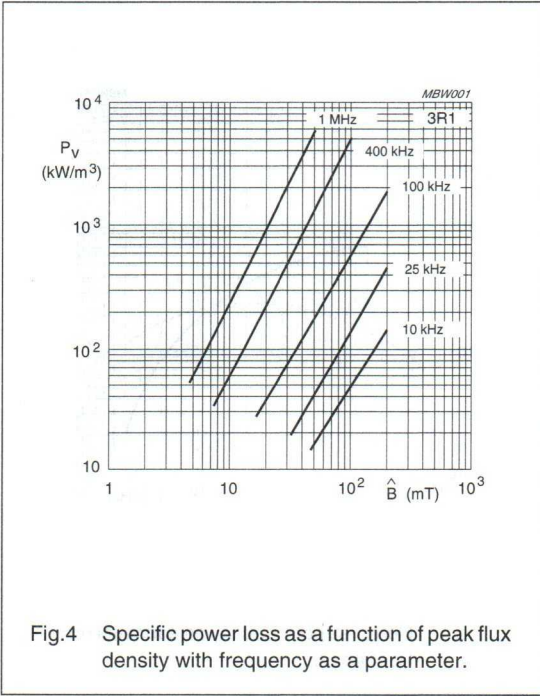


Fig.3 Typical B-H loops.

Material grade specification

3R1



Resonance

When 3R1 ring cores are driven exactly at their natural mechanical resonant frequencies, a magneto-elastic resonance will occur. With large flux excursions and no mechanical damping, amplitudes can become so high that the maximum tensile stress of the ferrite is exceeded. Cracks or even breakage of the ring core could be the result. It is advised not to drive the toroidal cores at their radial resonant frequencies or even subharmonics (e.g. half this resonant frequency).

Resonant frequencies can be calculated for any ring core with the following simple formula:

$$f_r = \frac{5700}{\pi \left(\frac{D_o + D_i}{2} \right)} \text{ kHz}$$

where:

- f_r = radial resonant frequency (kHz)
- D_o = outside diameter (mm)
- D_i = inside diameter (mm).

Material grade specification

4A11

4A11 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$700 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 270	mT
	100 °C; 10 kHz; 250 A/m	≈ 180	mT
$\tan\delta/\mu_i$	25 °C; 1 MHz; 0.1 mT	$\leq 100 \times 10^{-6}$	
	25 °C; 3 MHz; 0.1 mT	$\leq 1000 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 125	°C
density		≈ 5100	kg/m^3

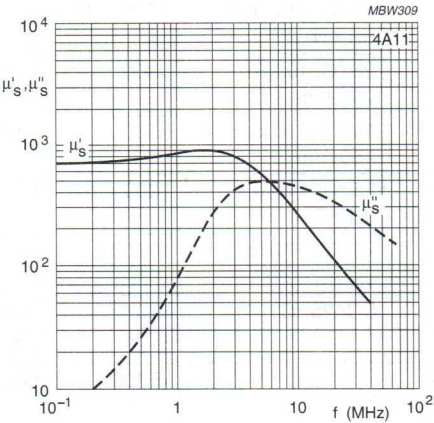


Fig.1 Complex permeability as a function of frequency.

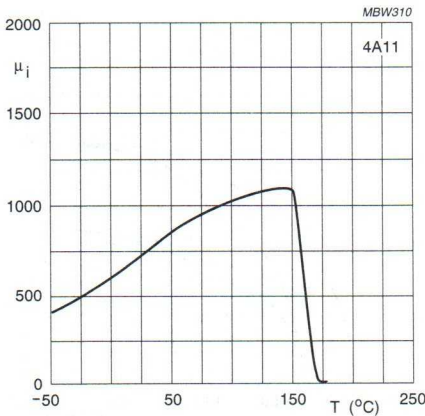


Fig.2 Initial permeability as a function of temperature.

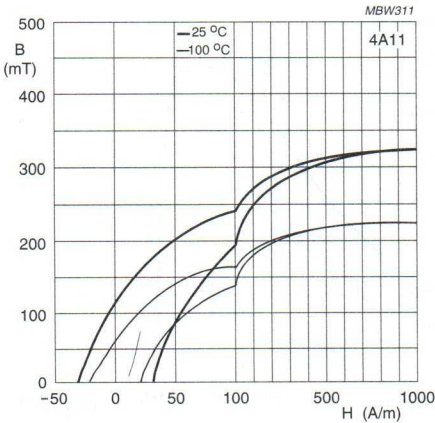


Fig.3 Typical B-H loops.

Material grade specification

4A15

4A15 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$1200 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 300	mT
	100 °C; 10 kHz; 250 A/m	≈ 180	mT
$\tan \delta / \mu_i$	25 °C; 1 MHz; 0.1 mT	$\leq 300 \times 10^{-6}$	
	25 °C; 3 MHz; 0.1 mT	$\leq 1500 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 125	°C
density		≈ 5100	kg/m^3

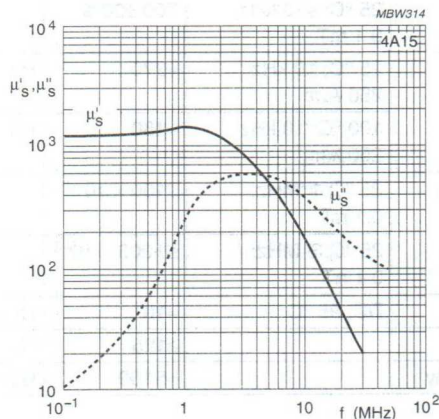


Fig.1 Complex permeability as a function of frequency.

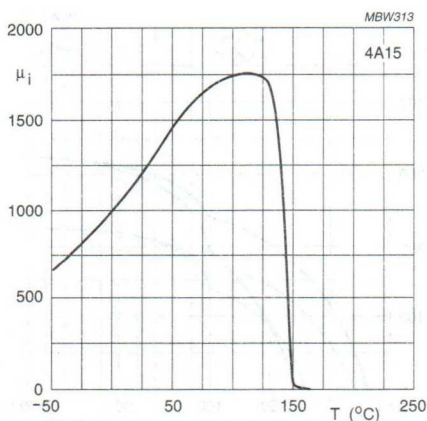


Fig.2 Initial permeability as a function of temperature.

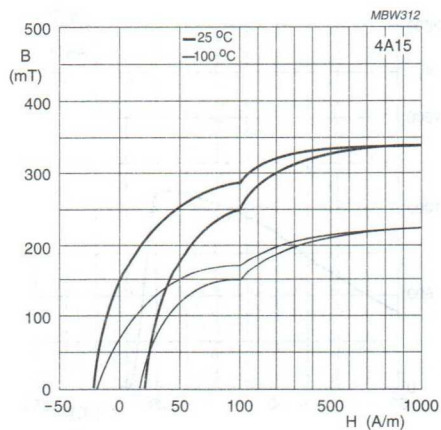


Fig.3 Typical B-H loops.

Material grade specification

4B1

4B1 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$250 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 310	mT
	100 °C; 10 kHz; 250 A/m	≈ 260	mT
$\tan\delta/\mu_i$	25 °C; 1 MHz; 0.1 mT	$\leq 90 \times 10^{-6}$	
	25 °C; 3 MHz; 0.1 mT	$\leq 300 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 250	°C
density		≈ 4600	kg/m^3

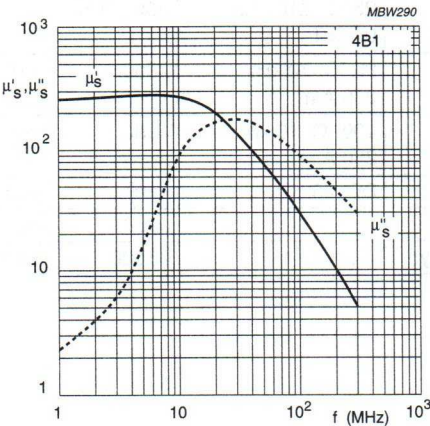


Fig.1 Complex permeability as a function of frequency.

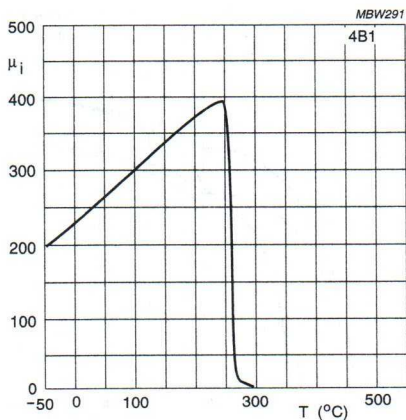


Fig.2 Initial permeability as a function of temperature.

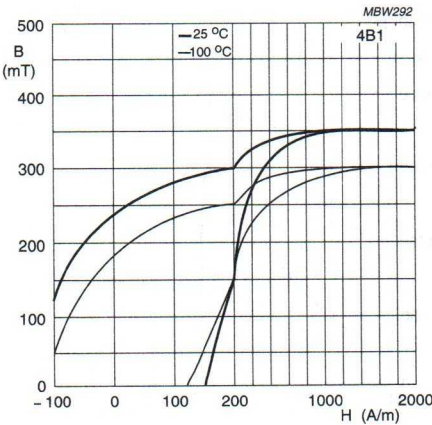


Fig.3 Typical B-H loops.

Material grade specification

4B3

4B3 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$300 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 300	mT
	100 °C; 10 kHz; 250 A/m	≈ 250	mT
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 250	°C
density		≈ 5000	kg/m^3

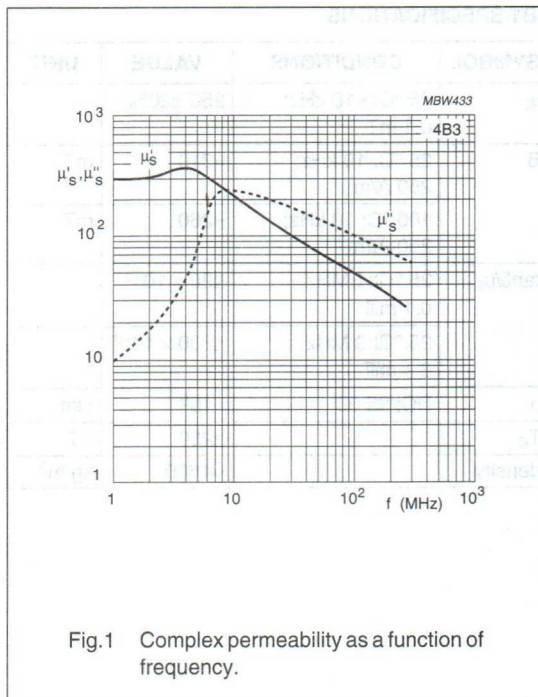


Fig.1 Complex permeability as a function of frequency.

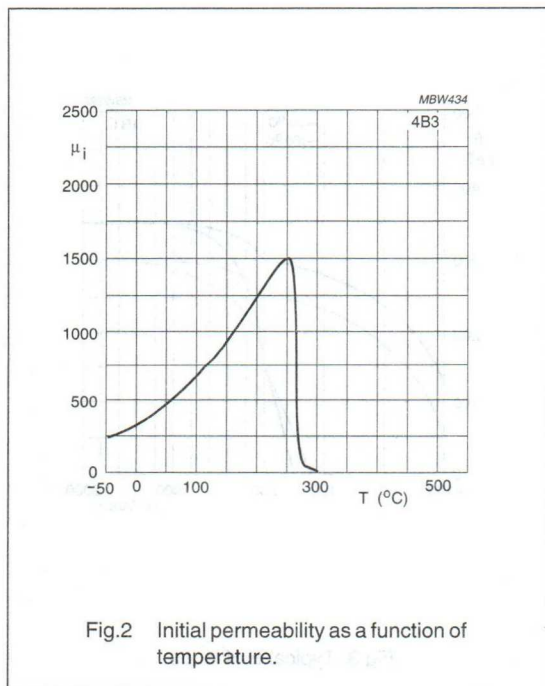


Fig.2 Initial permeability as a function of temperature.

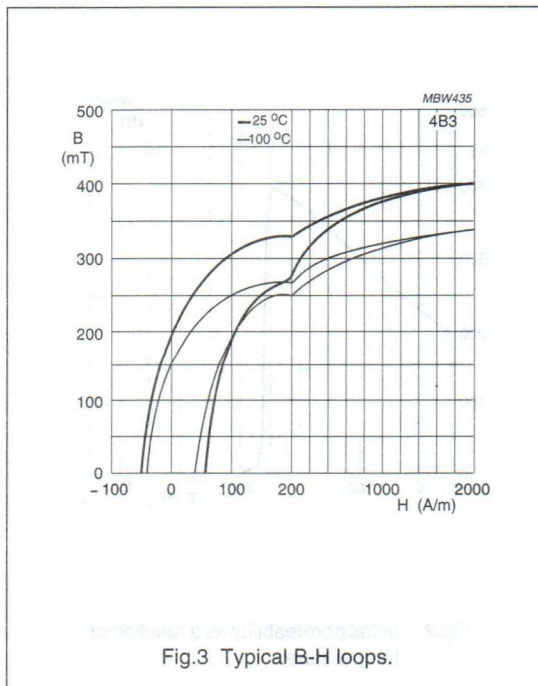


Fig.3 Typical B-H loops.

Material grade specification

4C65

4C65 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$125 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 300	mT
	100 °C; 10 kHz; 250 A/m	≈ 250	mT
$\tan\delta/\mu_i$	25 °C; 3 MHz; 0.1 mT	$\leq 80 \times 10^{-6}$	
	25 °C; 10 MHz; 0.1 mT	$\leq 130 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 350	°C
density		≈ 4500	kg/m^3

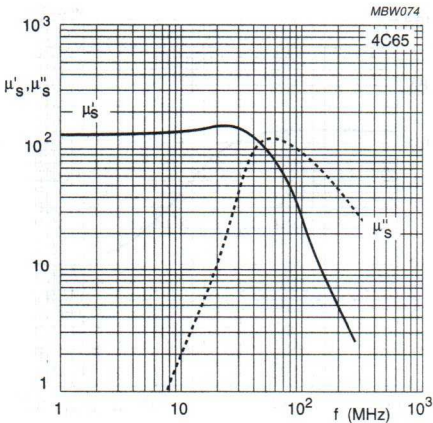


Fig.1 Complex permeability as a function of frequency.

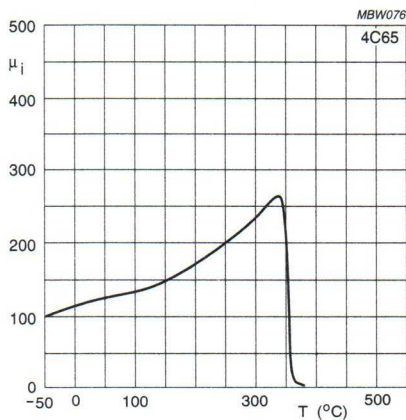


Fig.2 Initial permeability as a function of temperature.

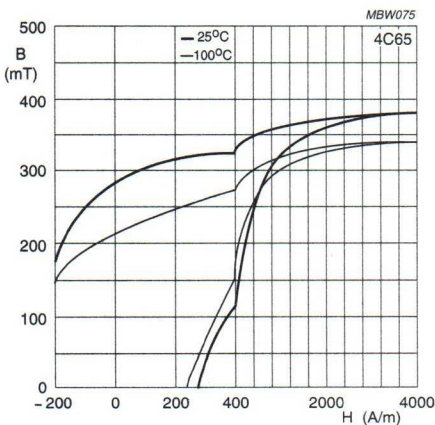
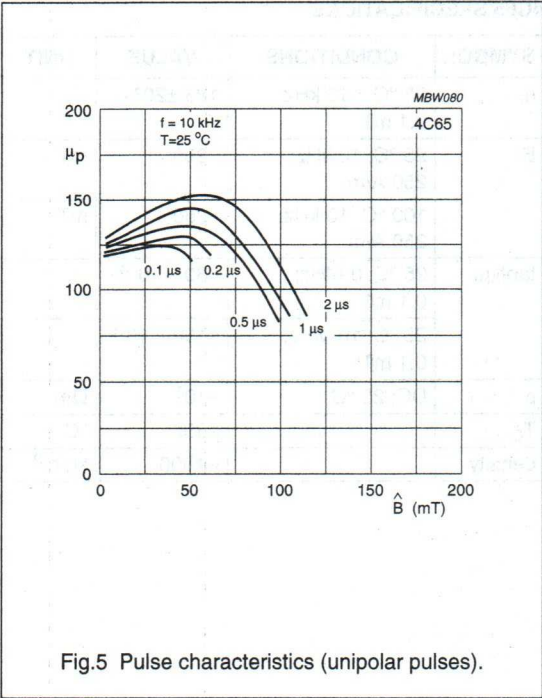
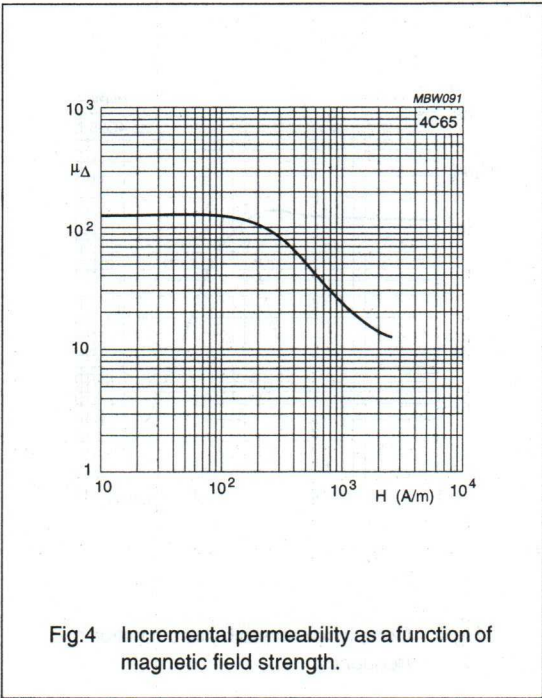


Fig.3 Typical B-H loops.

Material grade specification

4C65



Material grade specification

4D2

4D2 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$60 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 200	mT
	100 °C; 10 kHz; 250 A/m	≈ 180	mT
$\tan\delta/\mu_i$	25 °C; 10 MHz; 0.1 mT	$\leq 100 \times 10^{-6}$	
	25 °C; 30 MHz; 0.1 mT	$\leq 600 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 400	°C
density		≈ 4200	kg/m^3

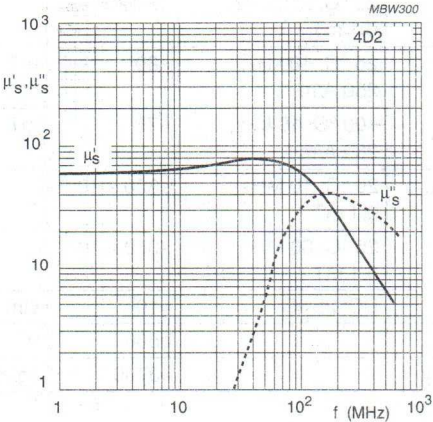


Fig.1 Complex permeability as a function of frequency.

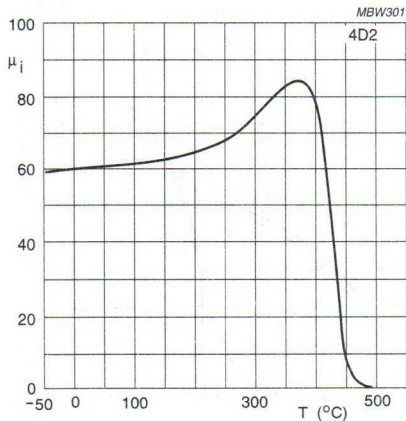


Fig.2 Initial permeability as a function of temperature.

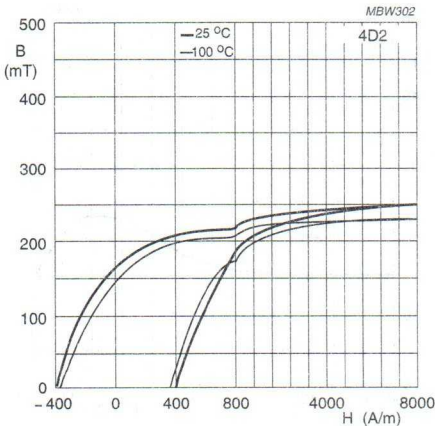


Fig.3 Typical B-H loops.

Material grade specification

4E1

4E1 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$15 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 80	mT
	100 °C; 10 kHz; 250 A/m	≈ 75	mT
$\tan \delta / \mu_i$	25 °C; 10 MHz; 0.1 mT	$\leq 300 \times 10^{-6}$	
	25 °C; 30 MHz; 0.1 mT	$\leq 350 \times 10^{-6}$	
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 500	°C
density		≈ 3700	kg/m^3

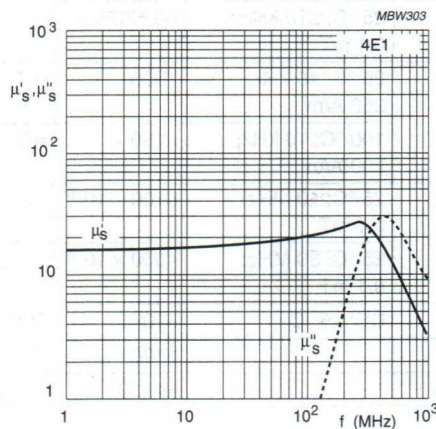


Fig.1 Complex permeability as a function of frequency.

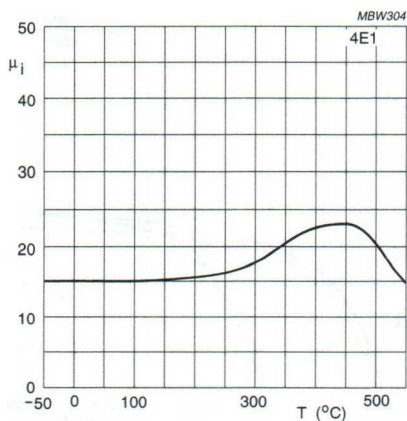


Fig.2 Initial permeability as a function of temperature.

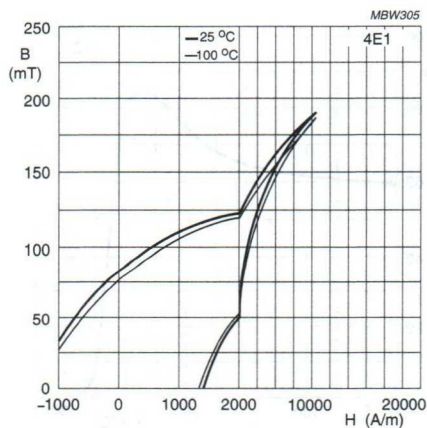


Fig.3 Typical B-H loops.

Material grade specification

4E2

4E2 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$25 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 150	mT
	100 °C; 10 kHz; 250 A/m	≈ 150	mT
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_c		≥ 400	°C
density		≈ 4000	kg/m^3

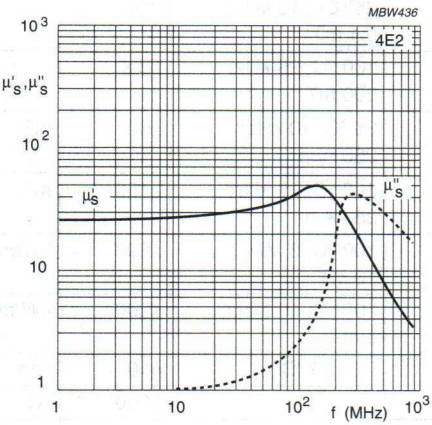


Fig.1 Complex permeability as a function of frequency.

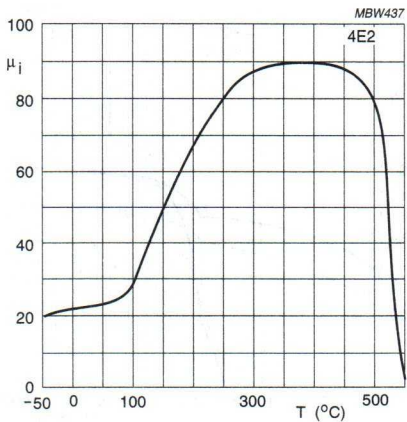


Fig.2 Initial permeability as a function of temperature.

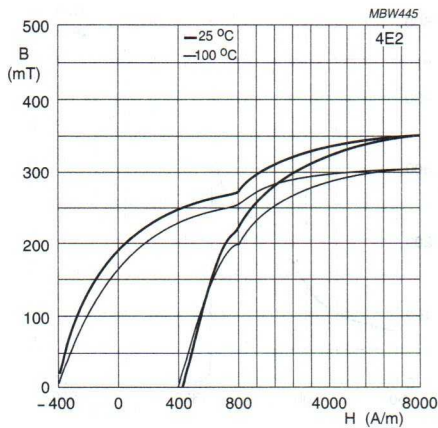


Fig.3 Typical B-H loops.

Material grade specification

Material grade specification 4F1

4F1 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	≈ 80	
μ_a	100 °C; 25 kHz; 200 mT	≈ 300	
B	25 °C; 10 kHz; 250 A/m	≥ 50	mT
	100 °C; 10 kHz; 250 A/m	≥ 100	mT
P_v	100 °C; 3 MHz; 10 mT	≤ 200	kW/m ³
	100 °C; 10 MHz; 5 mT	≤ 200	kW/m ³
ρ	DC; 25 °C	$\approx 10^5$	Ω m
T_C		≥ 260	°C
density		$\approx 4\,600$	kg/m ³

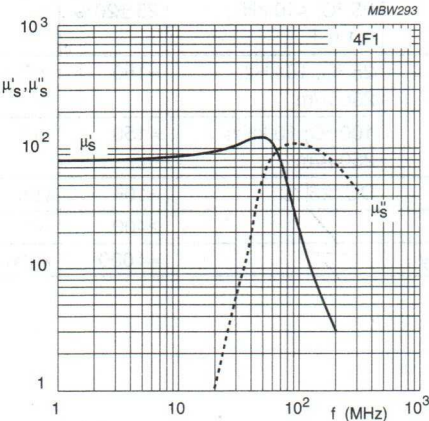


Fig.1 Complex permeability as a function of frequency.

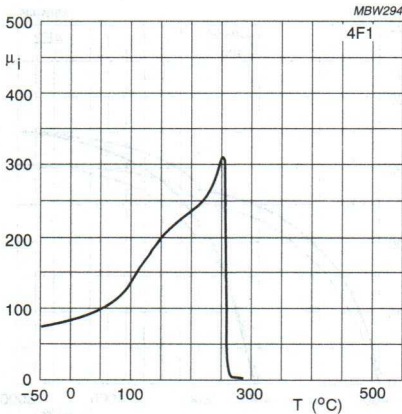


Fig.2 Initial permeability as a function of temperature.

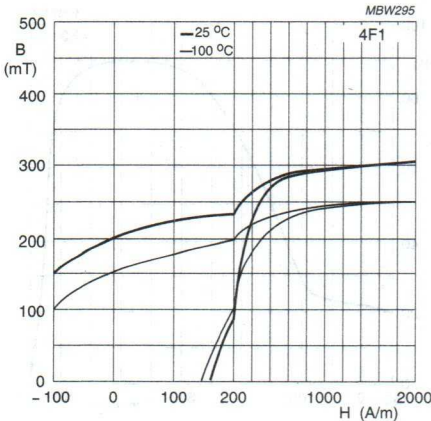


Fig.3 Typical B-H loops.

Material grade specification

4F1

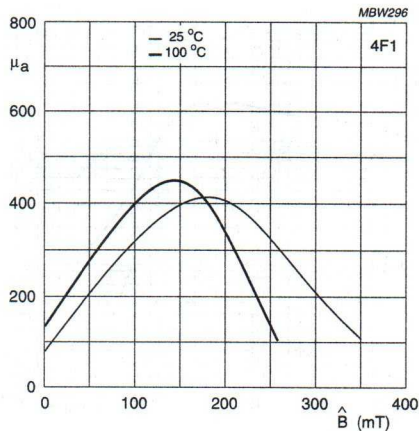


Fig.4 Amplitude permeability as function of peak flux density.

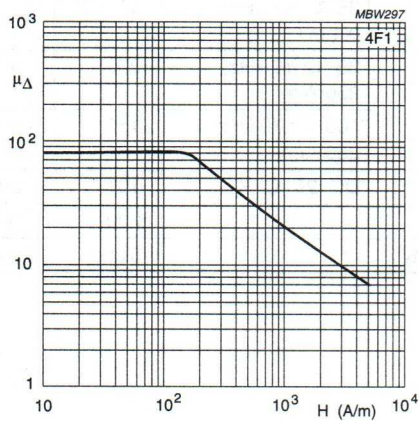


Fig.5 Incremental permeability as a function of magnetic field strength.

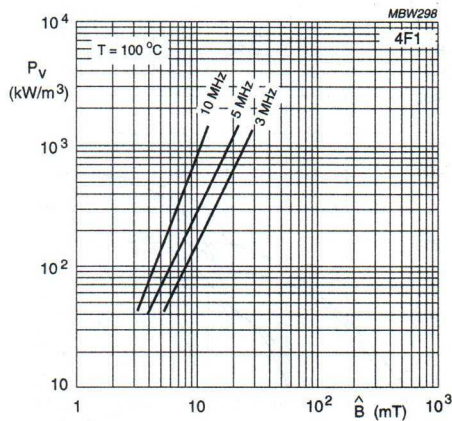


Fig.6 Specific power loss as a function of peak flux density with frequency as a parameter.

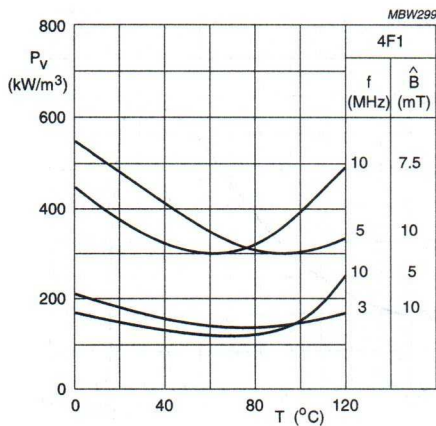


Fig.7 Specific power loss for several frequency/flux density combinations as a function of temperature.

Material grade specification

4M2

4M2 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$140 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 250	mT
	100 °C; 10 kHz; 250 A/m	≈ 150	mT
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_c		≥ 200	°C
density		$\approx 5\,000$	kg/m^3

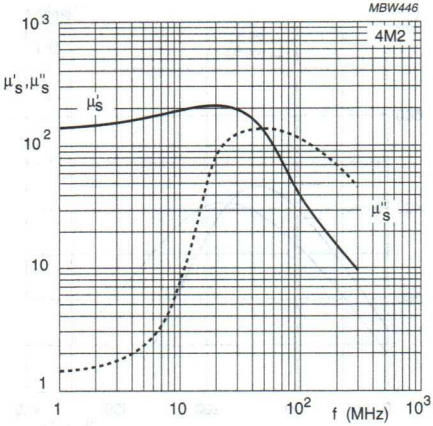


Fig.1 Complex permeability as a function of frequency.

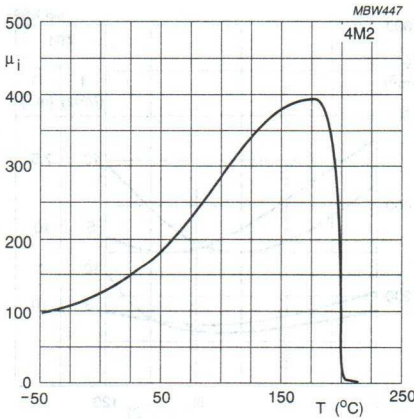


Fig.2 Initial permeability as a function of temperature.

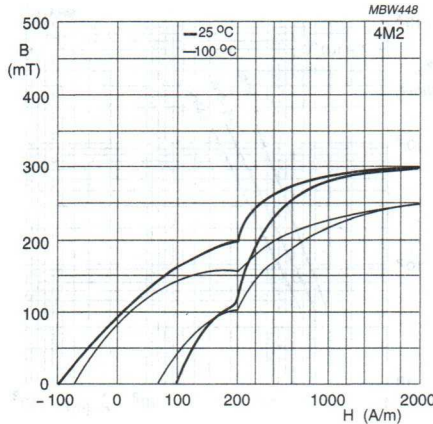


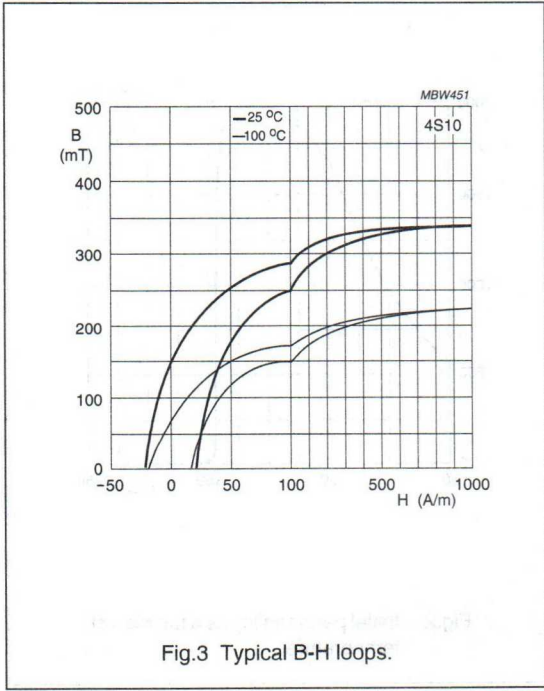
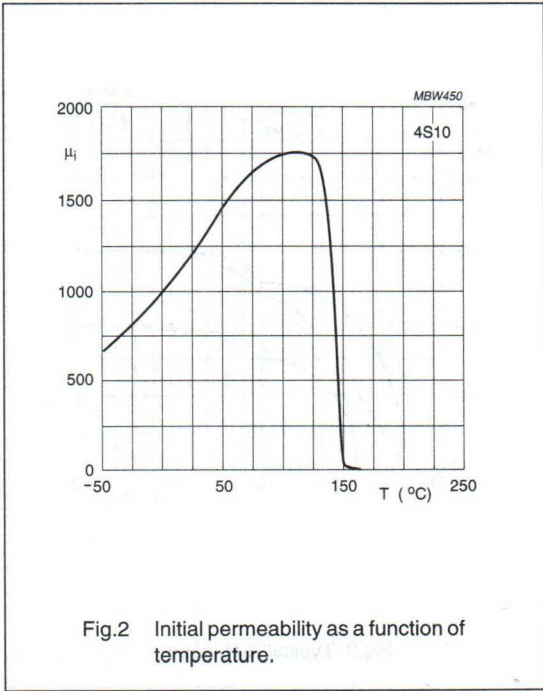
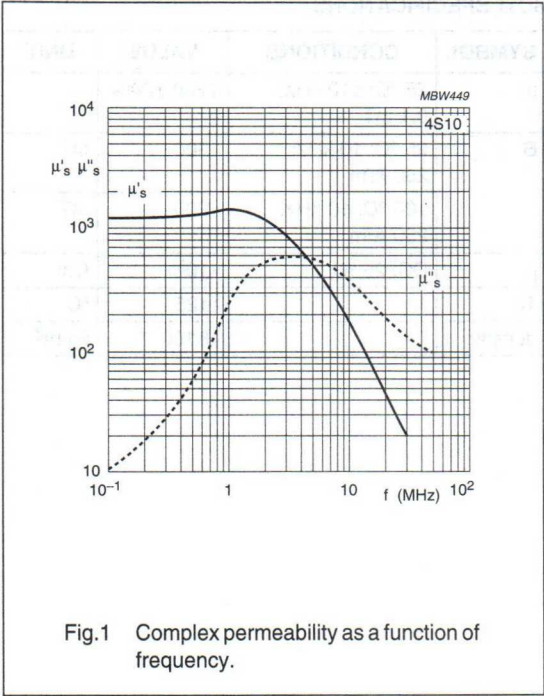
Fig.3 Typical B-H loops.

Material grade specification

4S10

4S10 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$1200 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 300	mT
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 125	°C
density		≈ 5100	kg/m^3



Material grade specification

8C11

8C11 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$1200 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 300	mT
	100 °C; 10 kHz; 250 A/m	≈ 200	mT
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_C		≥ 125	°C
density		≈ 5100	kg/m^3

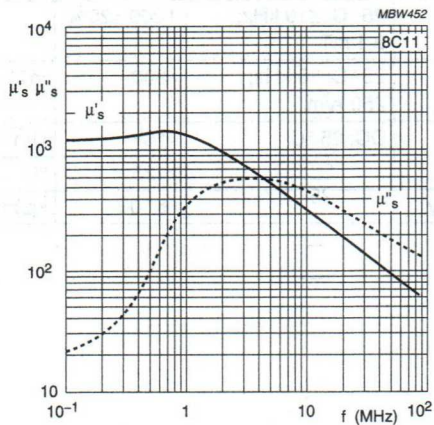


Fig.1 Complex permeability as a function of frequency.

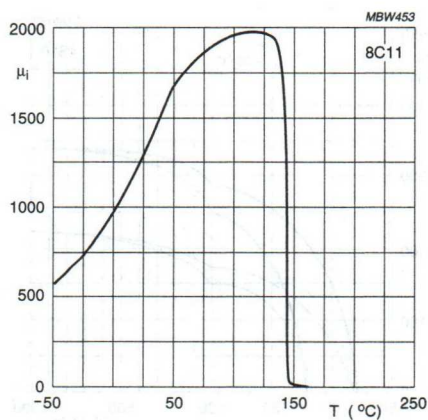


Fig.2 Initial permeability as a function of temperature.

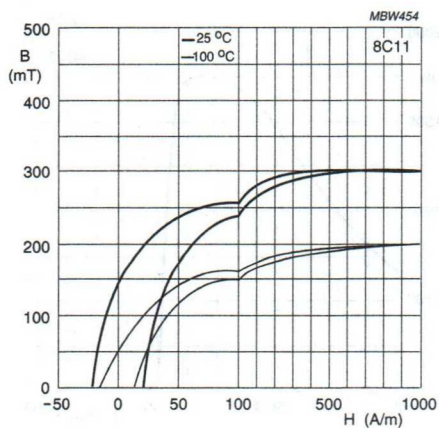


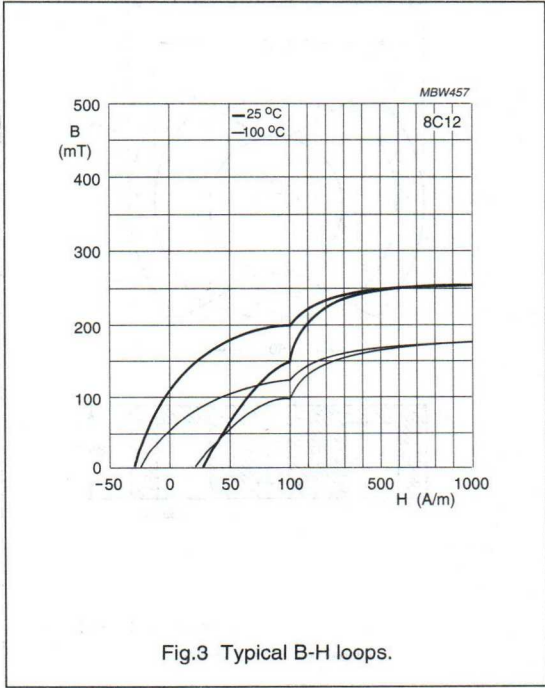
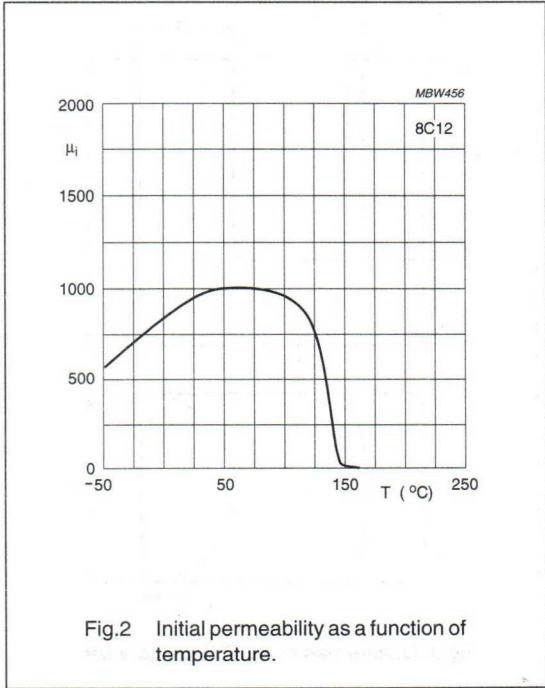
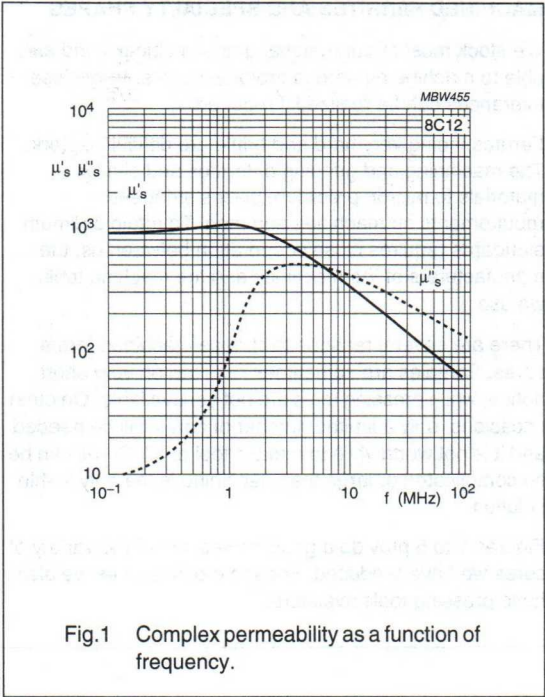
Fig.3 Typical B-H loops.

Material grade specification

8C12

8C12 SPECIFICATIONS

SYMBOL	CONDITIONS	VALUE	UNIT
μ_i	25 °C; ≤ 10 kHz; 0.1 mT	$900 \pm 20\%$	
B	25 °C; 10 kHz; 250 A/m	≈ 230	mT
	100 °C; 10 kHz; 250 A/m	≈ 150	mT
ρ	DC; 25 °C	$\approx 10^5$	Ωm
T_c		≥ 125	°C
density		≈ 5100	kg/m^3



Machined ferrites

Survey

MACHINED FERRITES AND SPECIALTY SHAPES

We stock most of our material grades in blocks and are able to machine numerous prototype cores. Very close tolerances can be realized if required.

Ferrites, being very hard and brittle are difficult to work. The machining and grinding of ferrites and similar materials to micron precision, places stringent requirements on machines and men. To attain optimum standards requires close cooperation between us, the manufacturers of the machines and the machine tools we use.

There are several reasons to choose machined ferrite cores. Samples are sometimes required on very short notice, while pressing tools are not yet available. On other occasions, only a limited number of cores will be needed and it is not worthwhile to make a tool at all. Cores can be so complicated or large that machining is the only viable solution.

Figures 1 to 5 provide a good impression of the variety of cores we have produced. For some of the cores we also have pressing tools available.

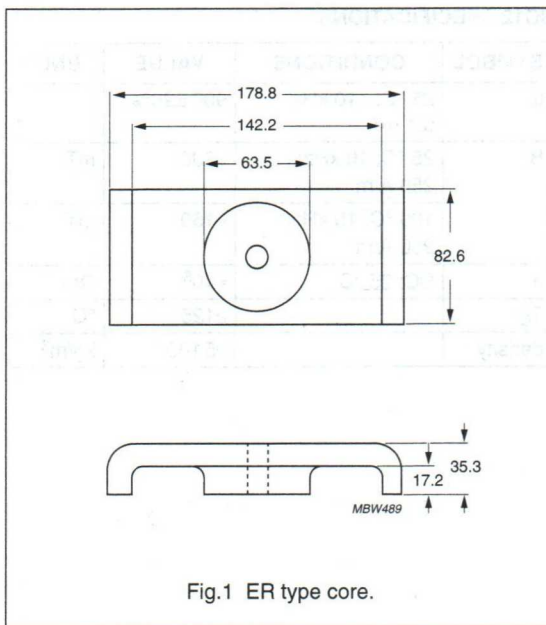


Fig.1 ER type core.

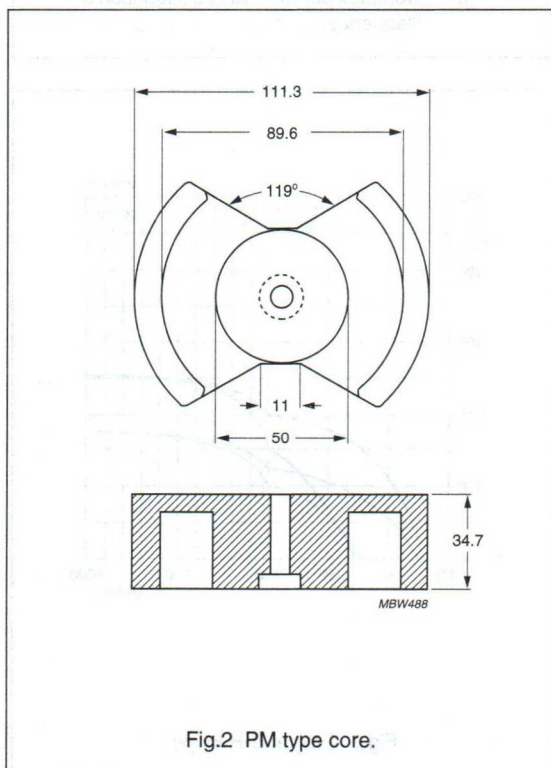


Fig.2 PM type core.

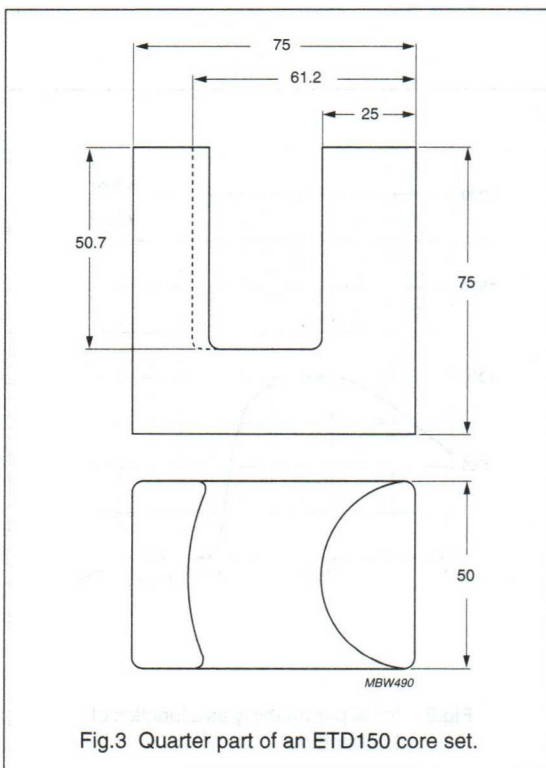


Fig.3 Quarter part of an ETD150 core set.

Machined ferrites

Survey

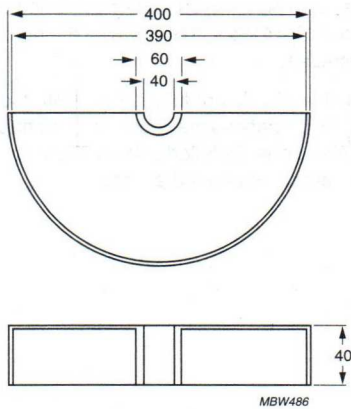
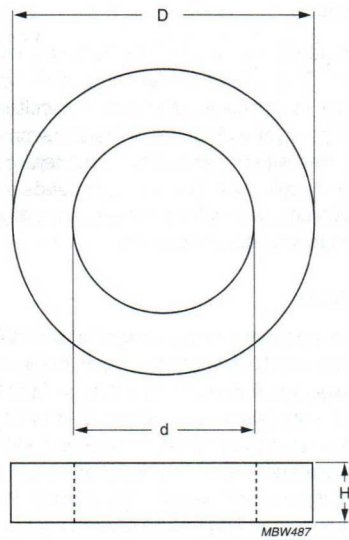


Fig.4 Hufe P core section.

Fig.5 Example of large ring cores:
T90/40/35, T120/60/35, T130/80/35.

Ferrites for particle accelerators

Introduction

FERRITE IN SCIENTIFIC PARTICLE ACCELERATORS

The application

Ferrites are used extensively in modern scientific experiments. One of the most exciting and advanced applications is in particle accelerators. Scientists are trying to discover the mysteries of the universe by smashing atomic particles with titanic forces. This requires particle beams to be accelerated to very high speeds and guided into a collision chamber with the help of specially designed magnetic rings and kicker magnets.

Our materials

At Philips' research and development laboratories located in Eindhoven, The Netherlands, we can build on 50 years' experience in ferrite technology. We developed the required materials which fulfil the demanding specifications. Due to our long involvement with ferrite technology, we are one of only two major suppliers in the world who support such demanding projects. Because of the extremely demanding nature of the specifications, these magnetic rings and blocks are designed and developed in close interaction with the scientists. This has enabled us to develop unique material grades, which are processed in our highly controlled production environment to deliver the required product performance.

Our product range

Our range of large ring cores and blocks was developed especially for use in scientific particle accelerators. Applications include kicker magnets and acceleration stations. Dynamic behaviour under pulse conditions is important for both applications, so special ferrite grades are optimized for low losses at high flux densities. These large rings have also been used successfully in delay lines for very high powers such as in pulsed lasers or radar equipment. Sizes other than those mentioned in the following tables can be made on request.

- Standard range of sizes
- Optimized grades for particle accelerators
- Other sizes on request.

General properties of the grades are described in the section on Material Grades. Specific properties, related to their use in particle accelerators, are provided in the following table.

Relevant properties of ferrites in accelerator applications

Properties specified in this section are related to room temperature (25 °C) unless otherwise stated. They have been measured on sintered, non-ground ring cores of dimension $\varnothing 25 \times \varnothing 15 \times 10$ mm which are not subjected to external stresses.

Products generally do not fully comply with the material specification. Deviations may occur due to shape, size and grinding operations. Detailed specifications are given in the data sheets or product drawings.

Ferrites for particle accelerators

Material grades

MATERIAL GRADES

Material grades and relevant values

PARAMETER	8C11	8C12	4M2	4E2	4B3
μ_i ($\pm 20\%$)	1200	900	140	25	300
μ_{rem} approx.	850	600	130	20	—
B_s 25 °C (mT, 800 A/m)	≥ 300	280	250	250	≥ 300
B_s 40 °C (mT, 800 A/m)	≥ 280	250	220	220	—
H_c (A/m, after 800 A/m)	≤ 20	30	100	500	< 80
ρ DC (Ωm)	$> 10^5$	$> 10^5$	$> 10^5$	$> 10^5$	$> 10^5$
T_c (°C)	≥ 125	≥ 125	≥ 150	≥ 400	≥ 250
μQ in remanence 200 kHz:					
10 mT		15×10^3			
20 mT		9×10^3			
50 mT		4×10^3			
μQ in remanence 500 kHz:					
10 mT		10×10^3			
20 mT		6×10^3			
50 mT		25×10^3			
μQ in remanence 1 MHz:					
5 mT		10×10^3	20×10^3		
10 mT		75×10^3	20×10^3		
20 mT		5×10^3	15×10^3		
30 mT		—	8×10^3		
μQ in remanence 2.5 MHz:					
5 mT			20×10^3		
10 mT			20×10^3		
20 mT			15×10^3		
30 mT			7×10^3		
μQ in remanence 5 MHz:					
5 mT			15×10^3		
10 mT			15×10^3		
20 mT			10×10^3		
30 mT			7×10^3		
μQ in remanence 10 MHz:					
5 mT			12×10^3		
10 mT			10×10^3		
μQ in remanence 80 MHz:					
1 mT				2.5×10^3	
μQ in remanence 100 MHz				2×10^3	

Ferrites for particle accelerators

Material grades

PARAMETER	8C11	8C12	4M2	4E2	4B3
Decrease in μQ (%), measured 10 ms after application of DC bias (approx.)		10	15	30	
μ_A with DC bias field (approx.):					
0 A/m		600	130		
250 A/m		120	80		
500 A/m		50	40		
1000 A/m		22	22		
2000 A/m		8	12		
3000 A/m		5.5	8		
Frequency range (with or without DC bias) in MHz		0.5 to 10	2 to 10	20 to 100	
Application area and special features	kicker magnets; high resistance	high frequency ratio possible with DC bias	fast recovery after magnetic bias	high frequency material	high ($B_s + B_r$)

Ferrite for particle accelerators

T76/38/13

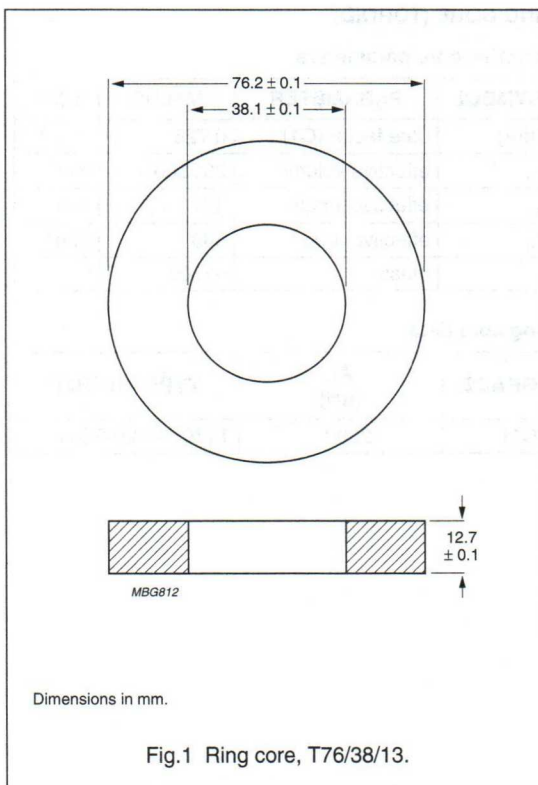
RING CORES (TOROIDS)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.716	mm^{-1}
V_e	effective volume	38500	mm^3
l_e	effective length	166	mm
A_e	effective area	232	mm^2
	mass	≈ 220	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
4M2	≈ 250	T76/38/13-4M2
8C11	≈ 2000	T76/38/13-8C11
8C12	≈ 1600	T76/38/13-8C12



Ferrite for particle accelerators

T170/110/20

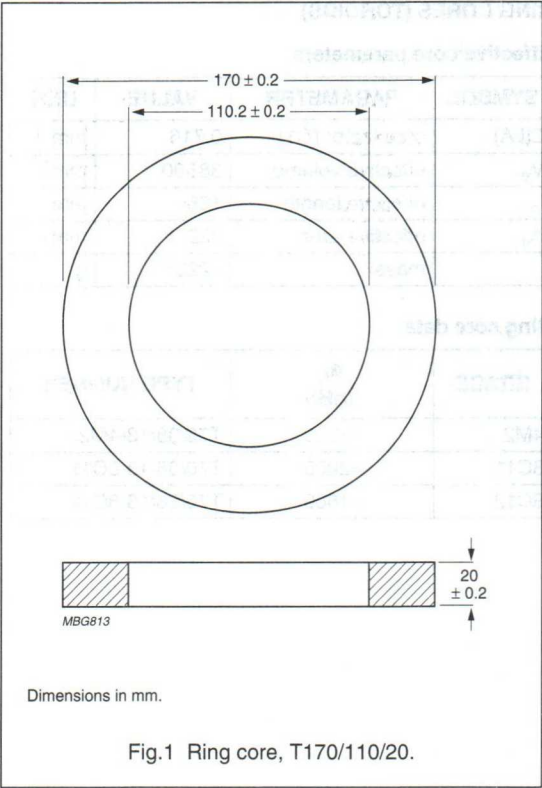
RING CORE (TOROID)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.725	mm ⁻¹
V_e	effective volume	251 500	mm ³
l_e	effective length	427	mm
A_e	effective area	589	mm ²
	mass	≈1300	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
8C11	≈2600	T170/110/20-8C11



Ferrite for particle accelerators

T240/160/20

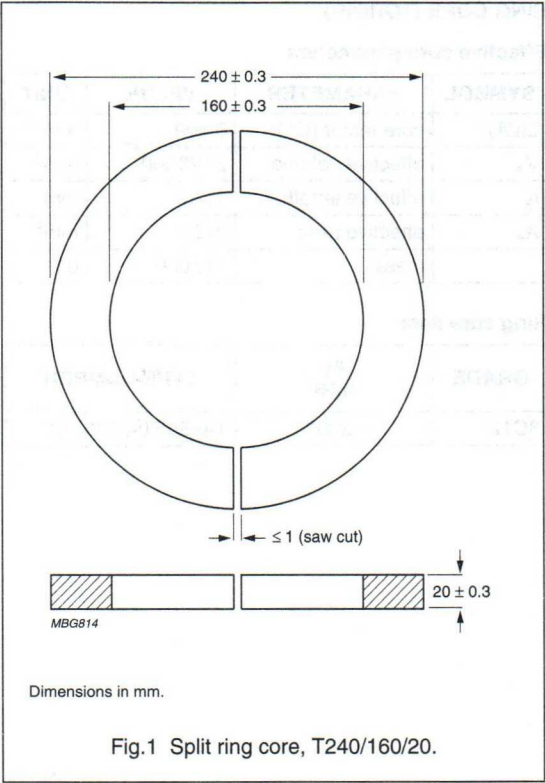
SPLIT RING CORE (TOROID)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.774	mm^{-1}
V_e	effective volume	482000	mm^3
l_e	effective length	611	mm
A_e	effective area	789	mm^2
	mass	≈ 2500	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
8C11	—	T240/160/20-8C11



Ferrite for particle accelerators

T498/270/25

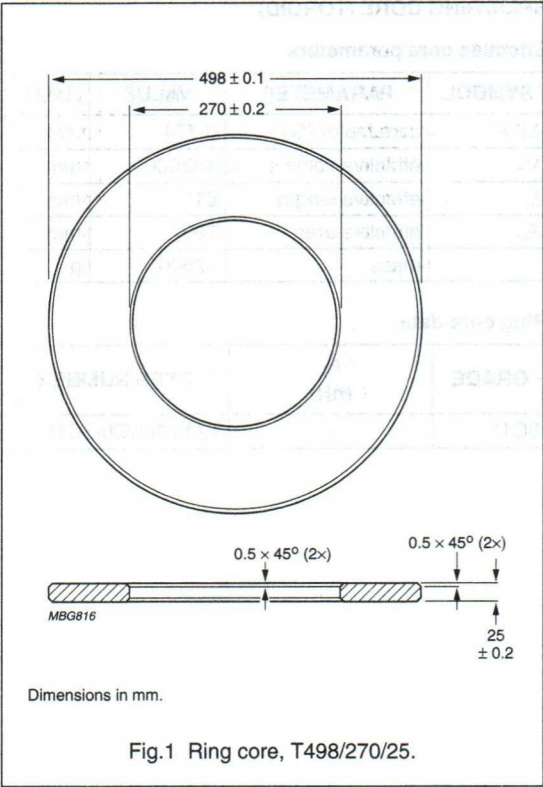
RING CORE (TOROID)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.409	mm^{-1}
V_e	effective volume	3120000	mm^3
l_e	effective length	1130	mm
A_e	effective area	2760	mm^2
	mass	≈ 17000	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
8C12	≈ 2800	T498/270/25-8C12



Ferrite for particle accelerators

T498/300/25

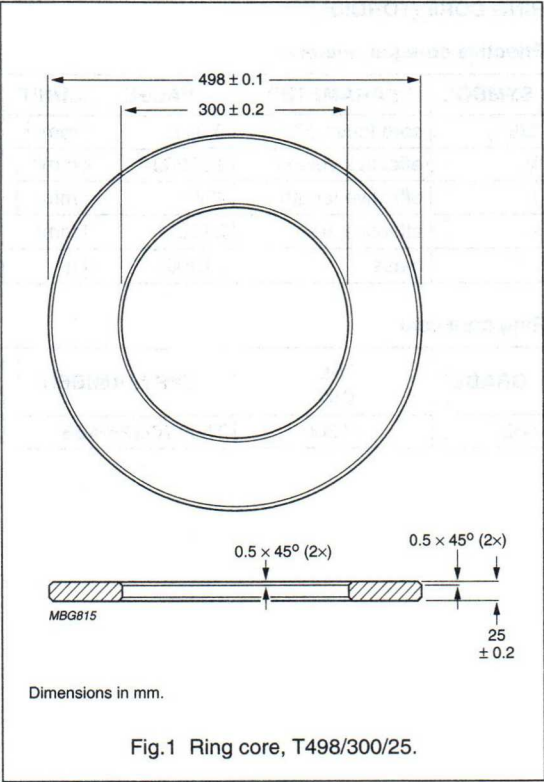
RING CORE (TOROID)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.496	mm^{-1}
V_e	effective volume	2900000	mm^3
l_e	effective length	1200	mm
A_e	effective area	2420	mm^2
	mass	≈ 15000	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
8C12	≈ 2300	T498/300/25-8C12



Ferrite for particle accelerators

T500/240/25

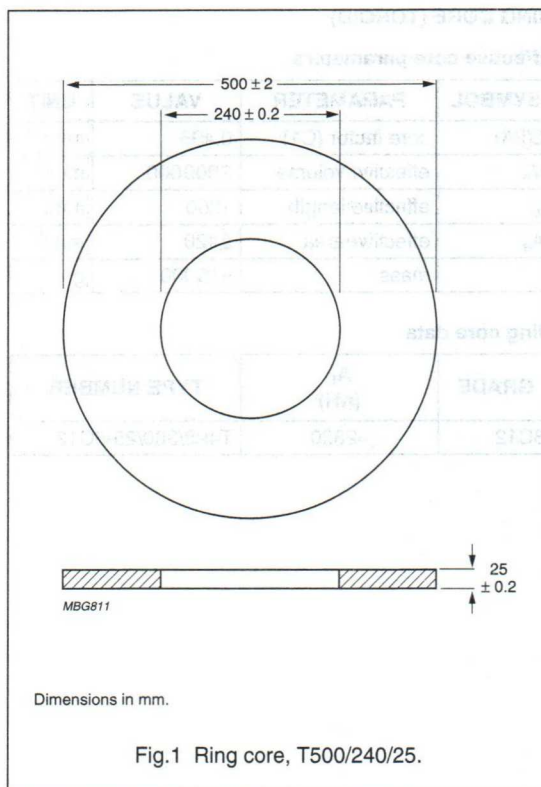
RING CORE (TOROID)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.342	mm ⁻¹
V_e	effective volume	3300000	mm ³
l_e	effective length	1060	mm
A_e	effective area	3100	mm ²
	mass	≈19000	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
4B3	≈1300	T500/240/25-4B3



Ferrite for particle accelerators

T500/300/25

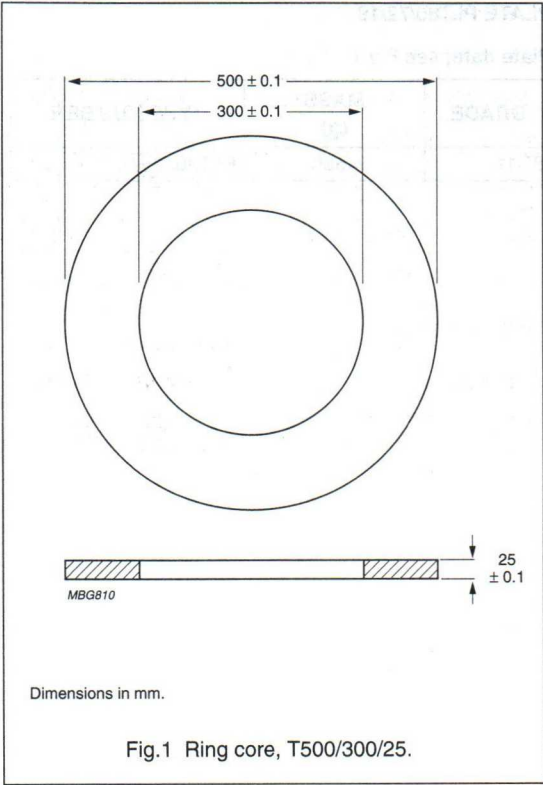
RING CORE (TOROID)

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.49	mm^{-1}
V_e	effective volume	2950000	mm^3
l_e	effective length	1200	mm
A_e	effective area	2450	mm^2
	mass	≈ 16000	g

Ring core data

GRADE	A_L (nH)	TYPE NUMBER
4M2	≈ 350	T500/300/25-4M2



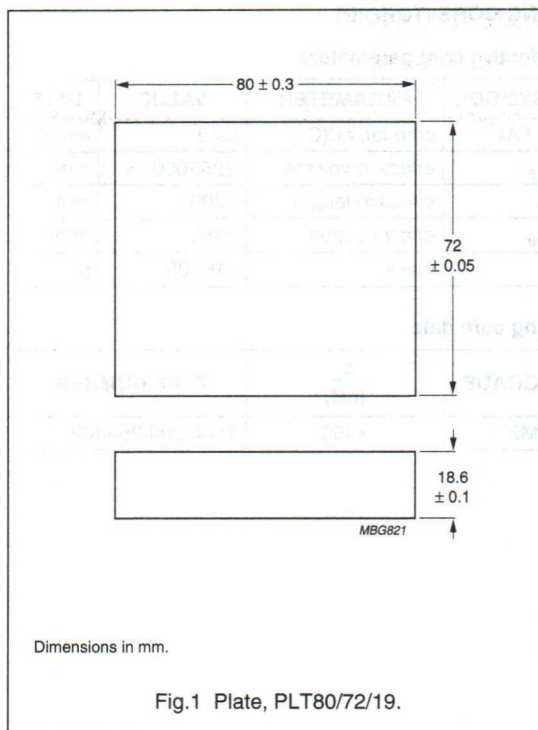
Ferrite for particle accelerators

PLT80/72/19

PLATE PLT80/72/19

Plate data; see Fig.1

GRADE	MASS (g)	TYPE NUMBER
8C11	≈550	PLT80/72/19



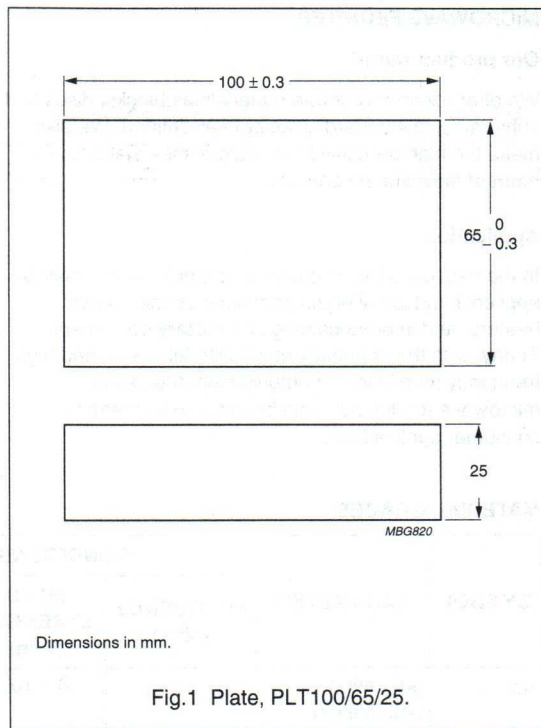
Ferrite for particle accelerators

PLT100/65/25

PLATE PLT100/65/25

Plate data; see Fig.1

GRADE	MASS (g)	TYPE NUMBER
8C11	≈800	PLT100/65/25



Microwave ferrites

Introduction

MICROWAVE FERRITES

Our product range

We offer microwave ferrite materials as blocks, discs and substrates, in standard sizes or user-defined. We also make the high permittivity ceramic bodies that form the heart of dielectric resonators.

Application

In the past decades, microwave technology was mainly applied in industrial equipment such as microwave heaters, and in broadcasting and military equipment. Today, with the popularity of satellite television and high frequency mobile telecommunication, the use of microwave ferrites has also become widespread for consumer applications.

Microwave components

Isolators and circulators are key components in microwave technology. Isolators are used to separate an amplifier from its load, to avoid possible damage by reflected power. Circulators make it possible for transmitters and receivers to share the same antenna, or to use an antenna for simultaneous transmission and reception. Both components are based on special microwave ferrite grades, usually yttrium ferrites, also known as garnets.

MATERIAL GRADES

SYMBOL	PARAMETER	CONDITIONS			5G1	5G2	5G8	UNIT
		FREQUENCY (MHz)	FIELD STRENGTH (A/m)	TEMP. (°C)				
J _S	saturation polarization		8×10^5	25 ± 5	178 ± 9	100 ± 9	182.5 ± 9	mT
ΔH	line width	9600			2000 ± 600	1800 ± 600	< 800	A/m
ΔH _K	spin wave line width	9600			> 24	—	> 24	A/m
H _C	coercivity		800		35	—	15.9	A/m
tan δ _(ε)	dielectric loss factor	9600			< 2×10^{-4}	< 2×10^{-4}	< 3×10^{-4}	
ε'	dielectric constant				15.5 ± 0.5	14.6 ± 0.5	15.3 ± 0.75	
	temperature coefficient of J _S		8×10^5	0 to 25 25 to 60	−0.36	−0.29	−0.61	mT/K
g	Landé factor			25 ± 5	2.00	2.05	2.00	
B _r	remanence		800		120	—	102	mT
B _s	saturation flux density		800		145	—	—	mT
T _C	Curie temperature				240	220	230	°C
ρ	resistivity			25 ± 5	> 10 ⁴	> 10 ⁴	> 10 ⁸	Ωm
	density				5140	5060	5210	kg/m ³

Microwave ferrites

Discs

DISCS

Our standard range of microwave ferrite discs is shown in Table 1. Customized sizes are available on request.

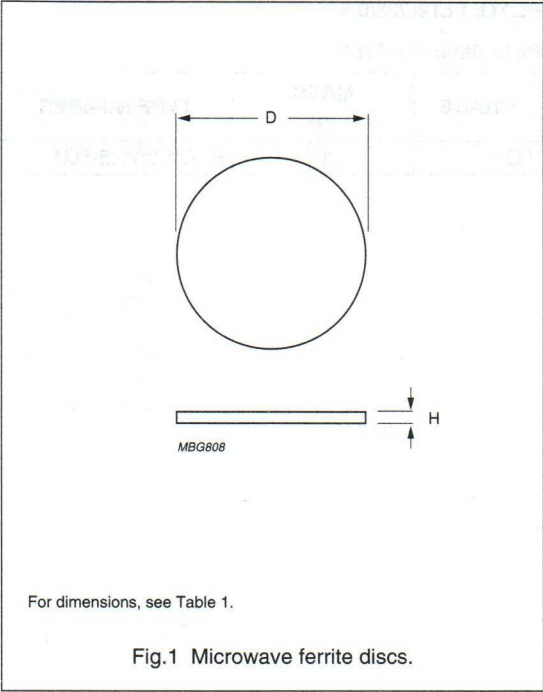


Table 1 Disc data; see Fig.1

GRADE	D (mm)	H (mm)	MASS (g)	TYPE NUMBER
5G1	25	1.5	≈3.8	DSC25/1.5-5G1
	27	1.5	≈4.4	DSC27/1.5-5G1
	32	1.0	≈4.1	DSC32/1-5G1
	32	2.0	≈8.2	DSC32/2-5G1
	37	1.0	≈5.5	DSC37/1-5G1
	37	1.5	≈8.2	DSC37/1.5-5G1
	51	1.5	≈10.5	DSC51/1.5-5G1
	56	2.9	≈12.5	DSC56/2.9-5G1
	67	2.0	≈36	DSC67/2-5G1
5G2	20	1.0	≈1.6	DSC20/1-5G2
	25	1.0	≈2.5	DSC25/1-5G2
5G8	25	1.0	≈2.5	DSC25/1-5G8

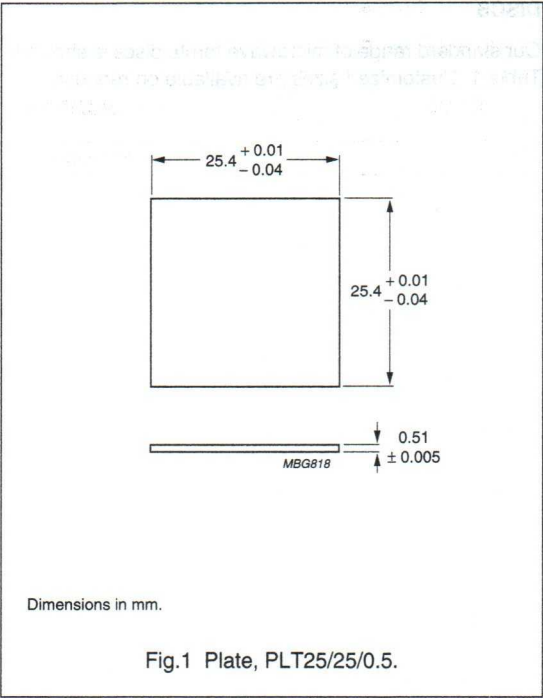
Microwave ferrites

PLT25/25/0.5

PLATE PLT25/25/0.5

Plate data; see Fig.1

GRADE	MASS (g)	TYPE NUMBER
5G1	≈1.6	PLT25/25/0.5-5G1



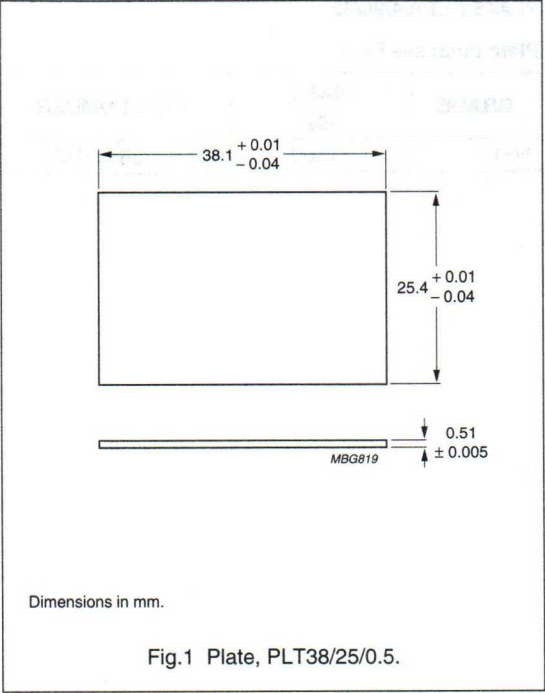
Microwave ferrites

PLT38/25/0.5

PLATE PLT38/25/0.5

Plate data; see Fig.1

GRADE	MASS (g)	TYPE NUMBER
5G1	≈2.4	PLT38/25/0.5-5G1



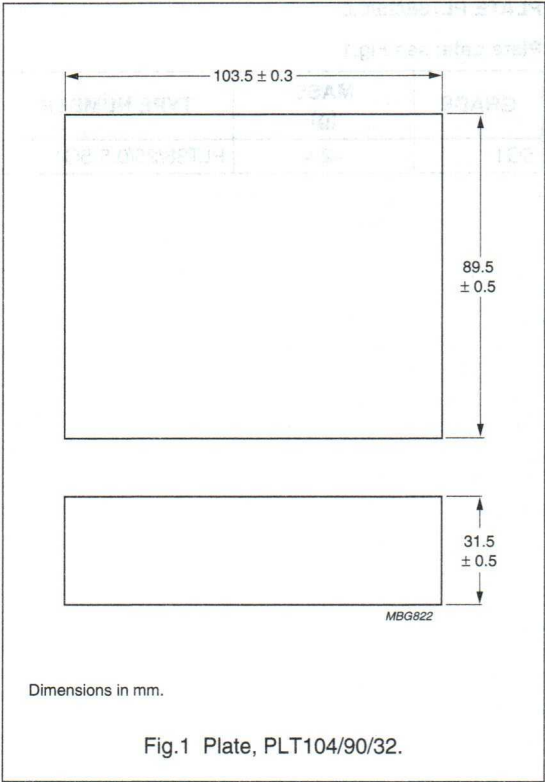
Microwave ferrites

PLT104/90/32

PLATE PLT104/90/32

Plate data; see Fig.1

GRADE	MASS (g)	TYPE NUMBER
5G1	≈ 1500	PLT104/90/32-5G1



Ferrites for EMC products

Introduction

FERRITES FOR ELECTROMAGNETIC SHIELDING AND ABSORPTION

Features

- Broad band absorbing tiles from 30 MHz to 1 GHz.
- Powders and granules to improve properties of surfaces and cables.
- Powders and granules for microwave (radar) absorption at 6 GHz and 20 GHz.

Absorbing tiles

Due to the increasing use of electronic equipment in houses and offices, there is a growing concern about electromagnetic pollution. As a result, regulations are being imposed on the permitted levels of radiation from electronic equipment, as well as its sensitivity to incoming radiation. Controlled measurements must be carried out to check the behaviour of the equipment, before bringing it on the market.

Measurements used to be performed in open-air sites to avoid reflections on walls. Indoor measurements are also possible in anechoic rooms. Walls and ceilings of existing rooms are covered with foam absorbers to attenuate reflected radiation. A drawback of these absorbers, however, is that they have to be rather thick (1 to 2 m) to be effective in the lower frequency range (<100 MHz), thus limiting the usable space in the room.

A new approach is to cover the walls with ferrite tiles, which save space and improve the absorption quality of the room down to frequencies of 30 MHz. Our range of ferrite tiles was developed to give optimum absorption of impinging electromagnetic waves in the frequency range 30 MHz to 1 GHz.

Figure 1 shows that grade 2S10 is effective from 100 MHz to 1 GHz. Figure 2 shows that grade 4S10 covers the range from 30 to 500 MHz. Attenuations between 10 and 30 dB can be reached, enough to bring the room within 3 dB of open site conditions.

Ferrite tiles are also effective in avoiding reflections from buildings or vehicles, and to screen parts of electronic equipment or bunches of cables.

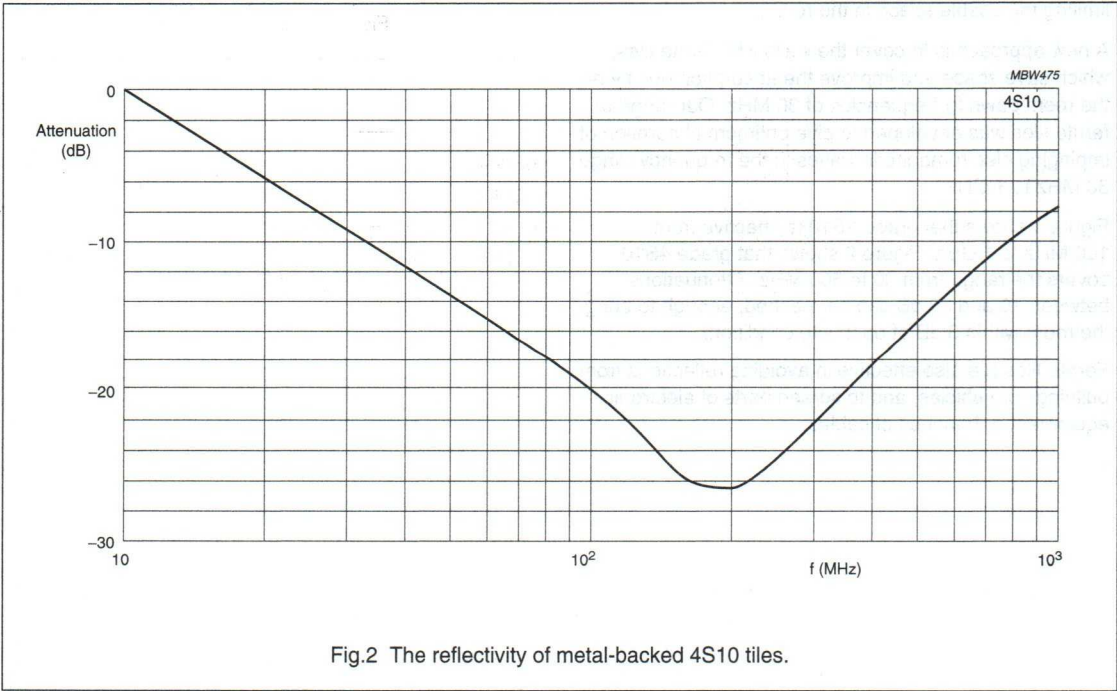
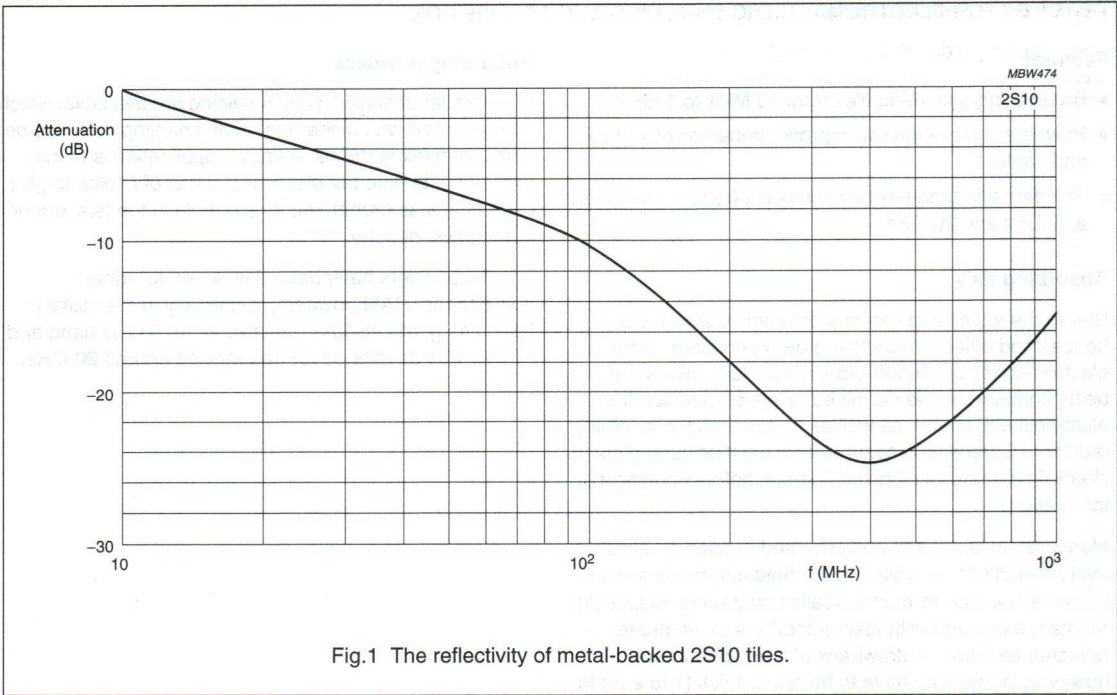
Absorbing powders

Powders for absorption and shielding are available, which can be mixed with binder materials enabling their use on more complex surfaces. A known application is to mix ferrite powder into the plastic insulation of cables to give them low-pass properties, for example in the telecom or automotive industry.

Special powders have been developed for radar applications (RAM powders), especially in the military field. The grade 4S50 is effective in the 6 GHz band and PFP10 was developed for frequencies around 20 GHz.

Ferrites for EMC products

Introduction



Ferrites for EMC products

Plates

ABSORBING FERRITE TILES

These tiles provide effective absorption of electro-magnetic waves in the frequency range from 30 to 1000 MHz.

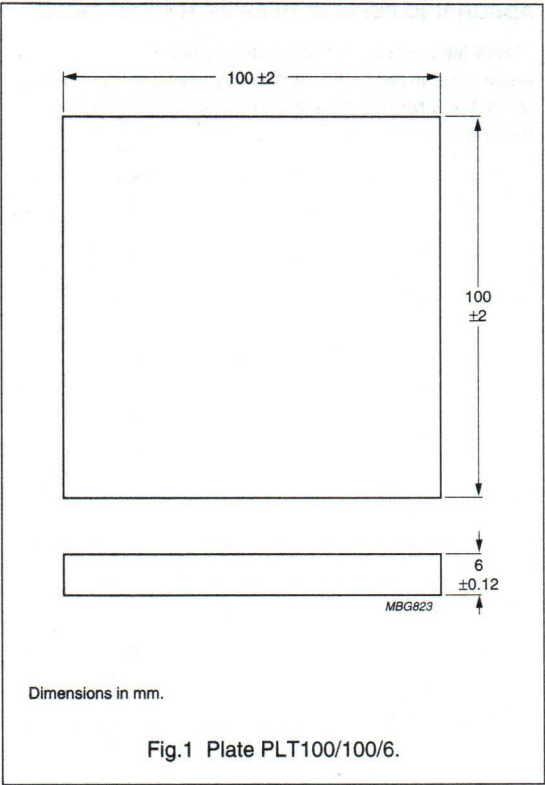


Plate data; see Fig.1

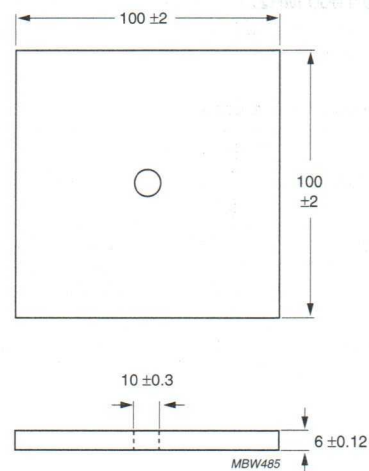
GRADE	FREQUENCY RANGE (MHz)	MASS (g)	TYPE NUMBER
2S10	100 to 1000	≈300	PLT100/100/6-2S10
4S10	30 to 1000		PLT100/100/6-4S10

Ferrites for EMC products

Plates

ABSORBING FERRITE TILES WITH FIXING HOLE

These tiles provide effective absorption of electro-magnetic waves in the frequency range from 30 to 1000 MHz; the central hole simplifies reliable fixation.



Dimensions in mm.

Fig.2 Plate PLT100/100/6/H.

Plate data; see Fig.2

GRADE	FREQUENCY RANGE (MHz)	MASS (g)	TYPE NUMBER
2S10	100 to 1000	≈ 300	PLT100/100/6/H-2S10
4S10	30 to 1000		PLT100/100/6/H-4S10

Ferrites for EMC products

EMI-absorbing powders and granules

SINTERED GRANULES

This coarse powder is made by sintering press granulate and is not milled afterwards. Therefore, it is a more economical solution when the large particle size is of no consequence, or if the powder is to be milled into the binder anyway.

Sintered granule data

GRADE	PARTICLE SIZE (µm)	TYPE NUMBER
2S10	<200	SINT. GRAN-2S10
4S10	<200	SINT. GRAN-4S10
4S50	<200	SINT. GRAN-4S50
PFP10	<200	SINT. GRAN-PFP10

SINTERED POWDERS

These are milled powders for applications such as absorbing paint, where a smaller particle size is required.

Sintered powder data

GRADE	PARTICLE SIZE (µm)	TYPE NUMBER
2S10	<10	SINT. POWDER-2S10
4S10	<10	SINT. POWDER-4S10
4S50	<10	SINT. POWDER-4S50
PFP10	<10	SINT. POWDER-PFP10

Ferrites for magnetic recording

Introduction

MAGNETIC HEADS

Magnetic heads are devices that can read from and write to magnetic information carriers such as tapes and discs. They are applied throughout industry, from simple audio cassette recorders via video recording to advanced disc drives in computer peripherals.

The basic function is always the same. A small magnetic circuit is provided with a winding and a short air gap, which runs in contact (or almost in contact) with the magnetic recording medium. During writing, the coil induces a magnetic flux in the core, which protrudes from the air gap, thus aligning the magnetic particles in the medium. During reading, the field of the aligned particles is picked up by the core area around the air gap and a voltage is generated in the winding.

For the writing operation, it is important that the ferrite has a high saturation flux density; for reading, the permeability should be high enough in the entire frequency range covered. Some magnetic heads, like video heads, are so small that the use of polycrystalline material leads to an unacceptable spread in properties. The active areas would contain only a few crystals which have different properties depending on the orientation of their crystal lattices.

Therefore, for such heads, monocrystals are used, which are cut in the preferred crystal plane. For magnetic heads running in contact with the tape, the ferrite should be dense, virtually without pores and resistant against abrasion.

Most of the designs are highly customized, so that in most circumstances, blocks and plates will be delivered to manufacturers of the complete devices for further machining.

Material grades

8E1, 8E2 AND 8E21

These manganese-zinc materials are intended for the production of erasing heads that are used in audio and video applications. Effective erasing of magnetic tape for a low-noise level requires a high level of induction at a frequency in the range 50 to 100 kHz. Thus, for the use in erasing heads, a low eddy-current-loss core material is recommended. Grade 8E1 is intended for erasing heads for iron-oxide or chromium dioxide tapes. The grades 8E2 and 8E21 are for erasing heads for metal tapes.

8X1

This MnZn single-crystal ferrite is mainly used for the manufacture of video recorder heads. The unique magnetic properties, homogeneity, outstanding wear resistance and the possibility to machine this material to extremely tight tolerances, makes 8X1 ideal for this and other applications where a specified signal level with high information density on a narrow track is required. The magnetic and mechanical characteristics of MnZn single-crystal ferrites depend on the direction of orientation of the crystal.

Please consult us for detailed information.

Ferrites for magnetic recording

Material grades

MATERIAL SPECIFICATIONS

Unless otherwise stated, all properties of the material have been measured at an atmospheric pressure of 86 to 106 kPa and at a relative humidity of 45 to 75%. The coefficient of expansion, α_m , is measured on a rod of approximately $2 \times 2 \times 10$ mm and is determined by: $\Delta L/L_{20}$ (T-20).

DESCRIPTION	FREQ. (kHz)	B (mT)	H (A/m)	TEMP. (°C)	8E1	8E2	8E21	8X1	UNIT
μ_i	≥ 10	< 0.1	—	25	3200	2800	3600	1800; note 1	—
B_s	ballistic	—	250	25	400	490	490	490	mT
$\tan \delta / \mu_i$	100	< 0.1	—	25	3×10^{-6}	3×10^{-6}	2.5×10^{-6}	2×10^{-3}	—
η_B	100	1.5 to 3	—	25	0.5×10^{-3}	0.5×10^{-3}	0.5×10^{-3}	—	T ⁻¹
power losses	45	100	—	25	40	40	20	—	kW/m ³
			—	85	60	60	20	—	kW/m ³
Curie temperature	4	< 0.1	—		180	180	210	180	°C
resistivity	DC	—	—	25	≈ 5	≈ 5	≈ 3	$\approx 3 \times 10^{-3}$	Ωm
density	—	—	—	25	4700	4700	4750		kg/m ³
hardness (Vickers)	—	—	—	—	560	730	730	730	Hv 0.05/30

Note

1. Typical $\mu_i = 600$ at 5 MHz measured on a ring core $\varnothing 9 \times \varnothing 5 \times 0.2$ mm.

Ferrites for magnetic recording

8E1

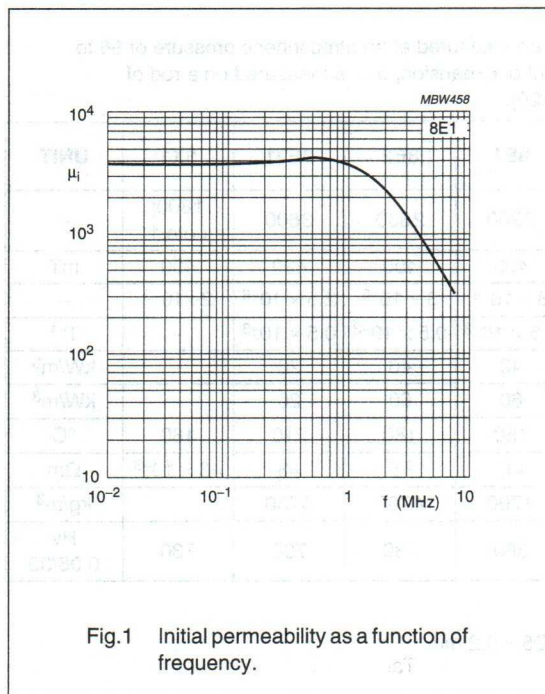


Fig.1 Initial permeability as a function of frequency.

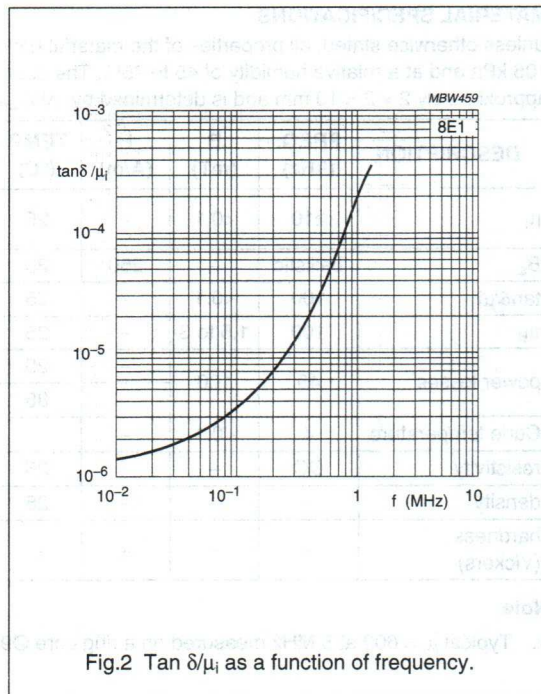


Fig.2 $\tan \delta / \mu_i$ as a function of frequency.

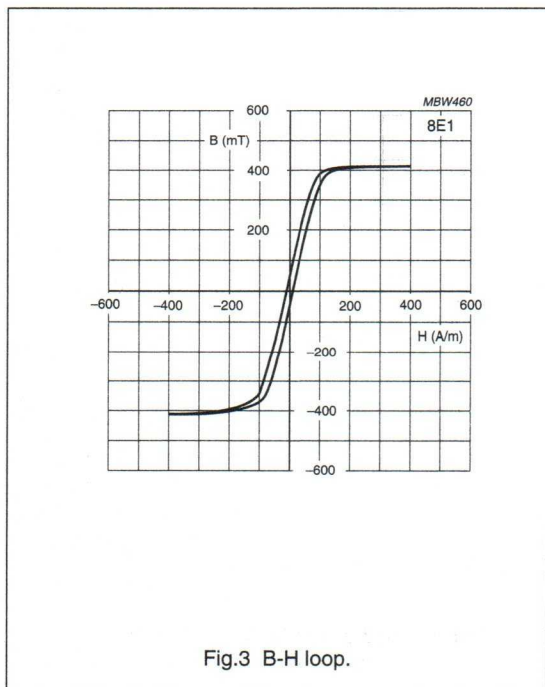


Fig.3 B-H loop.

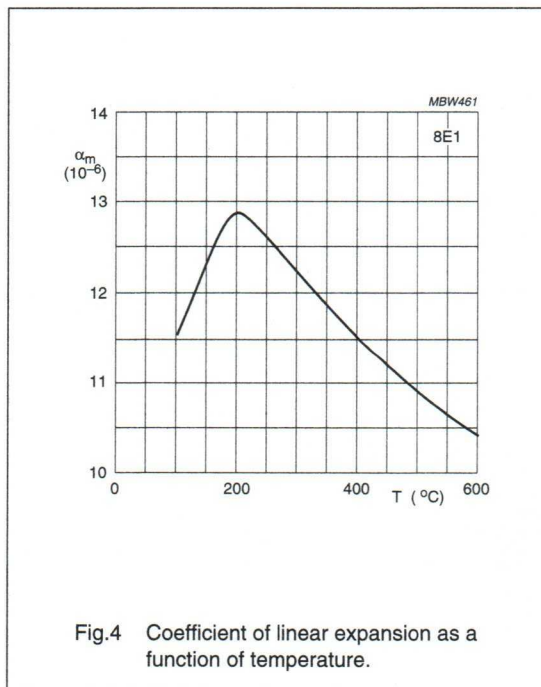


Fig.4 Coefficient of linear expansion as a function of temperature.

Ferrites for magnetic recording

8E2

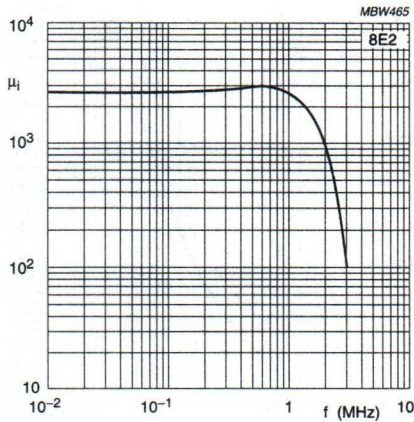


Fig.1 Initial permeability as a function of frequency.

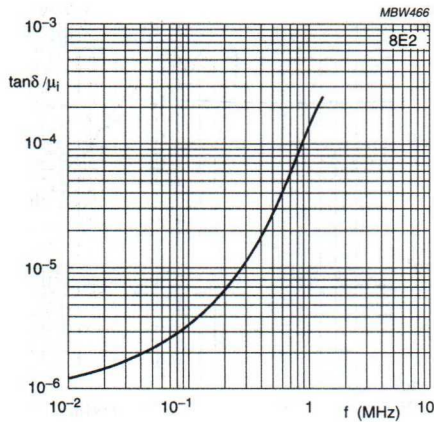


Fig.2 $\tan \delta / \mu_i$ as a function of frequency.

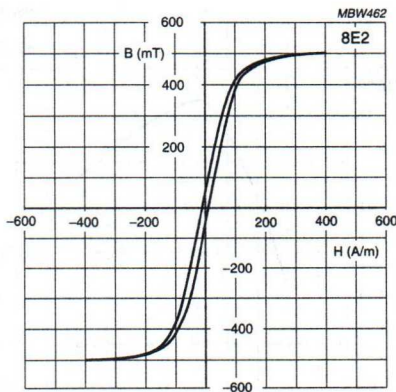


Fig.3 B-H loop.

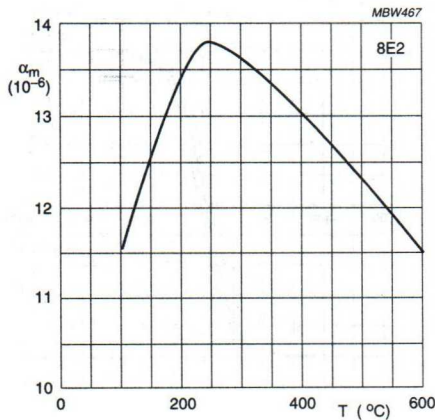


Fig.4 Coefficient of linear expansion as a function of temperature.

Ferrites for magnetic recording

8E21

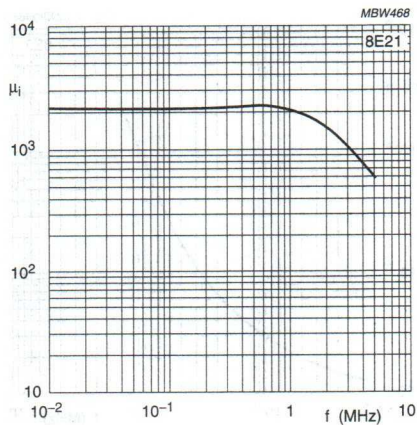


Fig.1 Initial permeability as a function of frequency.

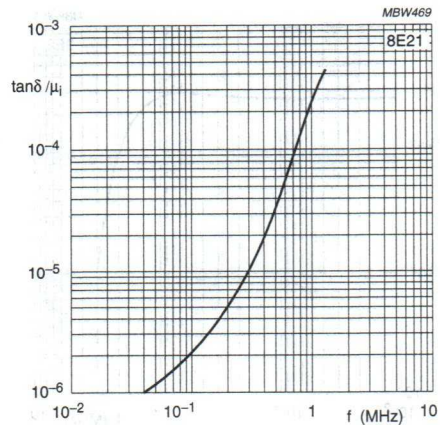
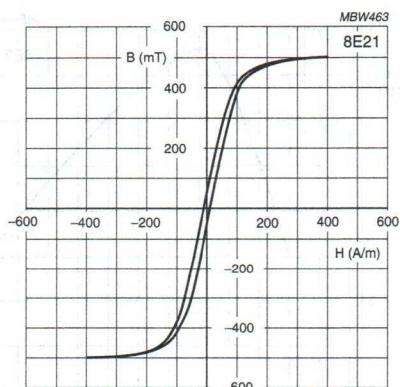
Fig.2 $\tan \delta / \mu_i$ as a function of frequency.

Fig.3 B-H loop.

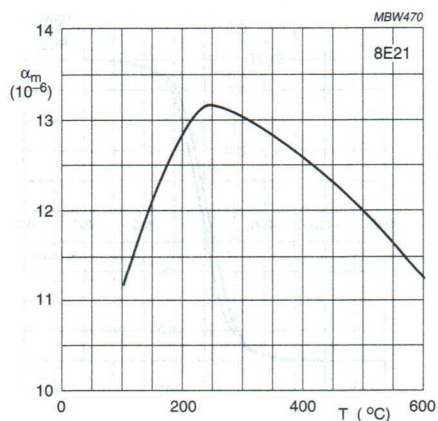


Fig.4 Coefficient of linear expansion as a function of temperature.

Ferrites for magnetic recording

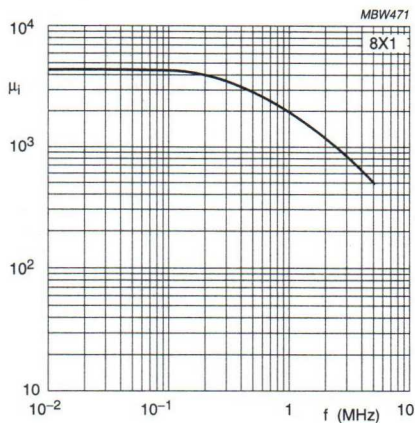


Fig.1 Initial permeability as a function of frequency.

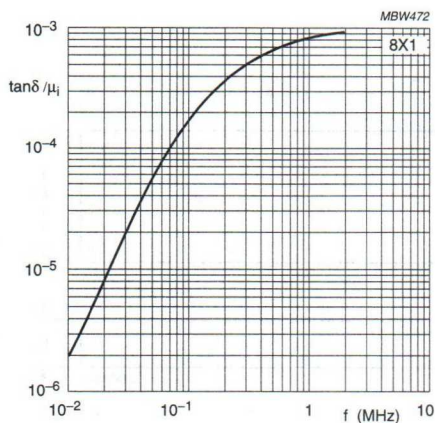
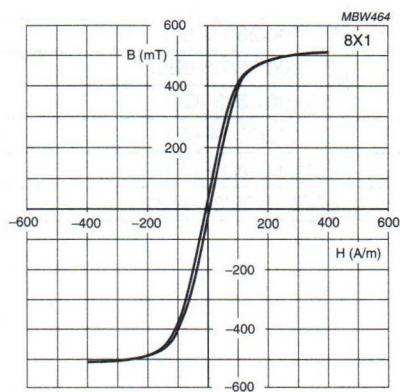
Fig.2 $\tan \delta / \mu_i$ as a function of frequency.

Fig.3 B-H loop.

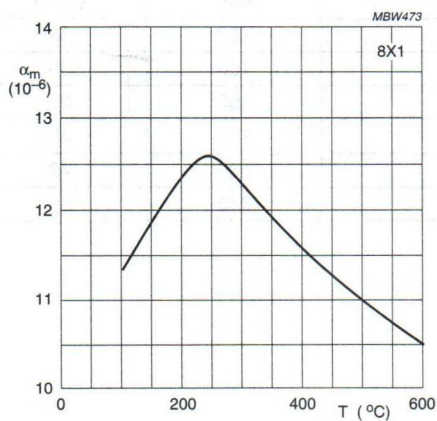


Fig.4 Coefficient of linear expansion as a function of temperature.

Ferrites for magnetic recording

Plates and bars

PLATES AND BARS

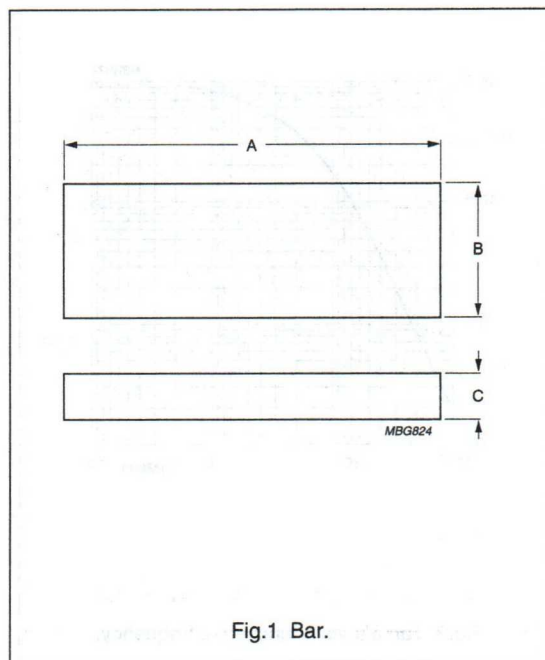


Plate and bar data; see Fig.1

GRADE	A (mm)	B (mm)	C (mm)	TYPE NUMBER
8E1	100	28	12.5	PLT100/28/13-8E1
8E2	100	35	7.8	PLT100/35/7.8-8E2
8E1	100	35	12.5	PLT100/3513-8E1
8E1	100	35	14	PLT100/35/14-8E1
8E1	100	49	14	PLT100/49/14-8E1
8E21	215	39	26	BAR215/39/26-8E21

Ferrites for magnetic recording

Single-crystal plates

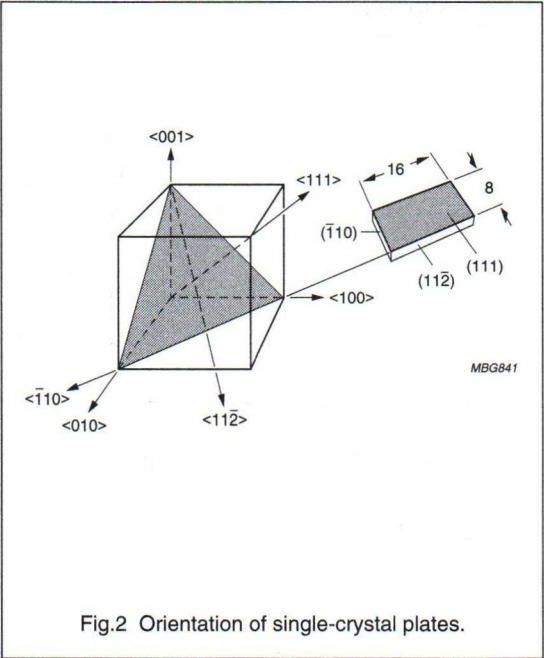
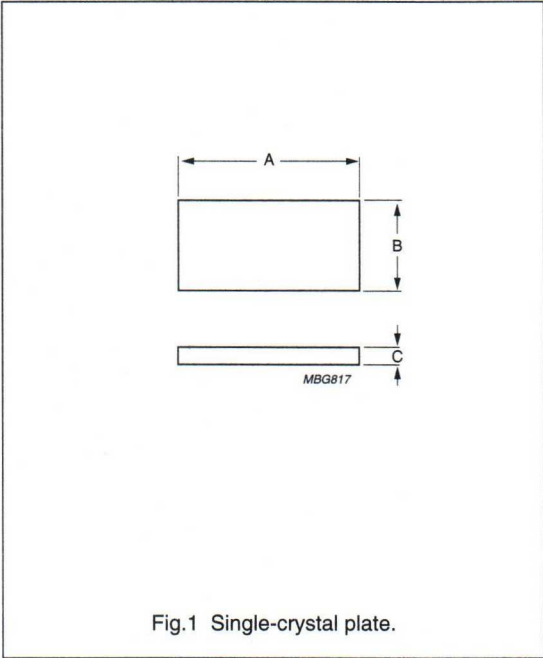


Plate data; see Figs 1 and 2

GRADE	A (mm)	B (mm)	C (mm)	ORIENTATION	TYPE NUMBER
8X1	16	8	1.52	111	PLT16/8/1.5-8X1

DATA HANDBOOK SYSTEM

DATA HANDBOOK SYSTEM

Philips Components data handbooks are available for selected product ranges and contain all relevant data available at the time of publication and each is revised and updated regularly.

Loose data sheets are sent to subscribers to keep them up-to-date on additions or alterations made during the lifetime of each edition.

Our data handbook titles are listed here.

Display components

Book Title

- | | |
|------|---|
| DC01 | Colour TV Picture Tubes and Assemblies |
| DC02 | Monochrome Monitor Tubes and Deflection Units |
| DC03 | Television Tuners, Coaxial Aerial Input Assemblies |
| DC04 | Colour Monitor Tubes |
| DC05 | Flyback Transformers, Mains Transformers and General-purpose FXC Assemblies |

Magnetic products

- | | |
|------|---|
| MA01 | Soft Ferrites |
| MA03 | Piezoelectric Ceramics and Specialty Ferrites |
| MA04 | Dry-reed Switches |

Passive components

- | | |
|------|--|
| PA01 | Electrolytic Capacitors |
| PA02 | Varistors, Thermistors and Sensors |
| PA03 | Potentiometers |
| PA04 | Variable Capacitors |
| PA05 | Film Capacitors |
| PA06 | Ceramic Capacitors |
| PA07 | Quartz Crystals for Special and Industrial Applications |
| PA08 | Fixed Resistors |
| PA10 | Quartz Crystals for Automotive and Standard Applications |
| PA11 | Quartz Oscillators |

MORE INFORMATION FROM PHILIPS COMPONENTS?

For more information about Philips Components data handbooks, catalogues and subscriptions, please contact your nearest Philips Components sales organization **(see address list on the back cover of this handbook).**

OVERVIEW OF PHILIPS SEMICONDUCTORS DATA HANDBOOKS

Our sister product division, Philips Semiconductors, also has a comprehensive data handbook system to support their products. Their data handbook titles are listed here.

Integrated circuits

Book	Title
IC01	Semiconductors for Radio and Audio Systems
IC02	Semiconductors for Television and Video Systems
IC03	Semiconductors for Wired Telecom Systems
IC04	HE4000B Logic Family CMOS
IC06	High-speed CMOS Logic Family
IC11	General-purpose/Linear ICs
IC12	I ² C Peripherals
IC13	Programmable Logic Devices (PLD)
IC14	8048-based 8-bit Microcontrollers
IC15	FAST TTL Logic Series
IC16	CMOS ICs for Clocks and Watches
IC17	Semiconductors for Wireless Communications
IC18	Semiconductors for In-Car Electronics
IC19	ICs for Data Communications
IC20	80C51-based 8-bit Microcontrollers
IC22	Desktop Video
IC23	BiCMOS Bus Interface Logic
IC24	Low Voltage CMOS & BiCMOS Logic
IC25	16-bit 80C51XA Microcontrollers (eXtended Architecture)
IC26	IC Package Databook

Discrete semiconductors

SC01	Diodes
SC02	Power Diodes
SC03	Thyristors and Triacs
SC04	Small-signal Transistors
SC05	Video Transistors and Modules for Monitors
SC06	High-voltage and Switching NPN Power Transistors
SC07	Small-signal Field-effect Transistors
SC08a	RF Power Transistors for HF and UHF
SC08b	RF Power Transistors for UHF
SC09	RF Power Modules
SC13	PowerMOS Transistors including TOPFETs and IGBTs
SC14	RF Wideband Transistors
SC15	Microwave Transistors (new version planned)
SC16	Wideband Hybrid IC Modules
SC17	Semiconductor Sensors

Professional components

PC06 Circulators and Isolators

MORE INFORMATION FROM PHILIPS SEMICONDUCTORS?

For more information contact your nearest Philips Semiconductors national organization shown in the following list.

Argentina: see South America
Australia: NORTH RYDE, Tel. +61 2 9805 4455 Fax. +61 2 9805 4466
Austria: WIEN, Tel. +43 1 60 101, Fax. +43 1 60 101 1210
Belarus: MINSK, Tel. +375 172 200 733, Fax. +375 172 200 773
Belgium: see The Netherlands
Brazil: see South America
Bulgaria: SOFIA, Tel. +359 2 689 211, Fax. +359 2 689 102
Canada: SCARBOROUGH, Tel. +1 800 234 7381, Fax. +1 708 296 8556
Chile: see South America
China/Hong Kong: HONG KONG, Tel. +852 2319 7888, Fax. +852 2319 7700
Colombia: see South America
Czech Republic: see Austria
Denmark: COPENHAGEN, Tel. +45 32 88 2636, Fax. +45 31 57 1949
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NOTES

High Component

EXPLANATION OF SYMBOLS AND ABBREVIATIONS	
DATA CATEGORY	
001	General information about the subject
002	Biographical data
003	Physical characteristics
004	Education and training
005	Employment history
006	Financial records
007	Legal records
008	Medical records
009	Psychological records
010	Social and family life
011	Travel and movement
012	Communication records
013	Security and intelligence
014	Investigative findings
015	Operational details
016	Administrative matters
017	Legal proceedings
018	Medical examinations
019	Psychological evaluations
020	Social and family background
021	Travel and movement logs
022	Communication intercepts
023	Security clearances
024	Investigative reports
025	Operational procedures
026	Administrative correspondence
027	Legal documents
028	Medical records
029	Psychological records
030	Social and family life
031	Travel and movement
032	Communication records
033	Security and intelligence
034	Investigative findings
035	Operational details
036	Administrative matters
037	Legal proceedings
038	Medical examinations
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065	Operational procedures
066	Administrative correspondence
067	Legal documents
068	Medical records
069	Psychological records
070	Social and family life
071	Travel and movement
072	Communication records
073	Security and intelligence
074	Investigative findings
075	Operational details
076	Administrative matters
077	Legal proceedings
078	Medical examinations
079	Psychological evaluations
080	Social and family background
081	Travel and movement logs
082	Communication intercepts
083	Security clearances
084	Investigative reports
085	Operational procedures
086	Administrative correspondence
087	Legal documents
088	Medical records
089	Psychological records
090	Social and family life
091	Travel and movement
092	Communication records
093	Security and intelligence
094	Investigative findings
095	Operational details
096	Administrative matters
097	Legal proceedings
098	Medical examinations
099	Psychological evaluations
100	Social and family background

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